PROSPECTS FOR SALINE AGRICULTURE ON TERSCHELLING

An exploratory study based on groundwater measurements and farmers' perspectives

Photo created by: J. Janson (18-05-2021).

Joke Janson (2646882)

1st supervisor: Pier Vellinga

Date: 30-06-2021
Words: 11.930

Abstract

Salinization of agricultural lands is expected to become a major threat to global food security within the coming decades. In some parts of the Netherlands, low-lying coastal polder areas are already facing threats of salinization caused by climatic and anthropogenic stresses. In this interdisciplinary research, prospects for saline agriculture in the low-lying polder area of the island of Terschelling were explored, using a combination of semi-structured interviews and salinity measurements, hereby generating new insights in the prospects for saline agriculture based on biophysical and social aspects. Local farmers' perspectives on saline agriculture were assembled prior and after salinity measurements in the local surface water and groundwater took place, hereby detecting the influence of salinity measurements on farmers' perspectives and actions. In addition, a range of experts was interviewed in order to establish a DPSIR framework of local salinization processes. The main finding from the biophysical analysis was that salinity levels increased, with decreasing distance to the coastal dike. The interview results showed that in some cases, presentation of the salinity maps influenced farmers' decision-making processes and actions. Contrary to expectations, farmers showed no renewed interest in the cultivation of saline crops of halophytes after presentation of the salinity measurements. Principal reasons for this were a lack of personal affinity, time, human capital and finance. This implies a lock in situation in the current status-quo of the agricultural sector of Terschelling, hindering the uptake of saline agriculture. Therefore, the introduction of agricultural entrepreneurs may increase the prospects for local saline agriculture to thrive. Additionally, as the local agricultural sector mainly consists of dairy farmers, experiments with salt tolerant forage grasses might be particularly interesting. Furthermore, in-depth hydrological research might introduce hydrological solutions for harmonizing local agriculture and salinization processes in the local polder area.

Keywords: salinization, saline agriculture, farmers' decision-making processes, Terschelling

Table of content

Acronyms

CSV comma-separated value

DPSIR Drivers, Pressures, State, Impact, Response

EC Electrical Conductivity

FAO Food and Agriculture Organisation

OECD Organisation for Economic Cooperation and Development

TPB Theory of Planned Behaviour

QGIS Quantum Geographic Information System

1. Introduction

Soil is one of our most important natural resources, as it provides us with the capacity to produce food and sustain human life on earth (Ruto *et al*., 2018). In the context of a growing population up to 9 billion people by the end of 2050, agricultural production has to increase by a rough 60% compared to the year 2006 (Lipper *et al*., 2014; FAO, 2018). However, global agricultural production is under severe threat due to salinization of agricultural lands all over the world (Ruto *et al*., 2018).

1.1. Global to local salinization processes

Salinization is both a land-use issue and a water resource issue which makes it a major cause for yield losses and reductions in agricultural productivity all over the world (Ruto *et al.*, 2018). In addition, climate change accelerates salinization rates in coastal areas due to a combination of sea level rise and salt water intrusion (Oude, 2001; Oude Essink, 2010; Pauw *et al*., 2012; Ruto *et al*., 2018). The total global coverage of saline or sodic soils was estimated on 932.2 million hectares in 2014, with societal costs rising up to 27.3 billion US dollars (Qadir *et al*., 2014).

In the North western part of the European Union, salinization will mainly occur due to sea-level rise (Ruto *et al*., 2018). This will lead to salt water intrusion, which will in turn lead to increased salinity levels in local groundwater used by nearby lowlands and agricultural areas (Ruto *et al*., 2018). The economic burden of salinization in Europe is expected to be mainly carried by the Netherlands, France and Germany with a direct financial burden estimated on a rough 600 million euros (Ruto *et al*., 2018). This estimation is based on the assumption that salinized lands will be half as valuable as non-saline, productive lands (Ruto et al., 2018; Ruto *et al*., 2021).

According to the Dutch KNMI climate scenario's, it is expected that sea level rise will contribute to salt water intrusion in the mainland of the Netherlands (Klein Tank *et al*., 2014). Two out of four scenarios indicate that a fresh water shortage will lead to salinization and decreases in fresh water quality (Klein Tank *et al.*, 2014). One research outlines that seawater intrusion in certain parts of the Netherlands has already reached between two to six kilometres inlands, measured from the coastline (Pauw *et al*., 2012). Climate modelling studies predict a significant increase in salinity of the Dutch water system within the next 50 to 100 years (Oude Essink, 2001). De Kempenaer *et al.* (2007) expect that by the end of 2030, 125.000 hectares in the Netherlands will be subjected to salinization. Especially the lowlands in coastal areas are likely to be affected by salt water intrusion through a combination of land subsidence and sea level rise (Rietveld, 1986; Oude, 2001; Oude Essink *et al*., 2010; Pauw *et al*., 2012).

Terschelling is a Wadden island, situated between Vlieland and Ameland. On Terschelling, low-lying agricultural lands are situated near the coastline, hence climate change is likely to increase salinization of these lands (Oude Essink, 2010; Pauw *et al.,* 2012). In addition, salty sea winds contribute to salinization of the soil above sea level, eventually leading to salinization of local groundwater (Kok, 2006; de Boer & Radersma, 2011). It is estimated that salt loads in the polders of the Wadden Region will double within the next two hundred years (Pauw *et al*., 2012).

In light of these threats, saline agriculture may play a pivotal role for sustaining agricultural production in these salt affected areas (Ladeiro, 2012; de Vos *et al*., 2016; Bergkamp *et al*., 2018; Negacz *et al*., 2021). Saline agriculture can be distinguished in two main objectives: increasing salt tolerance of conventional crops, or using naturally salt-tolerant crops, called halophytes (*Bergkamp et al*., 2018). In terms of livestock farming, saline agriculture may increase nutritional value of forage grasses for grazing cattle on salt effected areas (Masters *et al*., 2005). Other research points to the effectiveness of using specially selected halophytes as fodder, hereby reclaiming salt affected pastures (Kafi *et al*., 2010).

The potential and need for saline agriculture will increase as scientific research points to increased salinization rates of productive agricultural lands, in a relative short time span. Therefore, there is a call for more scientific research and experiments on the topic of salinization, using an integrated approach by establishing collaborations with farmers, scientists, local municipalities and international organisations (Ruto *et al*., 2018;Vellinga *et al*., 2021). In 2014, the European Union established the SalFar project, which aims at exploring the prospects for saline agriculture on a regional scale and subsidizes saline agriculture initiatives and research. On Terschelling, a local non-governmental organisation (NGO) called 'De Zilte Smaak', which is subsidized by the SalFar project, aims at exploring the prospects for saline agriculture on the island (Vellinga *et al*., 2021). However, not much scientific research on salinity levels of local surface and groundwater on Terschelling has been conducted yet since its establishment in Januari 2017. This is the first research on salinization on Terschelling to combine perspectives from the local agricultural sector with salinity measurement analysis.

This research contributes directly to some of the main objectives of De Zilte Smaak, by examining the prospects for saline agriculture on Terschelling, using an interdisciplinary approach by considering both biophysical and social aspects. In terms of the quantitative biophysical dimension, the research aims at creating insight in salinity levels of local surface water and groundwater in the polder area. In terms of the qualitative social dimension, the research collects farmers' perspectives on saline agriculture and examines the influence that knowledge-sharing may have on farmers' decision-making and actions. Previous studies on farmers' decision-making processes point to the need for more scientific research on the way agricultural advisory schemes and extension of services may influence farmers' decision-making processes (Bartkowski & Bartke, 2018). This research examines the way groundwater measurements may influence farmers' perspectives on saline agriculture, hereby attempting to fill the existing research gap as mentioned in previous literature (van der Ploeg, 1993; Edwards-Jones, 2006; Dessein & Nevens, 2007; Pascucci *et al*., 2015; Mills *et al*., 2017; Bartkowski & Bartke, 2018). In addition, farmers' perspectives are considerably important to include in the research, as local farmers may provide in-depth knowledge and insights in the social and ecological dynamics of the local polder area.

The societal relevance of the research can be found in the renewed insights in salinity levels of the local polder area. In light of climate change and expected sea level rise, the local agricultural sector could benefit from the newly gaining insights in salinity levels of local ditches and groundwater. The research provides directly applicable knowledge to the sector, hereby empowering farmers with the possibility to anticipate future salinization processes. This could in turn improve future local food production and security, hereby creating resilience against climate change influences.

1.2. Research questions

The objective of the research is to gain more scientific insights in the current prospects for saline agriculture on the island of Terschelling, by considering both biophysical and social aspects within the research. Groundwater measurements will be conducted and farmers' perspectives on prospects for saline agriculture will be explored. This results in the following main research question:

What are the prospects for saline agriculture on Terschelling based on salinity measurements and farmers' perspectives?

Here, the *independent variable* are the salinity measurements while the prospects for saline agriculture and farmers' perspectives are expected to be *dependent* variables. In order to be able to answer this research question, three sub-questions will be answered:

1. *What are the perspectives of farmers on prospects for saline agriculture on the island prior salinity measurements?*

2. *What are current salt levels of local groundwater and surface water in the polder area of Terschelling and what are the causes?*

3. *What are the perspectives of farmers on prospects for saline agriculture on the island in relation to the salinity measurement outcomes?*

2. Theoretical framework

The research uses two different theoretical frameworks to build upon. First, the analytic framework of Gabrielsen *et al*. (2003) on the Drivers, Pressures, State, Impact and Responses (DPSIR) is used to describe the current salinity situation on the island of Terschelling. This framework allows for an analysis of the impacts of salinization processes and to map the societal responses and changes, in respect to the driving forces and pressures. Second, the conceptual model provided by Mills *et al*. (2017) supports the understanding of farmers' decision-making processes and is used during the analysis of farmers' interview data.

2.1. DPSIR Framework

The DPSIR framework (Figure 1) was established in the early 1990's as an analytic tool for OECD countries (Gabrielsen & Bosh, 2003). The model shows the influence that human activities and economic development have on the environment, consequently leading to changes in the state of the environment (Gabrielsen & Bosh, 2003). These environmental changes will eventually lead to impacts on human lives, which requires a human response to undertake action in order to eliminate the impact that these underlying driving processes have on the environment (Gabrielsen & Bosh, 2003). Within this model, different feedback loops may exist, depending on different contexts. This analytic model provides a snapshot in time and creates an overview of constantly changing dynamic relations between the different indicators.

The driving forces consist of mainly demographical, social and economic indicators (Gabrielsen & Bosh, 2003). These underlying drivers result in higher pressures on the environment. For instance, a higher population growth results in higher pressure on agricultural lands by increasing monocultures and production maximization, which could in turn lead to biodiversity loss. Therefore pressures can be described as the release of emissions, resource use and land use (Gabrielsen & Bosh, 2003). The state indicators describe the quality or quantity of biological phenomena, physical phenomena, or chemical phenomena in a certain area (Gabrielsen & Bosh, 2003). The impact indicators strictly describe the way human use of the environment has changed due to these underlying drivers. Human health impacts are also included in this indicator. At last, the response indicators describe the man-made responses to compensate or prevent for these (expected) changes in the state of the environment (Gabrielsen & Bosh, 2003).

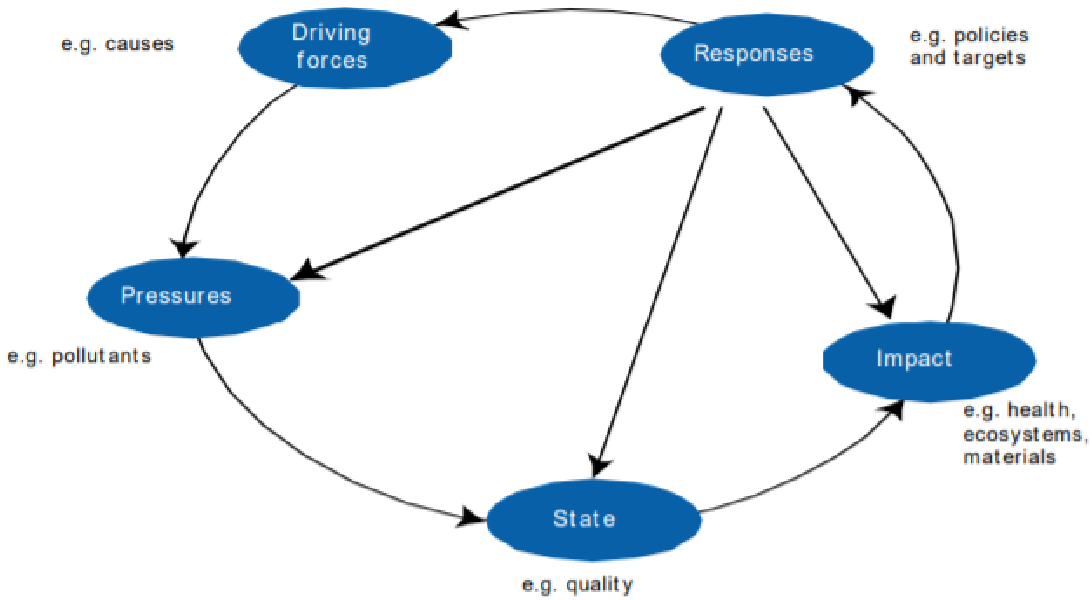

Figure 1. The DPSIR framework for reporting on environmental issues (Gabrielsen & Bosh, 2003).

In this research, the DPSIR framework serves as an analytic tool for describing the local salinization processes on Terschelling. Guion *et al.* (2011) describe how triangulation in qualitative research is used to establish validity of the research by incorporating and comparing multiple perspectives. In order to collect all necessary data on the different indicators of the DPSIR framework, data was triangulated in order to create a complete and trustworthy overall picture of the salinization processes of the low-lying polder area. For instance, interview data was compared with scientific articles on the topic of salinization in the Wadden region. In addition, expert interviews were conducted, reviewing the salinity measurements and impacts of salinization on local biodiversity.

2.2. Modelling farmer decision-making

The conceptual model of Mills *et al.* (2017) was used to give an overview of the different factors influencing farmers' decision-making processes. Since farmers play a major role in this research, a theoretical background that describes the dynamics of farmers' decision-making allows to create an integrated understanding of these processes. Farmers' decision-making processes have been studied by academia for over several decades (Mills *et al.*, 2017). Previous research explained heterogeneity in farmers' decision making through differences in individual characteristics, resources, their problem definition, reference groups, social environments and the Theory of Planned Behaviour (van der Ploeg, 1993; Edwards-Jones, 2006; Dessein & Nevens, 2007; Pascucci *et al.*, 2015; Mills *et al.*, 2017; Bartkowski & Bartke, 2018).

Mills *et al*. (2017) aimed at creating an integrated assessment of farmers' *ability* and *willingness* to adopt environmentally friendly activities. Their framework was based on a combination of a literature review and 78 qualitative face-to-face interviews with farmers in the United Kingdom (Mills *et al*., 2017). The framework is divided in three concepts: the *willingness* to adopt (values, attitude, beliefs, norms), the *ability* to adopt (financial, biophysical, external drivers) and farmer *engagement* which can be through both private and public factors (Mills *et al*., 2017). Engagement with advice or support networks can influence farmers' decision-making by creating interest, knowledge-sharing, or moral feelings of responsibility (Mills *et al*., 2017).

In this research, the conceptual framework created by Mills *et al*. (2017) is used to draw a comprehensive overview of the influencing factors on environmental decision-making among farmers (Figure 2).The *willingness to adopt* refers to intrinsic factors influencing farmers' environmental behaviour. In this topic, previous research mainly focussed on the Theory of Planned Behaviour (TPB). In short, the TPB aims at predicting and understanding personal behaviour, by looking at personal attitudes, social influences and perceived behavioural control (Mills *et al*., 2017). The latter consists of personal perceptions on the feasibility of fulfilling a specific task (Mils *et al*., 2017). *Self-identity* refers to what extend a farmer considers his personal behaviour as being part of himself, reflecting his personal worldview (Mills *et al*., 2017). *Farmer engagement* occurs when a farmer is actively interested and enters into dialogue with environmental experts (Mills *et al*., 2017).

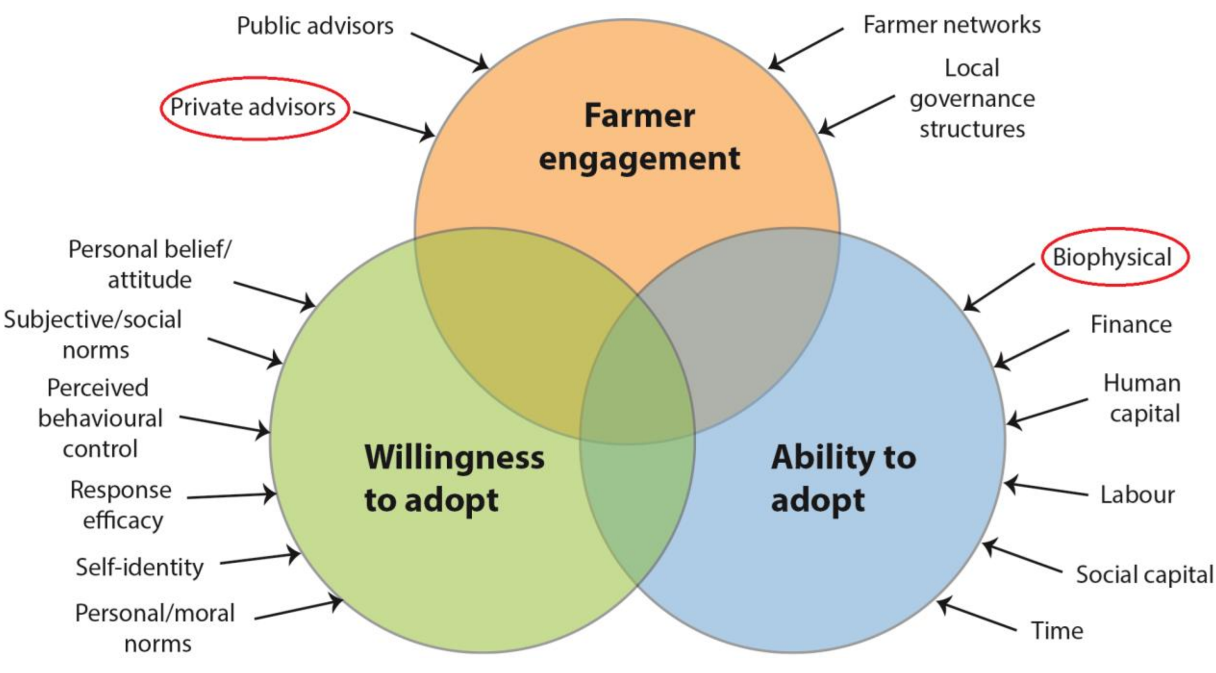

Figure 2. Conceptual framework for farmers' environmental decision-making (Mills *et al*., 2017).

This research will demonstrate the way an extension of services, which is in this case the opportunity to measure and map groundwater salinity on a local scale, may influence farmers' decision-making and perspectives on saline agriculture on the island of Terschelling. The research will also highlight the influence that biophysical factors (salinity levels), may have on farmers' perspectives. However, as described earlier, there are substantially more influencing factors in farmers' decision-making processes. Since these influential factors are considerably context-specific, the framework was only used as a starting point for deductive analysis of the interviews. In this way, harmonization between the conceptual framework and research goals is supported. There is also allowed for new factors to emerge or others being removed, which implies a more inductive and grounded approach.

3. Methodology

Data was collected on the island of Terschelling during two separate periods. The interviews prior measurements were conducted in the period between the 5th of April until the 23th of April, 2021. In the same period, groundwater and surface water measurements were conducted using a handhold EC meter, provided by Acacia Water. In the second period, between May 17th until May, 27th, 2021, follow-up interviews were conducted with participating farmers as well as some newly interested farmers. This section will start with a thorough description of the methods used during the research.

3.1. Groundwater and surface water measurements

257 salinity measurements were executed in the period between the 9th of April until the 24th of April. Measurements were only conducted on pastures of participating farmers. Therefore, the study area was dependent on the location of these particular pastures. The pastures were located along the Wadden Sea coastline, stretching from Nieuw Formerum up to the border of Oosterend (Figure 3). In addition, 88 follow up measurements were conducted in May. Since there were more participating farmers at that time, the study area increased towards the South-western part of the polder area, hereby including the Strieper polder.

Figure 3. Study area of the research.

The handhold EC meter was connected via Bluetooth to an android phone, where measurement data was presented on the screen in mS/cm. This data was saved and directly transported onto the online platform of Fixeau Mobile, which is only accessible to the user and members of Acacia Water. Both surface water and groundwater measurements were conducted. It is important to differentiate between those two measurements, as there could be differences in salinity levels. As illustrated in figure 4, deep ditches may be characterized by a relative higher influence of saline groundwater seepage (de Louw *et al*., 2011). Therefore, groundwater measurements are expected to have relatively lower salt levels compared to surface water measurements.

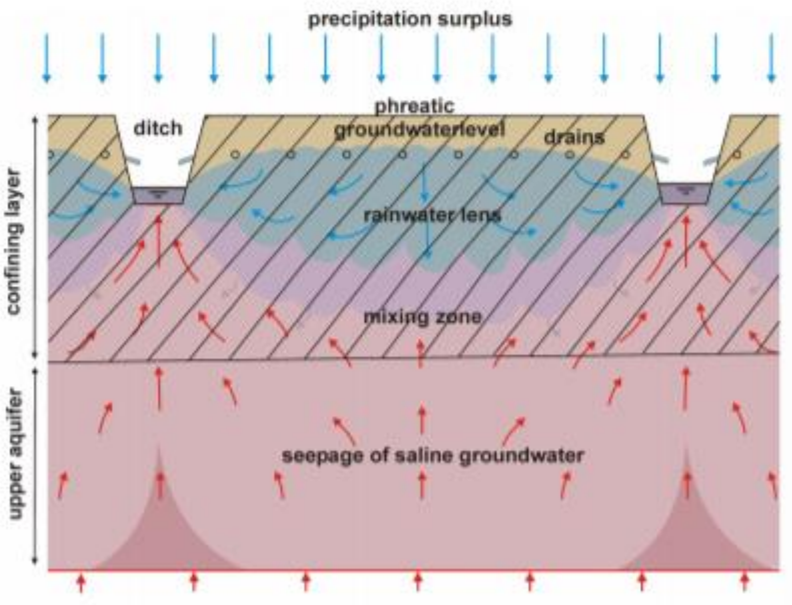

Figure 4. Conceptual visualisation of a shallow rainwater lens on top of saline groundwater seepage (De Louw *et al*., 2011).

Groundwater measurements were conducted by drilling a hole of approximately 1.2 meters deep, using a hand drill. Since saline water is heavier and less mobile compared to fresh water, salinity levels could increase with the depth of the ditch. Therefore, measurements were conducted in both the surface layer (10 cm below the surface) as the deep layer (10 cm above the bottom) of the ditches. However, often not much difference was being found between the shallow and deep measurements. According to one of the interviewed hydrologists, this could be due to a mixture of the deep layer and the surface layer caused by winds or water flows. According to another interviewed hydrologist, different temperatures could have caused differences in measured salinity levels.

The salt load of water was measured in Electrical conductivity (EC, in Ds/M). The EC value is a function of different elements: Natrium, Potassium, Magnesium and Calcium. Therefore, a high EC value does not necessarily mean high levels of Natrium. In table 1, classifications of non-saline to very brine water are presented, based on their electrical conductivity and salt concentrations. this table was created by Rhoades *et al*., (1992).

Table 1. Classifications of saline water (Rhoades *et al*., 1992).

Water class	**Electrical conductivity (dS/m)**	**Salt concentration (mg/l)**	**Type of water**
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7-2	500-1500	Irrigation water
Moderately saline	2-10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15000	Secondary drainage water and groundwater
Very highly saline	25-45	15000-35000	Very saline groundwater
Brine	>45	>35000	seawater

This classification was used during the analysis of the groundwater measurements on the island. In addition, the National Research Council (NRC) created a classification of the salt tolerance of dairy cows, as presented in table 2 (de Boer & Radersma, 2011). The two tables create a clear overview of the different salinity classes and their effects on livestock production. These tables were used during the analysis of the measurements and as communication tools during farmers' interviews.

Table 2. Salt tolerance of dairy cows (National Research Council, 2001). *Cl-concentration measured by multiplying salt concentration by 0,54.

EC value (Ds/M)	**Salt concentration (Mg/L)**	**Cl concentration (Cl/L)***	**Comments**
< 2,5 +/-	<1000	<540	Safe, no health issues
2,5 – 5,5 +/-	1000 – 2999	540- 1.620	Light diarrhoea when cows are not used to this
5,5 – 8,5 +/-	3000 – 4999	1620-2700	Cows might reject the water, temporary diarrhoea might occur. Dairy production might be suboptimal.
8,5 – 11,5 +/-	5000 – 6999	2700 – 3780	Water is harmful for pregnant cows or lactating cows. May be used if maximum dairy production is not necessary.
> 11,5 +/-	>7000	>3780	Avoid offering water to cows. Drinking results in health issues and/if lowered dairy production.

In order to calculate the EC values of the different categories of salt tolerance of dairy cows, the chloride concentration per litre has to be converted into EC values. In order to do this, the chloride concentration ratio of the method from Mulder & Spoelstra (1995) was used. These calculations for conversion of chloride concentrations into EC values were offered and verified by J. Velstra, one of the experts. Based on table 2, an additional map was created presenting the salt tolerance of dairy cows, as expressed in the salinity levels in the surface water. This map was interesting for farmers, as it provided directly applicable knowledge.

In addition, salinity levels were presented in relation to monthly weather patterns. This data was modified from the local weather station in Hoorn. Since evaporation rates influence salinization rates, the monthly precipitation deficit or precipitation surplus was used. The precipitation surplus or deficit is calculated by the difference between the monthly precipitation and the monthly evapotranspiration. The exact calculation, according to the method of Makkink is as followed:

Precipitation surplus = *precipitation surplus of the day + precipitation surplus of previous days * 0,980*

3.2. Analysis in QGIS

For analysing the groundwater measurements, the data was exported from the online platform of Fixeau Mobile as a Comma Separated Value file (CSV file). Calibration of the EC meter only took place after the measurements in April were finished, which indicated a 3%~ difference in the measurements. In order to correct for this, all the measurements conducted in April were multiplied by the factor 1,03. In this way, the results were still corrected for the conversion factor of the handhold EC meter. The corrected results were separated in groundwater measurements and surface water measurements, and uploaded as a CSV file in QGIS with GRASS software as a new delimited text layer. Since calibration was executed during the follow-up measurements in May, this particular CSV file did not have to be edited. As a background layer, the global open road map was used. To explore the measurement data, the symbology was edited to ‘Gradual’ and classified in 4 different categories based on Rhoades *et al*., (1992). In addition, salt tolerance of dairy cows categories were created based on the report from the National Research Council (2001). The appropriate colours were chosen and in the end, the final maps were created in a new print layout, adding a northern arrow, a scale bar and a legend.

3.3. Semi-structured interviews

The objective of qualitative research is to create a deeper understanding of the complex social worlds of human lives and experiences (Saldaña, 2021). Semi-structured interviews are widely used in qualitative social research as they can generate deeper insights in the local context and individual perspectives (Kallio *et al*., 2016). They are characterized by a predefined set of questions that allow for an open response, which may lead to unexpected insights. This fits the exploratory character of the research: detecting influential factors on farmers' decision-making and perspectives on saline agriculture. The semi-structured interview questions can be found in the appendix of the research. One important thing to keep in mind is the fact that during qualitative research, it is important to remain reflexive. The researcher always has to take into account the fact that his or her personal believes, attitude and assumptions may have influenced the research outcomes (Berger, 2015).

3.3.1. Data collection and sampling

All farmers were identified through snowball sampling as this appeared to be the most effective method for gathering respondents. This resulted in 8 participating farmers in April, consisting of four conventional dairy farmers, two organic dairy farmers (father and son), one organic sheep farmer and one cranberry cultivator. Since no measurements were conducted on the parcels of the cranberry producer, there was no follow-up interview in May. In mid-May, follow-up interviews presenting the measurement results were conducted with every farmer that participated in April. In addition, one extra organic dairy farmer, one beef farmer and one fruit cultivator participated in the research, resulting in ten in respondents by the end of May. In total, 9 farmers and 2 cultivators participated in the research. Since there are only fourteen active farmers on the island, this was considered to be a representative number of respondents.

Groundwater and surface water measurements were also conducted on the pastures of the newly participating organic dairy farmer and the fruit cultivator, in order to be able to maintain the same research structure in the month of May. This means that these farmers were also interviewed before and after groundwater measurements took place. Since the organic beef farmer had pastures in the middle of the study area, measurements conducted in April were assumed to be representative for his own pastures. Therefore, only one interview was conducted with this particular farmer, asking questions before and after presentation of the salinity maps. For securing anonymity throughout the research, only a distinction between farmers and cultivators was made in the results section. Each interview lasted between twenty to thirty minutes and took place in the farmers' homes. Before the start of every interview, the respondent was informed about the goals and means of the research. Interviews were summarized as quickly as possible to avoid any chances of data loss. Informed consent was give via email, by agreeing with the final interview summaries. All interviews with farmers were conducted in person and recorded using a mobile phone.

3.3.2. Expert interviews

In order to triangulate data, expert interviews were conducted via Zoom or face-to-face. Like the interviews with farmers, expert interviews were summarized as quickly as possible and later on send via email for informed consent. Experts were incorporated in the research because of their relative objective evaluation and knowledge on the subject of salinization in the polder area of Terschelling, bringing new scientific insights and information to the research. All the experts were practical experts, meaning that they mainly worked in advisory schemes. Therefore, the selection processes was mainly based on snowball sampling, or via referrals in interviews.

Experts were asked to give an interpretation of the measurements and to describe the underlying processes of salinization, the indicators of salinization, future perspectives on salinization processes on the island, the influence of historic salt marshes and sea channels, as well as practical solutions for farmers. Since both hydrology and biology are important areas of study within the research, experts from both fields were approached. Experts had functions in both private as public domains. The participating experts are shown in table 3. In text, experts are referred to by their expert referral number as presented in table 3. Their interviews can be found in the appendix of the research.

Table 3. Participating experts in the research.

Expert referral	Name	Specialization
E1	J. Schaap	Hydrologist
E2	J. Velstra	Hydrologist
E3	A. Doeksen	Chair of the local bird watch
E4	Forest ranger	Local forest ranger of Terschelling
E5	A. Kok	Geohydrologist & local polder area history

3.3.3. Analysis of the interviews

Analysis of farmers' interview summaries consisted of identifying overarching concepts and patterns. During this stage, the theoretical framework of Mills *et al.* (2017) served as a coding guide, hereby ensuring coherence and completeness of the analysis. This means that a deductive coding strategy was applied. For every reoccurring concept, the frequency of occurrence in interview data was described. These concepts supported the answering of sub questions one, three and four. Some relevant and describing quotes were added to the summaries in the results section. Since the interviews were conducted in Dutch, quotes were translated into English. In addition, the DPSIR framework was used for creating a first impression of the underlying processes and causes of salinization of the polder area. These statements were later on verified via expert interviews.

During the analysis of expert interview summaries, the DPSIR framework functioned as the most important analytic coding tool for detecting the underlying processes and causes of salinization of the polder area of Terschelling. In this analysis, the same coding strategy as during the analysis of the farmers' interviews was applied: frequency of reoccurring concepts was counted and was used in order to answer sub-question 2.

4. Results

The results of the research are separated in the order of the posed research questions. First, the prospects for saline agriculture based on farmers' perspectives prior water measurements is summarized and analysed using the theory of Mills *et al*. (2017) for detecting influential factors on farmers' decision-making processes. Second, the salinity levels of the groundwater and surface water are analysed through QGIS. In addition, underlying drivers and dynamics of salinization processes in the study area are described, using the DPSIR framework. Third, the influence of the presentation of the salinity measurements on farmers' perspectives on saline agriculture prospects is determined.

4.1. Farmers' perspectives on saline agriculture prior measurements

In this section, the first sub-question will be answered by providing a thorough analysis of the interview results of the interviews prior measurements took place:
"*What are the perspectives of farmers on prospects for saline agriculture on the island prior salinity measurements"*

These results are based on the answers of the six participating farmers and one cultivator in the period of April, as well as the two additional participating farmers and one cultivator in the period of May that were interviewed prior measurements took place. If a farmer had no explicit opinion about a certain topic, or the topic did not come up during the interview, the farmer was omitted from the results on that particular topic.

Since perspectives on prospects for saline agriculture might be influenced by personal future perspectives on salinization on the island of Terschelling, it is important to include personal future perspectives in this section. In addition, actions undertaken in reaction to salinization of the polder area might also be influential on the willingness to adopt saline agriculture. Therefore, the section starts with two summaries of these two elements.

4.1.1. Perspectives on future salinization processes

Seven out of the nine farmers with pastures in the polder area, confirmed that they experience damage from salinization on some of their pastures near the dike. Eight out of nine participating farmers with pastures in the polder area, described that their pastures near the dike have always been less productive: *"For as long as I can remember, the production value has always been relatively low on those pastures, that is not something that is only recently occurring."* (F1).

Five out of nine farmers expected that salinization will increase over time. One of the farmers took the effects of climate change and sea level rise into doubt, hence, he had no incentive to think that salinization would increase over time. Another farmer explained that salinization will only become a major problem, once the polder area is below sea level. However, he did not think that this was likely to happen any time soon. One farmer did not think that salinization is increasing, rather, it is only more noticeable due to increased periods of droughts. In addition, he was not afraid that his pastures would experience salt related damage, as the water in his ditches always remained fresh. One of the farmers thought the salinity problem of the island is probably even bigger than expected. Both the cranberry cultivator and the fruit cultivator did not think their farmlands would suffer from salinization, as they are located next to the dunes. Five farmers argued that salinization is amplified by lowered groundwater tables, leading to a decreased pressure of the fresh water lens.

4.1.2. Responses to salinization of the polder area

Four farmers described how their cows came 'running back' to the stables after spending a hot summer day on the pastures near the dike: "*Yes, we have seen our cows come running back to the stable after spending a whole day on the pastures near the dike, thirsty searching for fresh water."* (F4).

In response to these saline ditches, these four farmers invested in tap water infrastructure, covering all the pastures they use for their cows to graze on, hereby assuring a fresh water supply for their cows throughout the grazing season. Because of this response, their problems with salinity of the ditch water are for the greater part solved. One farmer explained that he did not invest in a tap water infrastructure, since he has no saline ditches. He argued that this was due to the relatively high pressure of the fresh water lens on the location of his farm. Another farmer argued that his beef cows are more resilient against salt level, leading to less incentive for investing in tap water infrastructure. Two other farmers explained that they keep the water table in their ditches relatively high by pumping fresh water from the dunes through their ditches, resulting in lowered salinity levels in their surface water.

Another response for coping with salinization, as described by two farmers, is by giving salt affected pastures back to nature. Farmers receive nature subsidies from the government if they leave these low yield pastures to rest during the breeding season. In this way, they can still earn some money with pastures that have lost their production value due to salinization. Therefore, there could be less economic incentive to start thinking about other options for maintaining agricultural production on these salt-affected pastures: *'There is no urgent need (...) here on the islands, we are all financially supported by the granting of nature subsidies."* (F4).

4.1.3. Perspectives on saline agriculture

Seven out of nine farmers explained that the saline garden has failed to reach economic vitality over the last years. This is mainly due to a combination of the labour intensive character of the production of halophytes, and the low generated outputs. Three farmers specifically pointed out that the saline garden is only functioning because it receives yearly financial support from the European Union.

Another foremost reason why farmers showed no interest in the uptake of saline agriculture, was due to different, personal interests. As one farmer described*: "I find no pleasure in horticulture (…) I am a dairy farmer because I like being a dairy farmer, working with animals, everything comes together (..) horticulture and dairy farming are simply two completely different things."* (F3). Seven out of nine farmers had a similar answer and explained that they have personal affinity with being a dairy farmer. Therefore, they showed no interest in the uptake of the cultivation of saline crops or halophytes.

In addition, five farmers explained that saline agriculture is not geographically bounded to the island of Terschelling, especially since most experiments take place in separate buckets, using a different soil than the local clay ground. They explained that this kind of agriculture could be practiced along the whole Dutch coastline, in places with a better suitability, labour power, knowledge and machinery for the cultivation of halophytes. Two farmers argued that halophytes like Samphire should remain a niche product, by creating special products and delicacies that would be attractive for tourists to buy. Three farmer explained the way organisational tensions could make it difficult to upscale saline agriculture on these *'holy pastures'* (F6) near the dike. Two farmers were especially not in favour of the saline garden, as it disturbs the meadow bird populations in the area near the dike.

Three out of nine farmers expressed that they liked the idea of trying to increase the production value of these salt affected pastures near the dike. According to them, the most interesting option would be to search for salt tolerant, deep-rooting grasses instead of (fodder) halophytes. One farmer described that saline agriculture might have the potential of becoming economically profitable, if it could upscale and focus on the production of one single specialized niche product. According to him, it might become a new agricultural tradition on the island, however, this would take a considerate amount of time.

Both the cranberry cultivator as the fruit cultivator showed no interest in adopting saline agriculture. This is due to the fact that fruits and cranberries have a low salt-tolerance, therefore, saline agriculture could negatively affect their yields. In addition, both cultivators did not suffer from salt affected pastures, as both companies are located right next to the dunes. Therefore, they were not afraid that their parcels or their fresh water resources would suffer from salinization any time soon. In addition, they explained that it would require extra work to carry saline water to their parcels. The fruit cultivator also explained that halophytes are labour intensive and that it would not bring an additional value to her self-picking garden, since tourists would not be interested in a kilogram of Samphire. Therefore, she argued that special, delicate halophytic products might be more interesting.

4.1.4. Conclusion

The majority of respondents were not interested in the uptake of saline crops or halophyte cultivation in their own future farm planning due to both their *willingness to adopt* and their *ability to adopt* saline agriculture. Most important, reoccurring reasons for this were the labour-intensive character and low rewards in production output of saline agriculture. In addition, three farmers argued that there is a lack of knowledge and suitable machinery on the island of Terschelling. This resulted in negative perspectives on the economic prospects for saline agriculture on the island. In addition, the majority of farmers explained that they felt no personal affinity for saline agriculture and therefore would not enjoy the cultivation of halophytes or saline crops. This influential factor is therefore added to the *willingness to adopt* dimension in the theoretical framework of Mills *et al*. (2017), as shown in figure 5.

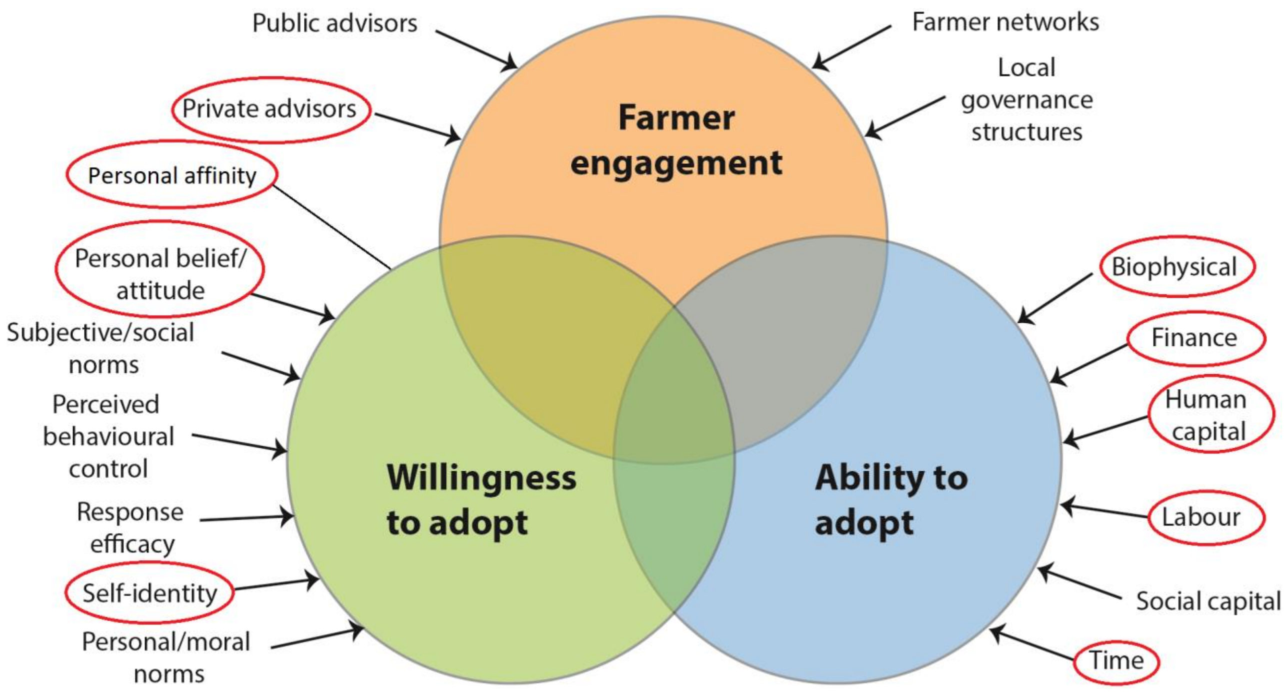

Figure 5. Determined influential factors on farmers' perspectives and decision-making processes on saline agriculture. 'Personal affinity' was added as one of the influential factors on the *willingness to adopt.*

Both the cranberry cultivator and the fruit cultivator showed no interest in horizontal inclusion of the cultivation of halophytes. Both explained that the chances of salt related damage in the future were low, due to the location of their farmlands. Moreover, the fruit producer explained that the labour-intensive character and the low demand of raw products from tourists made the cultivation of halophytes less interesting to include in the self-picking garden. Nonetheless, one farmer argued that saline agriculture might become interesting in the future, if it would be possible to upscale and focus on the production of one single successful niche product.

4.2. Current salinity levels and their causes

There are many different reasons why salinization occurs in the Netherlands. According to previous literature, omnipresent caused of salinization on Terschelling, are a combination of higher evaporation during summertime, salty sea winds, agricultural activities, historical floods, sea water intrusion and saline seepage due to sea level rise (Kok, 2006; Oude Essink, 2010; Pauw *et al*., 2012; de Louw *et al*., 2011; Ruto *et al*., 2018). These underlying drivers and pressures lead to a degrading state of the environment, which requires a societal response for coping with salinization. Therefore, the DPSIR framework is used as a suitable analytic tool for unravelling the salinization dynamics of the Terschellinger polder. In this section, the second sub-question will be answered:

"What are current salt levels of local groundwater and surface water in the polder area of Terschelling and what are the causes?"

4.2.1. Drivers

Population growth in combination with economic development leading to the intensification of the local agricultural sector can be seen as underlying drivers, putting pressure on the fresh water resources in Dutch deltaic areas (Oude Essink, 2001). Depletion of coastal fresh water aquifers for human use as a consequence of economic development leads to decreased pressure from the fresh water lens, hereby increasing seawater intrusion (Ruto *et al*., 2018)**.** Artificially lowered groundwater tables as a consequence of the intensification of agriculture in the polder area of Terschelling, leads to increased saline groundwater seepage (E1,E2,E3, E4).

Climate change can be considered as being an important indirect underlying driver of the salinization processes on the island (E1, E2, E3). Scientific models show that salinization is expected to increase on the islands of the Wadden region (Oude Essink, 2001; Oude Essink, 2010; Pauw *et al*., 2012). The expected sea level rise of 0,75 metres per century will accelerate these salinization processes even more in areas where the low-lying polders border the Wadden Sea (Pauw *et al*., 2012, E1, E2, E3, E5). This process is presented in figure 6. Estimations are that salt loads in the polders of the Wadden Region will double within the next two hundred years (Pauw *et al*., 2012).

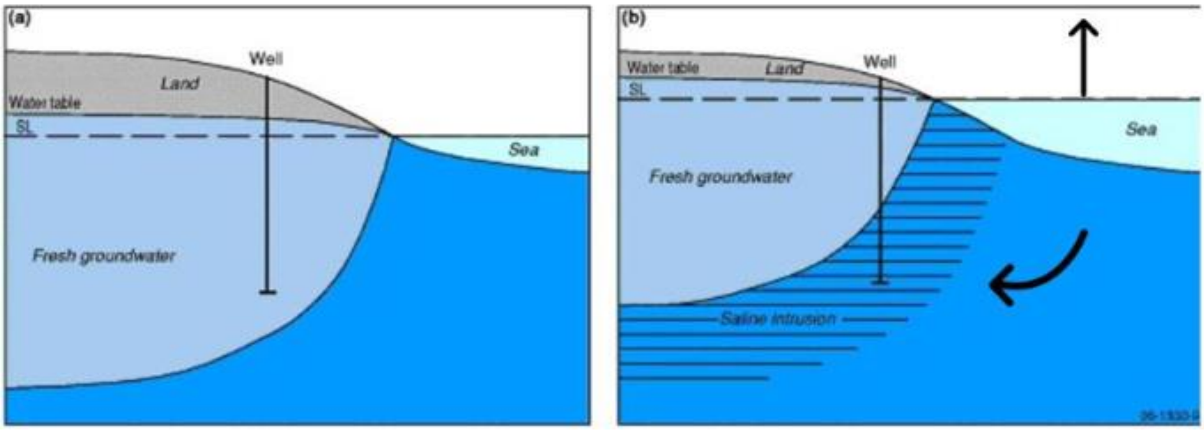

Figure 6. Salt water intrusion caused by sea level rise (Bergkamp *et al.*, 2018).

In addition, due to climate change, drought periods in the Netherlands are expected to be more intense and over a longer period of time (Klein Tank *et al*., 2014), hereby increasing evaporation rates and salt water intrusion in low-lying polder areas (Stichting Salt Farm Foundation, 2019; E1, E2).

4.2.2. Pressures

Anthropogenic measures and land subsidence are likely to increase salinization processes in low-lying polder areas in the Wadden region (Pauw *et al*., 2012). The Dutch agricultural system is built to discharge the precipitation surplus as quickly as possible, since heavy machinery fails to perform on wetlands (E1, E2). Therefore, groundwater tables in the polder area of the island are kept artificially low (E1, E2, E3, E4). The low-lying polder area is characterized by a shallow fresh water lens that is subjected to saline groundwater seepage (Pauw *et al*., 2012; E1 E2, E3, E4). Artificially lowering the water table in the polder area for agricultural purposes, results in an reduced pressure of the fresh water lens, which is naturally accompanied by increased saline groundwater seepage (Ruto *et a*l., 2018; E1, E2, E3, E4). Figure 7provides an overview of this salinization process in Dutch coastal areas.

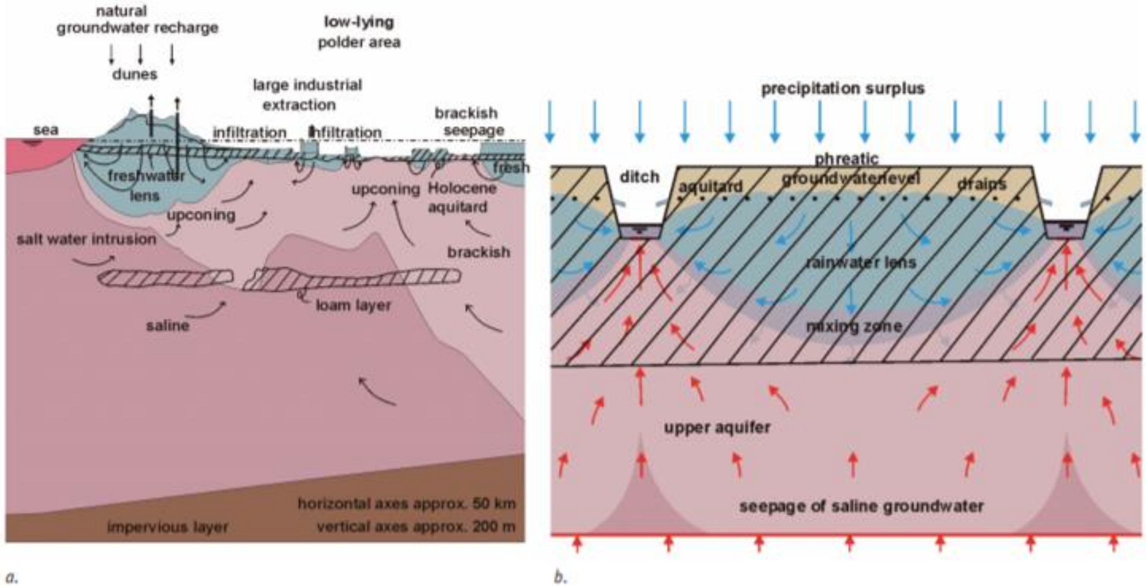

Figure 7. Salinization processes in the western Netherlands on a. regional; and b. local scale (Pauw *et al*., 2012).

In addition, historical seawater channels (Figure 8) and floods may influence salinity levels in the groundwater and surface water (E1, E2, E3, E5). This is due to the differences in soil structures. Historical seawater channels are characterized by a sandy soil, which is more permeable compared to the solid clay soils where the old salt marshes used to be (E1, E2). This sandy soil may lead to increased salt levels as it allows for higher saline groundwater seepage rates (E1, E2).

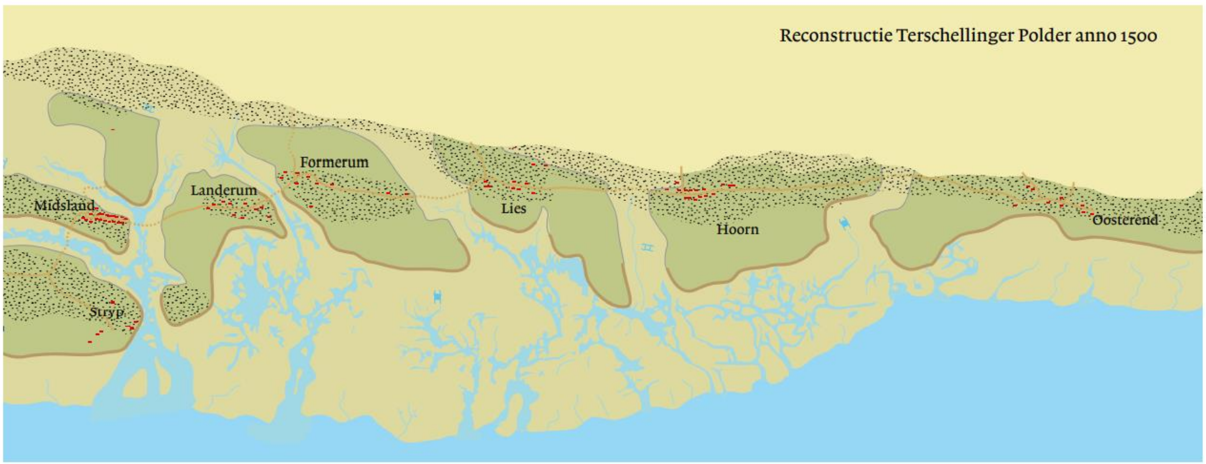

Figure 8. Reconstruction of the polder area of Terschelling in the 1500's (Kok & Kok, 2007).

Furthermore, precipitation deficiency in periods of drought create a thinner and hollow state of the fresh water lens (E1, E2, E4). This, in combination with the low-lying character of the polder area leads to a decreased buffer zone against saline groundwater seepage (de Louw *et al*., 2011; E2,E3,E4, E5). In addition, two farmers argued that the digging of the top soil layer may have decreased the space for the fresh water lens, which could in turn lead to higher salinization rates. This statement was later on verified by one of the experts (E5). One farmer argued that deeper ditches leave less space for the fresh water lens, hence accelerating salinization processes in those ditches. This statement was later on verified by one of the hydrologists (E1). He explained that deeper ditches lead to a lowered groundwater table, hence decreasing the pressure of the fresh water lens. One farmer described how salty sea winds contribute to the salinization of the pastures and ditches from above. This process is called *'the salt spray effect'* (Kok, 2006) and was also described by two experts (E1, E5). At last, one farmer argued that the salt exploitation in the Wadden sea contributes to land subsidence. This is also described by Speelman *et al*. (2009) and Pauw *et al*. (2012), who describe how land subsidence as a consequence of salt- and gas exploitation in the Wadden Sea (Rommel, 2004) increases relative sea level rise. However, one of the experts doubted whether this could really lead to land subsidence of Terschelling (E5). He thought that the relatively early establishment of the dike in the 1500's is the main cause of the low-lying character of the polder area (E5). This establishment halted natural sedimentation processes, resulting in relatively lower elevation levels of the polder of Terschelling, compared to other Wadden islands (E5).

4.2.3. State

The biophysical state is described through the EC measurements in surface water and groundwater. As described in the method section, 257 measurements were carried out in April, in local ditches and groundwater of pastures from participating farmers. This resulted in a study area of approximately 400 hectares, stretching from Formerum to Oosterend. As shown in figure 9, surface water measurements were categorized by the salinity classes as created by Rhoades *et al*. (1992). From the map, it becomes clear that salinity levels of the ditches are especially high near the dike. As described earlier, this could be the result of sea water intrusion and seepage, in combination with sea level rise and land subsidence (Rietveld, 1986; Oude, 2001; Speelman *et al*., 2009; Oude Essink *et al*., 2010; de Louw *et al*., 2011; Pauw *et al*., 2012).

The more inlands the surface water measurements were conducted, the lower the EC value of the ditches and groundwater. Interesting to notice is the high salinity level of the ditch more inlands, with a value of 10-25. This is something that one of the farmers described in an interview as well, where he explained that sometimes, the ditches more inlands are more saline compared to the ditches near the dike. This farmer also described how the water in the ditches during hot summers turned some kind of blue. He thought this had something to do with the salinity levels. This was later on verified by one of the hydrologists, who described that a blueish colour is an indicator of upcoming saline groundwater seepage (E2).

Also interesting to notice is the fact that the ditches on the left side appeared to have lower EC values on average, along the whole vertical axis. All measurements stayed below a value of 10 EC.

According to both hydrologists, this might be due to the fact that in those ditches, the groundwater table was kept relatively high, using pumped up water from the dunes (E1, E2, F5). On other pastures, water tables are relatively low, leading to increased influence of saline groundwater seepage (E1, E2, E3, E4). The pasture on the right side of the study area did not to suffer from saline ditches or ground water. This is in line with that farmers' expectations. The hydrologists thought this might have something to do with the fact that his pastures are relatively close to the dunes (E1, E2).

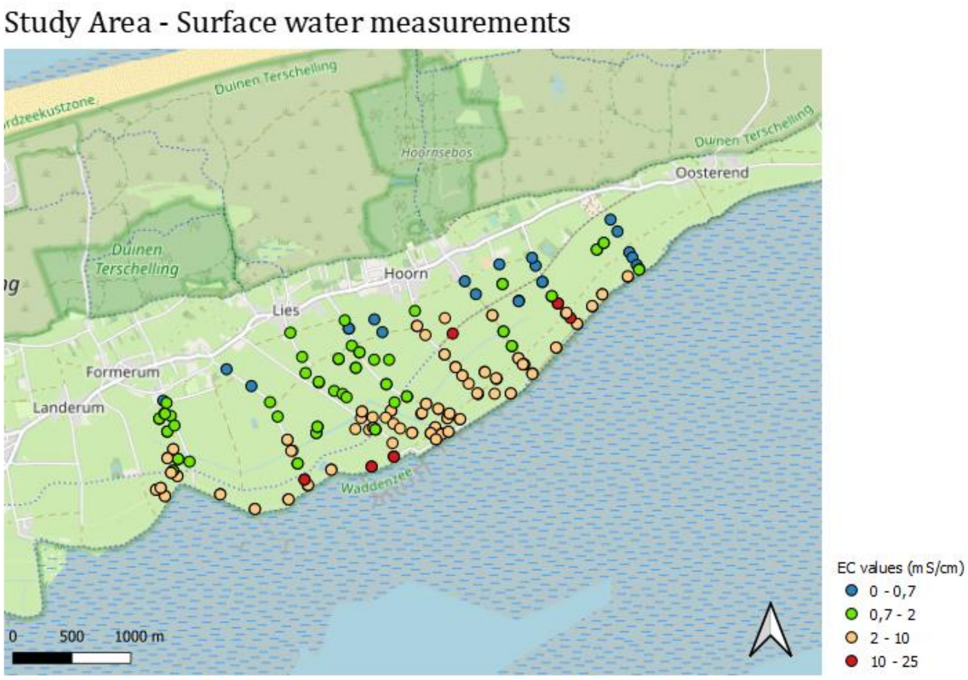

Figure 9. Surface water measurements from April categorized by EC values.

Unfortunately, less groundwater measurements were conducted in the study area (Figure 10). This is due to the fact that there were some pastures where access was prohibited, due to breeding meadow birds, rest period or because they were owned by other non-participating farmers. When looking at the groundwater measurements, it seems that the salinity levels of groundwater remain relatively more fresh compared to the surface water measurements next to them. This could imply a positive effect of the fresh water lens, protecting against saline seepage (E1). However, as shown in figure 10, there are also some pastures next to the dike that experience high levels of salinity in the groundwater. This was also visible in the reduced productivity of English rye-grass on those pastures.

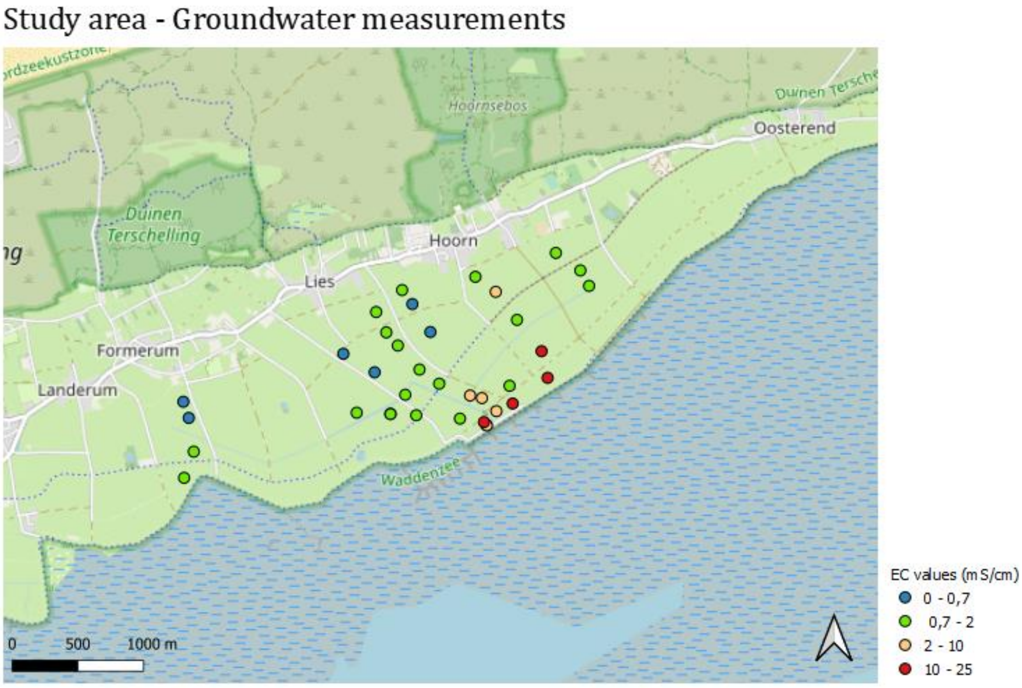

Figure 10. Groundwater measurements in April categorized by EC values.

In order to detect a seasonal effect on salinization processes in the low-lying polder area of Terschelling, some follow up measurements were conducted in May. As shown in figure 11, the study area in May increased a bit towards the South-western part of the island, as more farmers participated. Since fewer measurements were conducted, both the groundwater and the surface water measurements could be displayed in one single map. Interesting to notice is that once again, there is one ditch with relatively high salinity levels more inlands (behind Hoorn).

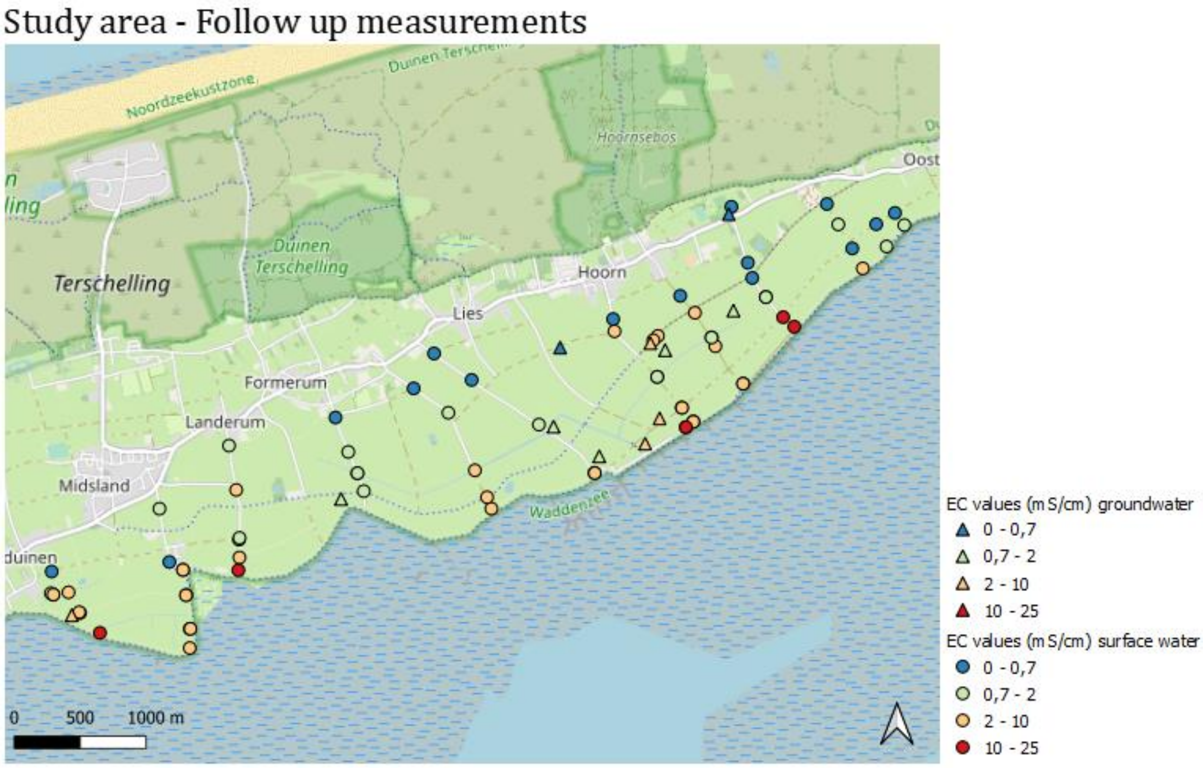

Figure 11. Follow up groundwater and surface water measurements conducted in May.

Contrary to expectations, this study did not find a significant difference between salinity levels in May, compared to salinity levels in April. This could be due to the fact that both periods were characterized by a considerable amount of precipitation (E2). According to the data derived from the weather station in Hoorn, the monthly precipitation surplus in April, 2021 was 28,5 mm, which is categorized as '*slightly wet'* (Logboekweer, 2021). In the second period in May, the precipitation surplus had an average of 108.8 mm, which is categorized as *'very wet'* (Logboekweer, 2021). This may explain the relatively lower salinity levels in the period of May.

These salinity levels may lead to various changes in the state of the local environment. Salinization in coastal areas can for instance have negative influences on local biodiversity (Pereira *et al.*, 2019). First, it results in a changed vegetation on areas that are affected by salinity (E2, E3, E4). The soil life changes as well due to salinization, especially numbers of worms are decreasing (E3). Since worms are a major source of food for some of the meadow birds, bird populations are changing on the pastures near the dikes (Table 4). Two farmers noticed how especially seagull populations are increasing on pastures near the dike, while the protected meadow birds like lapwings and godwits are disappearing from these patches of land. The more saltier the lands, the lower the population of meadow birds and the higher the population of oystercatchers (E3).

Table 4. Mutations in main (meadow) bird nesting sites on Terschelling. Modified from the local Bird Watch (2021).

Bird species	**2012**	**2020**
Godwits	277	230
Lapwings	362	356
Oystercatcher	380	1251

4.2.4. Impact

There are several impacts deriving from salinization in the polder area of the island. First, it leads to lower grass yields of the protein rich English-ryegrass. This grass species appears to be less salt-tolerant compared to other vegetation on the island. Farmers do receive some subsidy if they assign these unproductive lands as nature, however, their profit might be higher if these lands were more productive. These nature subsidies lead to land abandonment of those pastures with lowered production value. In addition, the clearest and probably most important impact for farmers was that during long periods of drought, their cows would not drink the water from the ditches near the dike anymore. This leads to a substantially lowered milk production of dairy cows, after spending a day on the salt-affected pastures. As this is one of the most important impacts on local farmers, one additional map was created, showing the salt tolerance of dairy cows based on surface water measurements (Figure 12).

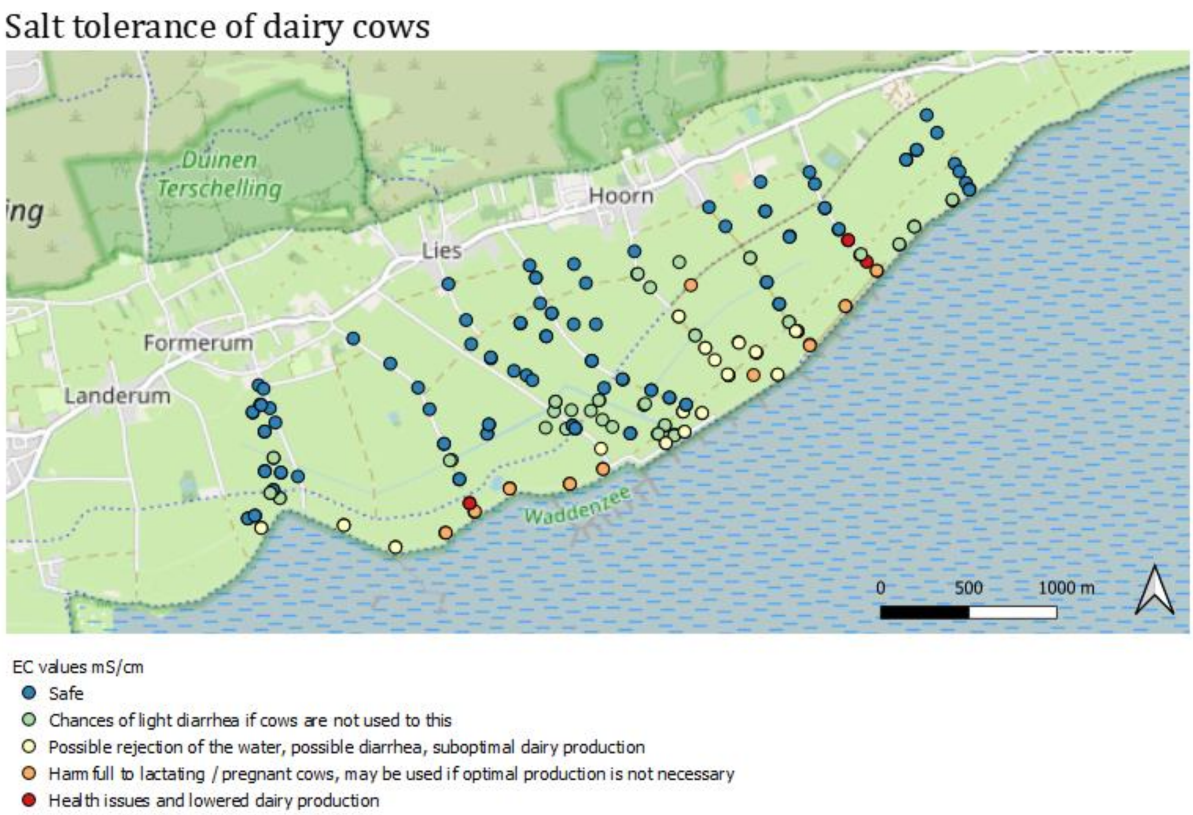

Figure 12. the salt tolerance of dairy cows, based on the categories created by the National Research Council (2001).

As shown in figure 12, there is a substantial amount of ditches that could lead to serious health issues or lowered production among productive dairy cows. This map was created using the different categories as provided by the National Research Council (2001). This map was found to be interesting by the participating farmers, as it illustrated the direct impact of salinization on their farming systems. The main response was to invest in tap water infrastructure to assure a fresh water supply for their productive cows. However, this creates an extra economic burden for these farmers.

4.2.5. Response

Four out of nine farmers responded to salinization of their ditches and groundwater, by installing water pipes and water bowls for their cows. By doing this, they can assure their cows have access to fresh water the whole year round. If a pasture has not enough yield or production value, they may also choose to give the land '*back to nature'*, for which they receive a certain amount of nature subsidy per hectare per year. This results in land abandonment across the polder area.

One of the farmers was in favour of creating a new salt marsh in front of the dike. This could reduce the amount of seawater intrusion. The restoration of the salt marshes could not only serve as a natural sea defence mechanism, it could also increase the natural habitat for bird populations and native halophytes (van Loon-Steensma *et al*., 2014). Historically, there used to be salt marshes on different locations in front of the dike (Teunis *et al*., 2017). This is shown in figure 13, presenting a map of the study area as of 1850.

Figure 13. Map of Terschelling as of ca. 1850 (van de Klundert, 2013).

These salt marshes have disappeared due to a combination of factors. First, the dike prevented for the salt marshes to shift landwards (van Loon-Steensma *et al*., 2014). In addition, the enclosing dike is suspected of changing the influence of the tides, causing increased erosion of the salt marshes (van Loon-Steensma *et al*., 2014). Therefore, one of the hydrologists explained that the restoration of the salt marshes would be hard to achieve, as natural sedimentation processes are hampered by those different drivers (E1).

Another posed solution is the capture and storage of precipitation surplus in the winter and autumn, which could be used for flushing of the polder area when needed (E3). However, the local forestry would not be in favour of this flushing solution, as it could lead for the invasive plant species (*Crassula helmsii*) to expand its territory towards the polder area (E4). However, capture and storage of the precipitation surplus in the dunes does create a higher pressure from the fresh water lens, where the farmers in the low-lying polder area may benefit from (E1, E4).

Another, more promising way for securing fresh water storage, is by installing local, manually steered weirs in local ditches surrounding the pastures of farmers (E1, E2, E3, E4). In this way, farmers can regulate individually how much water they retain during periods of precipitation surplus. This creates the possibility for local fresh water storage and higher water tables in some of the local ditches. However, in order to achieve the maximum advantage from this option, farmers should be able to measure the EC values of the ditch water themselves, so that they can decide in which ditches they would want to store fresh water and which ditches would be too salty (E1). Two of the farmers are already committed to heightening of the local water table, would it be for different motives. They mainly keep the groundwater levels high in order to attract meadow birds. However, they did argue how it might reduce salinity problems on their pastures, which is also recognized by experts (E1, E2, E3, E4). The measurements conducted on their pastures also verified this by showing lower salinity levels on average.

One of the hydrologists claimed that it could also be possible to create a fresh water storage in the deeper soil layers beneath the polder area (E2). According to him, this has already be proven to be successful on the island of Texel.

At last, searching for salt tolerant, deep-rooting forage grasses might be an interesting response as claimed by some of the farmers and the local bird watch (E3). This could increase the production value of the salt-affected pastures, hereby decreasing the economic burden of the farmers. Recommendations for further research on this topic will follow in section 5.

4.2.6. Conclusion

Based on these results, a DPSIR framework of the salinization processes of the polder area of Terschelling can be established. The DPSIR framework of salinization created by Negacz *et al*. (2021) was used as a starting point. However, due to the context specific character of salinization problems, some alterations were made. For instance, artificially low water tables were added under the pressure part. Other alterations are the declined milk production being amongst one of the impacts. Especially the responses are very much context specific. For instance, experimenting with deep-rooting forage grasses may not be posed as a solution elsewhere. The resulting DPSIR framework is visualized in figure 14.

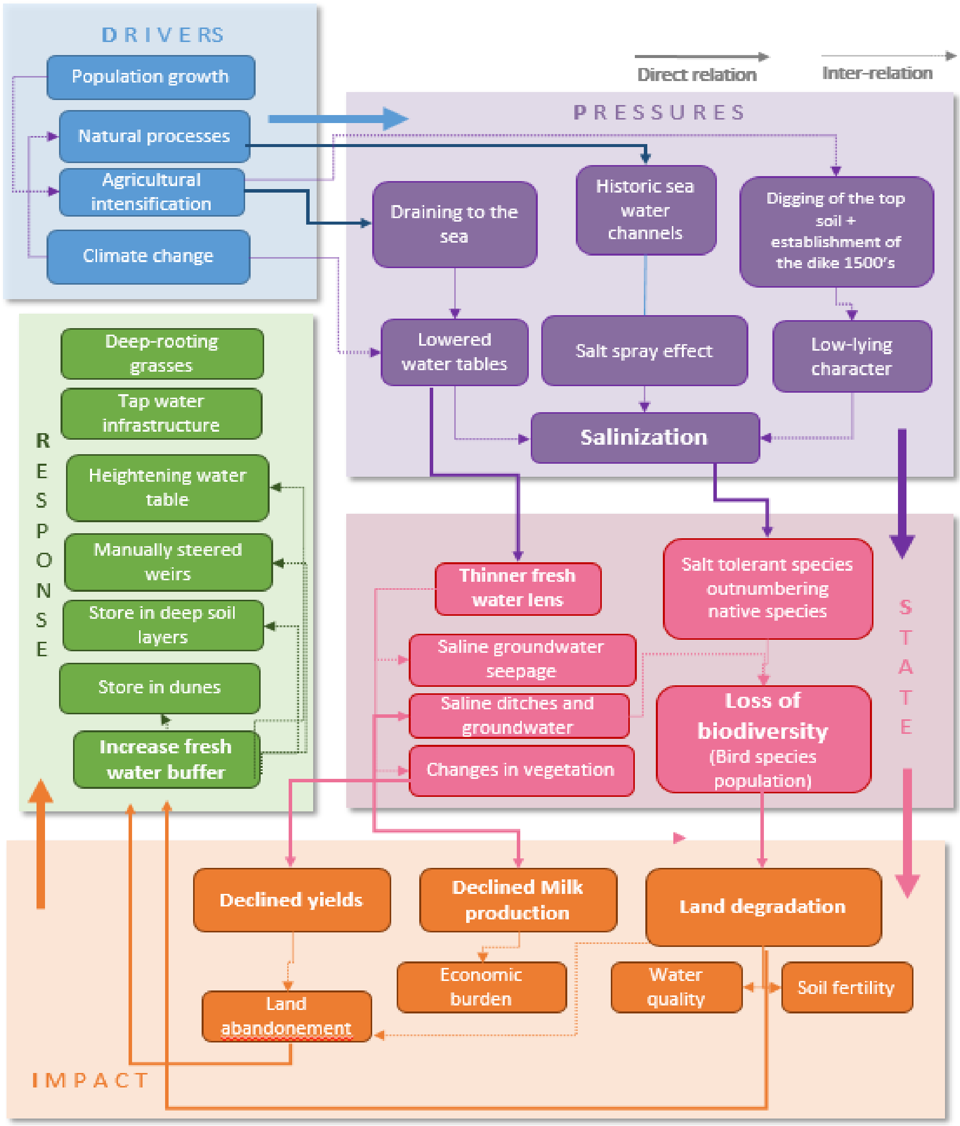

Figure 14. the DPSIR framework of salinization in the low-lying polder area of Terschelling.

This figure is a simplified overview of the many underlying processes as described in the previous sections. There might be even more interrelations between the different elements. However, in order to maintain readability of the framework, only the main indirect and direct relationship are presented.

4.3. Farmers' perspectives after presentation of the measurements

As described by the theoretical framework of Mills *et al*. (2017), biophysical factors might influence farmers' decision-making processes. In this section, the influence that salinity levels of local groundwater and surface water might have on farmers' perspectives on the prospects of saline agriculture on the island of Terschelling will be detected:

"*What are the perspectives of farmers on prospects of saline agriculture on the island in relation to the salinity measurement outcomes?"*

The results are based on the interview data after presentation of the salinity maps to nine participating farmers and one fruit cultivator in the month of May.

4.3.1. Interpretation of the results

The measurements were according to the expectations of six out of nine participating farmers. Two farmers explained that the measurements showed higher salinity levels more inlands, which was not according to their expectations. One farmer explained that the measurements were lower than he expected. Therefore, he was not worried about salinization.

Five out of nine farmers noticed the one inland saline spot and argued that this could be the consequence of saline groundwater seepage. This saline spot was in line with the expectations of one of the farmers, who described that previous measurements also indicated that this particular ditch was more saline than ditches near the dike. This specific ditch also appeared to be more saline during follow-up measurements in May. This is an interesting finding which might be important to consider in further hydrological research.

4.3.2. Responses to salinization

Regarding the influence of the salinity maps on future farm planning, two out of nine farmers responded by increasing their tap water infrastructure sooner than planned. For one of the interviewees, the salinity map of salt tolerance of dairy cows influenced decision-making on which ditch to close off from cows to drink from during summer time. Another participant explained how the measurement outcomes affirmed his plan for creating a stronger current in the saline ditches, using a local water pump. According to him, this could increase the drainage of saline water, hereby lowering salinity levels.

Six out of nine farmers showed interest for the installation of manually steered weirs for local capture and storage of precipitation surplus. These weirs could facilitate the differentiation of water tables between different pastures. This might lead to a higher pressure from the fresh water lens and less water shortage during summer time, hence decreasing problems with salinization. Five out of nine

participating farmers showed interest in experiments with salt tolerant, deep-rooting forage grass species. This solution would be better suitable for the agricultural sector on the island, compared to the current experiments taking place on the saline garden. However, four farmers pointed to the fact that the pastures near the dike are characterized by a solid, non-permeable clay ground, which is almost impossible to plough for sowing new forage grasses. Therefore, four farmers explained that their main response was to give these pastures near the dike back to nature, hereby receiving a financial compensation. In this way, it is still possible to earn some money with these low-productive pastures.
Four farmers argued how heightening of the water table in the low-lying polder area will increase the pressure of the fresh water lens, leading to lower salinization rates. However, two other farmers argued that this would lead to the flooding of some of their lowest pastures. in addition, one farmer explained that this might lead to shorter grassroots, which in turn might increase the grasses' vulnerability to droughts.

None of the participating farmers gained renewed interest in the adoption of saline agriculture in their farming system. In addition, the local fruit cultivator showed no renewed interest, as the measurements affirmed that she did not suffer from salinization on her farmlands. One farmer argued that the saline garden will continue to exist, on the precondition that there will become another person for taking-over the responsibility and maintenance of the saline garden.

4.3.3. Conclusion

For three out of nine participating farmers, presentation of the measurements influenced their decision-making processes in their farm management: Two farmers reconsidered their tap water infrastructure planning by increasing their infrastructure even more or by increasing the speed of implementation. One of those farmers also showed some renewed interest in deep-rooting, salt tolerant forage grasses as a replacement for the English ryegrass on those less productive pastures near the dike. Another farmer would not allow anymore for her cows to drink from the local ditch, as it appeared to be to saline and could probably lead to health issues among her dairy cows.

Remarkable is the fact that the confrontation with salinity levels did influence their decision-making on their farm management, without leading to renewed interest in the adoption of saline agriculture. They were mainly focussed on improvements in the fresh water supply of their dairy cows and/or improving the production value of their pastures near the dike. This reaction could be explained by the fact that they felt no personal affinity for the cultivation of saline crops or halophytes. Therefore, they were unlikely to include cultivation practices in their daily farming schedules.

5. Discussion

5.1. Strengths & weaknesses

This interdisciplinary research generated detailed insight in the current salinity levels in the low-lying polder area of Terschelling, which could support both farmers' decision-making and municipal decision-making processes. In addition, the research contributes directly to some of the main objectives of the Zilte Smaak Foundation by presenting an indication of prospects for saline agriculture on the island, based on both biophysical and social aspects. Using a combination of farmers' perspectives, expert interviews and literature reviews, data has been triangulated and verified across different dimensions. By combining multiple perspectives and theoretical knowledge, an integrated assessment of the salinization issues in the low-lying polder area of Terschelling has been made. In addition, the research has contributed to increased knowledge on salinity levels in the local polder area, which could spark the debate around saline agriculture among local agricultural actors. Moreover, the salinity measurements could support further hydrological research in the low-lying polder area. Here, especially the one saline spot inlands is an interesting finding that should be taken into account, as it could be an indicator of saline groundwater seepage.

However, there are certain limitations to the research in temporal, social, biophysical and analytical dimensions. First of all, the study is characterized by a relatively short time span. Water measurements were conducted over a period of only two weeks in mid-April and several days in mid-May. Therefore, the study only provides a 'snapshot' in time. Salinity levels may differ across different seasons as a result of variations in precipitation and temperature patterns. In addition, there was not accounted for the influence of that the tides of the Wadden Sea might have on salinity levels. In turn, one of the farmers explained that the soil on the island is characterized by relatively high Magnesium concentrations, which is also one of the components of the EC value function. Therefore, actual salinity content of the groundwater and surface water might be lower than measured. At last, the research is characterized by a limited geographical scope. Therefore, it might be hard to generalize the research findings across different regions, as the findings are substantially context specific.

Regarding the social dimension of the research, not every farmer of the island was included in the research. Therefore, not all farmers' perspectives on prospects for saline agriculture on the island were included. However, since 9 farmers and two cultivators participated in total, and there are only 14 farms on the island, it can be concluded that the majority of farmers has been covered in the research. Another important thing to keep in mind is the fact that during qualitative research, it is important to remain reflexive and to consider the fact that the researchers' personal characteristics might have influenced the research outcomes.

5.2. Recommendations

As the research is characterized by a limited temporal and spatial scope, it might be interesting to conduct further long-term research in the hydrological situation of Terschelling. The newly generated insights in local fresh water and saline water fluxes could support future decision-making processes on different practical hydrological solutions for improving the fresh water supply in the polder area. Further hydrological research may discover yearly patterns of salinization processes. This could in turn lead to increased knowledge and insight among farmers on what to expect and how to anticipate expected salinization processes on their pastures. As stated by one of the hydrologists, it would be useful if farmers could independently measure the salinity measurements in their own ditches. In this way, they are empowered and can decide for themselves in which ditch to place local weirs.

Regarding recommendations on further research for saline agriculture, it might be interesting to experiment with the production of halophytes or salt-tolerant crops that could be used as fodder for livestock, as the local agricultural sector mainly consists of dairy farmers. However, previous research indicates possible negative side-effects on livestock when solely fed with halophytes (Masters *et al.*, 2007). In addition, many salt tolerant crops actually consist of a substantial amount of non-protein nitrogen matter, leading to a lower nutritional value and lower energy intake (Masters *et al.*, 2007; Norman *et al.*, 2007). Therefore, it would be more interesting to focus on salt tolerant forage grasses in further research.

Previous research has been conducted on the use of halophytic forage grasses as a replacement for conventional forage grasses (Norman *et al.*, 2013). There are over more than 7500 grass species (*Poaceae*) with a substantially varying salt tolerance across different species (Marcum, 2008). Systemic processes of plant selection for livestock production on saline pastures might significantly improve total production values (Masters *et al.*, 2007). Perennial ryegrass (*Lolium perenne L.*) is known for its high yield and good quality in temperate regions across the globe (He *et al.*, 2018) and is the homogenous vegetation on the pastures of the conventional farmers used for grazing on Terscheling. The species is ranked as '*moderately salt-tolerant'* (He *et al.*, 2018) with an approximate salt tolerance between 4 to 8 dS/m in the top soil (Marcar, 1987). Therefore, it could be interesting to sow other, more salt-tolerant grass species that could be used for foraging of dairy cows.

Not much research has been conducted yet on this topic on the island of Terschelling. One research conducted on the island of Texel, described Lucerne (*Medicago sativa*), as being highly salt tolerant, nutritious for livestock and could additionally be used as green manure (de Vos *et al.*, 2015; Leendertse & Blok 2020). Lucerne tolerates salt levels up to 16 dS/m in the soil surface, which is a considerably high salinity level (de Vos *et al.*, 2015). Lucerne is a widely known species and could be used as fodder directly via grazing as well as for dry fodder (de Vos *et al.*, 2015). In addition, recent research conducted in the Netherlands on the sustainability aspects of Lucerne showed that it contributes to soil improvement by its deep rooting character, water retention capacity and natural nitrogen fixation (Leendertse & Blok, 2020).

In addition, there are some clover species with a moderate salt-tolerance, which might be interesting to consider as well, especially since Lucerne is mostly sowed in a mixture with different grasses and clovers when livestock fodder is the main production objective. These are the White clover (*Trifolium repens*), the Honey clover (*Melilotus*), the Strawberry clover (*Trifolium fragiferum*) and the Bird's-foot trefoil (*Lotus corniculatus*). The honey clover tolerates EC values of 20 dS/m and is already used in seed mixtures in the United States on saline forage pastures (de Vos *et al*., 2015). However, more detailed research is needed for determining which seed mixtures generate the highest yields in the particular environmental context of Terschelling.

At last, based on the research outcomes, one other recommendation derives. As described earlier, the majority of the farmers did not show interest in the cultivation of saline crops, due to reasons of time, finance, human capital and personal affinities. Therefore, the saline garden does not seem to fit the character of the local agricultural sector. These research outcomes are not surprising and support previous literature on transition management for sustainable development. The outcomes namely reflect a *'lock-in situation'* which can only be overcome with the introduction of new, diverse and creative actors, rather than introducing new government-based institutionalizations like subsidies (Loorbach, 2007; Kern & Smith, 2008; E5). Internal or external innovative entrepreneurs may spark the debate around a sustainability transition and may even change the long-term goal setting of a particular sector (Loorbach, 2007). Therefore, a recommendation based on both the research outcomes and previous literature, might be to search for new innovative entrepreneurs, who are ready to invest in the relatively experimental stage of saline agriculture on Terschelling, instead of trying to change the current *locked-in* agricultural actors.

6. Conclusion

The objective of this interdisciplinary research was to generate insight in the prospects for saline agriculture on Terschelling, based on farmers' perspectives and local groundwater and surface water salinity measurements. Based on farmers' perspectives, it can be concluded that the majority of the farmers thinks that the prospects for development of saline agriculture on the island are low.

Main reasons were the labour-intensive character, lack of personal affinity and low economic incentives for the adoption of saline agriculture in their farming systems. One farmer who is actively involved in De Zilte Smaak Foundation, thought that the saline garden could be economically profitable, on the precondition that the production output and labour power would scale up. However, this requires new, innovative actors with the right amount of resources to invest in saline agriculture. The presentation of the salinity maps had no influence on farmers' perspectives on saline agriculture and their willingness to adopt the cultivation of saline crops or halophytes in their daily farming routines. Nevertheless, three farmers aimed at implementing some adjustments in their farm management in response to presentation of the salinity measurements, mainly with the aim of protecting their dairy cows against negative influences of salinization processes.

Regarding water salinity measurements, it can be concluded that salinity levels of the surface water and groundwater increased, with decreasing distance to the coastal dike. In addition, it may be concluded that the surface water is characterized by higher salinity levels compared to the groundwater, which is according to the expectations of the hydrologists. Furthermore, the salinity measurements provided directly applicable knowledge to the respondents, leading in some cases to direct changes in farm management strategies. Altogether, using a DPSIR framework, it can be concluded that the pastures near the dike suffer from a substantial amount of pressures and environmental changes: salinity levels are high, bird populations are changing, cattle cannot drink from the ditches, English ryegrass is not growing, and biodiversity is changing, leading to significant losses in production value.

According to several climate modelling studies, salinization rates in the Wadden region will continue to increase over time. Therefore, it is important that action will be undertaken in order to avoid further agricultural problems deriving from salinization of the vulnerable low-lying polder area of Terschelling. The findings of the research suggest several courses of action that might lead the way towards harmonization between salinization processes and local agriculture.

7. Acknowledgements

Hereby I would like to thank my first supervisor Pier Vellinga for his guidance, support and feedback throughout the research project. In addition, I would like to thank Kate Negacz and Matilda Petersson for their additional guidance and suggestions during our weekly zoom meetings. Furthermore, I want to express my appreciation and gratitude to every participating farmer, cultivator and expert for sharing their valuable time, knowledge and perspectives, and turning this research into the valuable and educational experience that it has been to me. I want to thank in particular Jouke Velstra (Acacia Water) for facilitating the measurement equipment and for helping with the final data conversion. I want to thank Z. Malek and S. van Denzen for their support and guidance through the final data analysis and visualization in QGIS. I also want to thank my fellow student Suzanne van Veen for her support, input and sharing of ideas during our stay on Terschelling. At last, this research project was conducted as part of the Interreg VB North Sea Region SalFar project and the ERA-NET Cofund FOSC SALAD project. I want to thank the participating organizations, in particular The Waddenacademie (Leeuwarden) and De Zilte Smaak (Terschelling) for supporting the research.

8. References

Bartkowski, B., & Bartke, S. (2018). Leverage points for governing agricultural soils: A review of empirical studies of European farmers' decision-making. In *Sustainability (Switzerland)* (Vol. 10, Issue 9). MDPI AG. https://doi.org/10.3390/su10093179

Berger, R. (2015). Now I see it, now I don't: Researcher's position and reflexivity in qualitative research. *Qualitative research*, 15(2), 219-234.

Bergkamp, J., Berndsen, A., Meulenberg, V., & Prins, K. (2018). The socio-economic and ecological potential of saline agriculture on islands.

de Boer, H. C., & Radersma, S. (2011). *Verzilting in Nederland: oorzaken en perspectieven* (No. 531). Wageningen UR Livestock Research.

De Kempenaer, J. G., Brandenburg, W. A., & van Hoof, L. J. W. (2007). *Het zout en de pap: een verkenning bij marktexperts naar langeretermijnmogelijkheden voor zilte landbouw* (No. 07.2. 154). InnovatieNetwerk.

Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy policy*, 36(11), 4093-4103.

De Louw, P. G., Eeman, S., Siemon, B., Voortman, B. R., Gunnink, J., Van Baaren, E. S., & Oude Essink, G. H. P. (2011). Shallow rainwater lenses in deltaic areas with saline seepage. *Hydrology and Earth System Sciences*, *15*(12), 3659-3678. doi:10.5194/hess-15-3659-2011.

de Vos, A., Bruning, B., van Straten, G., Oosterbaan, R., Rozema, J., & van Bodegom, P. (2016). *Crop salt tolerance under controlled field conditions in The Netherlands, based on trials conducted at Salt Farm Texel*. Salt Farm Texel.

De Vos A., Van Rijsselberghe A.M.J., Kieft, H. (2015). Zilt Perspectief. Kennis en kansen voor teelt en verwerking van gewassen op zilte landbouwgrond rond de Wadden afgestemd op de unieke natuurlijke en landschappelijke kwaliteiten met aandacht voor educatie en kennisverspreiding. *Eindverslag Waddenfondsproject 209829*. Stichting Zilt Perspectief.

Dessein, J., & Nevens, F. (2007). 'I'm Sad To Be Glad'. An Analysis of Farmers' Pride in Flanders. *Sociologia Ruralis*, *47*(3), 273-292.

Edwards-Jones, G. (2006). Modelling farmer decision-making: concepts, progress and challenges. *Animal science*, *82*(6), 783-790.

FAO. (2018). *The future of food and agriculture – Alternative pathways to 2050*. Rome. 224 pp. Licence: CC BY-NC-SA 3.0 IGO.

Gabrielsen, P., & Bosch, P. (2003). Environmental indicators: typology and use in reporting. *EEA, Copenhagen.*

Guion, L. A., Diehl, D. C., & McDonald, D. (2011). Triangulation: Establishing the validity of qualitative studies. *EDIS*, 2011(8), 3-3.

He, A. L., Niu, S. Q., Zhao, Q., Li, Y. S., Gou, J. Y., Gao, H. J., ... & Zhang, J. L. (2018). Induced salt tolerance of perennial ryegrass by a novel bacterium strain from the rhizosphere of a desert shrub Haloxylon ammodendron. *International journal of molecular sciences*, 19(2), 469. doi:10.3390/ijms19020469.

Kafi, M., Asadi, H., & Ganjeali, A. (2010). Possible utilization of high-salinity waters and application of low amounts of water for production of the halophyte Kochia scoparia as alternative fodder in saline agroecosystems. *Agricultural Water Management*, *97*(1), 139-147. doi:10.1016/j.agwat.2009.08.022.

Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of advanced nursing*, 72(12), 2954-2965. doi: 10.1111/jan.13031.

Kok, A. (2006). Salinization above sea level on the Dutch Wadden Islands. In *Paper SWIM-SWICA conference Sardinia (Italy).*

Kok, A., & A. Kok. (2007). *Aastermiede & Wachthuusplak. Veldnamen op Terschelling in duin en polder*. Gorcum B.V.

Klein Tank, A., Beersma, J., Bessembinder, J., Van den Hurk, B., & Lenderink, G. (2014). KNMI 14: Klimaatscenario's voor Nederland. *KNMI publicatie*.

Ladeiro, B. (2012). Saline agriculture in the 21st century: using salt contaminated resources to cope food requirements. *Journal of Botany*, 2012. doi:10.1155/2012/310705.

Leendertse, P., & Blok, A. (2020). Bijdrage van luzerne aan Europese milieu-en klimaatdoelstellingen.

Logboekweer. (2021, July, 1). *Neerslag en neerslagoverschot/-tekort Terschelling, 'gemiddeld systeem'.* https://www.logboekweer.nl/Neerslagoverschot/Terschelling_NOV.pdf.

Loorbach, D. (2007). Transition management. *New mode of governance for sustainable development. Utrecht: International Books*.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., ... & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature climate change*, 4(12), 1068-1072. | DOI: 10.1038/NCLIMATE2437.

Mulder, J. R., & Spoelstra, J. (1995). *Een geohydrologische systeembeschrijving van het noordelijke deel van het herinrichtingsgebied Bergen-Schoorl* (No. 325). DLO-Staring Centrum.

National Research Council. (2001). Nutrient requirements of dairy cattle, National Academy of Science. *Washington, DC.*

Negacz, K., Bruning, B., & Vellinga, P. (2021). Achieving Multiple Sustainable Development Goals through Saline Agriculture. In *Future of Sustainable Agriculture in Saline Environments* (pp. 13-28). CRC Press. DOI: 10.1201/9781003112327-1.

Norman, H. C., Masters, D. G., & Barrett-Lennard, E. G. (2013). Halophytes as forages in saline landscapes: interactions between plant genotype and environment change their feeding value to ruminants. *Environmental and Experimental Botany*, 92, 96-109. http://dx.doi.org/10.1016/j.envexpbot.2012.07.003.

Marcar, N. E. (1987). Salt tolerance in the genus Lolium (ryegrass) during germination and growth. Australian Journal of Agricultural Research, 38(2), 297-307.

Marcum, K. B. (2008). Saline tolerance physiology in grasses. In Ecophysiology of high salinity tolerant plants (pp. 157-172). *Springer*, Dordrecht.

Masters, D. G., Norman, H. C., & Barrett-Lennard, E. G. (2005). Agricultural systems for saline soil: the potential role of livestock. *Asian-Australasian Journal of Animal Sciences*, 18(2), 296-300.

Masters, D. G., Benes, S. E., & Norman, H. C. (2007). Biosaline agriculture for forage and livestock production. *Agriculture, ecosystems & environment*, *119*(3-4), 234-248. doi:10.1016/j.agee.2006.08.003.

Mills, J., Gaskell, P., Ingram, J., Dwyer, J., Reed, M., & Short, C. (2017). Engaging farmers in environmental management through a better understanding of behaviour. *Agriculture and Human Values*, *34*(2), 283-299. DOI: 10.1007/s10460-016-9705-4.

Oude Essink, G. H. P., Van Baaren, E. S., & De Louw, P. G. (2010). Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands. *Water resources research*, *46*(10). https://doi.org/10.1029/2009WR008719.

Oude Essink G. H. P. (2001). *SALINISATION OF GROUNDWATER RESOURCES IN THE DUCTH DELTAIC AREA: MODELLING, MONITORING, CLIMATE CHANGE AND SOLUTIONS*. Deltares.

Pascucci, S., Dries, L., Karantininis, K., Martino, G., Ambrosius, F. H., Hofstede, G. J., ... & Beulens, A. J. (2015). Modelling farmer decision-making: The case of the Dutch pork sector. *British Food Journal.*

Pauw, P., de Louw, P. G. B., & Oude Essink, G. H. P. (2012). Groundwater salinisation in the Wadden Sea area of the Netherlands: Quantifying the effects of climate change, sea-level rise and anthropogenic interferences. *Geologie En Mijnbouw/Netherlands Journal of Geosciences*, *91*(3), 373–383. https://doi.org/10.1017/S0016774600000500

Pereira, C. S., Lopes, I., Abrantes, I., Sousa, J. P., & Chelinho, S. (2019). Salinization effects on coastal ecosystems: a terrestrial model ecosystem approach. *Philosophical Transactions of the Royal Society B*, *374*(1764), 20180251. https://doi.org/10.1098/rstb.2018.0251.

Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R. J., ... & Noble, A. D. (2014). Economics of salt-induced land degradation and restoration. In *Natural resources forum*. Vol. 38, No. 4. 282-295. DOI: 10.1111/1477-8947.12054.

Rhoades, J. D., Kandiah, A., & Mashali, A. M. (1992). The use of saline waters for crop production-FAO irrigation and drainage paper 48. *FAO,* Rome, 133.

Rietveld, H. (1986). Land subsidence in the Netherlands. In *Proceedings of the 3rd international symposium on land subsidence* (Vol. 151, pp. 455-465).

Rommel, M. C. (2004). Morfologische veranderingen als gevolg van bodemdaling door gaswinning. *Rapportnr.: 2004.004.*

Ruto, E., Gould, I., Bosworth, G., & Wright, I. (2018). The state, causes and impact of soil salinization: a global overview. *S*ALFAR Work Package 3 Baseline January 2018 Report.

Ruto, E., Tzemi, D., Gould, I., & Bosworth, G. (2021). Economic Impact of Soil Salinization and the Potential for Saline Agriculture. In *Future of Sustainable Agriculture in Saline Environments* (pp. 93-114). CRC Press.

Saldaña, J. (2021). *The coding manual for qualitative researchers*. SAGE Publications Limited.

Speelman, H., Oost, A., Verweij, H., & Wang, Z. B. (2009). De ontwikkeling van het Waddengebied in tijd en ruimte. *Position paper geosciences. Leeuwarden: Waddenacademie*.

Stichting Salt Farm Foundation (2019). *Verzilting in Nederland*. https://saltfarmfoundation.com/nl/verzilting-innederland/#:~:text=De%20droge%20en%20hete%20zomer,de%20bodem%20en%20het%20oppervlaktewater.

Teunis, M., M. Dorenbosch & B. Doedens. (2017). Kwelderherstel Terschelling. Definitief ontwerp. Rapport Bureau Waardenburg 16-254, Bureau Waardenburg - Culemborg / *Stichting Landschapstheater en Meer* – SLeM,- Amsterdam.

van de Klundert, B. B. (2013). Boerenlandschap van Terschelling.

Van der ploeg, J.D. (1993). Rural sociology and the new agrarian question: a perspective from the Netherlands. *Sociologia Ruralis*, Vol. 18 No. 2, pp. 240-260.

van Loon-Steensma, J. M., Slim, P. A., Decuyper, M., & Hu, Z. (2014). Salt-marsh erosion and restoration in relation to flood protection on the Wadden Sea barrier island Terschelling. *Journal of coastal conservation*, 18(4), 415-430. DOI 10.1007/s11852-014-0326-z.

Vellinga, P., Rahman, A., Wolthuis, B., Barrett-Lennard, E. G., Choukr-Allah, R., Elzenga, T., ... & Negacz, K. (2021).Saline Agriculture: A Call to Action. *In Future of Sustainable Agriculture in Saline Environments* (pp. 3-12). CRC Press.

Annex 1. Semi-structured interview questions

Interview questions sub-question 1:

1. To your knowledge, is any of your field affected by salinity and how would you recognize this?
2. Do you have an idea about how salinity on Terschelling could develop in the future?
3. What would you do if increasing salinity is likely to negatively affect your production within the next 20 to 50 years?
4. Would you rather adapt your agricultural methods or mitigate salinization by flushing with fresh water, and why?
5. What are the limitations of these responses to high salinity levels?
6. (Why) would you consider saline agriculture as an interesting/not interesting option?
7. We are planning to measure the quality of your ditch water and groundwater to find out whether salinity intrusion is occurring in your fields. How do you feel about this and what do you expect?
8. What would be your response if salinity levels are higher than you expected?

Interview questions sub-question 3:

1. These are the salinity levels of your ditch water and groundwater. How do you feel about the measurement outcomes?
2. Do the measurement outcomes influence the future planning of your farm?
3. What do you expect of future productivity of your lands, based on the measurements?
4. Did the measurements change your interest in saline agriculture?

Interview questions sub-question 4:

1. Except for salinity, could you point out some other factors that contribute to your decision-making on agricultural practices?
2. In your opinion, what are the most limiting factors of saline agriculture?
3. What should change in order to make saline agriculture an interesting option for you ?

4. Do you think other farmers would be interested in saline agriculture?
5. Have you ever heard other farmers considering saline agriculture?
6. Would you consider saline agriculture if other farmers practice it as well?
7. Do you think saline agriculture has the potential of becoming a new custom/tradition on the island? Why do you think this?

Annex 2. Expert interviews

E1. Hydrologist

Date: 6-05-2021, 12:30
Place: Noordwijk, South-Holland
Method: Zoom

Joris Schaap is an independent hydrologist and soil scientist as of 2015.

According to you, what could be a reason the low difference between shallow and deep surface water measurements?

Salt mixes easy with fresh water and therefore, results between shallow measurements and deep measurements in surface water might not differ that much, especially when the water is flowing. One should also take note of the fact that the measurements took place in spring, which is a relatively wet period compared to other seasons.

What would you expect from salinity levels across different seasons?

There could be a temporal effect of salinity levels, where levels would be higher during a dry and hot summer period, causing a lowered pressure from the fresh water lens and a relatively higher upward pressure of saline groundwater (seepage). Therefore, it might be interesting to search for places during summer time, where saline groundwater seepage is relatively high. This seepage could also explain the higher EC values measured in the middle of the study area. This lowered pressure on saline groundwater is caused by two elements: lowered water levels in the ditches and lower precipitation leading to a smaller fresh water lens. It could be interesting to conduct some follow-up measurements in May, drawing some structural lines and conduct some strategic measurements. As a suggestion, take measurements along 4 vertical lines, from dune to sea, conducting 4 measurements on each line. It would be interesting to find out whether the salt gradient would have shifted as a consequence of seasonal effects

How may historical salt marshes and old sea water channels influence salinity levels in the groundwater and surface water?

In the past, historical flooding events in different parts of the Netherlands caused a short increase in salinity of the top soil in the first place, but after approximate two years of precipitation excess, this salinity was actually flushed away and salinity conditions become more or less the same as before the flooding events. Therefore, historic salt marshes are not always necessarily characterized by higher levels of salinity. However, most salt marshes are lowlands and therefore, they could be more salty since they have a smaller fresh water lens. In the past, Terschelling used to flood once in a while, leading to local sea water channels. These channels could become visible on the map created in the research. These channels would be characterized by their higher salinity levels. Therefore it might be interesting to compare the salinity map with an elevation map of the study area.

What could be practical solutions against salinization of the polder area of Terschelling?

Restoration of the salt marshes outside the dikes would require a lot of effort and it might be possible that these salt marshes would disappear after a longer period of time due to erosion and the fact that there is no natural in and outflow of water. This decreases the natural sedimentation and creation of the salt marsh. The most practical solution would be to store fresh water in the dunes. It might be possible to store fresh water in the local ditches, by installing small weirs. These weirs could be heightened in times of heavy precipitation, keeping fresh water in the ditches instead of draining this straight in to the sea. There is a risk that pastures might become too wet, however, farmers would be able to manage these weirs themselves. Pumping up fresh groundwater could draw saline groundwater up into the surface layer of the soil and the rooting zone.

The use of fresh water from the dunes may result in lower salinity levels. This is what the organic dairy farmer is already doing. The organic sheep farmer is relatively closely located to the dunes, so therefore, his pastures and ditches might suffer less from salinization. In addition, shallow drain pipes(50 – 60 cm deep) might increase the fresh water lens in the top soil. This is however, a more expensive solution.

What is the influence of climate change on salinization processes in the polder area?

Especially extreme droughts are likely to increase salinization processes in the short term. Drain pipes lead to an artificially lowered groundwater level, causing drought stress during summer times. In addition, drainage might reduce the pressure on saline groundwater. Most grasses are pretty salt-tolerant, therefore it is more likely to be a drought related problem. Sea level rise is a slow occurring factor, currently not yet that much influencing salinization processes in the Netherlands. Droughts during summer time lead to decimetres difference in groundwater tables, whereas sea level rise occurs by millimetres. Therefore, as of now, droughts have a more intense effect on salinization processes than sea level rise.

Do you have any other advise for the interpretation of the measurement results?

It would be important to differ between groundwater measurements and surface water measurements, since these are two different water systems. Even if surface water measurements show a high salinity, groundwater could be fresh due to the fresh water lens. Therefore, crop growth would not be negatively affected and farmers would not have to worry too much. In addition, since there was not that much difference between the deep measurements and surface measurements of the surface water, it might be okay to include them in one map.

After returning to Terschelling in May, it appeared to be that there is actually no drainage system in the polder area. Therefore, the hydrologist was approached one more time via e-mail contact, asking about other influential factors apart from local drainage systems. The answer was as followed:

"The fact that there is no local drainage system does not influence the water system that much. In the end, it all depends on the local groundwater table. This water table might be held artificially low by using drainage pipes, however, this could also be exercised through deep ditches, a low surface water table and trenches. Drainage pipes support the lowering of this water table. The best explanation is by drawing a summer and winter situation sketch:

- during winter time, there is precipitation surplus. The local trenches are supporting drainage of the precipitation surplus, there is a relatively thick fresh water lens and the lens is bold.

- during summer time, there is more evapotranspiration and precipitation deficiency, deep ditches cause draining, resulting in a hollow groundwater table and a relatively thin freshwater lens. The ditches are likely to become more saline since the saline seepage from the Wadden sea increases."

E2. Hydrologist

Date: 12-05-2021, 12:30
Place: Noordwijk, South-Holland
Method: Zoom

Jouke Velstra is the director and senior advisor of Acacia Water. He is specialized in advisory schemes for water supply systems in the Netherlands and Europe.

What is your overall interpretation of the measurements?

One can clearly see a salinity gradient through the polder area. The closer to the dike, the more saline the ditches and groundwater are. If there would be a local drainage system, this might decrease the fresh water lens, hereby increasing the influence from upcoming saline groundwater. This could in turn lead to higher salinity levels in the ditches and groundwater of pastures. this could even lead to salt damage in the rooting zone of the grasses on the pastures. If the pressure of saline groundwater is high, drain pipes might actually have a positive influence, lowering salinization processes. In this case, the drain pipes are draining the excessive saline groundwater away from the surface layer of the soil. However, if the pressure from the saline groundwater is not that high, drainage might actually increase salinization processes by artificially lowering the groundwater table, reducing the pressure and buffer of the fresh water lens. The use of small trenches for draining excessive rainwater might therefore be a better option, since this does not affect the fresh water lens. As of now, there is no detailed knowledge about the saline groundwater seepage in the polder area. The pressure of saline groundwater might be just below NAP. This means that the closer the soil surface is to the sea level, the higher the saline seepage could be. In addition, a lower soil surface leads to less room for the fresh water lens. Therefore, the lower the land, the smaller the fresh water lens and the higher the pressure and influence of saline seepage.

Salinity levels in groundwater and surface water of the organic sheep farmer might be lower, due to the relatively close location to the dunes. The organic dairy farm uses fresh water from the dunes to keep the water levels in his ditches high. Therefore, levelling his ditches might increase pressure from the fresh water lens, leading to lowered salinity levels in the ditches and groundwater. Salinity levels in May, compared to April, might not differ that much, since precipitation patterns have been quite high in both periods. . Blueish water, as described by one of the farmers, could be an indicator for upcoming saline seepage water. The blue colour is caused by a combination of iron and sulphate concentrations. The water might even turn a bit white in the deeper parts of the ditches.

What could be an explanation for the opposite results than expected in differences between shallow and deep surface water measurements?

The difference between shallow and deep surface water measurements could be influenced by high temperatures and /or the mobility of the water. Most of the times, salty water is less mobile and heavier than fresh water. This results in fresh water flowing on top of salty water. In addition, temperatures may influence the location of saline water. Higher temperatures in shallow water may lead to relatively higher salt concentrations at the surface level. This could explain why some of the measurements showed higher salinity levels in shallow surface water, instead of the other way around. However, in order to determine whether temperature was the actual cause of these flipped salinity levels in some of the ditches, more research is needed.

How may historical salt marshes and seawater channels influence salinity levels of surface water and groundwater?

The influence of historic salt marshes mainly depends on the soil structures. Clay might decrease saline levels since it has a more solid structure compared to sand. Sandy soils have a better capillary function and lowered resistance, hereby supporting salinization processes better compared to clay. A good thick clay layer might therefore decrease the influence of saline seepage water. The historic channels are characterized by a sandy soil, hence, salinity levels might be higher on these particular locations. That is something that might be seen from the measurements. Salinity is a function of the soil structure and characteristics, location, saline groundwater seepage and drainage methods. It might be interesting to compare heights and soil structures with the measurements, and see what could have influenced salinity levels of the ditches and groundwater. Since it seems that height levels don't differ that much, soil structures may be more interesting and more contributing to differences between the measurements. In addition, it might be interesting to take some measurements close to the old channels and see how they differ.

He does not know If salinity is getting worse. They have only been studying salinization for 10 years, where the first years were mainly focussed on understanding the system dynamics. Regarding the groundwater measurements, he did not expect these salinity levels. If it is already saline now in spring, it could be even higher than expected during summer time. He has seen similar salinity levels on only two other places in the Netherlands (Zeeland and Friesland). It might be due to the fact that the pastures next to the dike are very low, compared to other pastures. The top surface of these pastures is just above or below NAP, leaving almost no space for the fresh water lens. In addition, historically there was no dike. The building of the dike might have caused some land subsidence.

What is the influence of climate change on the salinization processes in the polder area?

Evaporation of grasses might increase, leading to a higher saline groundwater seepage. The increased pressure of saline groundwater seepage, in combination with sea level rise will have the most effect on salinization processes in the coming 30 years. Droughts are leading to more salinization problems in the short term.

What are your future perspectives on salinization processes in the polder area?

For the future, salinity might increase, even faster than we might expect. So we need to start thinking about solutions. For this particular part of Terschelling, we should use the fresh water from the dunes better, decreasing the amount of fresh water that runs off straight into the sea during wet periods. A 'smart' fresh weir might overcome this problem. This weir is constructed in such a way, that it halts the deeper saline water currents and allows fresh surface water to flow through the ditches. The focus should be on separating the fresh water flux from the saline water flux by determining which ditch may be saline and which ditch should remain fresh. As of now, such things have not been discussed yet, since there was no urgent need for this. The agricultural system in the Netherland is focussed only on the drainage of excessive precipitation. Therefore, our water management has to change. The capture and storage of fresh water in the dunes is not very likely to become a success, since the dunes are already saturated with fresh water. Therefore, local capture and storage of fresh water in the polder area might be a suitable solution. This water could be stored in deep soil layers, creating an underground fresh water basin. This solution is already successful implemented in Texel.

E3. Chair of the local birdwatch

Date: 21-05-2021, 13:30
Place: Formerum, Terschelling
Method: in person

As of now, A. Doeksen has been the chair of the local birdwatch for over 15 years. He is actively involved with the counting of bird populations on the island.

Did the bird populations change due to salinization in the polder area?

Mainly oystercatchers are increasing their territories more inlands. Numbers of lapwings and godwits are decreasing on the pastures near the dike and are nesting more inlands. These meadow bird populations are vulnerable to salinization, because they do not drink saline water and the number of worms decreases substantially if salinity levels are high. Therefore, lapwings and godwits mainly nest where salinity levels are low. This is also noticeable when comparing the salinity measurements with the nesting sites of the different meadow bird populations. In addition, lowering the fresh water table leads to decreasing numbers in meadow bird populations. Seagull populations are not increasing due to salinization. These colonies are actually decreasing substantially in numbers, however, it has yet to be determined what are the underlying causes of this inclination.

What do you think of the goose populations on the island?

The goose populations are disturbing the meadow bird populations by shortening the English ryegrass and pushing native meadow birds aside. Especially the grey goose population puts additional pressure on the meadow birds and productivity of the pastures, since these gooses also breed and settle on the island, hereby extending goose related damage during all seasons. The brent-goose population only hibernates on the island and leaves at the end of May. These brent-gooses have been hibernating on the island for over decades. Interesting to notice is that they only seem to be interested in the homogenous, protein rich English ryegrass pastures. They are not attracted by organic pastures that have increased biodiversity. The grey goose population will cause major problems in terms of productivity of the pastures and meadow bird populations.

What are the underlying processes leading to salinization in the polder area?

Climate change is one of the drivers of salinization in the polder area, due to sea level rise. In addition, the intensive character of the local agriculture requires low water tables in the ditches, which leads to less pressure of the fresh water lens. The lower the fresh water level in the ditches, the lower the pressure from the fresh water lens and the higher the influence the saline seepage water may generate. In addition, the polder area is relatively low-lying compared to other Wadden islands. This could be due to the relatively early establishment of the dike, leading to halt on the natural processes of the sedimentation of clay..

What is the influence of old sea water channels on salinization processes in the polder area?

The historical sea water channels lead to higher salinity levels in the groundwater and surface water. This can be indicated by different vegetation, tasting the surface water and looking at the bird populations that breed in these pastures.

Is salinization increasing over the time, to your knowledge?

There have always been salt affected pastures in the polder area of Terschelling. Whether it has increased over time, I am not sure. However, the lowered water table in the polder may lead to increased pressure from saline groundwater seepage.

How do you recognize salt affected pastures?

Salt affected pastures can be characterized by a couple of indicators. There are for instance differences in local vegetation: seawood, restharrow, bottle sedge, beaked tassle weed are indicators of brackish water. These salt tolerant flowers and plants are mainly growing on the places where historical sea channels used to be. Many of them are endangered and are on the red list. As described earlier, bird populations may also change due to salinity levels of the surface water. At last, simply tasting the water also generates insight in the salinity of the surface water.

What are practical solutions for salinization of the polder area?

The fresh water surplus that is present in the dunes should be used for flushing of the saline ditches in the polder area. This option needs to be discussed with the local nature organisation. Ditches streaming from the dunes should remain open, so that they work in favour of the agricultural landscape in the polder area by increasing the water table. This could have positive consequences for the meadow bird populations in the polder. In addition, it would be interesting to search for salt tolerant, deep-rooting and nutritional grasses and plants. These plants could serve as green manure, increasing permeability and fresh water storage in the solid clay soils.

What do you think of the saline garden initiative?

At the saline garden, saline groundwater is pumped up from deeper soil layer and is used for irrigation of the halophytes. Sometimes, sea water is even directly used as irrigation water on the pasture behind the dike. The experiment should be disconnected from the other water systems in the polder area. As of now, it accelerates salinization of the polder area. The location of the saline garden should be on top of the location of saline seepage, instead of next to it. This would be a more suitable location. With a different approach, it might be interesting.

What are your perspectives for the future of the Terschellinger polder, regarding salinization processes?

Salinization of the polder area will progress if fresh water levels remain low. Problems with salinity will become worse and the agricultural sector will be the bearer of this. Vlieland is an example where the agricultural sector has completely disappeared. However, the agricultural sector has to remain in order for meadow birds to survive. Therefore, it is important to support this sector and to search for new ways in which this sector might flourish in the decades to come.

E4. Local forest ranger

Date: 25-05-2021, 11:00
Place: West-Terschelling
As of now, he has been a forest ranger on Terschelling for over ten years.

During your career as a forest ranger, have you seen any changes in the landscape as a consequence of salinization?

Regarding salinization, not much has changed over this period. The dunes and forests of the island do not suffer from salinization, as the dunes function as a natural fresh water storage. The dunes retain a lot of excessive precipitation water, which increases the pressure of the fresh water lens, hereby eliminating the amount of saline groundwater seepage. The fresh water buffer in the dunes might even be increasing.

How does this fresh water buffer increase?

This could be explained through the process of the natural sedimentation of sand, supporting the natural growth of the dunes. This leads to increased water storage capacity of the dune area. in addition, this natural growth heightens the dunes in front of the sea, leading to a stagnation of the fresh water flow from dune to sea. Since the polder area is the lowest part of the island, fresh water flows from the dunes to the dike. This low-lying character of the polder also causes higher chances of salinization. Since the dunes are relatively high and stretched out, the water storage capacity is high. Some ditches have been closed, leading to a lowered amount of water flowing straight to sea. This could in turn positively affect the low-lying polder area, since more counter-pressure against sea water intrusion and seepage is generated, via the increased pressure from the fresh water buffer.

How do the salinization processes in the polder area influence the biodiversity of the polder?

This is not my area of expertise, therefore, I might not have an interesting answer. You could contact the local ecologist.

What do you think of the solution for increasing the fresh water flow from dune to sea?

This would increase the water drainage from the dunes to the sea, leading to a lowered pressure from the fresh water lens. This might in turn negatively affect the polder area.

What do you think of the solution of manually steered weirs?

Being a forest ranger there is less initiative for this solution in the polder area as it is not of our concern. We can however secure he water storage in the dunes, generating a higher pressure from the fresh water lens, securing this throughout the year, even in periods of droughts. However, it sounds like an promising solution if those weirs are in the form of 'water treads', starting high and ending low.

What would be the consequences for the polder area of the invasive plant species is entering the polder area?

It would namely be an economic burden, since it requires more cleaning of the ditches. It is salt tolerant, and grows namely in wet places. It has lower chances of invading the pastures of farmers.

According to you, what would be the best response to salinization in the polder area?

Retaining as much fresh water as possible, using the dunes as a 'sponge'. In addition, more water should be retained in the local ditches. This requires a heightening of the water table or reducing the depth of the local ditches.

What are the main causes of salinization on the polder area?

The lowered water table, leading to a higher influence of saline groundwater seepage.

What is the role of climate change in these salinization processes?

Namely the summer droughts will increase these processes, since it reduces the pressure from the fresh water lens. The dunes have also suffered from drought periods, leading to negative influences on the local biodiversity.

What do you think about the prospects for saline agriculture on the island?

He explained how the saline garden initiative has worked for changing mind-sets around the topic of halophytes. However, the question remains whether it would be interesting and suitable for the local agricultural system. He argued that a dairy farmer would not be likely to switch towards the cultivation of halophytes or saline crops. In turn, if saline agriculture would be implemented on the island, the market should also be ready for this, which is as of now, not the case. There should be more restaurants and shops that put these saline dishes on their menus or shelves. He told that as a forest ranger, he knows which halophytes are edible and he has tasted them as well. He was in favour of saline excursion on the salt marshes, at it connects people to nature. However, he explained that it is important to keep the yields low, in order to avoid overexploitation of the salt marshes.

E5. Geohydrologist

Date: 4-06-2021, 14:00

Place: Noordwijk

Commisioned by Vitens, A. Kok has conducted research in 2017, to determine whether the fresh water buffer of the island is big enough to become self-sufficient. He focussed mainly on the way the fresh water lens was stretching along the polder area.

What is your interpretation of the measurements?

You can clearly see the salinity gradient across the polder area. it could be useful the convert the EC values into chloride concentrations, there is a representative correlation between those two. In 2017, the CLIWAT project was started in order to determine the balance between fresh and salt water on the island. The research used a helicopter to measure the electronic conductivity. It became clear that for some parts of the polder area, the salinity levels stretched more inlands. This was in correlation with the old sea channels. You could use a elevation map (AHN) to determine whether there is a correlation between your salinity measurements and the elevation levels of the polder area. especially around Midsland and Formerum, the old sea channels used to stretch substantially far inlands, almost up until the dunes. There used to be a relatively deep sea channel between Midsland and striep, which was used for shipping. There could be fossil saline groundwater water on those places.

Was there a cooperation between farmers and scientists in this CLIWAT project?

No, there was no cooperation, we were mainly focussed on discovering the places of the fresh water lens and saline seepage. However, the research outcomes are freely accessible and farmers could use this information in their profit.

Did you also focus on the effects of climate change on salinization processes?

Yes, some predictive calculations and models were generated, discovering the effects of different climate scenarios on the fresh water lens of the island.

Conversation about the purposes of the research..

What do you think about the prospects for saline agriculture on the island?

Not only terschelling, but every coastal zone of the Netherlands is likely will suffer from salt water intrusion in the future. Therefore, it would be interesting to shift towards saline agriculture in those coastal regions. It would be better to adapt for these salinization processes, instead of working against it. There are always front runners, and those are the people that are needed to create a successful transition. In light of climate change, saline agriculture will become more and more suitable for the character of the coastlines and it will be important to grow towards this kind of agriculture.

Do you think that the solid clay soils will create problems for saline agriculture on those pastures near the dike?

I do not know for sure, but on Texel there have been a lot of experiments. I do not know what kind of crops would be suitable for these areas with clay soils. However, there are examples of saline agriculture on clay grounds, so it is not impossible.

According to you, what are the foremost causes of salinization on Terschelling?

The dike of Terschelling is built relatively early, in the 1500s. This resulted in less natural sedimentation, leading to a relatively lower elevation of the island, compared to other Wadden islands like Vlieland or Schiermonnikoog. This natural sedimentation stopped after 1500. In combination with climate change induced sea level rise, salt water intrusion and seepage has more influence. There is less buffer between the upper soil layer and upcoming saline groundwater. With CLIWAT, we made some calculations and predictions on this. Sea level rise, in combination with summer droughts, will lead to a lowered pressure of the fresh water lens. This leads to higher salinization rates compared to 30 years ago.

Is there also relative land subsidence due to salt and gas exploitation in the Wadden sea?

No, I don’t think that this has any effect on Terschelling. The polder is relatively lower compared to other islands, due to the building of the dike.

What is your future perspective for the polder of terschelling?

I hope that the polder area will remain diverse, with lower parts and higher parts and visible old sea channels. The polder is very good for meadow birds because of this diversity. The variation and small scaled character of the local agriculture should stay. I hope that the local agricultural sector can take these characteristics into account and that they can make a special, small scale product out of this, using short supply chains. This is already being done by some.

What could be solutions for managing salinization of the polder area?

You should see salinization as an opportunity, rather than a threat. Cultivation of halophytes on a larger scale could therefore be interesting. However, I do not have that much knowledge about this particular topic. but I think that the islanders are innovative enough to make this work.

Do you think that the erosion of the old salt marshes in front of the dike, have an influence on the salt water intrusion in the polder area?

No, I do not expect that.

Could the digging of the top soil on some pastures, after the redistribution of the pastures in '53, have influenced salinization processes?

Yes, this lowers the pastures even more, resulting in less space for the fresh water lens. This results in less pressure of the fresh water lens, which leads to increased saline groundwater seepage. The redistribution of the pastures was very disturbing, new ditches were created.