# Skimming the surface: Analysis of vegetation stress in Lauwersmeer using remote sensing techniques

Group 6: TEAM DORA – for explorative research

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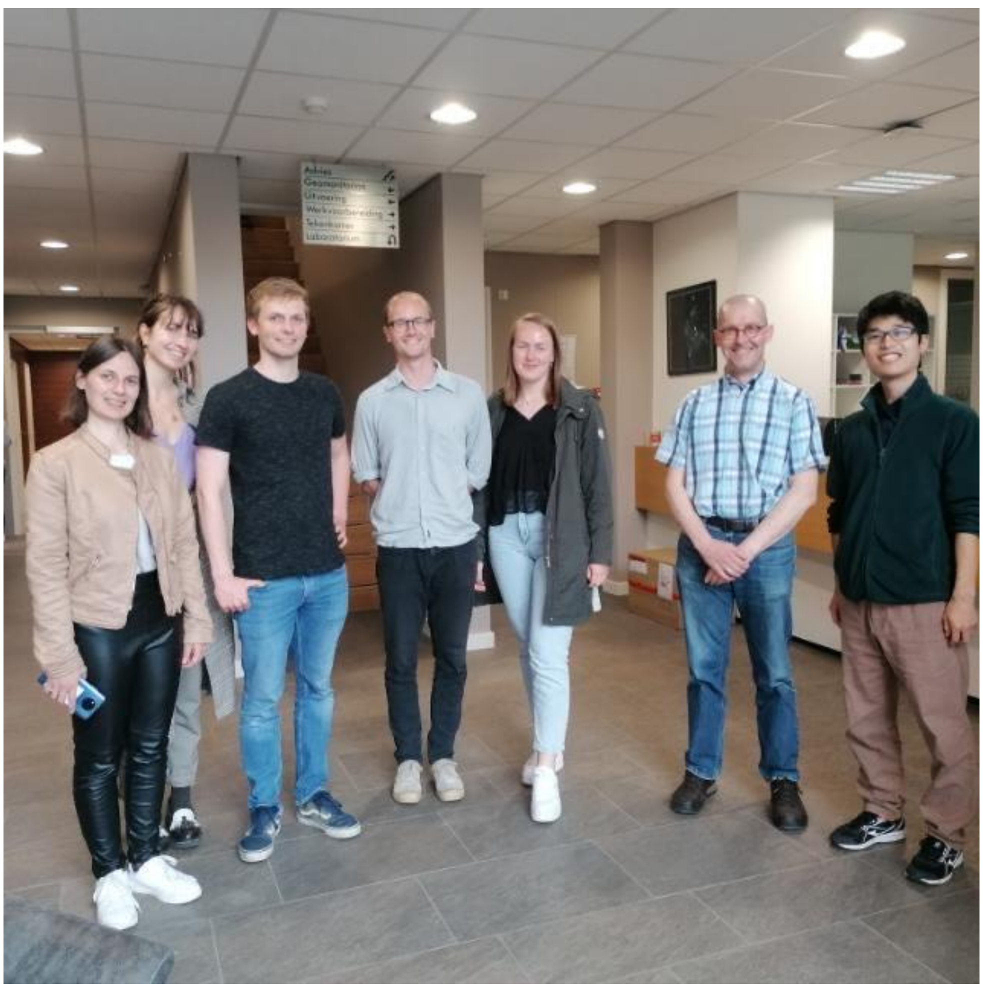

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# Executive summary

Plant stress is one of the major threats to vegetation. Plants may experience stress which can be caused directly or indirectly by water shortages, nutrient imbalance and salinity fluctuation. Therefore, it is important to evaluate and monitor plants stress as an indicator of subsurface imbalances. Remote sensing (RS) has been widely used in plant stress monitoring because of its reliability, accessibility and cost-effectiveness. The objective of this research is to explore the potential of RS to monitor plant stress for the years 1973-2022 and to identify locations prone to stress for additional investigation in Lauwersmeer in the Netherlands. The research approach is based on two main steps. Firstly, acquire historical Landsat satellite data and measure plant stress based on vegetation indices. Secondly, identify locations in Lauwersmeer prone to plant stress. Thus, the deliverables of this research are: a trend analysis of the vegetation stress in De Rug area from 1973 until 2021; a trend analysis of the vegetation stress in the agricultural area near De Rug over the same years; and a map with locations where vegetation stress was highest over the same years.

# Introduction

Coastal regions worldwide have experienced environmental changes caused by climate change, land cover and land use change, sea level rise, water level change and anthropogenic activities (IPCC, 2021). For a century, the Netherlands has been struggling with increased salinity and the global changes will further accelerate environmental changes (including salinization) in the future (Paul J. Taillie et al., 2019a). These changes have created serious challenges to agriculture and the sustainability of natural areas (Galieni et al., 2021).

Vegetation stress can be caused directly or indirectly by water shortages, elevation, nutrient imbalance (Baret et al., 2007) and salinity fluctuation (Daliakopoulos et al., 2016b; Kleefstra et al., 2018; Wen et al., 2020). Vegetation stress comes from a range of factors that can affect plants health in the following ways (Baret et al., 2007): limit the potential growth of vegetation, reduce leaf area index (LAI) of canopies, decrease the ability of plants to use light effectively (Barton, 2012), decrease chlorophyll content, and increase canopy temperature. Therefore, monitoring and evaluating vegetation stress is very important for improvement of the condition of affected canopy areas (Baret et al., 2007).

Vegetation stress monitoring is based on the interaction between electromagnetic radiation and plants (Galieni et al., 2021). The changes in canopy can be expressed by changes in a canopy state variable such as photochemical reflectance index (PRI) or in biomass such as the Normalized Difference Vegetation Index (NDVI), chlorophyll content, or surface temperature (Baret et al., 2007). Since any stressful condition can affect plant physiology and biochemical responses, canopy status could be derived from alterations observed in plant-electromagnetic radiation relationship, on specific spectral domains (Galieni et al., 2021).

Therefore, it is necessary to have a monitoring system for vegetation stress which can be used to monitor plants' health status (Galieni et al., 2021). Remote sensing (RS) has been widely used in vegetation change monitoring and plant stress detection because of its potential to monitor large scale changes, reliability, accessibility and cost-effectiveness (Ghauri and Zaidi, 2015; Najafi, Fatehi and Darvishsefat, 2019; Muavhi, 2021).

Several studies attempted to assess vegetation dynamics using RS. To the best of the authors' knowledge, the literature review highlights the contribution of RS on monitoring vegetation changes and stress in large areas. Sun et al. (2015) assessed vegetation changes in northern China, using RS and vegetation indices. Kiapasha et al. (2017) investigated the trend of long-term vegetation trends throughout the Hyrcanian forests using RS and climatic data. Najafi et al. (2019) investigated vegetation change trends in Kermanshah city, Iran based on RS and vegetation indices.

## Study area

The Lauwersmeer is a lake on the border of Friesland and Groningen and is surrounded by the National Park Lauwersmeer (Figure 1). It used to be an estuary but was closed off in 1969 for flooding safety. As water upstream is still discharged into the lake, the water has become fresh over the years and the water level is stable and low, opposed to how it used to be before it was closed off. This stable, low and fresh water poses a danger to the fish stock, the riparian vegetation and the bird populations (Beukema et al., 2016). Thus, nature conservation groups consider increasing the inlet of salt water to the lake to have a natural salinity gradient (Waterschap Noordzijlvest, 2021). However, it scares farmers as it might salinize their ditches, which would prevent them from using the water for irrigation (Berkenbosch, 2021).

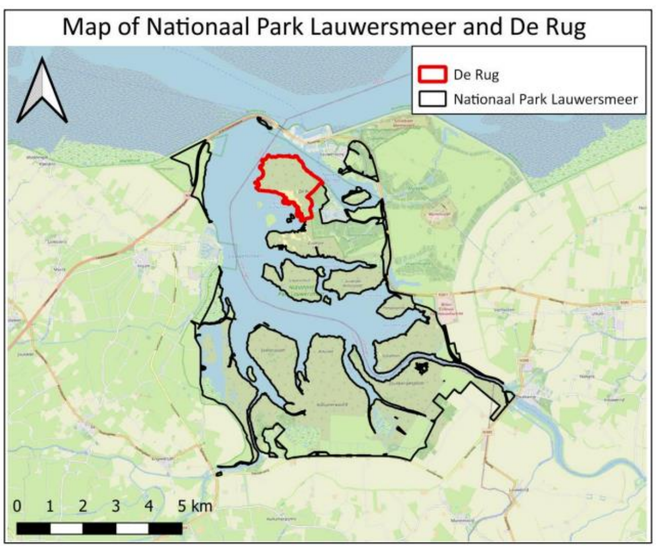


**Figure 1**| Map of study area (from De Vries, 2022).

# Problem Analysis

Wiertsema and Partners is a consultancy company that specializes in geo-monitoring of the subsurface. To answer questions of (potential) clients, they are interested in whether RS can be an affordable and easy technique to use. Therefore, Wiertsema and Partners would like to know how RS can be an effective tool for them in answering questions from clients.

To explore the possibilities of RS in the Lauwersmeer area, Wiertsema and Partners highlighted the following topics:

1. <u>Monitor trend in vegetation stress</u>

The geohydrological system of the Lauwersmeer area is being influenced by changes in management of surface water levels and land use. These management changes can have an effect on the stress level of the vegetation in the protected nature area.

2. <u>Identify locations for new monitoring wells in agricultural fields</u>

In order to take management decisions in the Lauwersmeer area, the effects of changes in management of surface water on agriculture must be clear. As there is no monitoring strategy for the surrounding agricultural areas yet, Wiertsema and Partners would like to identify optimal locations for monitoring wells (i.e., most vulnerable to vegetation stress by changes in management) by monitoring stress in agricultural fields with Remote Sensing.

The specialization of Wiertsema and Partners is geo-monitoring of the subsurface. They have established a team to improve efficient exchange and use of their own acquired datasets. To support and extend their monitoring activities, they would like to improve the connection between available below- and above-ground datasets.

Based on a better understanding of the vegetation pattern changes, an improved monitoring plan, for monitoring effects of changes in land and water management, can be developed. The main stakeholders of the effects of the project can be found in appendix I.

Before Wiertsema and Partners start off with research, they would like to know what potential interesting locations for measurement are. Areas of interest can often be spatially extensive, and as this is a consultancy company the research needs to be cost-effective. With the help of remote sensing, Wiertsema and Partners hopes to use this as an exploratory tool at the start of a new project. Human activities (abstractions and constructions) in the subsurface often express themselves in the vegetation. For example, an increase in soil salinity causes plant stress in glycophytic plants. This effect can be observed and measured using vegetation indices. Other causes of vegetation stress could be drought, the use of pesticides or the leaching of poisonous chemicals. At the moment, Wiertsema and Partners has little experience in the process of using RS for exploratory research. To improve the efficiency of the process the goal is to use RS to gain insight into possible areas of interest. As Wiertsema and Partners is not specialized in monitoring surface areas, it is also necessary to develop a workflow on how to analyze surface data using satellite data.

## Objectives

Considering the problems and backgrounds above, the objectives of this project are as follows:

1. <u>Monitor the trend of vegetation stress in the Natura-2000 area from approximately 1973 until 2021.</u>
   Identify temporal trends of vegetation stress in the Natura-2000 area after the Lauwersmeer was cut off from the sea.

2. <u>Identify locations where vegetation is stressed in the Natura-2000 area and agricultural area.</u>
   Locations where the stress is highest over time are interesting monitoring locations to Wiertsema and Partners.

3. <u>Evaluate whether elevation influences vegetation stress</u>
   Vegetation stress might be caused by salinity. If there is not salinity problem, vegetation in locally elevated areas experience more stress than vegetation in local depressions, because they are further from the ground water. However, due to salinization, vegetation in the local depressions can experience more stress due to salinity (Kleefstra et al., 2018).

4. <u>Make the work reproducible and easy to understand according to quality parameters.</u>
   The work should be reproducible, so Wiertsema and Partners have a base to further develop their knowledge on using RS techniques and do similar analysis in other areas.

## Approach

To meet our objectives, the workflow consists of four main steps: 1) Data acquisition, 2) Vegetation index calculation, 3) Time series trend analysis of a vegetation index for objective 1, 4) detection of stressed areas for objective 2, 5) correlation between vegetation stress and elevation for objective 3, and 6) Quality and reproducibility assessment for objective 4 (figure 2). Here, the trend analysis and the stress locations in the natura-2000 area and agricultural fields will be done. The historical satellite data will be gathered, dating from approximately 1980 up to 2021. A map of the Algemeen Hoogtebestand Nederland (AHN) will be used to correlate vegetation stress and elevation. Analysis will be performed in Google Earth Engine and R. To attain the fourth objective, every step of the approach will be written down clearly so Wiertsema and partners can understand and repeat them.

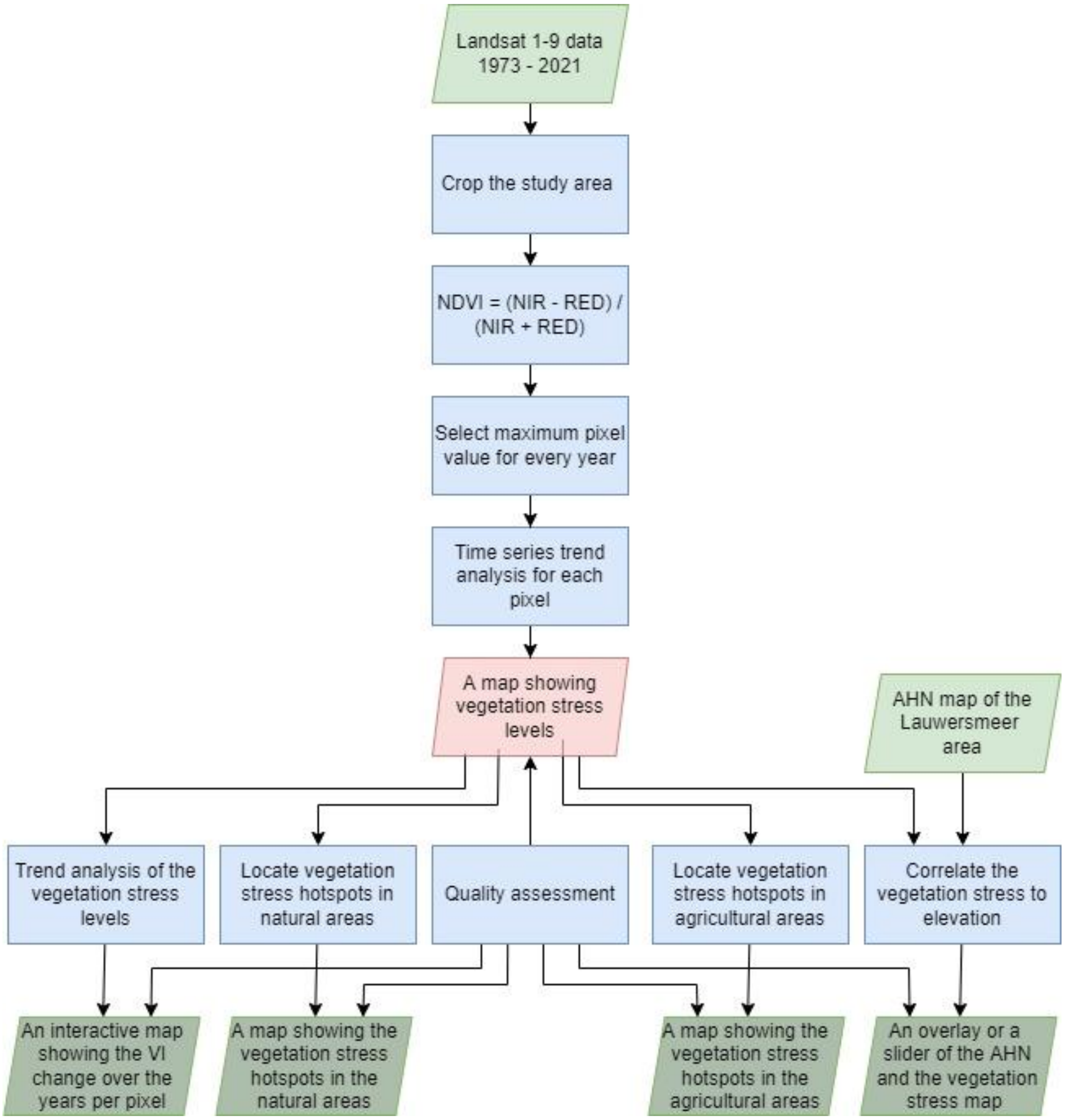


**Figure 2** | Proposed workflow for the project.

## Data acquisition

In order to observe plant stress, changes in a Vegetation Index (VI) – an indicator of plant stress – from year to year will be observed. Data from different Landsat satellites will be used to calculate these vegetation indices. However, to compare satellite images within and between years, atmospherically corrected images are required. Therefore, either satellite images that are already pre-corrected need to be obtained, or images need to be atmospherically corrected by using a correction method (e.g., the darkest pixel correction method). This is the first action in the workflow (Figure 2).

## Calculating vegetation indices

The list of different VIs is extensive, and a selection of VIs must be made. As vegetation stress can result in a lower biomass production, VIs that can give an indication of biomass productivity. Considering the available bands of Landsat data and vegetation types in the Lauwersmeer region, the NDVI will be used.

To correctly compare the VIs, yearly differences in seasonality (e.g., long winters or mild summers) must be considered. Besides, temporal peaks of the vegetation index that are caused by different plants having diverging growing periods should also be considered. Therefore, to correct the differences in seasonality and growth stages, the maximum pixel value of the VI map over the summer period will be chosen (Bao et al., 2014).

### Temporal trend analysis to monitor vegetation stress (for objective 1)

After obtaining maximum vegetation index values for each year of the growing season, a temporal trend analysis of vegetation stress can be created. This trend will be analyzed using a Student's t-test, to assess whether the trend is significant. Trends with $p < 0.05$ will be determined to be significant. A positive significant slope is identified as green, and a negative significant trend is identified as red. Gradual scaling is used. Linear trends will be conducted using a non-parametric Theil-Sen regression, to account for the outliers (Lui et al., 2021; Fensholt et al., 2021).

### Detection of the most stressed location (for objective 2)

Locations where vegetation is most stressed will be detected by identifying the trends in VI change over the years. Besides, locations based on the recent trends (i.e., 2012-2021) will be detected. This recent trend will be compared to the long-term trend, and it will be indicated whether these trends significantly differ.

### Correlation with elevation (for objective 3)

Lower elevated areas may experience less stress because of higher water availability but more stress because of higher salinity levels (Kleefstra et al., 2018). Usually, elevation can be a good indicator for vegetation stress, however, as the area is characterized by its salinity levels, the lower parts are expected to be more stressed because of salinity. Therefore, a correlation between the vegetation stress and the elevation levels will be derived to explore what the effect of elevation on the contribution of elevation to vegetation stress. This correlation will be visualized by making an overlay of the vegetation stress map and the elevation map or by creating a slider with vegetation stress on one side and elevation on the other side.

## Quality frame and control

To assure quality, a quality framework is used. This quality framework is assessed by the following: reproducibility and usability, positional accuracy, completeness, temporal quality, thematic accuracy, and logical consistency. How these will be assessed is explained below.

### *Reproducibility and usability (for objective 4)*

Wiertsema expects a tool (code or interactive map) to assess vegetation trend analysis of an area of interest. The key product, next to a vegetation trend analysis map, is the reproduction of the methods used in this project. The product should be usable while having only basic GEE and R skills. This will be checked by providing the scripts with instructions to the commissioner or other students and check for reproducibility. Scripts will also be shared in the team, for regular demo's if the code runs smoothly, with minimal input. Every week, a meeting with Wiertsema is planned to check if the project is still going in the desired direction. If Wiertsema can use the instructions without further input and create vegetation trend maps themself, the project is a success, and the objective is met.

*The positional accuracy* is assessed by the difference between two geospatial layers (ESRI website, accessed on 20/05/2022). To be able to do this, a layer whose accuracy you want to evaluate and another layer which is used as reference is needed. Different Landsat satellite accuracies will be reported. Moreover, long-term satellite data records are crucial for quantifying trends in vegetation. As multiple generations of Landsat-satellites are used, pre-processing must be performed. It is important that trends in vegetation do not disappear by (pre-)preprocessing.

*Completeness* is the measure of the totality of features. Using the end products as a reference, the data can be assessed as being complete.

*Temporal quality* is the attributes and temporal relationship of the features. To assess the temporal quality, gaps in the dataset will be identified. For example, if a whole growing season was covered with clouds, this year can't be used in the analysis.

*Thematic accuracy* can be assessed if we were to use classification. If land cover use is classified, it is necessary to check whether the accuracy of the attributes within features are correct. As we will not use thematic classification, there is no quality frame available.

*Logical consistency* is defined by ESRI as "the degree of adherence to pre-established rules of data model's structure, attribution and relationship as defined by an organization or industry." For this, the project data management structure provided for use by the ACT-team will be used.

## Products and deliverables

### *Main end results:*

The main end-product will be a map that shows the trends in vegetation stress over the Lauwersmeer area. Every pixel of the map will be colored according to the size of the observed trend. If time allows it, this map will be interactive: when a pixel is clicked, a graph of the trend (Figure 3) will pop up. The map will show the areas with the highest vegetation stress over to indicate possible monitoring locations.

The map will be presented in a report explaining the uncertainty and what that might mean for the interpretation of these results. It will also present the findings of the relationship between elevation and vegetation stress. In addition, an explanation of which exact steps were taken and a guideline for the application of RS techniques to obtain these products will be included will be delivered to Wiertsema and Partners, so they can reproduce the results and apply them in a different area.

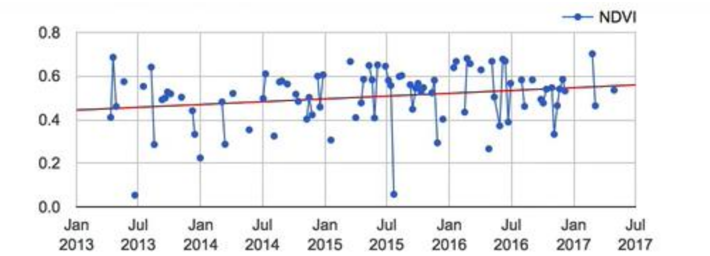


**Figure 3** |Example of a VI trend graph (from Landsat 8 time-series analysis with cloud masking (2017).

# Project management

This chapter discusses how the team will communicate and the major assumptions made for this project. Further information on the role of team members, the planning and the budget can be found in appendix II.

## Communication

### Internally in the team

The days that are scheduled for this project, we will start off with a short meeting (30 min) at 09:00 to briefly discuss our plan for the day and to discuss difficulties that we might have encountered. What we will discuss is:

- Progress of the day before;
- Progress planned for the day;
- Put verbal decisions in writing;
- Are we on schedule, and if not: what can we do about it?
- Whether team members need assistance, or the whole team needs assistance from the expert;
- Questions or issues team members have.

Internal communication will be done through orally, WhatsApp and Teams meetings when a team member is working remotely.

### Externally with commissioner, expert, and resource persons

External communication will be mainly and preferably be done by email. Furthermore, regular meetings with the commissioner are scheduled and can be found in Appendix II. Minutes will be made of every online and in real-life meeting.

## Assumptions

### Main assumptions

- Satellite data will be easily available with Google Earth Engine (GEE);
- Coding skills in GEE are sufficient;
- Scheduling is done with room to spare.

### Major risks

- Output is not spatially accurate enough to say anything about vegetation stress;
- Wrong interpretation of results (not taking uncertainty into account enough);
- There is limited data available to assess how well vegetation indices can indicate vegetation stress. NDVI has a high correlation with vegetation stress but is not applicable in every situation.

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# Appendix I

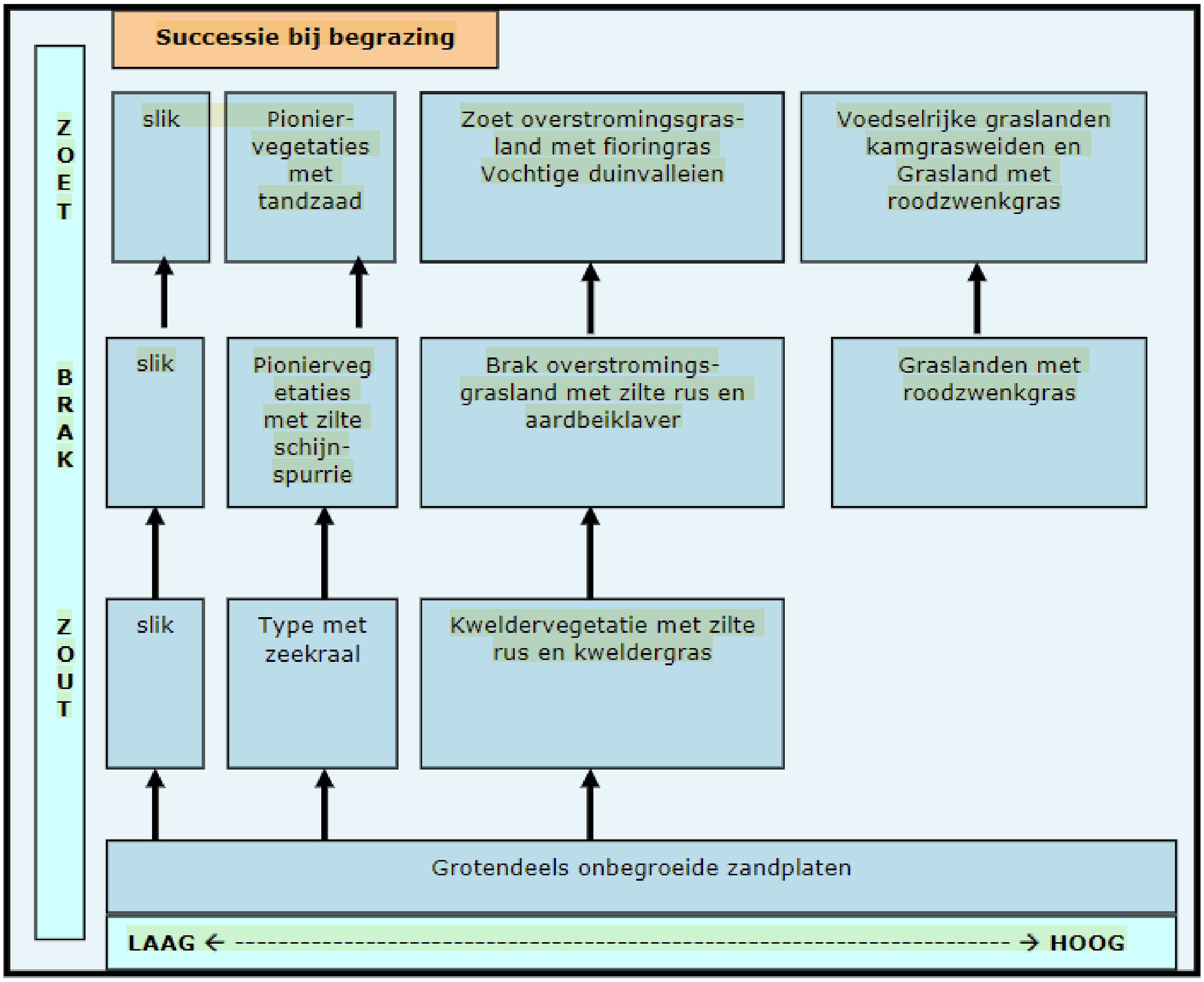


**Figure A1** | Succession schemes (based on Van der Veen et al. 2005).

## Background information on salinization

Wiertsema and Partners suspects there are two ongoing processes of salinization, of which the dominant explanation might vary of the area. The first focus is on possible seeping underneath the dikes surrounding the area. This process can be observed in the left part of figure A2.

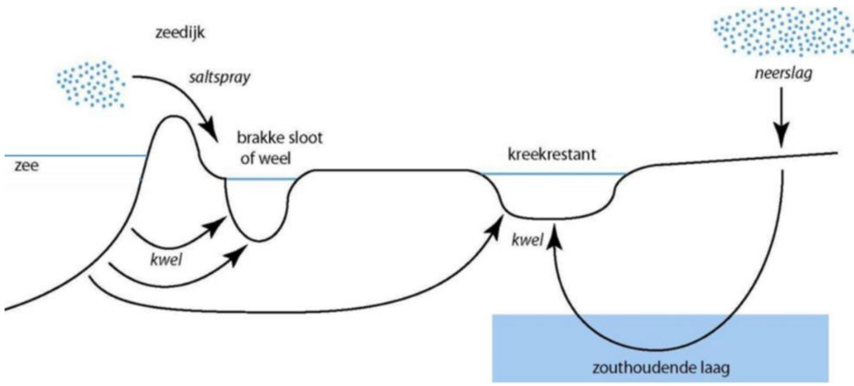


**Figure A2** | Seepage of sea water through the dikes; oozing of saline groundwater towards the surface (adapted from Jagers op Akkerhuis et al., 2013).

The dikes have closed off the area from the North Sea, which is saline. This seepage process is very slow and, therefore, the timescale of salinization is seen more in decades than in years. The water has been almost completely fresh since the closing of the dikes, with some areas in the North more brackish (depending on the opening and closing of the sluices).

The second probable cause is a residue of salt/brackish groundwater in the soil, from when the area was still in an open connection with the Waddenzee. It was observed that some areas of the land did not develop a large, fresh water lens. Rainfall did not lead to infiltration of the soil, which caused the soil to remain saline (Beheerplan Lauwersmeer, 2016). Staatsbosbeheer suspects there is some seepage/oozing, which causes the lower areas to remain saline (see right part in figure A1). As said before, this process of seepage, and most other soil processes are very slow. Because of this, it is important to look at large time-scale effects.

## Stakeholder Analysis

The main stakeholders that are affected by the lack of knowledge of how to use RS for monitoring of salinization in the Lauwersmeer area, is the state forestry management - Staatsbosbeheer (SBB). SBB oversees management of the natura 2000 area within the Lauwersmeer area. Having more knowledge on the use of remote sensing for salinity monitoring could save them money and time (as field measurements are costly) and might give them insight into the development of soil salinity throughout history. This insight into the temporal variability of salinity combined with the data on vegetation patterns and stress might show a trend, which SBB can take into account when making a new management plan. The Ministery of Agriculture, Nature and Food Quality (LNV) is responsible for SBB and dictates management policies.

Some parties are not directly affected by this lack of knowledge on the effect of salinization through RS but are affected by the decisions that are being made based on the outcome of this project; based on the outcome of the analysis, it might be decided to let more, or less saline water into the Lauwersmeer. The stakeholders that are most affected by the decisions are the farmers: they depend on non-saline ground water and sufficient non-saline irrigation water from ditches for their harvest. Moreover, the waterboards (Noorderzijlvest and Fryslân), are responsible for ground water and supplying farmers with enough fresh water for irrigation purposes and the farmers themselves. Lastly, the surrounding municipalities and recreationists want the Lauwersmeer to be a stable, beautiful, and safe area for recreational purposes, which could also be at risk based on the decisions made based on the problem solution.

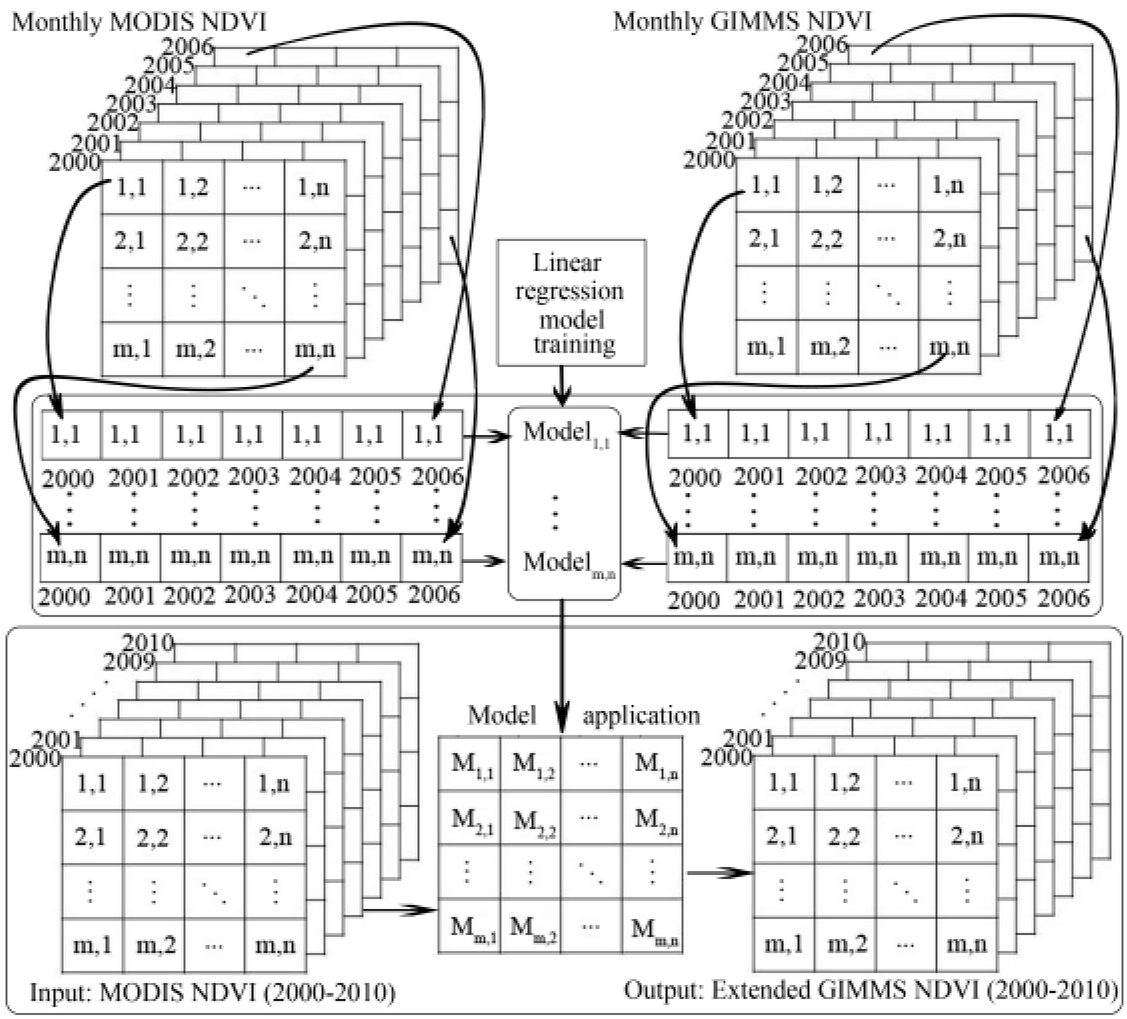


**Figure A3** | Monthly maximum of NDVI (From Bao et al., 2014)

# Appendix II

## Team

Table 1 describes the team and its added value and briefly the individual team members and their contribution to the team and the project.

**Table 1** | Roles, team contribution, and project contribution of all individual team members.

| NAME | ROLE | TEAM CONTRIBUTION | PROJECT CONTRIBUTION |
|---|---|---|---|
| **DAVEY DE GROOT** | Chair | Focus, fun and functional. | Knowledge about NDVI and stress in plants. Prepare an agenda for- and will chair most meetings. |
| **KRISTIE SWINKELS** | Secretary | Passion and optimism. | Knowledge of soil and vegetation. Take notes in most meetings. |
| **SHOYO NAKAMURA** | Controller | Ideas, focus and passion. | Progress, quality assessment, and budget |
| **MARIEKE BUUTS** | Member | Ideas, implementation | Ecological knowledge, work quality. Responsible for booking places to work. |
| **PERSA KOUTSOURADI** | Member | Ideas, implementation and patience | Technical knowledge and background in Google Earth Engine |

## Planning

Table 2 encompasses important dates (e.g., meetings and deadlines) for the course of the project. A Gannt chart of the main steps and activities can be found in table 3.

**Table 2** | Important dates.

| Time | Week | Schedule |
|---|---|---|
| 16 May 15:00 | 2 | Meeting 1 Wiertsema and Partners |
| 18 May 15:00 | 2 | Meeting 2 Wiertsema and Partners |
| 20 May | 2 | 1st proposal deadline |
| 23 May 14:00 | 3 | Meeting 3 Wiertsema and Partners |
| 25 May | 3 | 2nd proposal deadline |
| 9 June 14:00 | 5 | Meeting 4 Wiertsema and Partners |
| 12-14 June | 6 | Field work |
| 16 June 14:00 | 6 | Meeting 5 Wiertsema and Partners |
| 23 June 13:00 | 7 | Meeting 6 Wiertsema and Partners |
| 24 June | 7 | Finalize analysis |
| 28 June | 8 | Finalize report |
| 30 June | 8 | Presentation |

**Table 3** | Gannt chart of the main steps and activities.

| | | | Week | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Details | Main responsibility | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Meeting | Daily meeting | Everyone | | | | | | | | |
| | with Wiertsma | Everyone | | | | | | | | |
| | with Coach | Everyone | | | | | | | | |
| | with Expert | Everyone | | | | | | | | |
| Proposal | Introduction | Everyone | | | | | | | | |
| | Problem analysis | Marieke & Davey | | | | | | | | |
| | Objectives | Everyone | | | | | | | | |
| | Approach | Persa & Kristie | | | | | | | | |
| | Products and deliverables | Everyone | | | | | | | | |
| | Project management | Shoyo | | | | | | | | |
| | Whole structure | Everyone | | | | | | | | |
| | Final check | Everyone | | | | | | | | |
| Field work | Discussion with Wiertsma | Everyone | | | | | | | | |
| | Appointment with SBB | Kristie | | | | | | | | |
| | Conducting fieldwork | Everyone | | | | | | | | |
| | Presentation | Everyone | | | | | | | | |
| Analysis | Data collection | Everyone | | | | | | | | |
| | VI trend analysis | Everyone | | | | | | | | |
| | Elevation analysis | Everyone | | | | | | | | |
| | Quality frame | Everyone | | | | | | | | |
| | Creating final output | Everyone | | | | | | | | |
| Report writing | Results | Everyone | | | | | | | | |
| | Discussion | Everyone | | | | | | | | |
| Presentation | Preparation & practice | Everyone | | | | | | | | |
| | Presentaion | Everyone | | | | | | | | |

## Budget

The table below shows the estimated budget for carrying out the project (table 4).

**Table 4** | Estimated budget.

| Category | Details | Estimation (€) |
|---|---|---|
| office equipment | | 0 |
| copy and print costs | Poster and report | 20 |
| telephone costs | Internet during fieldwork | 15 |
| traveling expenses | Train, potentially car | 160 |
| unexpected costs | | 9 |
| Total Expenditures | | 204 |