Salt Marsh Stability

Assessing how salt marsh stability is influenced by grazing management of large herbivores and bioturbation of *Orchestia sp.* as part of coastal protection in The Netherlands

R. Raggers

Leeuwarden, 2019

van hall larenstein
university of applied sciences

Royal Netherlands Institute for Sea Research

university of groningen

Salt Marsh Stability

Assessing how salt marsh stability is influenced by grazing management by large herbivores and bioturbation by *Orchestia sp.* as part of coastal protection in The Netherlands

Graduate: **Rens Raggers**

Student code: **000006413**

Module code: **LKZ428VNAO**

Module name: **Thesis Research CMM**

Date: **March 13, 2019**

Supervisors from the Van Hall Larenstein University of Applied Sciences: **Joop van Eerbeek** and **Uche Obinna**

Opponent from the Van Hall Larenstein University of Applied Sciences: **Evelien Jager**

Supervisor and problem owner from the thesis organization University of Groningen and the Netherlands Institute for Sea Research: **Beatriz Marín Díaz**

Source front page picture: (Kieckens, 2018)

Source front page logo Van Hall Larenstein: (Agrofoodcluster, sd)

Source front page logo Royal Netherlands Institute for Sea Research: (WoodsversusWaves, sd)

Source front page logo University of Groningen: (RUG, 2016)

van hall larenstein
university of applied sciences

Royal Netherlands Institute for Sea Research

university of groningen

Summary
Salt marsh stability from 10 different salt marshes was studied in the Dutch Wadden Sea region and the Scheldt Estuary during October and November 2018. This report elaborates how salt marsh stability is influenced by bioturbation of *Orchestia sp.*, grazing of large herbivores and different soil and plant properties. The effect of the bioturbating *Orchestia sp.* was studied by comparing the presence and abundances between determined plots on every salt marsh. Grazed and ungrazed sites were studied whereby differences in grazing type was considered as well. Salt marsh samples were extracted from the soil to investigate on properties from water content, organic matter, bulk density, compaction and grain type. Thereby, vegetation type was taken into account by determining the dominated plant species present per salt marsh plot and studying differences in below-ground root properties. The aim of the research was to find which parameters affect to what extent salt marsh stability by exposing the soil samples to a water flow velocity of 2 meters per second under laboratory conditions within a water flow flume. Through statistical analyses, it was found that *Orchestia sp.* preferred a lower bulk density and a higher organic matter, but the presence or abundance was not found to relate with salt marsh stability. Grazers were able to make the soil more compact, but a more compact soil was not found significantly with erosion and grazing was therefore not found to influence stable salt marshes. The emphasis lied on discovering if soil properties or plant properties were more important for stable salt marshes, where it was found that both soil as plant properties influence soil erodibility. It was however found that grain type was crucial for salt marsh stability, whereby clayey soils are more resistant to water flow erosion than sandy soils and that the effect of *Orchestia sp.*, grazers and plant properties were negligible.

Table of content

1. Introduction

Hydraulic infrastructure techniques like seawalls, groynes, dikes and revetments are some of the flood defence management systems that protect the coastline from flooding. These hydraulic infrastructure techniques are built with hard materials such as rocks, steel and concrete, which aim to stop or obstruct natural processes to protect the coastline (Cross, 2016; ALevelGeography, 2018; EcoShape, 2018). Although these techniques can protect coastlines, they have drawbacks such as being very expensive due to the development and regular maintenance, their ability to cause erosion elsewhere by affecting the sand balance and are also not appealing to the eye (Jackson, 2014; BBC, 2018). Additionally, hard engineering techniques are short-term solutions because of the erosive effect from waves and are usually detrimental to natural value, since such techniques often stimulate land subsidence and hinders the natural accumulation of sediments. The capacity of shorelines to adapt to sea level rise is therefore compromising (Cross, 2016; Temmerman, et al., 2013). Especially in low-lying countries like The Netherlands, for which good coastal protection management is crucial since it has to deal with a high risk of flooding (Climate Change Post, 2018).

Building with Nature is an approach that exploits natural processes to reduce risks from consequences of climate change, such as sea-level rise and stronger waves (Wageningen University & Research, 2018). A form of Building with Nature is the establishment or recovery of foreshore ecosystems like tidal flats and salt marshes by utilising for instance the transport capacity of sediment by tides or the wave-attenuating effect of vegetation that in turn reduce coastal erosion (EcoShape, 2018). The Netherlands adopted a new coastal management program in 2014, called the All-Risk program (Kok, 2017). This program describes the implementation of new risk standards in flood protection and include ideas that focus on Building with Nature-inspired coastal protection solutions like tidal flats and salt marshes that absorb wave energy and reduce erosion on hydraulic infrastructure techniques (Kok, 2017).

Tidal flats and salt marshes are intertidal foreshore ecosystems that occur along the transition of land and sea. They develop naturally through sedimentation and tides, can be man-made by sand nourishment or their process has been stimulated by constructing sedimentation fields and ditching (Bakker, 2014; Esselink, et al., 2017). Building with Nature-based foreshore ecosystems like tidal flats and salt marshes enhance a lot of different functions, such as providing habitat wildlife, supporting breeding grounds for fish, offering recreational opportunities and protecting the coastline against flooding. Moreover, tidal flats are non-vegetated, muddy, soft sediment foreshore ecosystems that are generally located in estuaries and are at least once a day submerged (ScienceDirect, 2018; Bakker, 2012; Dyer, Christie, & Wright, 2000). Due to the morphology, width and elevation, tidal flats often form a buffer by dissipating wave energy and are able to reduce erosion on further intertidal habitats like salt marshes. Salt marshes are vegetated, marshy, soft sediment foreshore ecosystems which are more located near the coastline than tidal flats and are location dependent inundated, whereby big differences between low and high salt marshes occurs (*Fig. 1.1*). Low salt marshes are inundated almost every high tide, while high salt marshes only get inundated in case of storms or by extreme high water levels, which in turn influences the environmental characteristics (Dineen, 2010; Tempest, 2014; Kieckens, 2018). Salt marshes have to cope with sediment-supply based on tide that submerges the salt marsh, in which the elevation gradient plays an important role (Bakker, 2012). Elevation and height influence concentration levels of several abiotic factors like flood exposure and duration, salinity, aeration, temperature and sediment deposition that in turn control plant species to develop (Bos, Bakker, Vries, & Lieshout, 2002; Iles, 2001). In a more water-exposed low salt marsh, the pioneer-plant

Spartina anglica can be found in large numbers and in a more sheltered high salt marsh, the late-successional plant *Festuca rubra* is very common (Bakker, 2014).

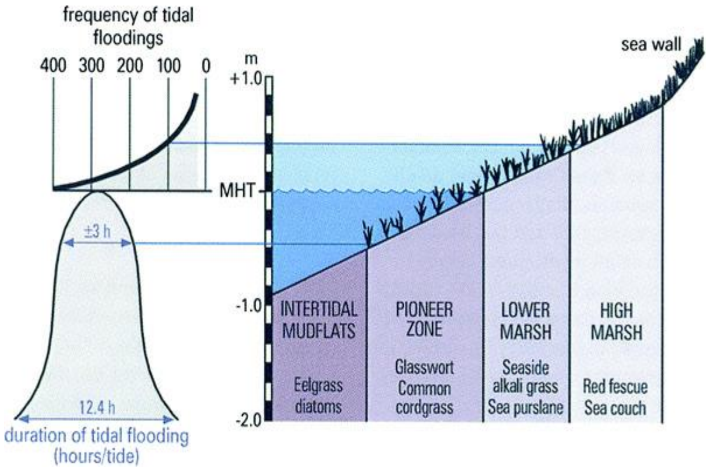

Figure 1.1. Lateral view of a salt marsh in relation to flood duration and frequency and the differences between high and low marsh zonation (Bakker, et al., 2016).

Variations in plant communities comes forth throughout species competition and future plant community replacement to reach a stable and mature, climax stage. The process of that development is called succession, which starts when pioneer plants colonize first in a steady-state environment. When another plant type thrives better in the certain area, the earlier vegetation gets overruled and a later, more mature vegetation succession stage occurs (Iles, 2001; Nix, 2017). Early succession plants like *Salicornia europaea, Spartina anglica* and *Suaeda maritima* are in this study referred as pioneer plant species (P) and colonize generally in watery, marshy conditions on open more low-lying places on salt marshes or on the transition zone to tidal flats. *Aster tripolium, Atriplex portucaloides, Atriplex pedunculata* and *Puccinellia maritima* are plant species of a later successional stage and can be found in the low salt marsh (L) (*Fig. 1.2*). Plant species of the high salt marsh (H) are *Elytrigia atherica, Festuca rubra, Phragmites australis* and *Scirpus holoschoenus* (Esselink et al., 2009).

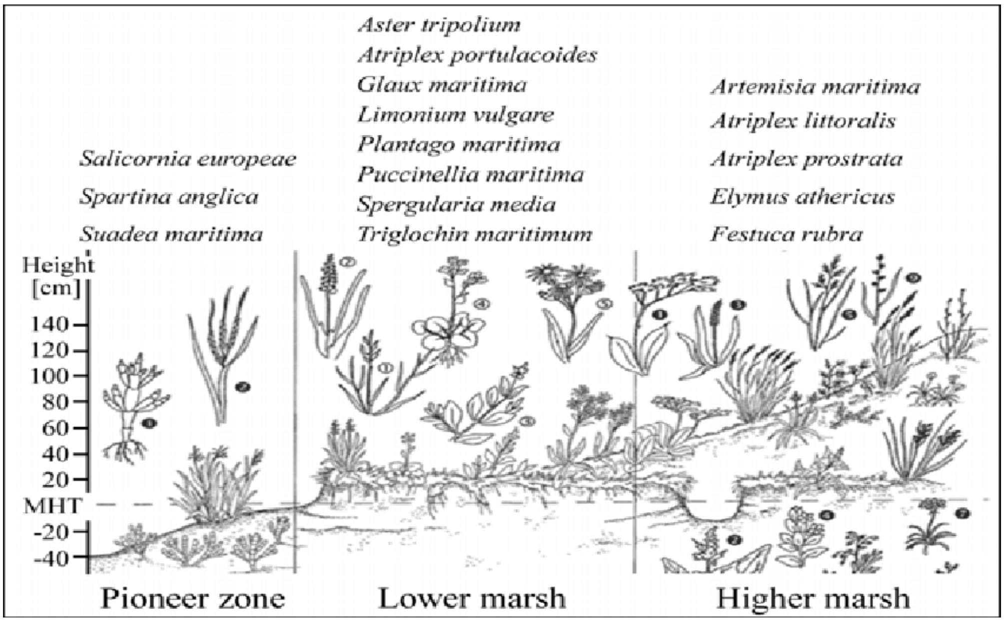

Figure 1.2. Variation in plant species per salt marsh zone, which can be classified as pioneer, low and high salt marsh vegetation types. (Minden, 2010)

Plant roots have the ability to trap sediment, whereby it is expected that the root length influence soil stability (NOAA, 2018; Thomas, Abbott, & Moloney, 2016). *Salicornia europaea*, for instance, has smaller roots than *Phragmites australis*, by which less soil stability is expected when *S. europaea* is present and *P. australis* is absent. Root properties can further be subdivided into coarse roots and rhizomes. Rhizomes are modified, underground hard and straight stem-like roots and coarse roots are thin, winding roots that sprout from the rhizome (*Fig. 1.3*), which might also affect the extent in which the soil is kept together (Canadian Wildlife Federation, sd). By trapping sediment, a salt marsh is able to grow and keep up with predicted sea-level rise (Department of Environmental Services, 2004; National Geographic, 2017). Because rhizomes are often thicker and longer than coarse roots and are able to hold the sediment in another way then roots do (Baessler, 2018), it is of interest to understand the differences between these plant characteristics and the effect it might have on salt marsh stability.

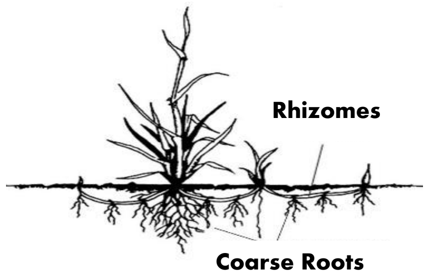

Figure 1.3. A plant with its roots, subdivided in rhizomes and coarse roots (Canadian Wildlife Federation, sd)

Salt marsh stability can furthermore be affected by human activities, including land use. A form of land use is agriculture, whereby salt marshes are utilised to function as grazing area for large herbivores such as cows, sheep and horses (also referred as cattle or livestock) (Esselink, et al., 2017). In the past, salt marshes were intensively exploitated by grazing which led to high nutrient and fertility levels on which plant species productivity and other benthic organisms still benefit from today. However, since the last quarter of the Twentieth century, it is known that high stocking densities ensured plant species and biodiversity to reduce due to the high ratio of plant consumption. Since then, a shift in management practices took place in which agriculture exploitation changed to nature conservation. To improve natural and ecological value, extensive grazing management has mainly been established. Cattle graze selectively on plant species and can thereby cause competitive displacement of plant species to reduce. This can create spatial heterogeneity in vegetation type and stimulate plant species diversity. Also, large herbivores graze on taller and higher vegetation types than smaller herbivores like geese and hares, in which foraging possibilities for smaller herbivores are enhanced by shortened vegetation (Bakker, 2014). It is expected that livestock can adjust the soil properties by trampling the sediment, which might make the soil more compact and could increase soil stability (Bakker, Kuijper, & Stahl, 2009). However, it is still unclear if, how and which grazing management type can be brought in relation to salt marsh stability. Throughout this research, grazed and ungrazed salt marshes will be studied to obtain the impact of grazing management on soil stability.

When a closer look is taken at the soil itself, it can be seen that a soil is composed of various kinds of particles and sizes which derived from the breakdown of rocks (mineral particles) or originate from the decomposition of plants and organisms (organic particles / organic matter). Generally, soils with a higher level of organic matter are better resistant against erosion (Ritter, 2018). Moreover, the soil consists of miniscule spaces in between the particles which are filled with air or water with nutrients. The size of the particles, also known as the grain size, influences the transport capabilities of water, nutrients and air within the soil. Different grain sizes are classified as clay (grain size <0,002 mm), silt

(0,002 mm – 0,06 mm) and sand (0,06 mm – 2 mm). The different amounts of clay, silt and sand in the soil defines the soil texture. A sandy soil texture is relatively looser than a clayey soil texture, because of the extent in which the grain particles can stick to each other, which in turn influence the erodibility (Brouwer, Goffeau, & Heibloem, 1985). Next to this, the water content in the soil might play an important role in the degree of erosion. Sandy soils with a lower water content tend to be more sensitive for erosion than clayey soils with a higher water content (Vermeire, Wester, Mitchel, & Fuhlendorf, 2005). The extent in which water is present in the soil is also important for roots to absorb in order to meet the plant's need to grow (Brouwer, Goffeau, & Heibloem, 1985). Another factor that influence plant growth, is the soil property bulk density. Bulk density can be described as the weight of a dry soil divided by the total volume of the soil. It has found that bulk density is a very good indicator of the suitability for root growth. In general, a low bulk density is desirable because a bulk density higher than 1.6 g/cm^3 tend to restrict roots growth (Brown & Wherrett, 2019). Because the aforementioned soil properties are important for erosion prone conditions (Thomas, Abbott, & Moloney, 2016; Osman & Barakbah, 2006; Alden, 2017), they will be studied in order to find a sediment type that represents stable salt marshes.

Additionally, soil properties can be influenced by the biotic factor bioturbation. Bioturbation indicates the reworking of soil properties by organisms and is key in ecosystem processes as it changes the surrounding soil morphology by for instance burrowing, ingesting or defecating of sediment particles over time (Alden, 2017). Moreover, bioturbators could change the composition of soil biomass and might positively stimulate plant growth in salt marshes by aerating the soil as a consequence of sediment burrowing and foraging activities on dead organic matter (Howison, Olff, Puijenbroek, & Smit, 2016). *Orchestia sp.* (henceforth: *Orchestia*) is a small bioturbating crustacean amphipods that lives in the soil of salt marshes and can grow to 18 millimetres (*Fig. 1.4*). *Orchestia* is able to change the physical and environmental soil properties and can be seen as an important ecosystem engineer in salt marshes because of two main reasons (Lowry, 2010; Kluijver & Ingalsuo, sd). Firstly, due to the burrowing activities of *Orchestia*, the soil becomes potentially aerated in an otherwise toxic environment. The oxygen-availability in salt marsh soils can be improved by *Orchestia* which stimulates plants to grow and in turn stabilize salt marshes due to the roots and rhizomes of such plants that hold the sediment (Bakker, 2014). Secondly, since *Orchestia* forages on dead organic matter, it decomposes leaf litter which in turn stimulates nitrogen mineralization. Plants need nitrogen to grow and because of foraging activities from *Orchestia*, this food source comes available whereby the vegetation productivity increases. This practice can ensure late successional vegetation and therefore salt marsh stability (Bakker, 2014; Schrama, Boheemen, Olff, & Berg, 2015). Because *Orchestia* is important in decomposition processes, it is expected that low abundances of *Orchestia* can be linked with reduced decomposition of organic matter in salt marshes. Schrama, Boheemen, Olf, and Berg (2015) have found that *Orchestia* can adjust the soil by reworking it, which has consequences for the vegetation and sediment type present. However, it is still unknown until what extent *Orchestia* influences salt marsh stability.

Figure 1.4. Orchestia gammarellus (male). Scale: 2mm. (Pérez-Schultheiss, 2014)

In the Netherlands, salt marshes can be found in the Wadden Sea region and the Scheldt Estuary. The salt marshes are an important part of the world heritage nature values due to their unique animal and plant life (Bakker, Esselink, Dijkema, Duin, & Jong, 2002). Beside that salt marshes are ecological important, they can also function as buffer by the reduction of erosion from wave-energy on hydraulic infrastructure techniques (Doedens & Dorenbosch, 2015; Kok, 2017; Bakker, 2014). There is however still insufficient knowledge and information about how salt marshes should be managed in order to increase natural value and how thereby coastal protection can be established before the All-risk coastal management program can be implemented. Soil and plant properties, bioturbation from *Orchestia* and grazing by large herbivores might play a crucial role in salt marsh stability, making them important factors to investigate (*Fig. 1.5*) (Department of Environmental Services, 2004; Bakker, 2014).

This research is carried out under the direction of the Royal Netherlands Institute for Sea Research (NIOZ), which is a national oceanographic and marine research institute that executes academically fundamental and applied research (NIOZ, 2019) and the Groningen Institute for Evolutionary Life Sciences (GELIFES), which is a research institute that strives to offer great insight of fundamental biological processes (RUG, 2017). The University of Groningen (RUG) and the NIOZ are part of the All-risk program for coastal protection management in the Netherlands (Kok, 2017), who fellow-execute this project. Other participating organisations who are related to the overarching All-risk project are research institutes, such as the Delft University of Technology, Utrecht University and Wageningen University, knowledge institutes and international academic partners like Alterra, Deltares and University of Tokyo, potential end-users as Arcadis, RoyalHaskoningDHV and Tauw and other organizations and waterboards like It Fryske Gea, Provincie Groningen and STOWA. For this research, soil samples were extracted from salt marshes along the Dutch Wadden Sea region and the Scheldt estuary for erosion experiments with fast water flow using a flow flume, located at the NIOZ office in Yerseke, Zeeland. Throughout these flume experiments, top soil erosion was studied and related to soil sample characteristics about soil and vegetation properties and data about *Orchestia* and grazing management to provide information for the All-risk program.

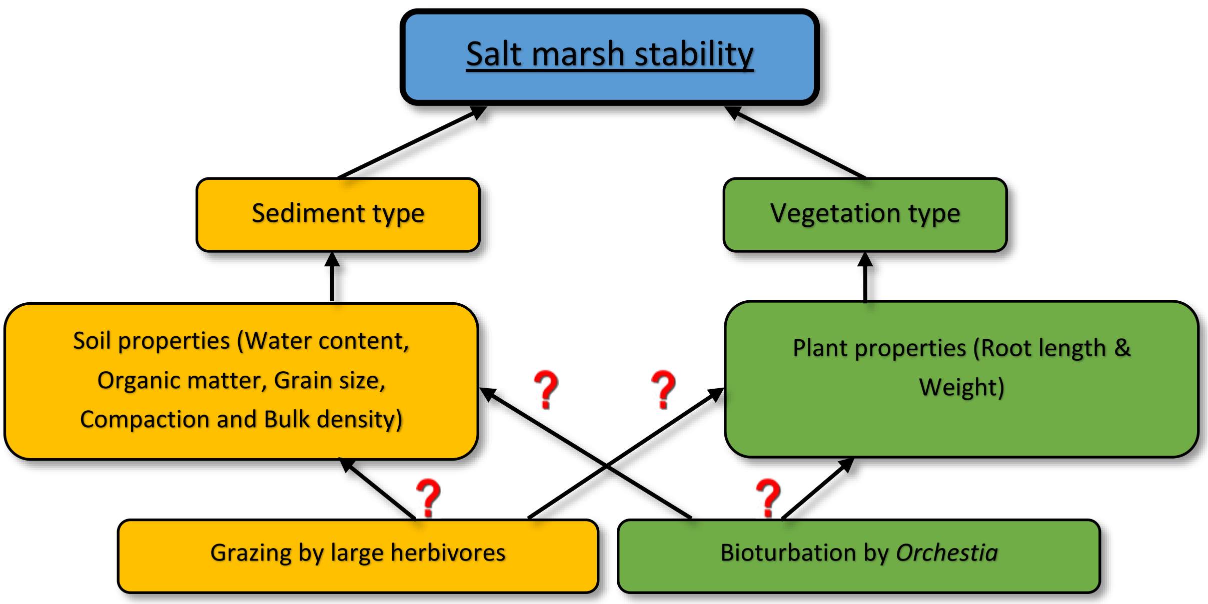

Figure 1.5. Schematic view of the research topics, the question marks indicate the unknown influences which will be studied during this thesis.

1.1 Problem statement

Protection opportunities of Dutch salt marshes are not fully utilized because some salt marsh stability factors are still unclear. For example, bioturbation from *Orchestia*, grazing management by large herbivores and soil and plant properties might have different effects on marsh stability. This results in uncertainties about how salt marshes could be managed in order to improve coastal protection.

1.2 Research objective

The aim of this project is to study several factors, such as bioturbation from *Orchestia*, grazing management by large herbivores and soil and plant properties, that influence salt marsh stability. Throughout this research, an advisory report for the NIOZ and the RUG will be written which then will be used as input to provide scientific advice for the overarching All-risk coastal management program. The advisory report will contribute to the understanding about how salt marsh stability is influenced by the aforementioned factors in Dutch salt marshes. This is necessary for governments and municipal councils to gain a better understanding of how salt marshes can be implemented for efficient coastal defence management.

1.3 Research questions

The main research question for this study is formulated as follows:

1) *How does grazing by large herbivores and bioturbation by Orchestia have an effect on saltmarsh stability?*

The main question will be answered trough the following sub-questions:

1 *What is the relation between the presence of Orchestia and the soil and plant properties?*
2 *What is the relation between grazing by large herbivores and the soil and plant properties?*
3 *What soil properties and vegetation types are related to more stable marshes?*

Thesis outline

Chapter 2 describes the research methodology that is been utilized to answer the research questions and shows which statistical analyses are used.

In **Chapter 3**, the obtained results from the used statistical analyses are presented as ‘raw data’.

The meaning behind the results are described in **Chapter 4**. Here, I evaluate my results with other outside sources and previous studies whereby possible errors or implications from the research are discussed as well.

The goal of **Chapter 5** was to conclude the discussed results in a compact style.

Chapter 6 addresses which recommendations can be made from the results of the research.

In **Chapter 7**, I would like to thank the persons who made this research possible and who have helped me through the thesis period.

2. Materials and Methods

2.1 Study Site

This thesis research has been started in November 2018 with studying 16 plots from 4 different salt marshes along the Dutch Wadden Sea main coast near Zwarte Haan, Holwerd, Uithuizen and Dollard (*Fig. 2.1*). However, after recognized that the retrieved dataset from those areas would be too small to provide statistically significant data, the dataset was expanded with data from 5 other salt marshes in the Scheldt Estuary (*Fig. 2.3*) and 1 other salt marsh at Schiermonnikoog (*Fig. 2.2*). Those salt marshes were studied in October and there were no differences in methodology between the samples areas in October and the samples areas in November, except for the survey on *Orchestia.* The *Orchestia*-survey was from November on expanded because it was found that the presence and abundance of *Orchestia* was more interesting than initially expected.

The research area consisted in total of 10 different salt marshes spread over the Dutch Wadden Sea region and the Scheldt Estuary. In the Wadden Sea region, 1 salt marsh located on the island of Schiermonnikoog and 4 salt marshes located along the Wadden Sea main coast near Zwarte Haan, Holwerd, Uithuizen and Dollard were studied. In the Scheldt Estuary, the other 5 studied salt marshes were located near Rilland, Ritthem, Paulina, Zuidgors and Waarde. At every salt marsh site, sampling plots were arranged in a 90-degree angle from the dike towards the sea (*Fig. 2.4*). The plots were based on different vegetation type, which were determined by observing the difference in vegetation type that dominate a certain area on the salt marsh. In total, 36 plots from 10 salt marshes at different locations were studied on grazing management, *Orchestia*, soil- and plant properties and salt marsh elevation from October to November 2018. The exact location along the salt marsh was determined using a GPS and the elevation was determined using a dGPS.

Figure 2.1. The location of the research salt marsh sites along the Dutch Wadden Sea (main land). The blue pins indicate the exact location and the names of the research sites (Picture extracted from Google Earth(2018) (Google Earth Pro, 2018)).

Figure 2.2. The 5 salt marshes in the Wadden Sea area. (Picture extracted from Google Earth(2018) (Google Earth Pro, 2018)).

Figure 2.3. The 5 salt marshes in the Scheldt Estuary. (Picture extracted from Google Earth(2018) (Google Earth Pro, 2018)).

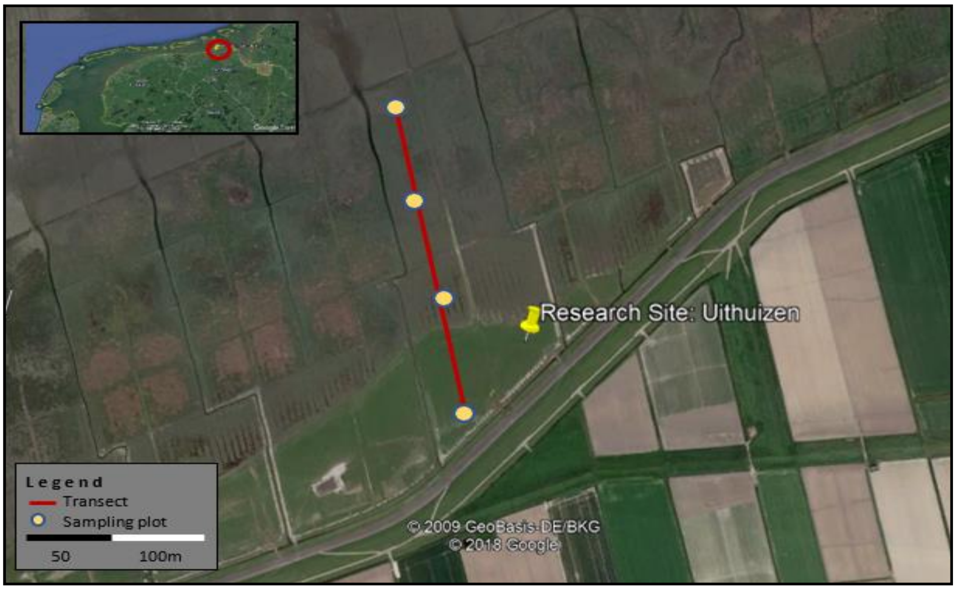

Figure 2.4. An example of a transect including sampling plots within a proposed salt marsh site (Picture extracted from Google Earth(2018) (Google Earth Pro, 2018)). The map upper left shows the map of the research region, the red circle indicates one of the proposed research sites (Picture extracted from Google Earth(2018) (Google Earth Pro, 2018)).

2.2 Method sub-question 1

To find an answer on the first sub-question "*What is the relation between the presence of Orchestia and the soil and vegetation properties?*", the following method was used. A survey on the presence and abundance of *Orchestia* was done and soil samples were extracted from the salt marshes to understand the soil and plant properties.

2.2.1 Fieldwork: Survey *Orchestia*

At the salt marshes that were studied in October (Schiermonnikoog, Paulina, Zuidgors, Waarde, Rilland and Ritthem), only the presence of *Orchestia* was studied and determined if *Orchestia* was present or absent. This was done by looking for emerging individuals from the soil while extracting the soil samples (see sub-chapter Fieldwork: Soil samples).

From November 2018, field measurements were conducted at the salt marshes of Zwarte Haan, Holwerd, Uithuizen and Dollard on the presence and abundance of *Orchestia*. The abundance was determined by counting the emerging species along 10cm on both sides of a 1-meter long measuring tape laid down on the soil. The upper layer of the soil (0-5cm depth) was thereby carefully unravelled using the hands and a small shovel to find the benthic organisms. Since the species might move, the numbers have been rounded and documented in the notebook. This data is later linked with data about soil and plant properties.

2.2.2 Fieldwork: Soil samples

Data about soil and plant properties was gathered by taking soil samples from every salt marsh plot. At every plot, 1 sediment sample of 2cm in diameter and 20cm long was taken from the soil using an iron core sampler. The sample was then sliced in the upper 0-5cm and the lower 5-20cm and stored in plastic zip bags with the name of the sampling plot and depth written on the bag. In total for this whole project, 72 soil samples were transported to the laboratory and initially stored in the freezer (-60°Celsius) for later experiments on determining soil properties. Also, at every salt marsh plot, 1 rectangular soil sample of 12cm wide, 40cm long and 25cm high was taken using an iron box frame (*Fig. 2.5a*). The iron box frame was hammered in the soil using a mallet and extracted from the salt marsh using shovels (*Fig. 2.5b*). The soil sample was then placed in a wooden structure with matching measurements and transported to the NIOZ office in Yerseke (*Fig. 2.5c*). The samples were kept in big yellow tanks that can be filled with water at a determined level to keep the sediment samples wet and prevent desiccation (*Fig. 2.5d*).

Figure 2.5. The different steps taken for extracting, transporting and storing the salt marsh soil samples. The rectangular iron core sampler (a) was hammer in the soil (b), extracted from the soil to place in a wooden structure (c) and transported and stored (d). (Photo: Beatriz Marin)

2.2.3 Laboratorial experiments: soil properties

In this sub-chapter, a description of how the soil properties (water content, bulk density, organic matter, grain size and soil compaction) were determined can be find here.

Water content

The water content was measured by calculating the difference of wet and dry weight of the soil sample. To determine this difference, the 'wet' soil samples within the plastic bags were weighted to the nearest 0.001 gram, using a laboratory scale (*Fig. 2.6a*). Then, the sample bags were put in a freeze-dryer for 5 days with a small opening in the bag to let the water evaporate (*Fig. 2.6b*). This freeze-drying technique ensures water to evaporate from the soil and thereby prevents the sample of desiccation, so the samples can still be used for other experiments (*Fig. 2.6c*). After the soil samples were freeze-dried, the dry weight was determined using the laboratory scale and the difference of the wet and dry weight was calculated.

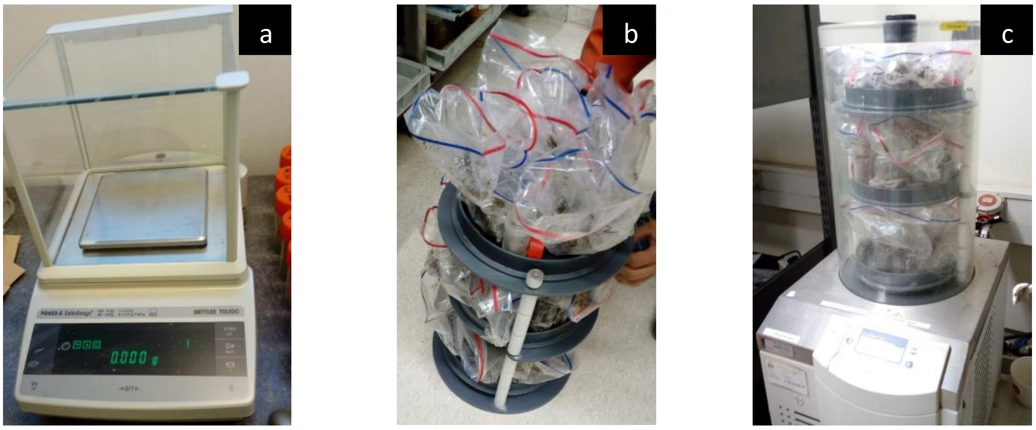

Figure 2.6. The laboratory scale and the freeze-drying technique shown for determining water content.

Bulk density

To calculate the bulk density, the dry weight of the soil sample and the volume of the sample is necessary. The dry weight is already known from the previous calculation for the water content, then the volume of the soil sample must be calculated. The known volume of 1 cm from the iron core sampler is 3,14cm^3, so the volume from the upper soil (5cm) is 15,8cm^3 and the volume from the lower soil (5-20cm) is 47,4cm^3. To calculate the bulk density of each soil, the weight of the soil sample is divided by the volume of the soil sample and expressed in g/cm^3 (*Fig. 2.7*).

$$\rho_b = \frac{M_{soil}}{V_t}$$

Figure 2.7. Formula for calculating the bulk density. (Brown & Wherrett, 2019)

Organic matter

Determining the organic matter was done by burning the organic matter from the soil sample and calculate the difference in soil weight. Sediment sub samples were therefore put in heat-resistant cups and then placed in a laboratory oven for 6 hours at 450°Celsius. 450°Celsius is the temperature on which the organic matter is burned and in turn keeps the sediment sample intact for other experiments on grain size determination. After 6 hours exposure in the oven, the samples were weighted and the difference was calculated. The subsamples were then stored in plastic jars for the next experiment on grain size.

Figure 2.8. The heat resistant cups filled with a soil sub sample of a salt marsh plot. On the right side of the picture, the plastic jars can be seen used for transportation.

Grain size

To determine the grain size, a particle size analyser was operated which detects the size of the particles from the sediment samples. For this experiment, the samples were sent to the NIOZ office in Yerseke where lab technicians operate the analyser and the results were sent back for analysation.

Compaction

To determine the compactness of the soil, a 5 kilogram weight was dropped on the salt marsh soil trough a 1m long and 15cm wide PVC pipe for 10 times so the soil gets compacted and a print is created. The created relative depth in the soil was then measured with measurement tape to determine the elevated compaction. Hereby applies, the higher the measured elevated compaction, the deeper the weight was penetrated in the soil.

2.2.4 Laboratory experiments: plant properties

The soil of each salt marsh plot was investigated on plant properties to understand the total root length per sample and the ratio between coarse roots and rhizomes. This sub-chapter described how the different properties from the plants are gathered through the determined methodology. Plant properties that were studied are length and weight of the roots from the different plant species from the salt marsh plots.

A subsample of 12cm wide, 8cm long and 25cm high (2400cm^3) was taken from every rectangular box core soil sample. This soil subsample was taken using a breadknife to cut the sample and then stored in plastic bags in the fridge (4-7°Celsius). In the laboratory, the roots were carefully distinguished from the sediment by clearing them from mud with water using a sieve with a mesh size of 500 micrometre.

Figure 2.9. A sample of the distinguished roots from the muddy soil sediment (a) and a subsample (b) *(photo: Beatriz Marin).*

After distinguishing the roots from the sediment and dividing the coarse roots and rhizomes (*Fig. 2.9a*), the separated coarse roots or rhizomes sample was put in paper bags and put in a laboratory oven for about 5 hours at 60°Celsius to evaporate the water completely. Then, a subsample (*Fig. 2.9b*) was taken and the total coarse roots or rhizomes sample and their subsample were separately weighted using a laboratory scale. Then, a picture of the subsample was taken after it was distributed laid down on a square, white plate with a small measurement tape stuck on it as reference point (*Fig. 2.9b*). The pictures were then imported on a computer and opened within the digital measuring program 'ImageJ' to measure the length of the roots. The length and the weight from the subsample were extrapolated to the known weight of the total sample to understand the total length of the roots.

2.3 Method sub-question 2

In this chapter, the method is described to find an answer on the second sub-question "*What is the relation between grazing by large herbivores and the soil and vegetation properties?*".

To find a relation between the grazing by large herbivores and the soil and vegetation properties, the gathered soil samples (Chapter 2.2.2) and laboratory experiments on soil and plant properties (Chapter 2.2.3 and 2.2.4) was used. Thereby, information about grazing management and type per salt marsh was requested by the NIOZ to relate with obtained date from the soil and plant properties which revealed that 1 site was extensively grazed by horses, 2 sites were extensively grazed by cows and 7 sites were ungrazed.

2.4 Method sub-question 3

The aim was furthermore to find an answer on the third research question: "*What soil properties and vegetation types are related to more stable marshes?"* It was of interest to understand if and how different salt marsh soils with different properties erode when exposed to fast water flow conditions. To explore this, the 36 rectangular soil samples extracted from 10 different salt marshes were placed in a channel/flume in which water would flow. The results were brought in relation to soil and plant properties, grazing management and the presence of *Orchestia*. This experiment indicates how stable and erosion resistant different salt marshes are.

Experiments with the Fast Flow Flume

The so called "Fast Flow Flume" is a flume of about 5m long, 1m high and 0,2m wide wherein water can flow at 2 meter per second, simulating waterflow conditions during heavy weather. A rectangular soil sample (12cm wide, 32cm long and 20cm high) was placed in the flume whereby the top layer of the sample was exposed to the water flow, inducing top layer erosion such as in a salt marsh. When the sample was put in the flume, the height of the sample is measured. Height measurements were done by putting a metal pin of 100cm long and 0,3cm in diameter through a plastic bar which consists of 12 holes in a line. While measuring, the bar struts on the walls of the flume at a determined height of 30cm straight above the sample in the flume. The height of the soil surface was measured following this procedure for 5 times; 1 before the water flow was turned on indicating as baseline measurement and 4 height measurements after durations of waterflow exposure (after 10 minutes, 1 hour, 2 hours and 3 hours). By doing so, the erodibility and duration were linked to understand how different soil types erode over time. The waterflow was controlled using rotary switches to turn the waterflow on or off.

The data from the gathered soil samples (Chapter 2.2.2), the laboratory experiments on soil and plant properties (Chapter 2.2.3 and 2.2.4) and the information from the grazing management (Chapter 2.3) was used to relate with the results from the Fast Flow Flume experiments.

Figure 2.10. The Fast Flow Flume in its natural habitat (a & b).

2.6 Statistical analyses

After determining the properties of all the samples from the salt marshes as described in the previous subchapters, the data is statistically analysed to find significantly differences and correlations for substantiating the data. An alpha level of 0.05 is used for all statistical tests and were conducted with the statistical software SPSS (IBM SPSS Statistics 25). To give the reader more understanding in the performed statistical tests, the used variables are explained in this subchapter. A schematic overview of all variables + description can be seen in Table 2 at the end of this chapter to give the reader more understanding in the done statistical tests.

2.6.1 Statistical tests for sub-question 1

***Orchestia* presence**

The variable Orchestia Presence indicates if *Orchestia* was present or absent in a salt marsh plot (n=36). It was of interest to understand the relation between the occurrence of *Orchestia* and soil and plant properties. To find a correlation between the presence of *Orchestia* and soil properties, the Spearman test for Correlation (R_s) was used.

***Orchestia* abundance**

Besides looking at the occurrence of *Orchestia* at every salt marsh plot, the abundance was studied using the measuring tape-method. This was done at the 16 plots from the 4 salt marsh sites along the Wadden Sea main coast (n=16), because it was expected that the abundance of *Orchestia* would have an effect on the soil and plant properties and in turn salt marsh stability. The data of *Orchestia* was categorized in no abundance (0 individuals), low abundance (1-15 individuals) and high abundance (>15 individuals) per salt marsh plot. *Orchestia* abundances varied between 0 and 65 individuals per plot. The choice on which correlation test is used is based on plotting the variables in a graph and see what kind of correlation might appear. A Pearson Correlation test (R^2) was used to find if there were linear correlations between *Orchestia* abundances and soil and plant properties. The Spearman Correlation test (R_s) is used after a monotonic relation is expected that is non-linear. Also, the analysis of variance test (one-way ANOVA) was used to find if there were any differences between *Orchestia* abundance groups and the other variables as determined that were found significantly correlated from the previous correlation tests. When the ANOVA-test found significantly differences between the groups as determined, a post hoc test was utilised to calculate how the abundance groups differed per soil and plant property. Thereby, it was of importance to check for the assumptions of homogeneity according to Leven's test to choose which post hoc test.

2.6.2 Statistical tests for sub-question 2

Grazing presence

To find out how grazing management influence salt marsh stability, two variables were created: Grazing presence and Grazing type (*Table 2*). The variable grazing presence contains if a salt marsh plot is grazed or ungrazed by livestock. To further understand if there are differences in soil and plant properties between salt marshes that are grazed or ungrazed, the Spearman test for Correlation was used.

Grazing type

Besides it was important to know if grazed and ungrazed salt marshes were correlated with soil and plant properties, it was of interest to understand whether there were differences in type of grazing management (ungrazed/cows/horses) and the studied variables. To find such differences, an analysis of variance test (one-way ANOVA) was used and to further explore which groups differed a post hoc test was used.

2.6.3 Statistical tests for sub-question 3

Erodibility

In this study, stability of salt marshes is expressed by measuring the final erosion in centimetres after the sample was exposed to a water flow velocity of 2 meter per second for 3 hours and brought in relation to the salt marsh properties. The variable Erosion was made to find what soil and vegetation type is related to more stable salt marshes. The soil and plant properties were tested by the final erosion, whereby the Spearman and the Pearson Correlation test was used. To find if there were differences in vegetation type on erosion, the analysis of variance test (one-way ANOVA) was used and to further understand which vegetation type differed on erodibility a post hoc test was consulted.

Table of Variables				
Variable Names	**Measurement Scale**	**Values**	**Description**	**Sample size (n=plot)**
Orchestia variables				
***Orchestia* presence**	Nominal	0=Absent, 1=Present	Presence and absence of *Orchestia,* where it is expected that the presence of *Orchestia* influences soil and plant properties as well as the erodibility.	n=36
***Orchestia* abundance**	Ordinal	0=No abundance, 1=Low abundance, 2=High abundance	The abundance was categorized in No abundance = 0 individuals, Low abundance = 1-15 individuals and High abundance = >15 individuals. It is expected that different abundances of *Orchestia* have an effect on soil and plant properties and the erodibility.	n=16
Grazing variables				
Grazing presence	Nominal	0=Absent, 1=Present	It is expected that there are differences in grazed and ungrazed salt marshes on the erodibility of the soil and that it influences soil properties.	n=36

Grazing type	Ordinal	0=No Grazing, 1=Cows, 2=Horses	The different types of grazing management will be tested as it is expected that different types of grazing have different effects on soil and plant properties in the salt marshes.	n=36 (cows = 6, horses = 3)
Erosion variable				
Erosion	Scale	Values range between 0,6 cm and 35,9 cm	The erosion in centimetres was measured to test with all other variables, to understand the erodibility of every salt marsh plot.	n=36
Soil variables				
Water content	Scale	Values range between 13,31% and 67,24%	To test how the water content in the soil have an effect on the erodibility, this variable was made.	n=36
Organic matter	Scale	Values range between 0,49% and 20,15%	Organic matter is an indicator of food availability and can have an effect on the erosion resistance. This variable was made to understand the effect on plant properties, grazing management and erodibility.	n=36
Bulk density	Scale	Values range between 0,4 g/cm3 and 2,7 g/cm3	This variable will be tested to see how bulk density influences the *Orchestia* properties and plant properties. It is also of interest how bulk density affect salt marsh erodibility.	n=36
Grain type	Nominal	1=Clay and 2=Sand	Grain type is classified in two values, whereby it is expected that clay has another effect on the erodibility than sand.	n=36
Compaction	Scale	Values range between 1cm and 10cm	The variable Compaction is made to test how grazing properties influence the elevation of the soil and to see if it has an effect on the erodibility.	n=36

Plant and vegetation variables				
Coarse roots length	Scale	Values range between 27,86cm and 13884,73cm	It is expected that the length of the coarse roots influences soil erosion and that it has a relation with the *Orchestia* and soil properties.	n=36
Rhizomes length	Scale	Values range between 28,41cm and 1274cm	It is expected that the length of the rhizomes influences soil erosion and that it has a relation with the *Orchestia* and soil properties.	n=34
Vegetation type	Nominal	1=Pioneer marsh spp., 2=Low marsh spp., 3=High marsh spp.	The different vegetation types represent the different salt marsh zones whereby it is tested how the different types have an affect on soil properties and erodibility.	n=36 (Pioneer = 10, Low = 8, high = 18)

3. Results

3.1 Results sub-question 1

3.1.1 *Orchestia* presence

The Spearman test for Correlation gave a moderate to strong negative significant correlation between *Orchestia* presence and bulk density (R_s = -.535, *p* = .001) (*Fig. 3.1*) and a moderate to weak positive significant correlation with vegetation type (R_s = .334, *p* = .046). There were further no significant correlations found between the presence of *Orchestia* and other soil and plant properties.

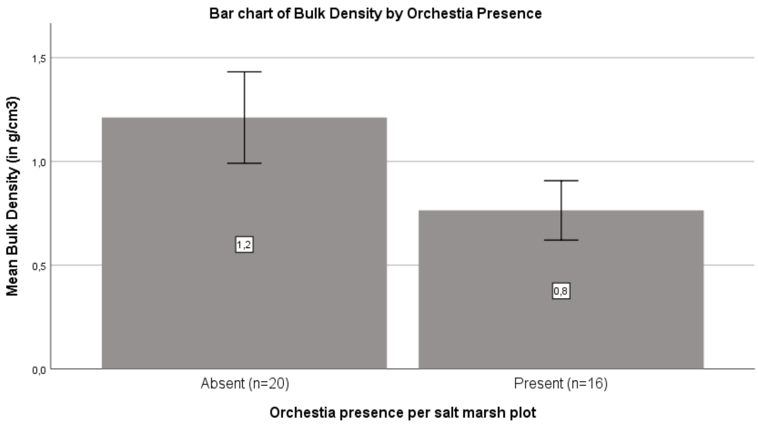

Figure 3.1. Bar chart of the bulk density by the presence or absence of *Orchestia* with numbers of mean ± SE.

3.1.2 *Orchestia* abundance

Orchestia abundance was strong positive significant correlated with soil properties water content (R^2 = ,702, *p* = .002) and organic matter (R_s = ,615, *p* = .011) and strong negatively correlated with bulk density (R_s = -,667, *p* = .005), but not with any other soil or plant property. The Pearson Correlation test showed furthermore that water content is pretty strong positive significantly correlated with organic matter (R^2 = .831, *p* = .001). The analysis of variance test (one-way ANOVA) gave significant differences between *Orchestia* abundance and water content (*F*(2, 13) = 6,571, *p* = .011), organic matter (*F*(2,13) = 7,342, *p* = .007) and bulk density (*F*(2,13) = 9,609, *p* = .003). After the one-way ANOVA-test found significant differences (*p* <.05) and Leven's test for Homogeneity gave insignificant values for the soil variables as determined (*p* >.05), the Tukey post hoc test was used and revealed that the water content was significantly higher in salt marshes with a high abundance of *Orchestia* (59.1 ± 7.2 %, *p* = .008) compared to no *Orchestia* abundance (42.2 ± 7.2 %). There were no significant differences found between high *Orchestia* abundance and low *Orchestia* abundance (*p* = .236) and between low *Orchestia* abundance and no *Orchestia* abundance (*p* = .580) by water content. The Tukey post hoc test revealed also that organic matter was significantly higher in salt marshes with high *Orchestia* abundance (16.2 ± 3.5 %, *p* = .006) compared to no *Orchestia* abundance (9.6 ± 2.5 %). There were no significantly differences between high *Orchestia* abundance and low *Orchestia* abundance (*p* = .075) and between low *Orchestia* abundance and no *Orchestia* abundance (*p* = .929) by organic matter. Furthermore, the Tukey test revealed that the bulk density was significantly lower in salt marshes with high *Orchestia* abundance (0.6 ± 0.1 g/cm^3, *p* = .002) compared to no *Orchestia* abundance (1.1 ± .2 g/cm^3). There were no significant differences between low *Orchestia* abundance and high *Orchestia* abundances (*p* = .070) and between low and no abundance (*p* = .708) on bulk density. Figure 3.2 illustrates boxplots of the water content, organic matter and bulk density by *Orchestia* abundances.

(1)

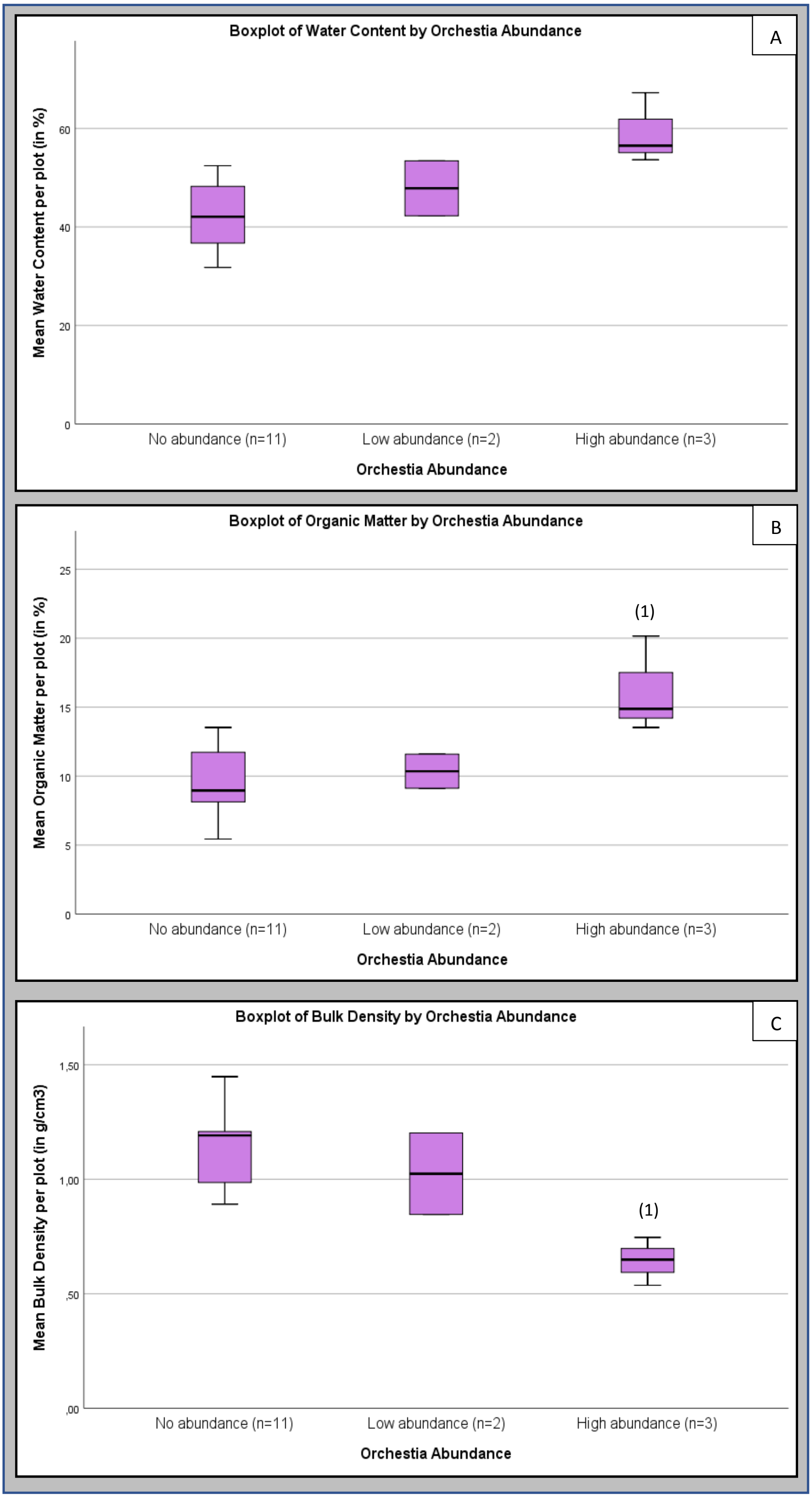

Figure 3.2. Box plots of the different *Orchestia* abundances by (A) water content (%), (B) organic matter (%) and (C) bulk density (g/cm^3) that show significant differences between the groups as determined (two-way ANOVA, where $P < .05$ is significant). The numbers in brackets indicate to which bar a significant difference was found (Tukey post hoc $p < .05$).

3.2 Results sub-question 2

3.2.1 Grazing presence

The Spearman Correlation test showed a moderate to strong negative significant correlation between the presence of grazing and compacted elevation ($R_s = -.422$, $p = .010$) and erosion ($R_s = -.448$, $p = .006$) (*Fig. 3.3*). Even when the sandy samples were excluded, there was a significantly correlation found between grazing presence and erosion ($R_s = -.421$, $p = .018$).

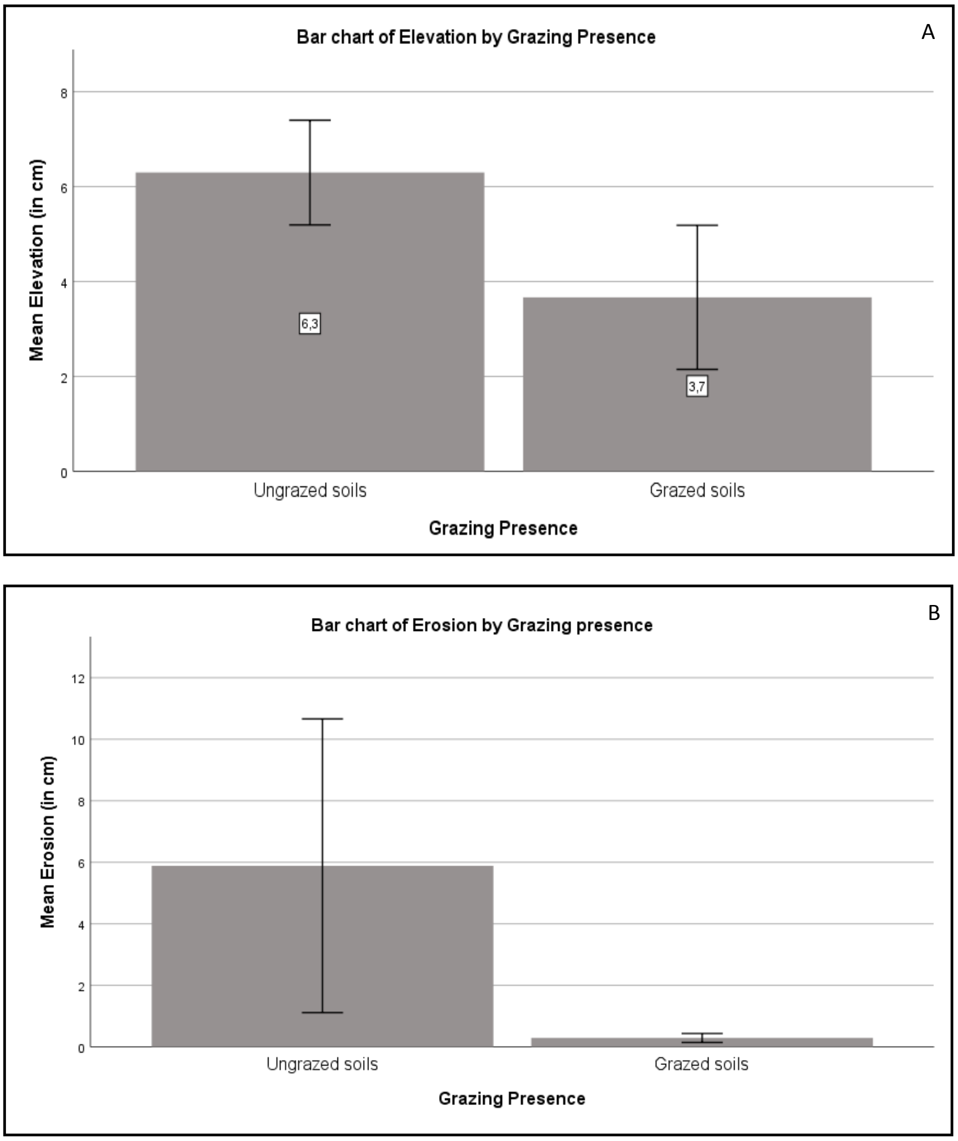

Figure 3.3. Bar charts showing the significantly difference of (A) elevation and (B) erosion (in cm) by the presence of grazers ($p < .05$). Both bars show mean ± SE.

3.2.2 Grazing type

Grazing type was moderate negative significantly correlated with compaction (R_s = -.433, p = .008). The ANOVA test gave significant differences between grazing type and compaction ($F(2,33)$ = 3,651, p = .037), but not for erosion (p = .427). The Tukey post hoc test revealed that the compaction was *marginally* significantly lower in salt marshes that were grazed by horses (2,3 ± 2,8 cm, p = .059) compared to ungrazed marshes (6,3 ± 2,9 cm). There were further no significantly (or marginally significantly) differences between plots grazed by cows and ungrazed plots (p = .264) and there were no significantly differences between different grazed plots by compaction mutually (*Fig. 3.4*).

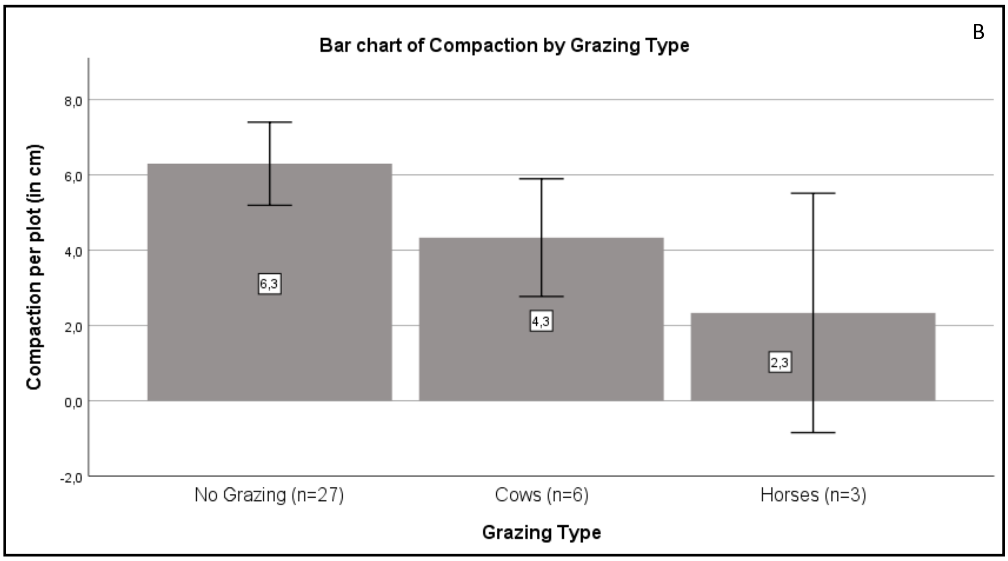

Figure 3.4. Bar chart (with numbers of the mean ± SE) showing the average compaction (in cm) divided per grazing type.

3.3 Results sub-question 3

3.3.1 Erodibility

The Pearson Correlation test revealed that erosion was pretty strong positive significantly correlated with grain type (R^2 = .875, *p* = .001) (*Fig 3.5*).

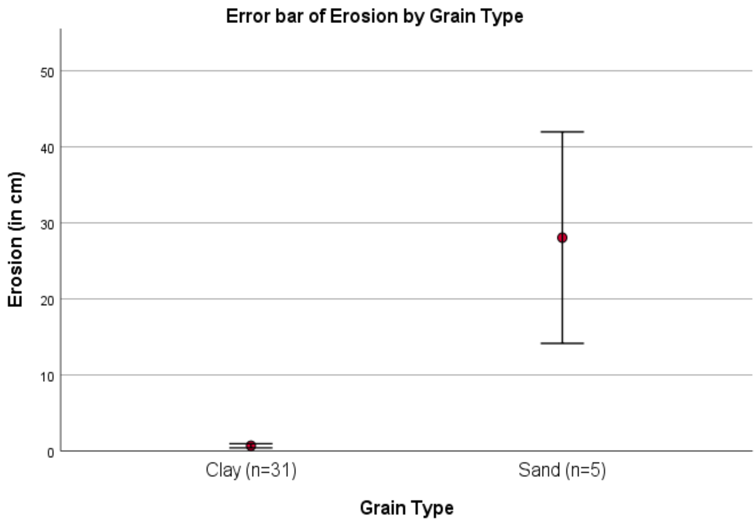

Figure 3.5. Error bar (with mean ± SE) of grain type by erosion (n=36).

The Pearson Correlation test gave a strong negative significant correlation of erosion with water content (R^2 = -.614, p = .001) and organic matter (R^2 = -.651, p = .001) and a strong positive significant correlation with bulk density (R^2 = .624, p = .001) (*Fig. 3*.8), but not with compaction (p = .504) when all samples were included. After the sandy samples were extracted from the clayey samples in the dataset, the Pearson Correlation test gave an insignificantly correlation between erosion and water content (p = .869), organic matter (p = .715) and compaction (p = .077) but a negative moderate significantly correlation with bulk density (R^2 = -.374, p = .035) (*Fig. 3.6*).

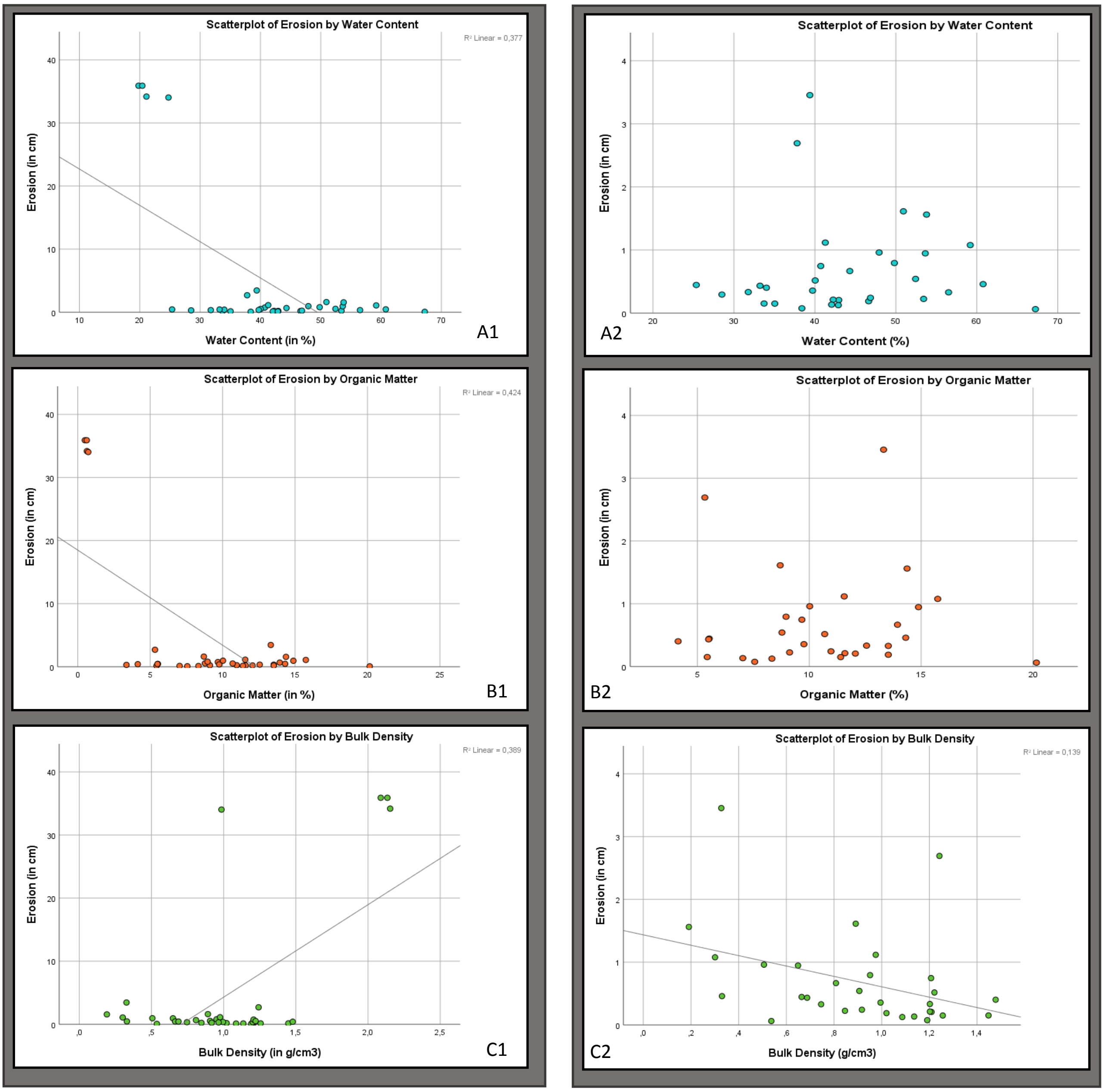

Figure 3.6. Scatterplots (with linear regression line if found significant) of water content (A), organic matter (B) and bulk density (C) by erodibility. The left graphs have sandy samples included (n=36), the right graphs are without sandy samples (n=31) to show the effect of grain type.

3.3.2 Vegetation type

The Pearson correlation test found a moderate to strong positive significant correlation between vegetation type and organic matter (R^2 = .571, *p* = .001) and a strong negative significant correlation with bulk density (R^2 = -.584, *p* = .001) (*Fig. 3.12*). There was no significantly correlation found between vegetation type and the other soil properties (*p* > .05). The one-way ANOVA test gave significant differences between vegetation type and organic matter (*F*(2,33) = 8,377, *p* = .001) and bulk density (*F*(2,33) = 10,557, *p* = .001). The Tukey post hoc test showed that organic matter was significantly lower in salt marshes with pioneer marsh spp. (5,1 ± 3,6 %, *p* = .001) compared to salt marshes with high marsh spp. (11,5 ± 4,2 %) and was *marginally* significantly lower compared to salt marshes with low marsh spp. (9,5 ± 3,9 %, *p* = .064). There were no significantly differences between low marsh spp. and high marsh spp. (*p* = .470) by organic matter. The Games-Howell post hoc test revealed that bulk density was significantly lower in salt marshes with low marsh spp. (0,9 ± 0,2, *p* = .012) and high marsh spp. (0,8 ± 0,4, *p* = .005) compared to salt marshes with pioneer marsh spp. (1,5 ± 0,5 g/cm^3). There were no significantly differences between low marsh spp. and high marsh spp. (*p* = .729) by bulk density (*Fig. 3.7*).

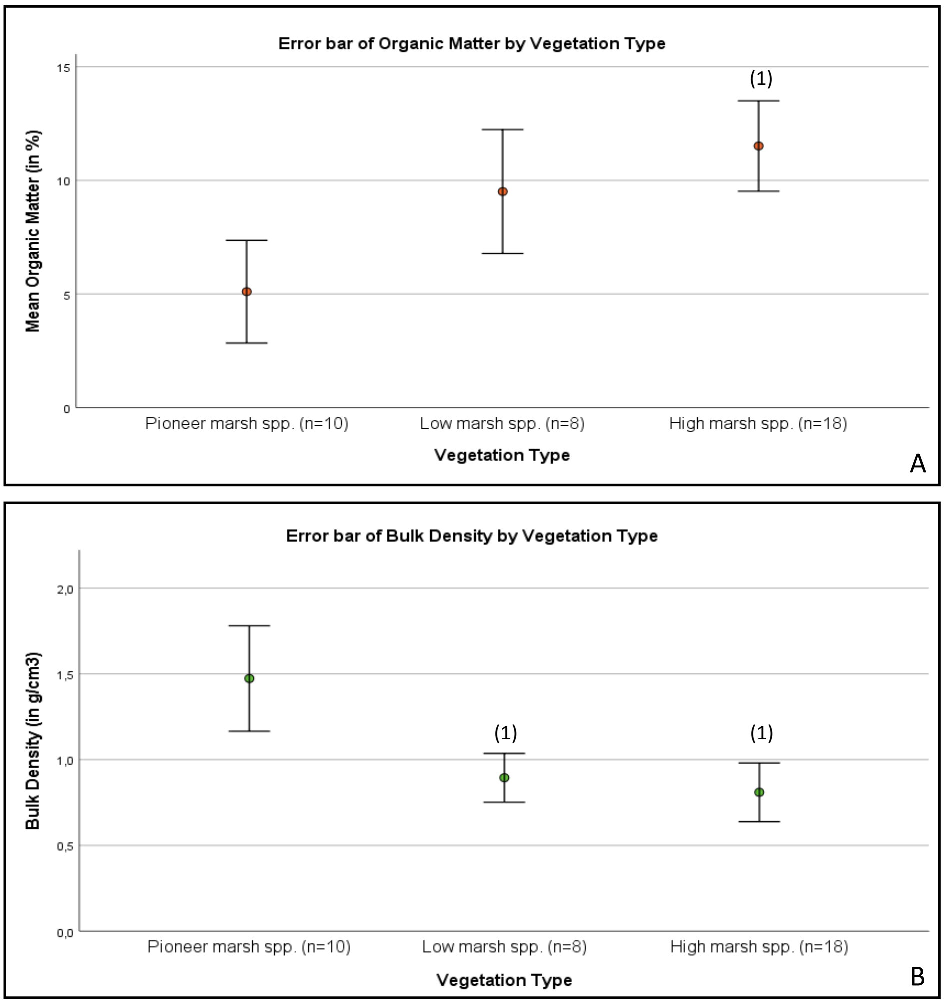

Figure 3.7. Error bars (with mean ± SE) showing the difference in (A) organic matter (%) and (B) bulk density (g/cm^3) per vegetation type. The numbers in brackets indicate to which bar a significant difference was found (Tukey post hoc *p* < .05 (A) and Games-Howell post hoc *p* < .05 (B).

When the different vegetation types were tested on correlation by erosion from all samples, the Spearman Correlation test showed that there was no significantly correlation (R_s = -.242, p = .155). When the sandy samples were extracted and the clayey samples were tested on correlation by erosion, the Spearman Correlation test showed also no significantly correlation (R_s = -.112, p = .548) (*Fig. 3.8*).

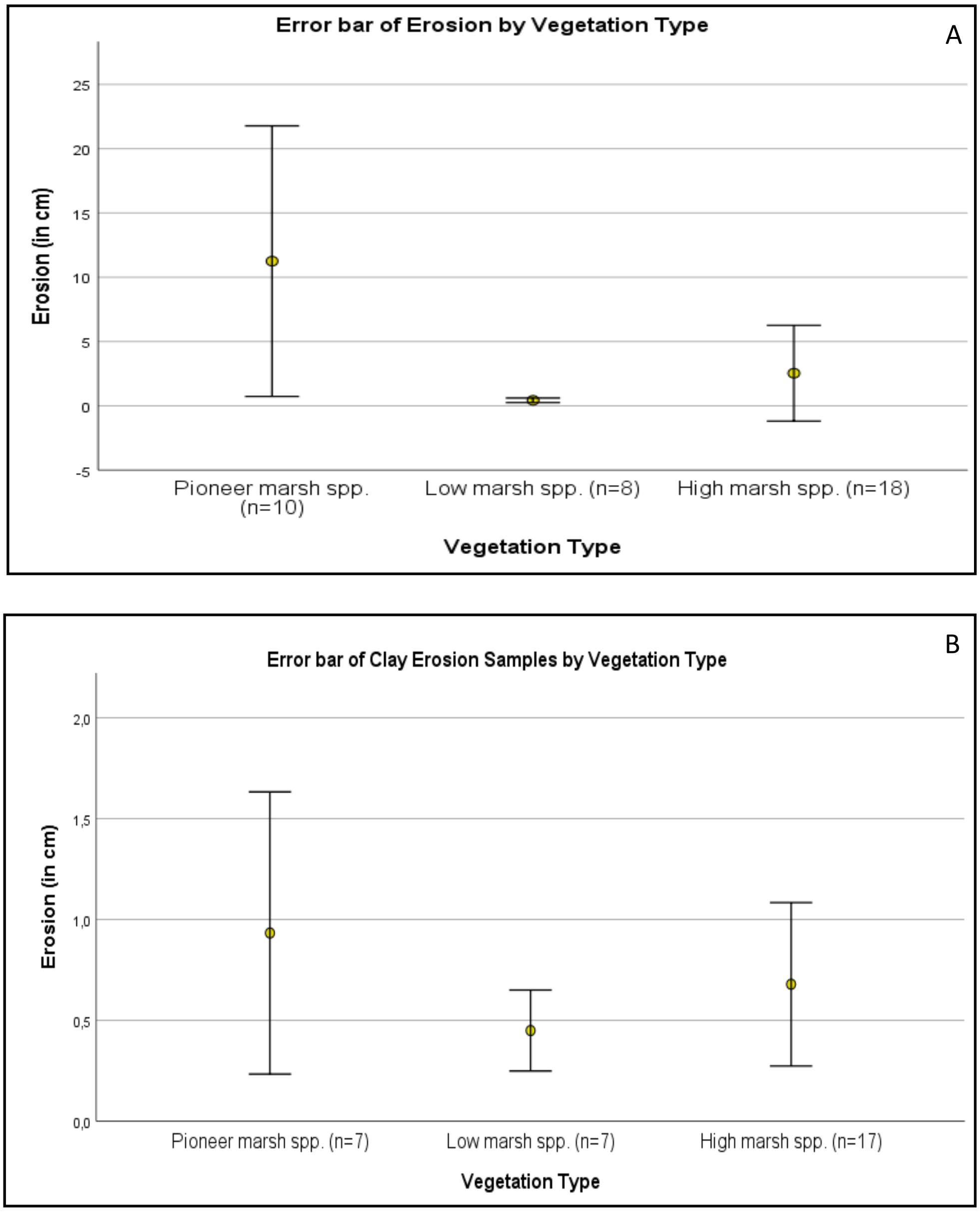

Figure 3.8. Error bars (with mean ± SE) of the different vegetation types by erodibility of (A) clayey and sandy samples together (n=36) and (B) only clayey samples (n=31) to show how the mean final erosion of vegetation types, sub-divided by grain type.

There was a moderate to strong positive significantly correlation between the different salt marsh plant species and water content (R_s = .371, p = .026) and organic matter (R_s = .618, p = .001) and a moderate negative significant correlation with bulk density (R_s = -.445, p = .007) (*Fig. 3.9*), but not with erosion (p = .194) as seen in figure 3.10.

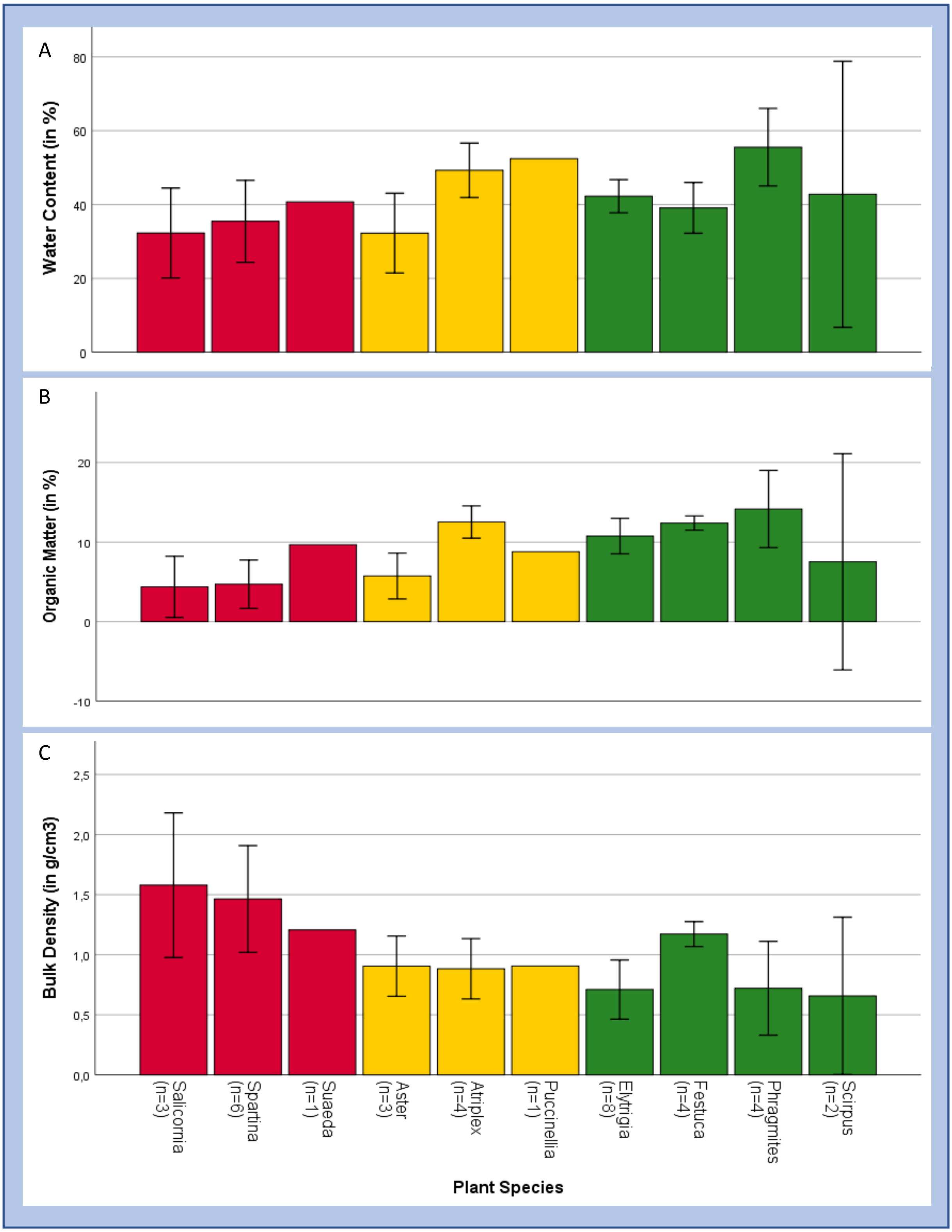

Figure 3.9. Bar plots (with mean ± SE) to show how the different plant species are correlated to (A) water content (%), (B) organic matter (%) and bulk density (g/cm^3) (p < .05). The colour of the bars indicates different vegetation types, for red as pioneer salt marsh spp., yellow is low spp. and green is high spp.

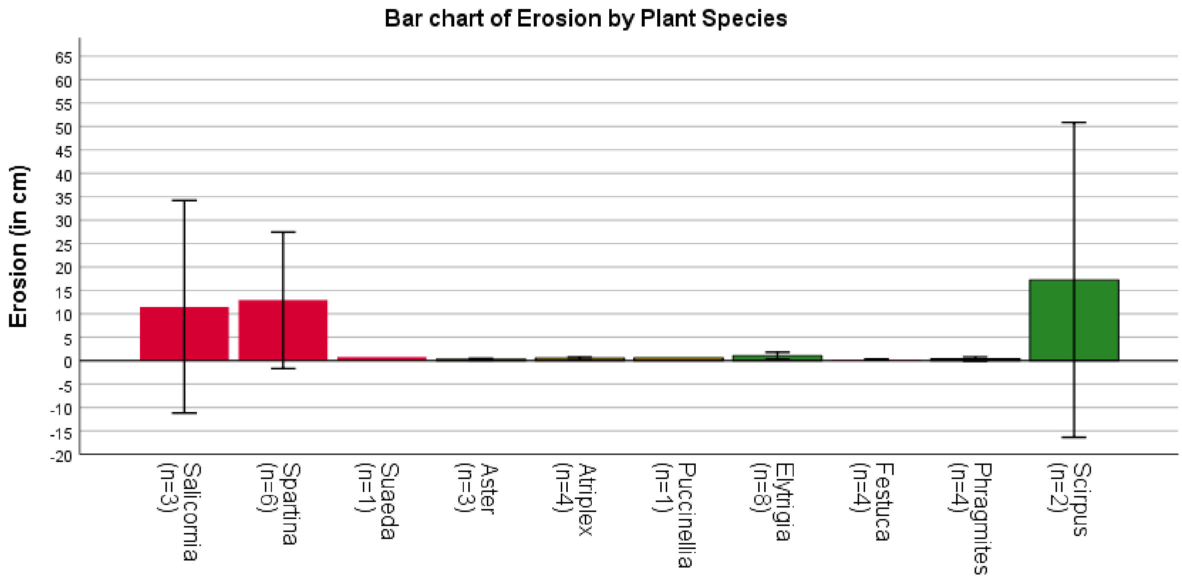

Figure 3.10. Bar plots (with mean ± SE) showing the erosion in centimetres of the different plant species, which was not significantly correlated (*p* = > .05).

The Spearman Correlation test showed a moderate positive significant correlation between the rhizome length and erosion (R_s = .380, *p* = .038) (*Fig. 3.11*).

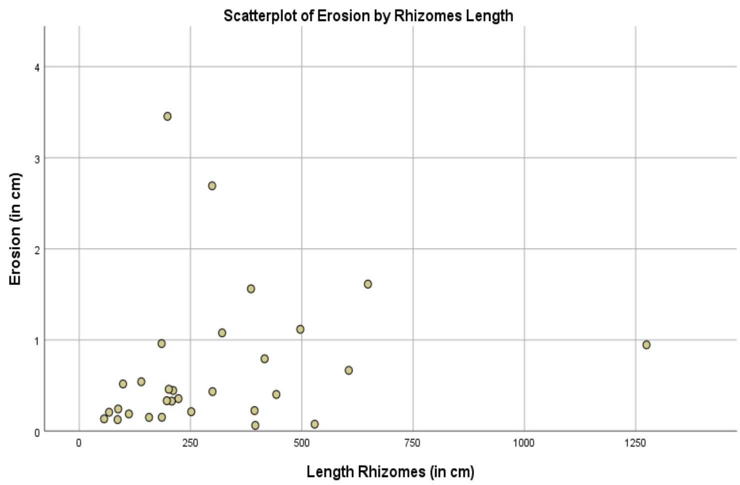

Figure 3.11. Scatterplot of the extrapolated total length of rhizomes per plot by erodibility (n=34).

4. Discussion

The relation between Orchestia and soil and plant properties

Orchestia was searched in all 36 salt marsh plots, whereof in 16 salt marsh plots *Orchestia* was found. From the soils in which *Orchestia* was present, the mean bulk density was lower than in soils were *Orchestia* was absent. The results show that *Orchestia* is common in soils with a bulk density between 0,6 and 0,9 g/cm^3 and that they are uncommon in soils with a bulk density between 1,0 and 1,4 g/cm^3. It is however not excluded that *Orchestia* do not live in soils with a higher or lower bulk density as shown, because *Orchestia* was also found in a soil with a bulk density of 0,2 g/cm^3. Moreover, *Orchestia* and other benthic organisms retrieve energy from feeding on organic matter. While breaking down the organic matter, nutrients are released in the soil that can be used for plants to uptake (FAO(1), sd). Thereby, it was found that there were more individuals present in salt marshes where organic matter and water content are both higher than average. The results of the soil properties in relation to the *Orchestia* presence and abundance indicates that *Orchestia* have specific soil preferences. Water in the soil is able to transport organic matter in the form of nutrients, which explains why it is found that water content is very strong positively correlated with organic matter. This reveals furthermore why high abundances of *Orchestia* are present in salt marsh soils that are high in water content, because there are a lot of nutrients present on which the *Orchestia* feed. Schrama, Boheemen, Olff, & Berg, (2015) have also found that while *Orchestia* feeds on organic matter, it stimulates plants to grow which can thereby reach a late-successional stage. Late-successional plants are mostly present in high salt marshes (Esselink, et al., 2017). By counting the presence of *Orchestia* per vegetation type, it was found that the *Orchestia* was present in 1 plot of pioneer marsh vegetation, 5 plots of low marsh vegetation and 10 plots of high marsh vegetation. The findings from Schrama, Boheemen, Olff, & Berg, (2015) can be related to my research because it is found that *Orchestia* occurred mostly in high salt marshes where organic matter is higher and where late-successional plants occur (*Fig. 3.12*). Furthermore, it is known that *Orchestia* is able to change sediment layers and soil properties by its bioturbating activities (Alden, 2017). Howison, Olff, Puijenbroek, & Smit, (2016) studied the bioturbation of *Orchestia* on two plant species from different successional stages, which were *Festuca rubra* (early-successional) and *Elytrigia atherica* (late-successional). They found that under stressed (waterlogging) conditions, *Orchestia* forages more on *Elytrigia* than on *Festuca* to survive, because *Elytrigia* is the higher quality plant. To relate their findings with my study, I found that *Orchestia* was more often present in salt marsh plots where *Elytrigia* was present than in any plot with other plant species. Additionally, *Orchestia* presence was not found in salt marsh plots in which *Festuca* was present. This could mean that besides *Orchestia* have preferences for certain soil properties, they also prefer specific plant species.

The only soil property that was both correlated to the presence and abundance of *Orchestia* and erodibility is bulk density. It is found that salt marsh soils with a low bulk density is correlated with less erosion and that *Orchestia* occurs in soils with a low bulk density. It is however not significantly found that *Orchestia* is related to erosion. It can therefore be concluded that salt marsh stability is not influenced by the presence of *Orchestia*.

The effect of grazing in salt marshes

It was of interest to explore if grazing management can be brought in relation to salt marsh stability. Since cows and horses weight about 500 kg (VoerVergelijk, sd; Dijke, Velthuis, & Penterman), it was expected that these grazers are able to compact the soil and indeed, it was found that the presence of grazers was significantly correlated with compacted elevation. When measuring the compaction in the field as explained in the method section, dropping the 5 kg weight ensured a mean deeper print in ungrazed soils (6,3 cm) than in grazed soils (3,7 cm). This means that grazed soils are more compacted than ungrazed soils, which is due to the weight of the grazers who make the soil more compact. It was also found that grazed salt marsh soils erode less than ungrazed soils. Additionally, it was expected that compacted soils are more solid and therefore less sensitive to erosion, but there was no significant correlation between compaction and erosion. So, although it was found that grazed salt marsh soils erode less than ungrazed salt marsh soils, it can not be directly linked with the presence of grazers because the only factor that grazers affect is compaction and compaction is not significantly correlated with erosion. It was found impossible to determine which elements influence soil erosion the most due to incomparable units used in the statistical model. Furthermore, there were no significant relations found with grazing type and plant species, because over the 10 studied salt marshes, there were only 3 different salt marshes in which 2 grazed by cows and 1 by horses and the other 7 salt marshes were ungrazed which is a very small sample group. Due to this small group size, it was unable to find significant relations with grazing type and plant species. Esselink et al., (2009) found however, that different plant species occur due to different grazing types. This is because plant-plant competition reduces when large grazers are present who consume the plants and thereby keep the vegetation short, hampering plant species to develop and spread. It is explored over the years that grazing management can be used as a tool to achieve natural value. There is experimented with different intensities and types of grazing (Berg, Esselink, Groenweg, & Kiehl, 1997) and it is found that intensive grazing management ensures a decrease in plant species and biodiversity. On the other hand, extensive grazing management is found to be suitable for achieving high biodiversity and to achieve different vegetation types or to prevent that one vegetation type dominate within a certain salt marsh (Esselink et al., 2009).

How soil and plant properties influence salt marsh stability

When exploring which factors are important for salt marsh erodibility, there were some significant correlations found with soil properties. It was found that high erosion occurred at samples with a low water content, low organic matter and high bulk density. However, it was found that grain type was mostly responsible for such correlations as seen in figure 3.8. Additionally, sandy samples ensured different erodibility than clayey samples. When the sandy samples were excluded, it was found that water content and organic matter were not significant anymore and the positive significant correlation from bulk density by erosion changed into a negative significant correlation. This all means that water content and organic matter do not influence erosion, but that bulk density and grain type are important factors for soil erosion. Clay samples only erode in total of about 2 cm and sandy samples have an average final erosion of almost 30 cm (meaning that it is eroded completely to the bottom of the sampling box). This result can be related to the Hjulström-theory, whereby clayey samples need a higher flow velocity than sandy samples due to the ability of grains of clay to stick to each other (Panchuk, sd). Furthermore in this study, there were significant correlations found between the different vegetation types and soil properties. The ANOVA-test showed that there were significantly differences between vegetation types and organic matter and bulk density. It was found that there were higher amounts of organic matter in high marsh types in relation to pioneer marsh types, which can be related to the height of plants. In general, taller plants are found in high marshes compared to pioneer marshes (Esselink, et al., 2017). Tall plants are based on a high productivity caused by a high organic matter and vice versa (FAO(2), sd). Because of this, there are more plants in high marshes. It is also found that a higher bulk density is related to less erosion and although there was no direct significantly correlation between vegetation type and erosion, a lower bulk density ensures less erosion and a lower bulk density is found in higher vegetation types, which also erode less than pioneer marshes. Moreover, characteristics of the plant species present on salt marshes were of interest too as it was found by previous studies that plant roots are able to stabilize the soil and control soil erosion (Gyssels, Poesen, Bochet, & Li, 2005; ScienceBuddies, 2015; Reubens, Poesen, Danjon, Geudens, &

Muys, 2007). It was found by Baets, et al., (2007), that length was an important plant property for soil stability and Yu, Wang, He, Chu, & Dong, (2008) found that larger rhizomes have an effect on soil erosion. In my research, it was found that soil erosion increased when the present rhizomes were taller, which shows thus the opposite of what other studies shown. It was furthermore found that pioneer marsh spp. had longer rhizomes than the other vegetation types. When looked at the erosion from the pioneer marsh spp., there were higher erosion numbers found due to the grain type that occurred in pioneer marshes.

5. Conclusion

Throughout this method and set-up, I was unable to find out if and how bioturbation from *Orchestia* influences salt marsh stability. It can be concluded that grazed salt marshes have a more compacted soil, but that compaction does not significantly affect erodibility, which means that grazing does not directly influence salt marsh stability. Although it was found that long rhizomes were found correlated with erosion, other soil properties were responsible for this effect and it was thus not found that plant properties and vegetation type influence stable salt marshes. All in all, it can be concluded that the soil properties grain type and bulk density are important factors for salt marsh stability.

6. Recommendations

To understand if and how *Orchestia* influence soil and plant properties and in turn soil stability, other kind of experiments should be done, like the ones that Schrama, Boheemen, Olff, & Berg (2015) did. My recommendation is therefore to perform experiments under controlled laboratory conditions, whereby different abundances of *Orchestia* are added to varies types of soils and study if the soil properties change over time. Thereby, the different types of soils should be exposed to water flow velocity using the fast flow flume as described in this study at chapter 2 to measure erosion differences. This way, it is possible to find out if and how the presence and abundance of *Orchestia* is related to salt marsh stability. For grazing management in salt marshes to achieve salt marsh stability, additional research should be performed with larger group samples. In this study, the emphasis was more placed to know and understand how salt marsh stability is influenced by soil and plant properties than on the influence of biotic effects, such as grazers. Therefore, the sample size of grazed salt marshes was too small to find significantly correlations on salt marsh stability and grazing presence. In future studies, it would also be important to take the extent of grazing intensity into account as it is expected that variations in intensive and extensive grazing regimes can lead to different salt marsh vegetation plants. Overall, to achieve higher ecological value and biodiversity, an extensive grazing regime should be managed. Grazing leads to compaction, but compaction does not lead to erosion, so it is not necessarily of high importance to take grazing regime into account when obtaining stable salt marshes. Finally, it can be with certainty said that salt marsh stability is foremost influenced by sediment type than vegetation type and thereby, that sandy salt marsh soils are subjected more to erosion than clayey soils.

7. Acknowledgements

I would like to thank my supervisor from the RUG and the NIOZ Beatriz Marin who helped achieving my thesis project. I have learned a lot from her on how to perform and write scientific research. I also want to thank my supervisors from the VHL Joop van Eerbeek, Uche Obinna and Evelien Jager for believing in me and supporting on writing my thesis.

Bibliography

Agrofoodcluster. (n.d.). Bijdragen aan een duurzame wereld. Retrieved on November 11, 2018 from https://agrofoodcluster.com/deelnemer/van-hall-larenstein/

Alden, A. (2017). *Bioturbation: How Plants and Animals Change the Surface of the Planet.* Retrieved on October 19, 2018 https://www.thoughtco.com/what-is-bioturbation-1440851

ALevelGeography. (2018). *Hard Engineering*. Retrieved on October 18, 2018 from http://www.alevelgeography.com/coastal-protection-and-management-hard-engineering/

Baessler, L. (2018). What Is A Rhizome: Learn About Rhizome Plant Facts. Retrieved on February 17, 2019 from https://www.gardeningknowhow.com/ornamental/bulbs/bgen/what-is-a-rhizome.htm

Baets, S. De, Poesen, J., Reubens, B., Wemans, K., Baerdemaeker, J. De & Muys, B. (2008). Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. *Plant and Soil, Volume 305 (Issue1-2), 207 - 226*. Retrieved on March 10, 2019 from https://link.springer.com/article/10.1007/s11104-008-9553-0

Bakker, J. P., Esselink, P., Dijkema, K. S., van Duin W. E & de Jong D. J. (2002). *Restoration of salt marshes in the Netherlands*. Retrieved on February 17, 2019 from https://www.researchgate.net/publication/40132984_Restoration_of_salt_marshes_in_The_Netherlands

Bakker, J. P., Kuijper, D. P. J., Stahl, J. (2009). *Community ecology and management of salt marshes.* Retrieved on December 11, 2018 from https://www.researchgate.net/publication/259372470_Community_ecology_and_Management_of_Salt_Marshes

Bakker, J. P. (2012). *Restoration of Salt Marshes.* Retrieved on October 12, 2018 from https://www.rug.nl/research/portal/files/2459877/2012RestorEcolBakker2.pdf

Bakker, J. P. (2014). *Ecology of salt marshes.* Retrieved on November 6, 2018 from https://www.waddenacademie.nl/fileadmin/inhoud/pdf/04-bibliotheek/2014_Ecology_of_salt_marshes_Jan_Bakker.pdf

Bakker, J. P., Baas, A. C. W., Bartholdy, J., Jones, L., Reussink, G., Temmerman, S., Pol, M. van de. (2016). *Environmental Impacts—Coastal Ecosystems*. Retrieved on February 15, 2019 from https://link.springer.com/content/pdf/10.1007%2F978-3-319-39745-0_9.pdf

BBC. (2018). *Hard engineering.* Retrieved on October 18, 2018 from https://www.bbc.com/bitesize/guides/z2234j6/revision/1

Berg, G., Esselink, P., Groenweg, M., & Kiehl, K., (1997) *Micropatterns in Festuca rubra-dominated salt-marsh vegetation induced by sheep grazing*. Retrieved on March 11, 2019 from https://link.springer.com/article/10.1023/A:1009727804007

Bos, D., Bakker, J. P., Vries, Y. de, Lieshout, S. van. (2002). *Long-term vegetation changes in experimentally grazed and ungrazed back barrier marshes in the Wadden Sea.* Retrieved on January 21, 2019 from https://www.rug.nl/research/portal/files/3051292/c6.pdf

Brouwer, C., Goffeau, A., Heibloem, M. (1985). *Irrigation Water Management: Training Manual No. 1 - Introduction to Irrigation* (Provisional edition). Rome, Italy: FAO. Retrieved on February 18, 2019 from http://www.fao.org/3/R4082E/r4082e03.htm#chapter%202%20%20%20soil%20and%20water

Brown, K., & Wherrett, A. (2019). *Bulk Density – Measurement*. Retrieved on March 9, 2019from http://soilquality.org.au/factsheets/bulk-density-measurement

Canadian Wildlife Federation. (n.d.). *Rhizome*. Retrieved on February 15, 2019 from http://cwf-fcf.org/en/about-cwf/contact-us/glossary/gardening/rhizome.html

Climate Change Post. (2018). *River floods The Netherlands.* Retrieved on December 13, 2018 from https://www.climatechangepost.com/netherlands/river-floods/

Cross, C. (2016, September 22). *The difference between soft and hard engineering*. Retrieved on October 18, 2018 from https://www.theswimguide.org/2016/09/22/difference-soft-hard-engineering/

Department of Environmental Services. (2004). Functions and Values of a Salt Marsh . *New Hampshire Department of Environmental Services*. 1-2. Retrieved on October 18, 2018 from https://www.des.nh.gov/organization/commissioner/pip/factsheets/cp/documents/cp-07.pdf

Dijke, S., Velthuis, A. & Penter, P. (2016). *Wat weegt een melkkoe anno 2016.* Retrieved on March 11, 2019 from http://edepot.wur.nl/394304

Dineen, J. (2010, May 10). *Tidal Flat Habitats*. Retrieved on October 18, 2018 from http://www.sms.si.edu/IRLSpec/Tidal_Flats.htm

Doedens, B., & Dorenbosch, M. (2015). *Kwelders Terschelling. Voorlopig ontwerp.* Retrieved on November 11, 2018 from https://rijkewaddenzee.nl/wp-content/uploads/2016/08/Kwelders_Terschelling_160111_A47.pdf

Dyer, K. R., Christie, M. C., & Wright, E. W. (2000). *The classification of intertidal mudflats.* Retrieved on October 18, 2018 from https://www.researchgate.net/publication/247810995_The_classification_of_intertidal_mudflats

EcoShape. (2018). *The Building with Nature philosophy*. Retrieved on October 18, 2018 from EcoShape https://www.ecoshape.org/en/the-building-with-nature-philosophy/

Esselink, P., Duin, W. E. van., Bunje, J., Cremer, J., Folmer, E. O., Frikke, J., Glahn, M., Groot, A. V. de, Hecker, N., Helwigg, U., Jensen, K., Körber, P., Petersen, J., Stock, M. (2017). *Salt marshes*. Retrieved on February 15, 2019 from https://qsr.waddensea-worldheritage.org/reports/salt-marshes

Esselink, P., Petersen, J., Arens, S., Bakker, J. P., Bunje, J., Dijkema, K. S., Hecker, N., Helwigg, U., Jensen, A.-V., Kers, A. S., Körber, P., Lammerts, E. J., Stock, M., Veeneklaas, R. M., Vreeken, M., Wolters, M. (2009). *Salt marshes*. Retrieved on February 15, 2019 from http://www.waddensea-secretariat.org/sites/default/files/downloads/08-saltmarshes-10-09-21_0.pdf

FAO[(1)]. (n.d.). *SOIL ORGANIC MATTER*. Retrieved on March 9, 2019 from http://www.fao.org/3/a0100e/a0100e05.htm

FAO[(2)]. (n.d). *INCREASED PLANT PRODUCTIVITY*. Retrieved on March 9, 2019 from http://www.fao.org/3/a0100e/a0100e09.htm

Google Earth Pro. (2018). Google Earth Pro. Retrieved on October 22, 2018 from Google Earth

Gyssels, G., Poesen, J., Bochet, E. & Li, Y. (2005). Impact of plant roots on the resistance of soils to erosion by water: a review. *SAGE Journals, Volume 29 (Issue 2), 189 - 217.* Retrieved on March 9, 2019 from https://journals.sagepub.com/doi/abs/10.1191/0309133305pp443ra

Howison, R. A., Olff, H., Puijenbroek, M. E., & Smit, C. (2016). Facultative grazing and bioturbation by macrodetritivores alter saltmarsh plant–plant interactions under stress. *Journal of Ecology, 104, 1149–1157*. Retrieved on October 19, 2018 from https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/1365-2745.12581

Iles, J. (2001). Requirements for Plant Growth. Retrieved on November 6, 2018 from https://www.extension.iastate.edu/forestry/publications/PDF_files/CTSPreqs.pdf

Jackson, A. (2014). Coastal Management. Retrieved on October 18, 2018 from https://geographyas.info/coasts/coastal-management/

Kieckens, E. (2019). *Kwelder*. Retrieved on November 11, 2018 from https://www.schierweb.nl/landschap-en-natuur/kwelder/

Kluijver, M. J., & Ingalsuo, S. S. (n.d.). Macrobenthos of the North Sea. Retrieved on October 19, 2018 from http://species-identification.org/species.php?species_group=crustacea&menuentry=soorten&id=479&tab=beschrijving

Kok, M. (2017). *Societal need for multifunctional flood defenses.* Retrieved on October 20, 2018 from https://repository.tudelft.nl/islandora/object/uuid:e2a8e655-de5a-41b7-b3fb-05497eda162e?collection=research

Lowry, J. (2010). *Orchestia gammarellus (Pallas, 1766)*. Retrieved on October 19, 2018 from http://www.marinespecies.org/aphia.php?p=taxdetails&id=103202

Minden, V. (2010). *Functional traits of salt marsh plants : responses of morphology- and elemental-based traits to environmental contraints, trait-trait relationships and effects on ecosystem properties.* Retrieved on March 4, 2019 from https://www.researchgate.net/publication/259752176_Functional_traits_of_salt_marsh_plants_responses_of_morphology-_and_elemental-based_traits_to_environmental_contraints_trait-trait_relationships_and_effects_on_ecosystem_properties

National Geographic. (2017). Sea Level Rise. Retrieved on October 17, 2018 from https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/?user.testname=none

NIOZ. (2019). *About NIOZ*. Retrieved on February 19, 2019 from https://www.nioz.nl/en/about

Nix, S. (2017). Stages of Forest Succession. Retrieved on February 15, 2019 from https://www.thoughtco.com/stages-of-forest-succession-1342605

NOAA. (2018). *What is a salt marsh?* Retrieved on October 18, 2018 from https://oceanservice.noaa.gov/facts/saltmarsh.html

Osman, N., & Barakbah, S. S. (2006). Parameters to predict slope stability—Soil water and root profiles. *Ecological Engineering, Volume 18 (Issue 1), 90-95.* Retrieved on October 18, 2018 from https://www.sciencedirect.com/science/article/pii/S0925857406000784

Panchuk, K. (n.d.). *Stream Erosion and Deposition*. Retrieved on March 3, 2019 from https://openpress.usask.ca/physicalgeology/chapter/14-3-stream-erosion-and-deposition/

Pérez-Schultheiss, J. (2014). Comparison of specimens of Orchestia gammarellus. Retrieved on October 19, 2018 from https://www.researchgate.net/publication/270162563_First_record_of_Orchestia_gammarellus_Crustacea_Amphipoda_Talitroidea_in_Chile_with_comments_on_its_morphologic_variability

Reubens, B., Poesen, J., Danjon, F., Geudens, G. & Muys, B., (2007). The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. *Trees, Volume 21 (Issue 4), 385 - 402.* Retrieved on March 10, 2019from https://link.springer.com/article/10.1007/s00468-007-0132-4

Ritter, J. (2018). *Soil Erosion – Causes and Effects*. Retrieved on February 18, 2019 from http://www.omafra.gov.on.ca/english/engineer/facts/12-053.htm

RUG. (2017). *Profile*. Retrieved on February 18, 2019 from https://www.rug.nl/research/gelifes/organisation/profile

Schrama, M., Boheemen, L. v., Olff, H., & Berg, M. P. (2015). *How the litter-feeding bioturbator Orchestia gammarellus promotes late-successional saltmarsh vegetation.* Retrieved on October 23, 2018 from https://research.vu.nl/en/publications/how-the-litter-feeding-bioturbator-orchestia-gammarellus-promotes

ScienceBuddies. (2015). *Can Plants Help Slow Soil Erosion?*. Retrieved on March 8, 2019 from https://www.scientificamerican.com/article/can-plants-help-slow-soil-erosion/

ScienceDirect. (2018). *Learn more about tidal flats*. Retrieved on October 18, 2018 from https://www.sciencedirect.com/topics/earth-and-planetary-sciences/tidal-flats

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T., & Vriend, H. d. (2013). Ecosystem-based coastal defence in the face of global change. *Nature, 504, 79-83.* Retrieved on October 18, 2018 from https://www.researchgate.net/publication/259200820_Ecosystem-based_coastal_defence_in_the_face_of_global_change

Tempest, J. (2014). *Salt marsh plants key to reducing coastal erosion and flooding*. Retrieved on October 18, 2018 from https://www.cam.ac.uk/research/news/salt-marsh-plants-key-to-reducing-coastal-erosion-and-flooding

Thomas, S. M., Abbott, K. C., & Moloney, K. A. (2016). Effects of aboveground herbivory on plants with long-term belowground biomass storage. *Theoretical Ecology, Volume 10 (Issue 1), 35 - 55.* Retrieved on October 18, 2018 from https://link.springer.com/article/10.1007%2Fs12080-016-0307-y

Vermeire, L. T., Wester, D. B., Mitchel, R. B., & Fuhlendorf, S. D., (2005). *Fire and Grazing Effects on Wind Erosion, Soil Water Content, and Soil Temperature*. Retrieved on February 12, 2019 from https://www.ars.usda.gov/ARSUserFiles/30300000/Publications/lance34-1559%5B1%5D.pdf

VoerVergelijk. (n.d.). *Gewicht pony/paard*. Retrieved on March 2, 2019 from http://www.voervergelijk.nl/informatie/47/gewicht-ponypaard

Wageningen University & Research. (2018). *Bouwen met natuur*. Retrieved on October 18, 2018 from https://www.wur.nl/nl/Dossiers/dossier/Bouwen-met-natuur.htm

WoodsVersusWaves. (n.d.). *Het experiment*. Retrieved on November 11, 2018 from http://woodsversuswaves.com/nl/

Yu, F.-H., Wang, N., He, W.-M., Chu, Y., Dong, M., (2008). Adaptation of Rhizome Connections in Drylands: Increasing Tolerance of Clones to Wind Erosion. *Annals of Botany, Volume 102 (Issue 4), 571 – 577*. Retrieved on March 9, 2019 from https://academic.oup.com/aob/article/102/4/571/165315