Universiteit Utrecht

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The effect of grazing on salt marsh vegetation patterns in relation to coastal safety and biodiversity.

Mohamed Ghoneim

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The effect of grazing on salt marsh vegetation patterns in relation to coastal safety and biodiversity.

By

M. H. Ghoneim

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Thesis Supervisors:	Dr. M. Rietkerk	Universiteit Utrecht
	Dr. Z. Zhu	NIOZ

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Universiteit Utrecht

Faculty of Geosciences

Preface

This is the final report of my master thesis in Sustainable Development (Environmental Change and Ecosystems track), at Utrecht University. The research is concerned with grazing to be used as a nature management tool that maximizes both nature and coastal protection goals. In this research, different grazing strategies were analyzed on the most important vegetation properties that were related to both wave attenuation and biodiversity preservation. I would like to thank the following people that supported me during this research.

Firstly, I would like to thank all those that guided, helped, and supervised me throughout this research. I want to thank Dr. Paul Schot for providing me with the necessary advice on how to approach the most suitable research of my choice through a series of lectures and personal encounters. I must acknowledge that in the beginning I faced difficulty finding the suitable topic. Nevertheless, with his guidance and instruction I managed to find a topic that was worth the time and dedication to explore. I would also like to thank Dr. Tjeerd Bouma for facilitating my request for undergoing research in this theme and for guiding me to Zhenchang Zhu. Moreover, I would like to thank Zhenchang Zhu for guiding me in defining the problem I aimed to tackle and for supervising me and aiding me in identifying the approach to my research and finally in providing me with the necessary relevant data for grazing and plant properties that were used to be statistically analyzed. I would like to thank Dr. Max Rietkerk for accepting to supervise my thesis and aiding me in making sure that the message of my research is communicable to audience that are outside this discipline. I would like to thank Dr. Maria Ferreira Santos for agreeing to be a second reader to my researcher and accepting my proposal to undergo this research in the first place. Without her, this research would not have been written.

I would like to thank NIOZ and Utrecht University and its employees for providing me a workspace at Yerseke and De Uithof. I would like to thank my fellow student colleagues at Utrecht University for providing me with general advice on how to start and progress with my research and also spend some recreational time with me. Finally, I would like to thank my friends and family for their support, and motivation throughout my research in part and my entire program as a whole. Thank you for making my time in Utrecht convenient. I thank the reader moreover for making the decision to read my thesis.

M. H. Ghoneim
Utrecht, October 2017

Summary

Grazing as a tool for both nature management and coastal protection is becoming an increasingly common method in wetland coastal zones populated with salt marshes. Taking short term resistant coastal management schemes like building seawalls and land reclamation was proven to lead to erosion of coastal areas and the destruction of their habitat through eutrophication. This is why it is important to make schemes like what is discussed in this research that aim to restore and reintroduce coastal ecosystems as instruments for coastal defence. Such changes are expected to be more proactive, effective and cost effective in the long run. The research focused on on how do different grazing regimes affect vegetation properties that are related with wave attenuation and biodiversity.

A literature study was undertaken in order to see which vegetation properties had the most effect on wave attenuation and biodiversity. It was discovered that plant height and plant height (structural) heterogeneity were the vegetation properties that most likely affected wave attenuation and biodiversity. As such these two properties were used to for statistical Kruskal Wallis tests on plant height data from Noord Friesland Buitendijks (NFB) area on order to discover how grazing contributed to plant height and structural heterogeneity. It was discovered that the grazing density, type of grazer as well as their spatial distribution across the plots and their dietary preferences were contributing factors in the creation of vegetation mosaics through plant height management. It was found that the type and density of grazer as well as time of the year have a very strong effect on height of plants while the plant type did not have strong effects on plant height.

The limitations were found mostly in the approach as it was the case with this research such as the absence of rotational grazing regime observation, limited data samples, lack of monitoring of weather conditions, and lack of inclusion of more types of grazers.

Overall, it was recommended that there must be further exploration of grazing regimes with more types of grazers, more types of plants and under higher frequencies. This is to ensure a more accurate representation of the phenomenon and its context dependency so as to take further steps to create a model that can be used to justify potential policy decisions with regard to coastal protection and nature conservation in these areas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Mean high tide	(MHT)
North Friesland Buitendijks	(NFB)
Puccinellia maritima	(PUC)
Festuca rubra	(FES)
Agrostis stolonifera	(AGR)
Low Grazing Density Cattle	(LC)
High Grazing Density Cattle	(HC)
Low Grazing Density Horses	(LH)
High Grazing Density Horses	(HH)
Rotation Grazing Regime	(R)
Suaeda maritime	(SUA)
Elymus repens	(ELY)
Aster tripolium	(AST)
Short Duration Grazing	(SDG)
Continuous Grazing	(CONT)

CHAPTER 1

INTRODUCTION

1 Introduction

1.1 Problem definition:

Sea level rise has become a very prevalent issue due to its largely significant and uncertain impact on the climate and environment. The gap of uncertainty is significant that a given projected increase of global temperatures of $4^{o}C$ by 2100 would create a rise between 0.5 and 2 meters in sea level. Even though the potential for the 2-meter increase is lower, the impact of only 0.5 meters can affect the lives of 187 million people who live close to deltaic and coastal areas (Nicholls et al., 2011). The rise in sea level can potentially have these negative impacts by altering coastal sediment structure and dynamics. Taking short term resistant coastal management schemes like building seawalls and land reclamation from marshes led to further erosion of coastal areas and the destruction of their habitat through eutrophication (Syvitski & Kettner, 2011). As such, it is important to make schemes that aim to restore and reintroduce coastal ecosystems as instruments for coastal defense. Such changes are expected to be more proactive, effective in the long run, and cost effective (Nicholls et al., 2011).

Salt marshes are one type of salt tolerant plant type that can be used to help protect coastal areas while maintaining biodiversity. They are mainly present in areas subjected to periodic flooding from both tidal and non-tidal mechanisms and host a variety of species that benefit from their presence whether that be insects, birds, or larger herbivores. They also effectively function to build up sediment aggregations that help build coastlines. The exploitation of salt marshes for grazing by livestock had raised questions about whether grazing regimes should be revaluated (Nolte, 2014). Salt marshes can be classified as areas of plants that can be exposed to periodic tides as they can exist in locations from just below the mean high tide (MHT) to high water levels during storm surges (de Vlas et al., 2013). One has to understand what is the purpose of looking at the effects grazing has on salt marsh ecosystems. The reason being is that it is important to understand how to use and manage intertidal ecosystems through grazing for coastal defense without compromising biodiversity and to a greater extent if possible make it an approach that actually benefits biodiversity of these coastal areas. Grazing that results in spatial heterogeneity could potentially help in nature protection. In addition, at optimal levels it can also create an efficient spatial arrangement of salt marshes that can help in wave attenuation and stabilize sediments. While the effect of grazing on vegetation patterns have been largely investigated, it is important to note that the investigation was limited in terms of looking at which properties were more affected and how it contributed to biodiversity and wave attenuation. Vegetation properties here refer to a number of things from the patch number and distribution of the vegetation to the canopy or stem height, density, and stiffness. As such this research will focus on how do different grazing regimes affect vegetation properties that are related with wave attenuation and biodiversity. From there it is possible to make more accurate recommendations in the future on how to better manage coastal salt marshes for both nature preservation and coastal protection.

1.2 Scientific and Societal Relevance

This thesis serves to complement current research with the issue of making coastal ecosystems cope with the annual rise in sea level, storms, and alteration of sediment dynamics by creating more novel coastal defense schemes that preserve the existing biodiversity and are also very cost efficient. The results that will be provided will be useful for future research in that the principles or “rules of the game” will help determine the biodiversity outcomes. These outcomes will be based on the vegetation properties caused by different grazing techniques. They will be integrated into a future model that can be a useful tool to find out which grazing management strategy would be most optimal to increase wave attenuation whilst preserving biodiversity in coastal habitats.
The lack of grazing of salt marshes can be as detrimental to coastal systems as overgrazing. It can compromise the biodiversity of coastal ecosystems by allowing selective competitive plant species to thrive while the rest to decrease in abundance. This can have detrimental effects for populations of other species that are dependent on plant diversity in one way or another such as populations of certain species of insects that might be less present as well as the type of birds that feed on those insects (de Vlas et al., 2013). The implications of this at the societal level is that it can also compromise the capability of the coast to increase wave attenuation leading to coastal erosion over time that could have recreational consequences as well as mass human displacement (Maldonado et al., 2013). It is also socially relevant to know which elements has more or less impacts on coastal ecosystems. With this knowledge it is possible to make the most optimal decisions in grazing management schemes that are most efficient both in costs and output.

1.3 Research aim

The research is being undertaken to find out how to maximize combined nature and coastal protection goals. In elaboration, the study looks at the influence of management types on the compatibility of wave attenuation and biodiversity taking the North Friesland Buitendijks (NFB) as a main source for data. Moreover, the scope of the research will look more into the effects of grazing techniques on the levels of biodiversity in general. As such, the research question is as follows:

To what extent do different grazing regimes affect vegetation properties that are related with wave attenuation and biodiversity?

This research will explore more how different grazing methods create different vegetation patterns, how can it be spatially expressed and how does biodiversity have a role. The sub-questions will be as such:

SQ 1: What are the most important vegetation properties associated with wave attenuation?

SQ 2: What are the most important vegetation properties associated with biodiversity?

SQ 3: How are vegetation properties in relation to wave attenuation and biodiversity influenced by grazing?

1.4 Hypothesis

The research proposes 3 hypotheses:

H1: It is expected that plant height, diameter and stiffness were predicted to be an important property associated with wave attenuation:

Firstly, vegetation patches or patterns are composed of alternating arcs of vegetation and normally bare ground that can also exist on slopes (Thiery d'Herbès & Valentin, 1995). These patches have been reported not only in arid ecosystems but various others. The underlying mechanism involves a positive feedback between plant growth and water availability (Rietkerk et al., 2004). In the case concerned high rainfall enhances this feedback but also the existence of high stocking densities can also limit plant biomass (Rietkerk et al., 2002).

It is expected that:

Canopy height will contribute positively to wave attenuation (Nolte, 2014)

Canopy diameter will contribute positively to wave attenuation due to it increasing the vegetation density per hectare (Nolte, 2014). Canopy diameter refers mainly to the density of the plant stem and this is important as the denser the plant is the more likely it is to reduce wave force (Paul et al., 2016).

Canopy stiffness will determine wave attenuation in such a way that if the canopy is too stiff it might break from the force of the wave and if it's too flexible it might not hold some of the force of the wave. As such an optimal level of stiffness is required to have high wave attenuation effects so that is also has some flexibility as to not break (Paul et al., 2016).

H 2: It is expected that plant height (structural) heterogeneity will have the most effect on biodiversity of Plants, Birds and Insects:

Structural heterogeneity will enhance plant species richness at optimal stocking densities. Too much grazing causing short vegetation can diminish plant species richness through consumption of flowers and/or trampling. Too little can cause homogeneity of a different character that involves dominant species of plants to overtake most other species thus decreasing richness. With insect species richness, it is expected that structural heterogeneity will contribute to a lesser extent to insect species richness than that with plant species richness. The reason being is that it is expected that there will be an inverse relationship between grazing density and insect species richness. As such, it is expected that bird presence will be directly proportional to insect species richness as insects are the main food source. This will also mean that there will be a similar relationship on structural heterogeneity with regard to insect species richness. This means that there will also be an inverse relationship with grazing density as birds depend on vegetation amount as place for nesting.

H3: Based on what was found for H1 and H2, it is expected that:

Findings of grazing density on structural heterogeneity will yield a range or threshold where optimal grazing will yield high numbers of mosaics of tall and short vegetation patterns whereby too much grazing will create less patches and short vegetation thrives while too little will also create less patches and tall vegetation thrives. It is expected also that cattle will have slightly higher number of patches in a given plot than horses since they have smaller patch sizes despite the fact that horses are more mobile. This can be expressed in the schematic graph in Figure 4:

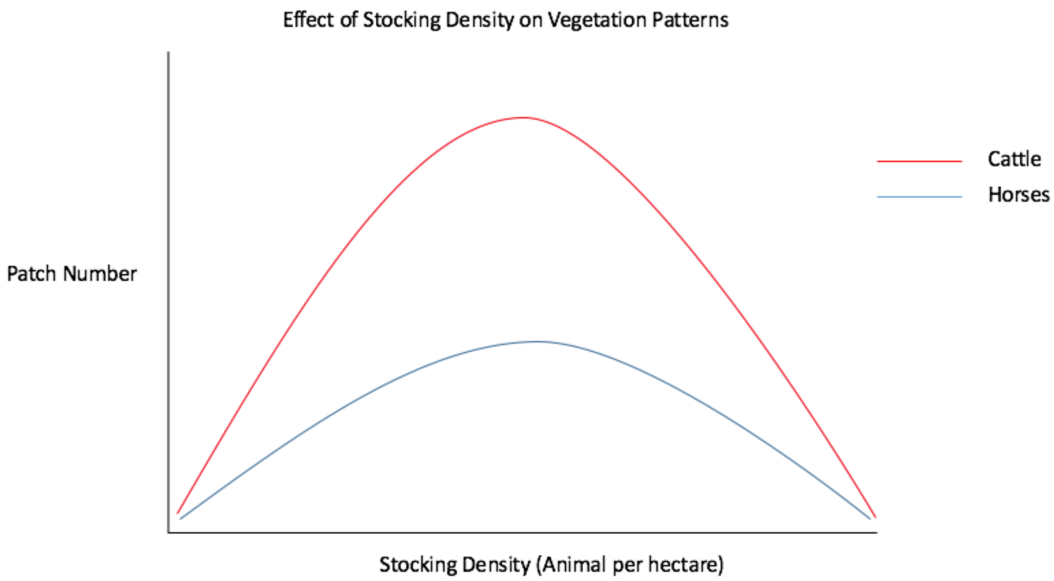


Figure 1.4.1: Projected Effect of Grazing on Vegetation Patterns for different herbivore species.

Under no Grazing regimes, there will be an absence of mosaic patterns and the presence of higher vegetation height overall, similarly for grazing regimes at high grazing densities there will be no mosaics too but with overall lower vegetation height for both cattle and horse grazers where at lower salt marshes there will be marginal lower height in vegetation. The mosaics of high and low vegetation patterns are expected to be present under lower grazing densities where for cattle, smaller patches will be present and more abundant while for horses, larger patches will be present and more abundant.

CHAPTER 2

METHODS

2 Methods

Here the approach starts with creating a literature review that aims to explore past studies that found which vegetation properties were associated with wave attenuation and biodiversity. Firstly, the literature was sorted in a way where the vegetation properties were categorized into subsections. For each subsection, past studies by different authors that explained the relationship between the selected vegetation property and that of wave attenuation or biodiversity were described in chronological order from the oldest study to the most recent one. The vegetation properties that were found to affect biodiversity were mapped in a series of conceptual diagrams that was based on the information past studies have shown with regard to relationships between each of the variables. To observe which properties were the most significant in affecting biodiversity, they were carefully selected on the basis of how many other variables did they mediate and moderate their effects on biodiversity levels of plants, birds, and invertebrates. In the case of wave attenuation, plots by Shepard Crain & Beck (2011) were used to determine which vegetation properties were the most effective in attenuating waves.

From there, the most significant vegetation properties that simultaneously had an effect on both wave attenuation and biodiversity were arbitrarily selected from the conceptual diagrams of both SQ1 and SQ2. The properties were found to be plant height and plant height (structural) heterogeneity. Since, plant height (structural) heterogeneity is classified as mosaics of tall and short vegetation, plant height was taken as the main variable to be used for statistical tests on. Data was used from the Noord Friesland Buitendijks (NFB) for 2016 for 3 months, 3 plant types, 2 types of grazers and at 2 different grazing densities to be plotted against both plant height and plant height (structural) heterogeneity which was represented as variance of plant height. A Kruskal-Wallis test was used to test for significance of grazing density, grazer type, plant type, and month on plant height data since the data failed the normality and transformation tests. With regard to plotting the data, bar graphs (with error bars) for each month were plotted. The x axis represented plant species at different grazing types and densities while the y axis represented the plant height for each plant type.

2.1 Protocol for Literature Review

2.1.1 For Vegetation properties and Wave Attenuation

In order to find out what are the most important vegetation properties associated with wave attenuation, the first step was to determine if there were past findings with regard to the relationship between these two aspects. In order to do that so it is easily readable, the past literature had to be sorted in such a way where the vegetation properties were categorized into subsections. The subsections were divided into two categories; the first being the vegetation properties that have the most effect on wave attenuation, and the second being other independent factors. Other independent factors are included in order to acknowledge that there are numerous external factors that are likely to influence the relationship between a particular vegetation property and its role in attenuating waves. For the first category the vegetation properties that were found and subjected to literature investigation were plant density, plant height, plant stiffness, vegetation inundation (abundance) and species identity. For the second category, the independent factors that were found in the literature were wave height, wave energy, water depth, distance of vegetation to shore, wind (storm surges), time, and sedimentation. The vegetation properties that were found to affect wave attenuation were already plotted by Shepard Crain & Beck (2011). To observe which properties were the most significant in affecting wave attenuation, they were carefully selected on the basis of the findings by Shepard Crain & Beck (2011).

2.1.2 For Vegetation properties and Biodiversity

The subsections for this literature section were divided into three categories; the first being vegetation properties that affect plant species richness, the second being invertebrate species richness, and the third being bird species richness. For the first category, the vegetation properties that were found and subjected to literature investigation were plant height, plant moisture cover, and plant density. For the second category, plant height, plant maturity was subjected to literature investigation. Within plant maturity, more investigation was done on whether botanical species composition had more effect on invertebrate abundance than plant height or structure. In addition, more was explored on how different invertebrates have different functional roles when it comes to different species of plants and literature was explored in that direction. Finally, for the third category, the vegetation properties that were found and subjected to literature investigation were plant height (when functionally used for nesting), plant height (when functionally used to spot prey), plant heterogeneity (both in structures and species), and other independent factors as well as looking at the anomaly of the geese. It was important to include a section for other independent factors for birds due to the fact that their population is affected by the presence or lack thereof of grazers who can contribute to their decreasing or increasing populations through trampling of their nests and also other insects that make up their diet. Moreover, it was important to include geese as a separate section because unlike most other bird species, they directly depend on plants for food in the form of grazing and as such they have a multifunctional role in their respective habitat.

The vegetation properties that were found to affect biodiversity were mapped in three different conceptual diagrams. One network diagram mapped the relationship of the associated vegetation properties with plant species richness, another diagram mapped the relationship of the associated vegetation properties with that of invertebrate species richness, the third diagram mapped the relationship of the associated vegetation properties with that of bird species richness. These diagrams were based on the information past studies have shown with regard to relationships between each of the variables. To observe which properties were the most significant in affecting biodiversity, they were carefully selected on the basis of how many other variables did they mediate, moderate their effects biodiversity levels.

2.2 Materials and Methods for data acquisition, analysis, and display

The most significant vegetation properties that simultaneously had an effect on both wave attenuation and biodiversity were selected from the conceptual diagrams of SQ2 and from the Shepard Crain & Beck (2011) graph from SQ1. The properties were found to be plant height and plant height (structural) heterogeneity. Since, plant height (structural) heterogeneity is classified as mosaics of tall and short vegetation, plant height was taken as the main variable to be used for statistical tests on.

2.2.1 Data acquisition

Data was used from the Noord Friesland Buitendijks (NFB) for 2016 for 3 months, 3 plant types, 2 types of grazers and at 2 different grazing densities to be plotted against both plant height and plant height (structural) heterogeneity which was represented as range of plant height.

The data was acquired from Zhenchang Zhu from the NFB for the year 2016. The data given and used were the plant height measurements for the months of June, August and November. This was the available data that was given and one reason why measurements were taken at these particular times is because during this period it is the mildest-warmest periods of the year and the time where plants are at peak growth and livestock are most active before winter settles in (Habetler, 2017). Moreover, the available three plant types were also used in the measurements, the plants were *Puccinellia maritima* (PUC) (Fig. 2.2.1.1), *Festuca rubra* (FES) (Fig. 2.2.1.2), and *Agrostis stolonifera* (AGR) (Fig. 2.2.1.3). The possible motive behind the selection of these species is that they are the most abundant in their respective plots and hence it is easier to identify their individuals and also make substantial conclusion about their relationship with regard to different grazing management strategies (Habetler, 2017). This leads to the final set of variables which are the grazing strategies. The acquired data had grazing strategies for cattle at both low (LC) and high (HC) grazing densities as well that of horses at low (LH) and high (HH) grazing densities in addition to a rotational grazing regime (R) between cattle and horses. For the sake of this research LC, HC, LH and HH were used in order to better compare different densities for different species in isolation. For each grazing density and type, for each plant type, for each month, there were 8 individuals that were sampled for plant height. The aforementioned data was presented in a Microsoft Excel document.

Figure 2.2.1.1: Puccinellia maritima (Habetler, 2017).

Figure 2.2.1.2: Festuca rubra (Habetler, 2017).

Figure 2.2.1.3: Agrostis stolonifera (Habetler, 2017).

2.2.2 Data analysis

The software that was used to statistically analyse the plant height data was the IBM SPSS Statistics software used for Mac 2017 model.

In order to test for significance of grazing density, grazer type, plant type, and month on plant height data a Kruskal-Wallis test was used. The reason being is that the sub-research question being explored in the case of this research is a differential question where the dependent variable being compared which is plant height is a scale variable. However, in order to make sure this is the most plausible statistical analytical method the plant height data had to be tested for normality using the Shapiro-Wilk Test.

In order to identify if the data obeys normality the p value of the grouping variables were checked to see if they are above 0.05. If this is the case for all the grouping variables, then the results obey normality. This was not the case with the vast majority of the grouping variables with the exception of Cattle grazer types and the month of November. As such, the plant height data had to be transformed.

The type of transformation that was most plausible to be used was the log(x) since all the plant height values available were all positive numbers and can be calculated for variance. The plant height variable was targeted for the transformation and a new transformed variables was named as Log Plant Height. This new variable was subjected to another Shapiro-Wilk significance test using the same method for Plant Height variable. This time all the grouping variables did not have p values that exceeded 0.05 and as such they still did not obey normality and it was clear that transformation did not work. Since there were more than 2 groups that were compared it was evident that a Kruskal-Wallis test was the most suitable statistical test to take.

The Kruskal-Wallis test was done four times to test for each grouping variable on their significance for plant height. When interpreting the results, if the p value was less than 0.05 this meant that there was a significant effect of the grouping variable on the plant height values. The further away the decrease in p value is from 0.05 the more effective the grouping variable was on plant height, the further away the increase in p value is from 0.05 the less effective the grouping variable was on plant height.

2.2.3 Data Plotting

The available plant height data was plotted on bar graphs (with error bars) for each month x axis represented plant species at different grazing types and densities while the y axis represented the plant height for each plant type. Since the vegetation properties that had the most effect were plant height and plant height (structural) heterogeneity, calculations were made so as to better represent these properties in a bar graph. A table was formulated on that basis and the bar graphs were plotted. For plant height, average plant height was calculated and was put in a table before being plotted. In the case of plant height (structural) heterogeneity, since it is considered to be mosaics of tall and short vegetation it was assumed that such heterogeneity can be measured by calculating the variance in order to observe the difference in height between the tall and short plants. In principle, it was considered that that higher the value of the variance meant that the value was more structurally heterogeneous.

CHAPTER 3

LITERATURE AND RESULTS

3.1 Vegetation properties associated with Wave attenuation

Wave attenuation was considered to be a function of plant amount creating an obstruction of the water column. Wave attenuation is best achieved through coastal protection management by conserving existing conditions or restoring elements that have been lost or damaged in addition to structural engineering approaches. Each of these management techniques involves synergistic benefits and/or trade-offs among the various ecosystem services provided by coastal systems to local communities. It was seen that conservation was the more pragmatic option for managers, as current biotic structures provide wave attenuation that is beneficial to coastal villages. However, it is important to take into consideration the non-linearity that exist when determining the area to be preserved. This non-linearity exists because the values of ecosystem functions like wave attenuation are highly dynamic and change over time and space. The functional role of biotic structures in protecting coasts was found to be context dependent on the type of vegetation and where this vegetation thrives. There are intertidal biotic structures like sea grass and salt marshes and sub-tidal like mangroves and kelps that live in the water. In this chapter and the research as a whole, focus will be turned on the intertidal biotic structures (Gedan et al., 2011).

In this chapter, the concept of wave attenuation for this research was stated and what type of biotic structures will be taken into account. Then the following vegetation properties (plant density, plant height, plant stiffness, plant inundation, plant zonation, and plant species) were evaluated along with other independent factors such as wave height, energy, water depth, distance to shore, wind, temporal dynamics, and sedimentation.

3.1.1 Vegetation properties that have most effect on wave attenuation

3.1.1.1 Plant density

One property that has an effect on wave attenuation is the density of the vegetation. In a study by Anderson & Smith (2014), it explored how wave attenuation is affected by flexible salt marsh vegetation. They tested waves under emergent conditions where there was varying submergence, stem density, incident wave height and peak wave period so as to determine which of these parameters were the most important. They discovered that overall wave attenuation depended on stem density and ratio of stem length to the depth of the water coming from the waves. They also found that higher frequency waves were more dissipated than lower frequency waves meaning that there was wave energy loss for all frequencies where the increase in dissipation was accompanied with the increase in frequency. This difference in attenuation between the frequencies increased with the existence of denser plants.

Habetler (2017) found that plant density varied with seasons and between species and as such, each of these species had different densities at different times of the year supposedly as a response to the external temperature. Habetler (2017) also found that with regard to height, there was no clear distinction in plant density for different species.

3.1.1.2 Plant height

Another property that has a considerable effect on wave attenuation is the plant height. Möller et al. (1999) quantified saltmarsh vegetation and its effect on wave attenuation. They found that there was no significant statistical relationship between density and wave attenuation. Möller et al. (1999) found that in locations with taller plants, wave height was positively related to wave attenuation up until a threshold where wave attenuation increase was not significant anymore. For shorter vegetation there was no significant relationship between wave height and wave attenuation. At the seasonal level, Möller et al. (1999) found that there was significant increases and decreases in vegetation density leading to an increase and decrease in wave attenuation.

Nolte (2014) looked at whether the height in vegetation has an effect on wave dissipation in the Wadden Sea and found that wave dissipation was affected by vegetation height. Habetler (2017) also found that Salt Marshes with short vegetation have unfavourable properties to attenuate waves while salt marshes with high vegetation are most capable of dissipating waves.

3.1.1.3 Plant stiffness

Plant stiffness is another vegetation property that affects wave attenuation. Paul et al. (2016) explored whether plant stiffness or biomass distribution are the main drivers for drag forces under extreme wave loading. They found that for low wave forcing it would have been preferable for plants to have thicker and stiffer stems in order to reduce the frontal area exposed to hydrodynamic forcing while for higher wave forcing it would have been preferable for plants to have more flexible shoots in regard to the high drag forces.

In another study Luhar & Nepf (2016) looked at wave induced dynamics of flexible blades and found that blade motion was governed by the ratio of the hydrodynamic forcing to the restoring force as a result of blade stiffness. For the former they found that the movement of the flexible blades reduced the hydrodynamic drag relative to a rigid blade of the same morphology except in some cases. Luhar & Nepf (2016) also discovered that pressure recovery near the blade tip lead to a reduction in wave forces. Moreover, the posture of the blades showed that the longer structures tended to twist near the tip possibly leading to further reductions in the hydrodynamic forces (Luhar & Nepf, 2016). They concluded also that since there is variation in vegetation stiffness, the drag coefficients (power of plant to attenuate waves) for one species will be different for other species.

Habetler (2017) looked at the drag of species at NFB and found that there is a positive relationship between drag coefficient increase and flexural rigidity (lower stem-flexibility).

3.1.1.4 Inundation

Another property that has an effect on wave attenuation is the vegetation inundation (abundance). Bockelmann et al. (2002) looked at the relationship between vegetation zonation, elevation and inundation (abundance) frequency in the Wadden Sea salt marsh. They found that at low shore heights there was exponential increase in inundation frequency while at high shore heights inundation became much less frequent (Fig. 3.1.1.4.1).

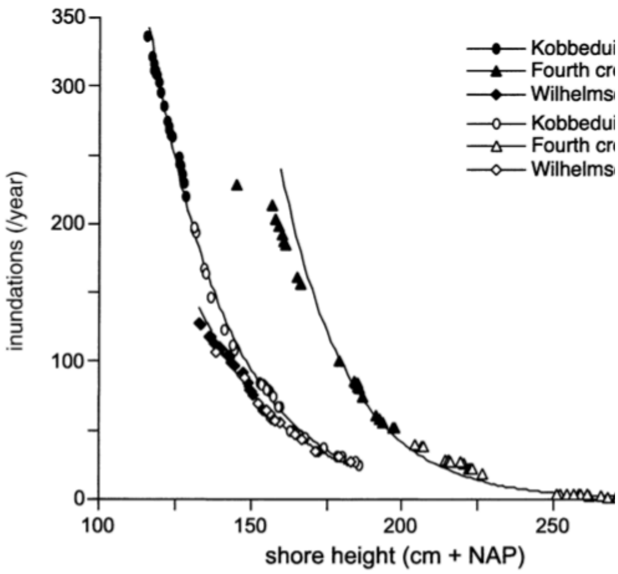


Figure 3.1.1.4.1: Relationship between shore height and inundation frequency (Bockelmann et al., 2002).

Moreover, Bockelmann et al. (2002) also found that different dominant species have a unique relationship to different shore heights. As such, zonation can be a result of various factors that interact of which inundation frequency or time only are two of these factors. This increase in inundation at low shore heights is also attributed to the evolutionary nature of some plant species that require water and a degree of salinity to survive making them more prevalent, closer to the shore and also serving the attenuate functional role (Bockelmann et al., 2002).

3.1.1.5 Species identity

One of the properties of vegetation that can have an effect on wave attenuation is the type of plant species. Each plant type has its own set of characteristic that can make it more or less suitable to pursue this functional role. Koch et al. (2009) looked at coastal protection as a function of species types and found that different types species have different types of effects on wave attenuation. For example, *Spartina* seemed to have more effect on wave attenuation during high tide than *Seagrass* at low tide (Fig. 3.1.1.5.1). This indicates that species types are major contributors to wave attenuation and can offset waves regardless of how high or low the tide is.

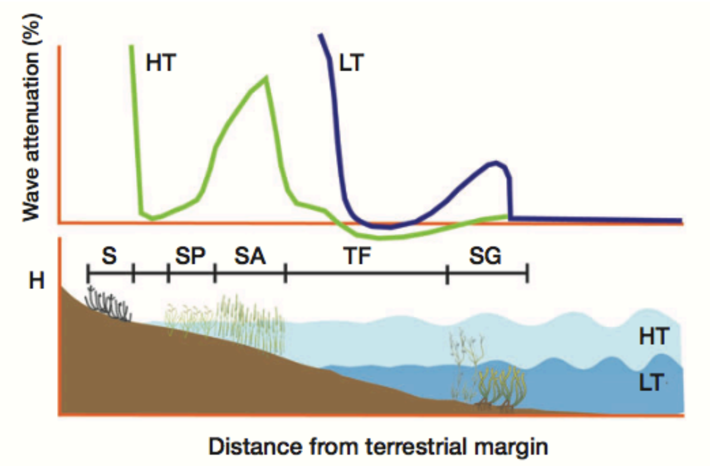


Figure 3.1.1.5.1: Schematic representation of wave attenuation (%) at high tide (HT) and low tide (LT) for different types of species. SG: Seagrass, TF: Tidal Flat, SA: Spartina alterniflora, SP: Spartina patens, S: Salicornia marsh (Koch et al., 2009).

Moreover, Habetler (2017) looked at guidelines for nature design building by developing salt marshes and focused on species types. She explored the contributions of a select set of plant species to wave attenuation in the winter season where wave activity is most dynamic. She explored the reliability of each species in terms of stem breakage where is the stem folds or breaks and their ability to reduce wave energy decreases. She found that *Suaeda maritime* (SUA) retained the highest wave attenuation value due to their characteristic of having longer and thicker stems and having a higher drag coefficient value than *Elymus repens* (ELY) and denser than *Aster tripolium* (AST) (Table 3.1.1.5.1). In paddocks where overall vegetation height is high (D) it can be seen that ELY had the largest vegetation coefficient while for paddocks with shorter vegetation overall (F and C) SUA had the largest vegetation coefficient.

Overall

In summation, what can be taken from this is that the stems of plants as well as their thickness slow water velocity. When the water flows into the vegetation, the vegetation responds with a drag force to counter its velocity. At low densities the phenomenon is locally based (Gedan et al., 2011).

3.1.2 Other independent factors

Beside the sets of Vegetation properties mentioned in the previous section that have a significant effect on wave attenuation. It is important to take into consideration that there are numerous other factors independent from vegetation property that also have an effect on wave attenuation. Among these independent factors mentioned in this section are the wave height or depth of the water, the energy of the waves, ground elevation or distance to shore, wind speed or storm surge frequency, seasonality (time), and sedimentation.

3.1.2.1 Wave height

Wave attenuation is not only dependent on vegetation properties that help through drag forces, but is also dependant on the height of the waves themselves. Vuik et al. (2016) found that the effect the foreshore has on wave loads varies depending on the ration of wave height to water depth. They found that vegetation approximately contributed to only 50% of the reductions in wave height through wave attenuation and as the wave height increased the contribution of vegetation decreased.

3.1.2.2 Wave Energy

One of the main drivers that can act as an opposing force to wave attenuation caused by plants is the strength and intensity of the waves. Habetler (2017) found that even in bare vegetation void foreshores wave energy dissipation was still present.

3.1.2.3 Water depth

When it comes to wave attenuation, water depth plays an important role in enhancing or mitigating this effect. Gedan et al. (2011) examined how wave attenuation was different across a ratio of water depth to vegetation height. They found that at partial submersion, vegetation is best capable of attenuating waves. This means that the ratio between vegetation height and water depth should be low enough so as not to have too much depth that can compromise the ability of plants to exert drag force as too little vegetation provides little resistance to water approaching to shore (Fig. 3.1.2.3.1B).

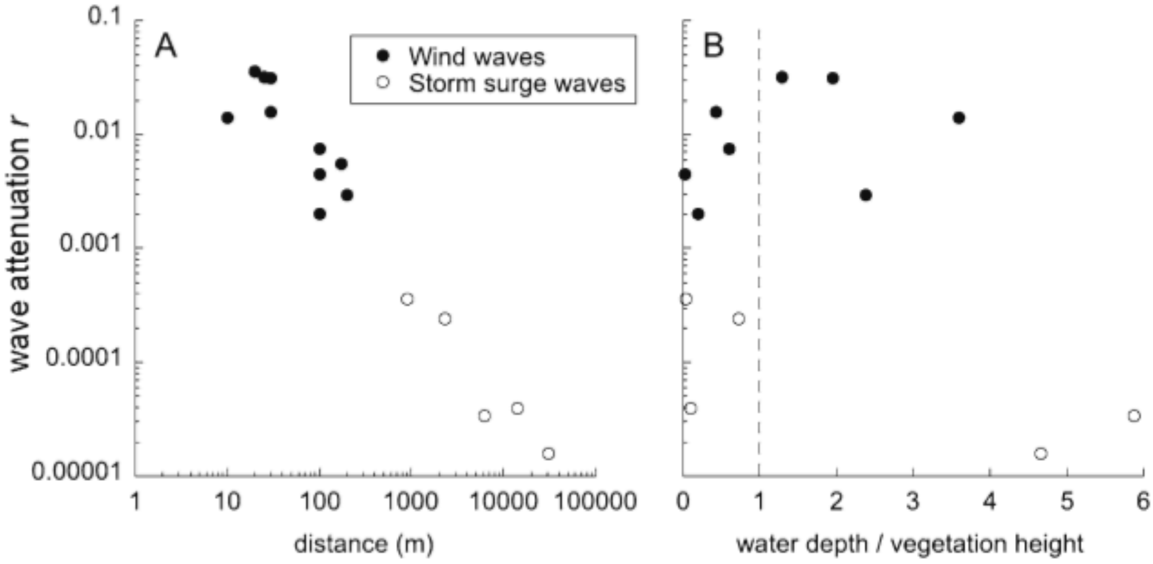


Figure 3.1.2.3.1: Relationship of wave attenuation to distance to shore (A) and water depth and vegetation height ratio (B) (Gedan et al., 2011).

3.1.2.4 Distance to Shore

The morphology of the shore and the distance of vegetation to shore are an important mechanism that drives wave attenuation. Hu et al. (2015) explored how to make use of shore morphology and distance of vegetation to shore to manage and restore salt marshes to as to effectively attenuate incoming waves. They found that the morphology of tidal flats determines the salt marsh elevation establishment as they affect hydrodynamic forcing and as such, have an effect on the overall extent of salt marshes on shore (Hu et al., 2015). Hu et al. (2015) found convex and gentler profiles were more preferable to host more salt marshes in comparison to concave profiles that were characterized to be much steeper. They also found that wave attenuation happened more on convex morphologies than concave morphologies due to the fact that convex morphologies had higher elevations of the foreshore leading to more effective wave attenuation as the distance to the pioneer zones were longer for wave breaking.

3.1.2.5 Wind

Wind that is caused by the different frequencies and extents of storm surges can have a significant effect on wave attenuation by compromising the present shoreline protection mechanisms that are in place. Gedan et al. 2011 looked at protective measures from storm surges and found that wave attenuation as well as shoreline protection are susceptible to non-linearity across time and space. They found that significant variation in the characteristics of storm can make both wave attenuation as well storm surge attenuation very complex due to factors pertaining to dynamics of the storm like the duration and direction and existence of barrier islands. Nevertheless, Gedan et al. 2011 did find that vegetation roughness slows down and reduces storm surges depending on wetland and storm characteristics.

Vuik et al. (2016) analysed the effect of vegetation on wave attenuation at severe storm conditions and found overall that foreshore vegetation with high width significantly reduces waves on coastal dikes during severe storm.

3.1.2.6 Temporal scale

Different times in the year can also have a significant impact on wave attenuation. As plant growth differs throughout the year so does the wave strength as a result of different variables of storms and water levels. Koch et al. (2009) looked at how coastal protection can vary over time and found that coastal protection depends on the timing of the natural processes that exists like storms. They found that coastal protection can be diminished if large storms happen when plant biomass and/or density are in lower abundances and distribution (Fig. 3.1.2.6.1).

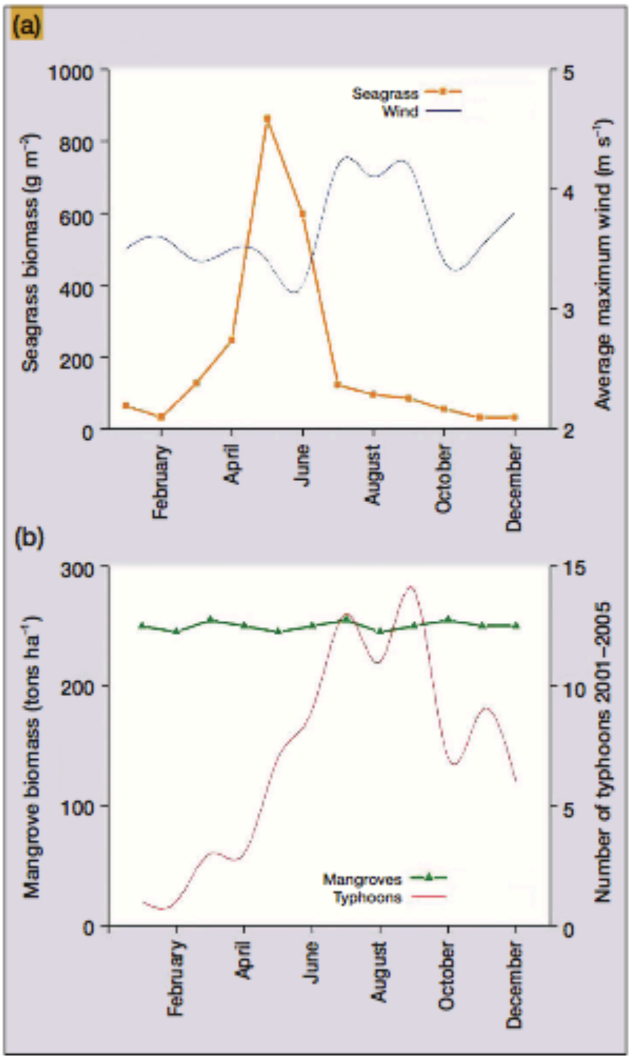


Figure 3.1.2.6.1: Biomass of coastal plant communities over time of the year (Koch et al., 2009).

Koch et al. (2009) concluded that for coastal protection to be most effective, it should be at a period where tide levels and storm surges are low and biomass of plants and other biotic structure are at their peak.

In another study by Hu et al. (2015), they proposed a “windows of opportunity” concept to explain vegetation establishment patterns over time. They found that some salt marshes were migrating over the years from seaward to landward (Fig. 3.1.2.6.2c and d) while others experienced a sudden gain due to storms or migration of channels or artificial dredging.

3.1.2.7 Sedimentation

Soil composition and compaction was also found to have a considerable effect on wave attenuation. Soil characteristics also are largely determined by plant biomass as well. Neumeier & Ciavola (2004) explored flow resistance and associated sedimentary processes in a *Spartina maritima* salt- marsh and found that erosion occurred more in unprotected, bare areas than in vegetated areas where flow resistance by the canopy and sediment binding by plant roots reduce erosion on the salt marsh. They also found that during storms, the effect *Spartina* canopy has on sediments has more to do with erosion protection than sedimentation enhancement during normal conditions. Moreover, they found that under normal conditions, the sedimentation rate is dependent on elevation and creek proximity and under high energy conditions sediment remobilization that happens in the bare areas. They found that the salt marsh was capable of capturing the whole grain-size range of sediments that were suspended in the water. As such, it was possible in this case that the sedimentation rate was higher within the vegetation than on the surrounding bare areas. They concluded that the arrangement of sediment types greatly depended on vegetation cover.

Feagin et al. (2009) looked at whether vegetation prevented wave erosion of the edges of the salt marshes. They found that soil type is the main variable influencing erosion rate despite plants not directly reducing wetland edge erosion. They criticized the idea that coastal vegetation always provides protection. They stressed on the importance of distinguishing between lateral (marsh edge) and medial (marsh interior) erosion, as interaction between waves and the shore is very different in every case. And as such, they concluded that coastal vegetation is best at modifying and controlling sediment dynamics to respond to gradual phenomenon like the rise in sea level.

Gedan et al. 2011 found that coastal wetland plants are capable of reducing erosion through direct and indirect mechanisms. They viewed that coastal wetlands can be effective at erosion reduction at low wave energy environments, but not as much in high wave energy environments as they can tear up plant rhizomes and expose deeper sediments hence increasing erosion. Nevertheless, it is important to note that those large waves can also act as a major source of inorganic sediment for these wetlands (Gedan et al., 2011).

Nolte (2014) found that salt marsh resilience to sea level rise is determined by their response ability to increased accretion rates. They found also that herbaceous predators could influence accretion rates by compacting soil with their foot movement decreasing sediment deposition. They found that both accretion rates and sediment deposition were higher in seaward areas than on landward.

Habetler (2017) also found that sedimentation rates in areas of high presence of grazers were lower than in areas of low presence of grazers due to soil compaction caused by their movement and thus solidifying the sediment particles protecting each other from being deposited.

3.1.3 Conclusion

3.1.3.1 Most effective vegetation properties summarized

In summary, it can be concluded that salt marsh vegetation had a significant beneficial effect on wave attenuation and shoreline stabilization and that they have value for mitigation of coastal hazards and adaptation to climate change in general. It was found that the vegetation properties of density, stiffness, height and size of the marsh were the most effective factors that had effect on wave attenuation and stabilization of the shore in brief (Fig. 3.1.3.1.1). When these factors overlap this can mean that large dense and tall marshes can attenuate waves better than small short and less dense marshes. It is important to note also that the seasonal (or temporal) variations can enhance or mitigate this effect throughout the year (Shepard Crain & Beck, 2011). For Figure 3.1.3.1.1 it is important to take into consideration that the results are shown across ranges of geographical and hydrodynamic cases.

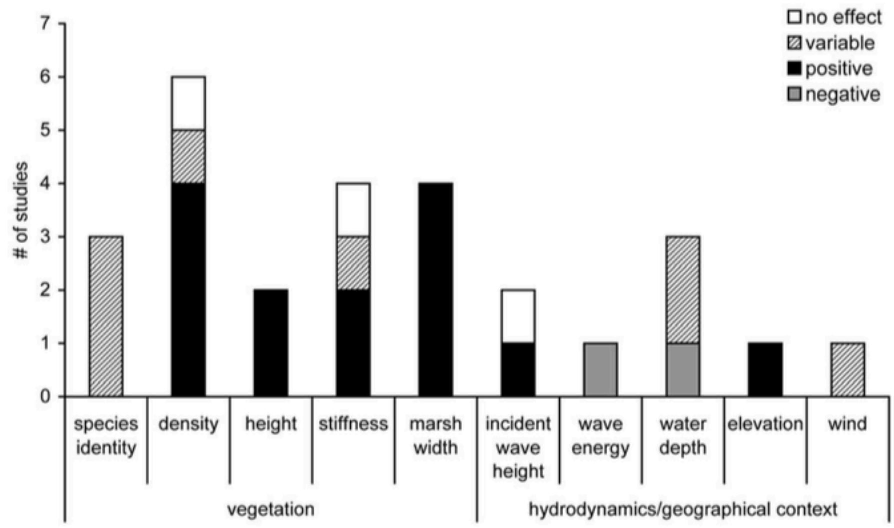


Figure 3.1.3.1.1: Factors (vegetation and independent) most important to wave attenuation (Shepard Crain & Beck, 2011).

3.1.3.2 Existing trade-offs

It is important to realize that with flood protection, there are trade-offs that can potentially compromise biodiversity goals. One of these trade-offs involves the elevation of the marsh. With high elevated marshes comes enhanced flood protection especially under severe storm conditions. However, this can compromise with meeting biodiversity goals that require lower vegetation elevation in order for it to be maximized (van Loon-Steensma & Vellinga, 2013).

3.2 Vegetation properties associated with Biodiversity

In this chapter, the concept of vegetation patterns for this research was stated and how is was applied. Firstly, would vegetation patterns imply patterns of different types of salt marsh species or the height of vegetation? As de Vlas et al. (2013) points out, vegetation patterns or patches occur when areas of tall vegetation alternate with short vegetation. These patches of tall and short vegetation are highlighted by the length of the stem of each plant individual and these patches are able to stay in this condition either due to a feedback process that involves growth and grazing which creates denser and more nutritious shoots or because there is presence of unpalatable plants. By unpalatable, this means that they are indigestible and provide other palatable plants with protection if they are surrounded with them (de Vlas et al., 2013).

In this chapter, biodiversity is represented in species richness values. There is a reason for using species richness in most studies and not species evenness. Species richness observes how many species are present while species evenness observes how equal the abundance of different species are, which is not primarily the focus of this research. The species observed in this research are that of plants, invertebrates (both insects and arthropods) as well as birds that have differing functional and feeding roles.

3.2.1 Vegetation properties and plant species richness

3.2.1.1 Height

One of the main vegetation properties that have a considerable effect on the species richness of plants is its height. Some of the ways in which plant species richness can be increased by the property of height is through the creation of a structurally diverse niche that helps in the reduction of aggressively competitive plant species to dominate the niche they are in (Nolte, 2014)

The predation hypothesis proposed by Milchunas Sala & Lauenroth (1988) states that the diversity of vegetation is high when the herbivores take measures to prevent dominant sets of prey from monopolizing resources. This hypothesis was proven to be correct in a number of past studies that explored the effect vegetation height had on the diversity of plant species in the sense that as vegetation is kept low it has higher diversity of plant species.

Loucougaray Bonis & Bouzille (2004) found that vegetation structural heterogeneity helped in the increase of plant species richness as competitive species were controlled through different types of herbivorous predators who were selective with their choice of prey. They found that the lowest levels of plant diversity were present in two situations. One in which vegetation height was overly high and one in which vegetation height was overly low. As such, Loucougaray Bonis & Bouzille (2004) recommended that in order to maintain a high plant species richness, there must be an acceptable range of vegetation length and structural heterogeneity which can only be achieved through a careful selection of herbivorous predators (Fig. 3.2.1.1.1).

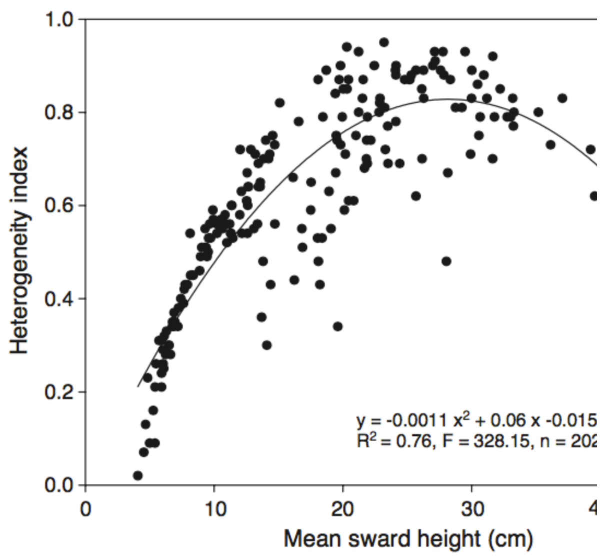


Figure 3.2.1.1.1: Relationship between plant heterogeneity and mean sward height (Tichit Durant & Kernéïs, 2005).

As such it can be agreed upon that vegetation height needs to be at an optimal range to maintain plant species diversity. If height is too short, this can make both competitive and non-competitive species go extinct in areas like Salt Marshes in the case of Nolte (2014). If height is too long the dominant highly competitive species will outnumber those less competitive than them due to the lack of herbivorous predation.

3.2.1.2 Moisture

Another vegetation property that has effect on the species richness of plants the moisture cover on stems and leaves of plants. The moisture cover on plants can differ within different environments but also within different times of year in the same niche (Olff & Ritchie, 1998). Another hypothesis proposed also by Milchunas Sala & Lauenroth (1988) known as the intermediate-disturbance hypothesis states that diversity is limited by two different extremes, from one extreme is external stress and from the other extreme competitive exclusion. It is illustrated on a graph by a bell-shaped curve showing species diversity on a stress gradient.

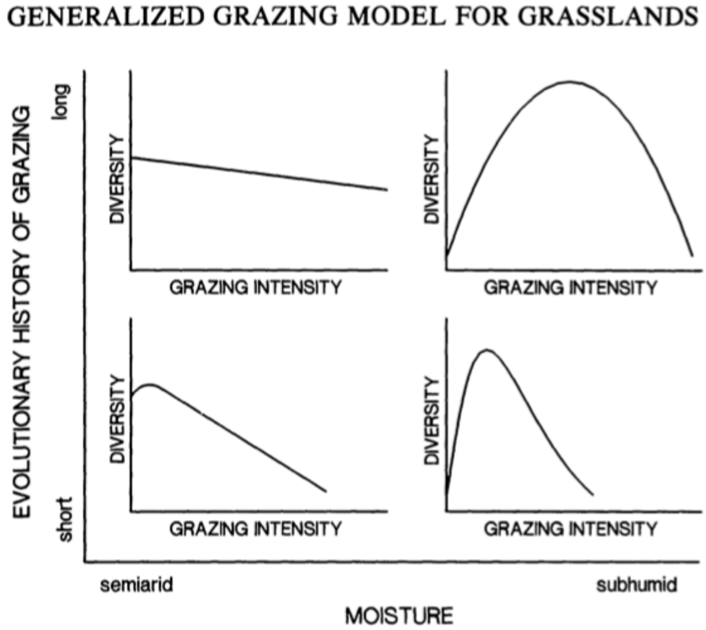


Figure 3.2.1.2.1: Plant diversity of grassland communities in relation to vegetation height for high and low gradients of moisture (Milchunas Sala & Lauenroth, 1988)

Figure 3.2.1.2.1 (Above) shows the effect plant moisture cover can have on diversity. In this section we are focusing on the graphs at the long term evolutionary history and it can be clearly seen that for vegetation with low moisture, plant species richness marginally increases with increasing height of vegetation (less grazing intensity). This is partly due to the lack of external nutrients needed to sustain the dominance of the highly competitive species. As such, the less dominant species who are adapted to conserve resources thrive better and are able to resist being overtaken by more aggressive species (Rietkerk et al., 2004).

3.2.1.3 Density (Protein and tissue content)

The protein content, tissue structure and overall density of vegetation is an important property that has an effect on the specie richness of plants. Herbivores have an effect on vegetation structural properties in that protein content can be higher for vegetation that is more vulnerable to predation due to the regenerative capacity of the stems (Bakker De Leeuw & Van Wieren, 1984). Tissue properties also influence the palatability of dominant plant species and as such this determines whether the herbivores are capable of mediating the extinction rates of some plant species in order to mitigate competitive exclusion (Olff & Ritchie, 1998).

3.2.2 Vegetation properties and invertebrate species richness

3.2.2.1 Plant Height (Size)

Just like its effect on the species richness of plants, plant height also has direct as well indirect effects on the specie richness of insects and arthropods. Dennis et al. (1997) found out that an average height of tussock sward that is not too long or too short was most favourable for species that were associated with indigenous grasslands. They also found that a mosaic of structurally different patches of grasslands varying in height greatly encouraged a large number of beetle species overall.

Petillon et al. (2007) explored the effects vegetation height had on the ground–active spiders and carabids in intertidal salt marshes in Western France. They discovered that for lower vegetation height species richness for ground beetles was higher than species richness for spiders. As for higher vegetation height, the result was reversed and ground beetle specie richness was lower while that of spiders was higher (Fig. 3.2.2.1.1). This result highlighted the importance of how this relationship between vegetation height and insect species richness is not straightforward and is very much dependent on the functional role of each insect species. As such, Petillon et al. (2007) recommended that a moderate height of vegetation is recommended to enhance species richness for both ground beetles and spiders and that such height should be present in June as it would have maximum effect for both types of species.

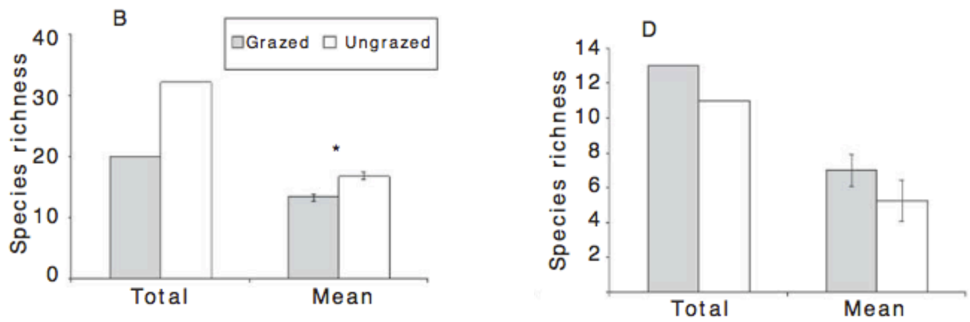


Figure 3.2.2.1.1: Comparison of Specie Richness level for Ground Beetle (D) and Spiders (B) at different vegetation heights (Grazing corresponds to lower vegetation and vice versa) (Petillon et al., 2007).

Other studies have also shown that most plant species are capable of hosting their own selection of insect species with their own set of characteristics (de Vlas et al., 2013). de Vlas et al. (2013) pointed out that marginally shorter vegetation rich in plant species are normally lower in insect species richness while in higher vegetation that is more homogenous insect species richness is higher. This is because insect species make better functional uses of the different layers of vegetation when they are tall in height. In addition, de Vlas et al. (2013) found that tall vegetation contributed not only to insect species richness but also higher densities of insects. Nevertheless, they concluded that comparatively there is approximately the same number of salt-marsh insect specialists occurring on the short as well as the tall salt marshes. As such, they concluded that the spatial variation of tall and short vegetation of salt marshes did not create an increase in the amount of specie richness of insects.

In another study, the linear relationship between insect species richness and vegetation height was also confirmed by Ford et al. (2013). They looked at how management of vegetation height in saltmarsh ecosystems has an effect on invertebrate diversity, their abundance and functional group structure. Ford et al. (2013) found also that invertebrates with larger bodies were dominant in the salt marshes that were taller. Specifically, they found that large and medium sized zoophagus and detritivorous beetles were more abundant on the tall saltmarshes due to the greater availability of plant detritus, unlike the smaller Hemiptera that were more prevalent in the shorter, moister saltmarsh vegetation. Large invertebrates prefer taller salt marsh because that protects them against bird predators that prefer prey with large body size. Therefore, it becomes more logical that smaller invertebrates have preference for shorter saltmarshes because there is less competition by the larger sets of invertebrates. In terms of species of spiders, Ford et al. (2013) found that the species of spiders who are foliage running hunters as well as the space web builders were more abundant on taller saltmarshes and those that functionally operated as ground runners. Other types like Linyphiidae aeronauts were more prevalent in shorter saltmarshes than the longer marshes in part due to their capability to disperse in open and disturbed niches where their competitors from the larger bodied invertebrate predators is lower.

van Klink et al. (2013) explored whether short or long vegetation mosaics maximize or minimize diversity of arthropods in the niche in comparison to homogenous tall and short vegetation. This was done by looking at the data of 20 years. They discovered that Arthropod richness was similar in patches of short vegetation and homogenous short vegetation, while patches of tall vegetation were similar to homogenous tall vegetation. Surprisingly, short mosaics were not richer in species than homogeneous tall vegetation, despite that there is co-occurrence of species from short, tall and mosaic vegetation (Fig. 3.2.2.1.2). Short and Tall mosaic refer to a range of short and tall plant heights in a mosaic that is considered collectively on average to be tall or short.

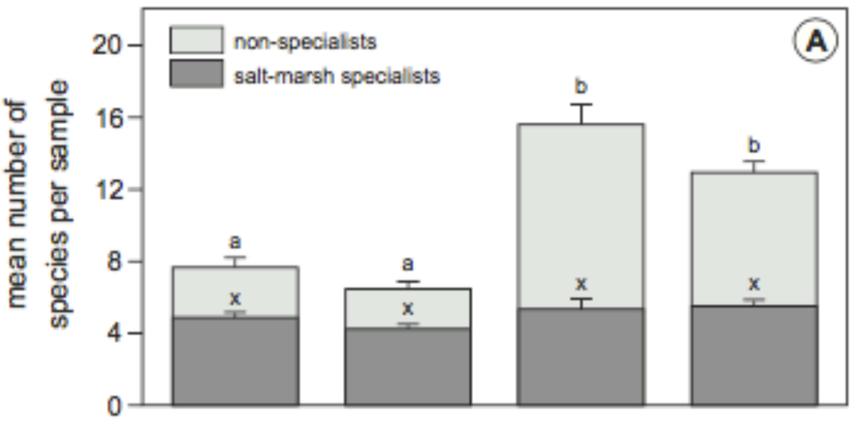


Figure 3.2.2.1.2: Mean number of arthropod species richness (left to right: homogenous short, mosaic short, mosaic tall, homogenous tall) (van Klink et al., 2013)

One possible reason for why high arthropod richness in short mosaics was not found was because of external factors such as the size of the patches that can possibly prevent rare species from reaching their population potential. But also, predator abundance may be too much for some of these species even at times in tall mosaics of vegetation. This does not however undermine the effects mosaic properties like grain size and tall/short vegetation proportionalities may have on arthropod specie richness. There was also the chance that body size of arthropods may determine the effect vegetation heterogeneity (plant species richness) on specie richness of arthropods. This means that larger bodied arthropods could exploit the short mosaics as large heterogeneous vegetation containing different resources like food plants, shelter and microclimates exist within close range in both short and tall vegetation. In addition, large bodied arthropods species could have more benefits from mosaics than smaller bodied arthropods (van Klink et al., 2013). Functional groups are something that should be taken into account with care when looking at the relationship between vegetation height (mosaics or not) and invertebrate species richness in general. As such, plant species richness greatly differed between short and tall vegetation, between the tall and short homogeneous and within the mosaics (van Klink et al., 2013).

3.2.2.2 Plant Maturity (Flowering)

Another factor that affects the specie richness of insects and arthropods is the diversity and maturity of plants. By maturity, we here refer to the flowering potential of each plant species. This is especially important for species of invertebrates that their functional role is to transport pollen and are agents in the pollination and reproductive process of these plants. Notable species that have this functional role are hoverflies, bees, as well as butterflies. Despite that, the size of the plant remains to be the overwhelming factor that determines specie numbers (de Vlas et al., 2013).

Luff (1966) looked at the abundance and diversity of the beetle fauna of grass tussocks and found that there are existing distinct microhabitats that can be present within field layers of grassland and also within plant structures of grass tussocks. This means that in such a niche, it is important that more knowledge of the microhabitat of a particular species is required so that it is possible to understand what preferences other types of species might have in order to classify them in their respective habitat based on their functional role (Luff, 1966).

Greater Effect

Dennis Young & Bentley (2001) looked at whether the botanical species composition has more significant or less significant effects on arthropods than vegetation height and structure. Their hypothesis was that epigeal arachnid assemblages would be more affected from vegetation structure than botanical species composition in the upland grasslands of Scotland. They discovered that through direct gradient analysis, botanical composition and mean vegetation height among other factors accounted for 48.5–53.2% of the variability in the species composition as well as relative abundance of arachnids. In lowland grasslands under various lengths of vegetation, spider assemblies were not as prevalent in fauna that exist in taller grassland, this shows that it is an effect caused by structural complexity rather than botanical diversity. Nevertheless, plant structure effects on arachnids are likely to act indirectly through food supply. This means that the prey requirement that make up part of the plant species composition for these arachnids are important for them to be more prevalent such as plant-hoppers (that live on specific host plants) that are attractive for arachnids like linyphiids (Dennis Young & Bentley, 2001). As such, it is important to point out that there were different conclusions that have been made from these studies of the response of arachnids to different vegetation lengths in lowland and upland grasslands. This is why it is important to note that most of the epigeal arachnid species were oversampled in the treatments with a taller average vegetation height. Nevertheless, species composition was overall underestimated in taller vegetation due to the selection bias towards smaller species located higher in the vegetation, by short duration and by sampling frequency over time. Therefore, it was concluded by Dennis Young & Bentley (2001) that varied heights in vegetation, is essential for maintaining the structural variability of grassland patches to keep a spatial mosaic favouring the optimum levels of arachnid fauna of the upland grasslands in Scotland.

Functional Roles

Woodcock et al. (2005) explored the management of vegetation heights on calcareous grasslands and its implications for the conservation of beetle communities. They found overall that there was minimal effect on the beetle specie richness by the changes in vegetation height. Nevertheless, vegetation height did have an influence on the species composition and guild structure of the beetles. Temporal factors as well as other floral characteristics are the most probable causes that have an influence on the guild structure of beetle communities. It was found that phytophagous (insects feed on plants) guild were in plots under a shorter patch of vegetation with longer temporal trends (10 years). These types of plots could be favourable for growth of forb plant species (flowering) which could have been otherwise outcompeted by taller graminoid (grass like) species and thus not be properly utilized by phytophagous beetles (Woodcock et al., 2005).

Accompanying this is also a decline in the proportions and abundances of polyphagous (eat various foods) and predatory (eat other insects) guilds. With Carabidae and Staphylinidae species making up most of this predatory/polyphagous guild this is partly due to their preference of tussock grasses and as such are dominant in tall vegetation or short vegetation that is under a short temporal trend (Woodcock et al., 2005).

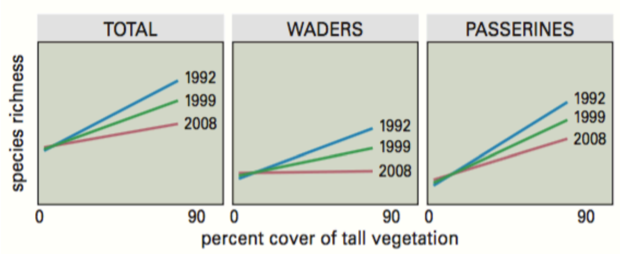
There is also evidence presented by Woodcock et al. (2005) that shows different guilds of invertebrates respond to different components of sward structure. This is evident in the predatory/ polyphagous guilds as they are dominant under the tussock dominated short vegetation with short temporal trends as well as tall vegetation. As such, a trade-off would exist with short vegetation as more of these plant species will provide a greater suitability to host monophagous or oligophagous (eat limited types of foods) phytophagous species. Regardless, it is plausible to mention that grass dominated swards of the tall vegetated plots allow higher overall biomass or increased root quality resources that are able to benefit root feeding beetles (Woodcock et al., 2005).

Finally, Woodcock et al. (2005) also stated that the species level structure of the beetle communities depended on the plant community composition even though management of vegetation possibly structures either directly or indirectly both communities.

3.2.3 Vegetation properties and bird species richness

Just like its effect on the species richness of plants and invertebrates, the specie richness of birds is also affected by vegetation properties. For example, de Vlas et al. (2013) explored the breeding bird populations of Dutch mainland salt marshes and vegetation height. From the analyses of pooling the species per group (waders, passerines and others), the outcome was that bird species richness increased with the percentage of tall vegetation that was present on a salt marsh. Nevertheless, it is important to note that at a longer temporal scale this effect became weaker (Fig. 3.2.3a).

Figure 3.2.3a: Species richness of breeding birds on Dutch salt marshes in Wadden Sea (de Vlas et al., 2013).



de Vlas et al. (2013) concluded that the reason for the decrease in the temporal effect is that with a longer temporal trend the species composition of the vegetation makes it unfavorable for a lot of the bird species to be present there. This does not however dismiss that there are some individual bird species that prefer shorter vegetation.

In another study by Mandema et al. (2014) that explored the effects of different livestock species and stocking densities on salt-marsh birds, they also found that total species richness especially that of shorebird species and the songbird species increased with increasing cover of tall vegetation. Moreover, they also found that Avocets were not abundant in tall vegetation. Like de Vlas et al. (2013), Mandema et al. (2014) found also that the abundance of all three of the investigated songbird species increased up to an intermediate when tall vegetation lasted over a more extended temporal period. Additionally, a strong positive relation was found for Reed Buntings with cover of tall vegetation. This could be attributed to the dead stems of tall vegetation servicing these birds with song perches. As such, tall vegetation provides protection for their nests in *Phragmites australis* tussocks or *Elytrigia atherica* (Fig. 3.2.3b).

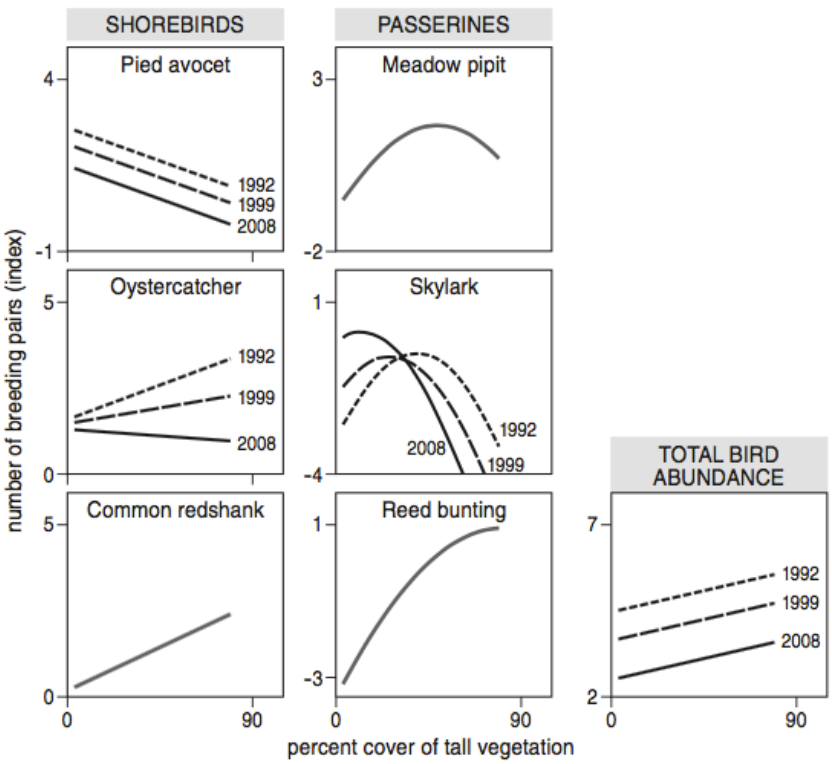


Figure 3.2.3b: number of breeding species in relation to percent cover of tall vegetation (Mandema et al., 2014).

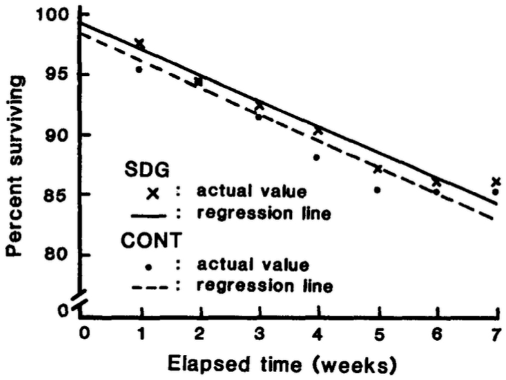
With regard to the Skylark graph, what can be observed and explained in the figure above is that the structural diversity of salt-and brackish-marsh plant communities at the time Skylarks population arrived may have changed over time. This could lead to a change in the preferred plant communities to breed in leading them to possibly shift to sites with a lower cover of tall plant communities (Mandema et al., 2014).

As such, the results of Mandema (2014) show that aside from the cover of tall vegetation, there are numerous other factors that determine the number of breeds for these species. Such factors could be that increased predation by carnivores like foxes that can act as a major influence on the decrease of breeding bird species.

3.2.3.1 Plant height (Nesting)

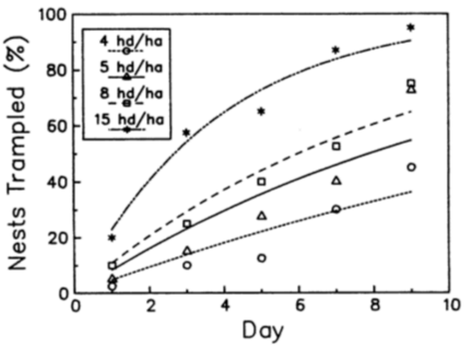
Koerth et al. (1983) explored simulated ground nests under short duration and continuous vegetation being short in length and how they are affected by the trampling of herbivores. They discovered that the trampling factor constituted only one of the many other factors that are involved in nest interaction. They also found that short vegetation as well as plains of spatial mosaics can make the nests of these birds vulnerable to predation. As such, it is evident that trampling under short duration (SDG) resulted in bird nests surviving more than under continuous (CONT) trampling (Fig. 3.2.3.1.1).

Figure 3.2.3.1.1: Survival curves for simulated ground nests under short-duration (SDG and continuous (CONT) (long temporal trend) both for short vegetation (Koerth et al., 1983).



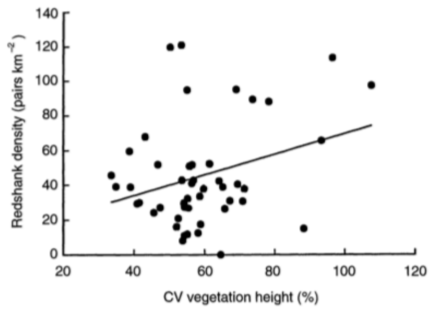
In another study made by Jensen Rollins & Gillen (1990), they looked at the effects of vegetation height on trampling loss of simulated ground nests. They discovered that overall, under shorter vegetation there were more nests that were trampled by herbaceous predators than under taller vegetation and that also there was a threshold of vegetation height that would cause significant disturbance of ground nesting birds (Fig. 3.2.3.1.2).

Figure 3.2.3.1.2: Response of nest trampling to vegetation height (Jensen Rollins & Gillen, 1990).



Norris et al. (1997) explored the density of Redshank *Tringa totanus* breeding on the salt-marshes of the Wash and its relation to its habitat and vegetation height management. They used multiple regression modelling and the results overall showed that there was a positive relationship between the density of redshanks and vegetation structural diversity. They found that in shorter vegetation dominated by sea-couch grass community had supported both the most structurally diverse vegetation and the highest breeding densities of Redshank, while in taller more uniform vegetation of similar habitats had significantly lower breeding densities of Redshank (Fig. 3.2.3.1.3). Norris et al. (1997) did note that a slight increase in Redshank breeding density could be balanced off by the increased risk of herbaceous predators trampling on nests.

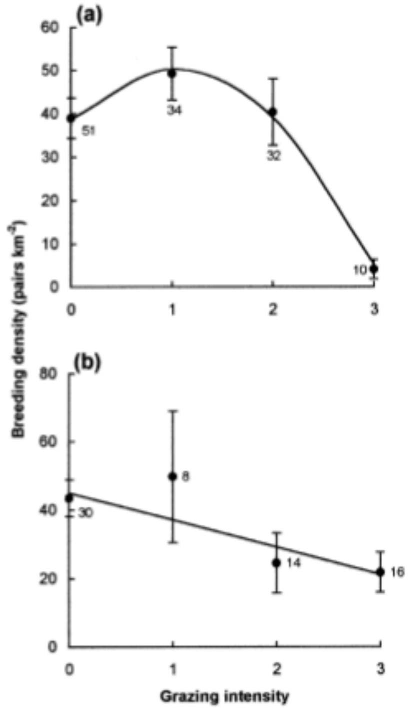
Figure 3.2.3.1.3: Relationship of Redshank breeding density to Vegetation height diversity (Norris et al., 1997).



In another analyses, Norris et al. (1997) demonstrated that Redshank densities rapidly increased with the increase in sea-couch grass community extent in short vegetation plots yet were less rapid at plots with taller vegetation. This could have been due to changes in vegetation structure as Redshanks were positively correlated with vegetation height diversity. This means that Norris et al. (1997) managed to show or at least suggest that vegetation height affects the sea-couch grass structure which in turn affects Redshank nesting suitability. Norris et al. (1997) also took into consideration the tidal factors that have an effect on breeding densities of Redshanks as they are likely to be a reason for causing low nesting success with flooding.

In another study by Norris et al. (1998), they explored whether the density of redshank Tringa totanus nesting on saltmarshes in Great Britain was declining due to changes in vegetation height management. They conducted 2 surveys and found in both of them that breeding densities were lowest in the short saltmarsh filled plots and that breeding densities were highest in slightly taller saltmarsh filled plots (Fig. 3.2.3.1.4).

Figure 3.2.3.1.4: Relationship between Redshank breeding density and Vegetation height represented as Grazing intensity (Norris et al., 1998)



Norris et al. (1998) showed that sites that were shortest in vegetation height also were vulnerable to the greatest decline in breeding density and as such these changes were enough to show the observed decline in breeding densities of Redshanks. They also showed that breeding densities declined most significantly on plots that had changed from being short to intermediate to tall vegetation. Norris et al., (1998) noted that the models were not identical for the included variables and recommended that in the short term, maintaining intermediate heights for vegetation would be the ideal management strategy.

de Vlas et al. (2013) explored the choice of nesting sites for Redshanks and Oystercatchers and they found that they breed at places with significantly taller vegetation. They also discovered that the differences in vegetation height did not necessarily lead to differences in density of nests especially in the study of the second year. In the quest for an optimal solution, de Vlas et al. (2013) concluded that it is favorable for salt marshes to increase in tall vegetation only on the short temporal term.

3.2.3.2 Plant height (Food source)

One of the main services vegetation height provides for most types of birds other than nesting is also being a food source for some bird species like geese. The geese anomaly will be explained in a more elaborate fashion in subsection 3.2.3.5. A study made by Patton & Frame (1981) on the effect of grazing in winter by wild geese on improved grassland in West Scotland found that these geese fed on farmland exclusively especially in upland grasslands as the grass there contained the necessary feed requirements for them. They also studied gizzard contents from 20 geese and based on these contents they have clearly shown to prefer sown ryegrass (Lolium) species of plants over the more indigenous grass species.

In another study, de Vlas et al. (2013) looked at Meadow pipits, vegetation and the food they gather for their young. They highlighted the importance of how vegetation height aids in the harvest of certain classes of invertebrates' species that can be favourable for ingestion by certain types of birds. They explored how some passerine species that breed on salt marshes need insects and spiders as a food source. As such, they discovered that Meadow pipits did not prefer areas of high variability of vegetation height and did not prefer very short vegetation.

3.2.3.3 Plant heterogeneity

The heterogeneity in plant height and/or type of species is also an important factor that affects the presence of birds in a particular niche because of reasons like nest protection and prey abundance. Tichit Durant & Kernéïs (2005) looked at the role of managing vegetation heterogeneity in creating suitable sward structures for breeding waders in agricultural landscapes. They found that even though waders share similar breeding habitat like wet grasslands, they are not attractive for all types of waders because each type prefers different sward heights. This is why they turned their focus more on lapwings and redshanks due to their abundance in presence in the study area. They discovered that short swards (~10cm) are more attractive for lapwings and medium swards (15-20cm) are more attractive for redshanks. They also found that in terms of heterogeneity (abundance of tussocks) both bird species are sensitive to it. Lapwings preferred grasslands not abundant in tussocks (5-15% of area), while redshanks preferred grasslands more abundant in tussocks as they use them functionally for making nests there. They also found that there was a slight trade-off between demand for short swards and nest trampling risks and as such it is important to find an optimal balance to benefit the birds most with as minimal risks as possible. As such, Tichit Durant & Kernéïs (2005) concluded that difference in spatial as well as specie heterogeneity of grasslands is key to provide suitable nesting areas for lapwings and redshanks.

Cerezo Conde & Poggio (2011) explored how pasture area and landscape heterogeneity are key determinants of bird diversity in intensively managed farmland in the Pampas. Overall they found that landscape structure strongly affects the bird communities. They found that species richness and abundance was higher in landscapes that had a higher proportion of land covered with pasturelands and higher compositional heterogeneity. They also explained that habitat area (as in habitat subdivision) has a much more profound effect than patch configuration (as mean patch perimeter-area ratio in determining species richness and abundance). They also discovered that compositional heterogeneity was more important for open-habitat and grassland species than species that are specified in pastureland area. Cerezo Conde & Poggio (2011) also investigated the vulnerabilities and they found that some bird species' ability to make use of other habitats make them less vulnerable to the fragmentation effects done by habitat subdivision because they find less resistance to move through the landscape matrix. Nevertheless, a lot of the bird species' population dynamics were disturbed by such subdivision that increased their risk of local extinctions due to the lack of structural connectivity. They could not find a straightforward explanation for the difference in the effects in landscape modification on specie richness and abundance of birds.

Mandema et al. (2014) found that Redshank and Oystercatcher nests were present in sites containing taller vegetation with more variation and patterns than found at random sites. These patterns existed in moderate length vegetation as well. As such, moderate to high lengths of vegetation that create patterns would potentially be beneficial to Redshanks and Oystercatchers in terms of providing safe sites for their nests. Moreover, Mandema et al. (2014) found that Redshanks and Oystercatchers chose nest sites with significantly higher average edge values than at random sites. This meant that they preferred spatial variation in canopy height around the nest sites as it can potentially provide camouflage for the nest and simultaneously retaining an open view and escape routes from the nests (Fig. 3.2.3.3.1).

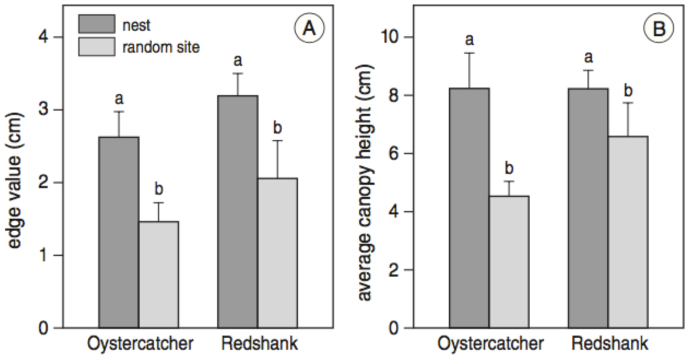
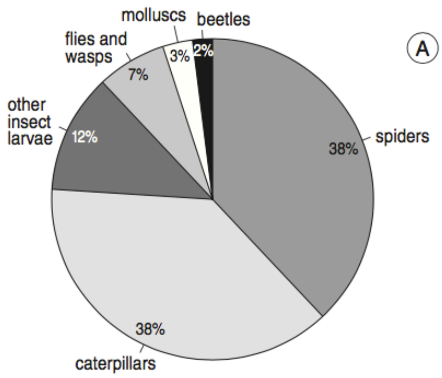


Figure 3.2.3.3.1: Redshank and Oystercatcher abundance and nest site preference in relation to average canopy height (B) and edge value (A) (Mandema et al., 2014).

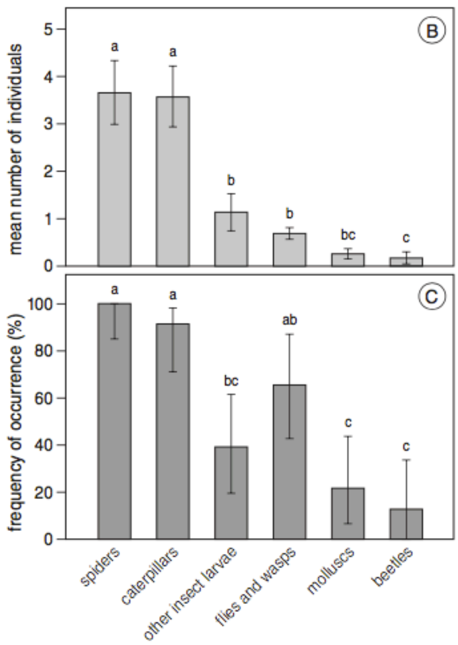
In addition, Mandema et al. (2014) also found that the increase in spatial diversity in canopy height can cause an increase in prey diversity for birds. In terms of diet, they found substantial evidence that there is selective foraging for larger prey. This is because there is abundance of large spiders and caterpillars comprising more than 80% of the nestling diet found in the faecal samples than in the field (Fig. 3.2.3.3.2).

Figure 3.2.3.3.2: Percentage of diet selectivity by birds (Mandema et al., 2014).



For Meadow pipits, Mandema et al. (2014) found strong evidence for selectivity in the choice of their prey. They did not however find preference for feeding in short and patchy vegetation like in the other habitats contrary to other results, which made them therefore have preference to more homogenous vegetation. This might suggest that vegetation patchiness describes better Meadow Pipit feeding behaviour than vegetation height (Mandema et al., 2014) (Fig. 3.2.3.3.3).

Figure 3.2.3.3.3: Diet composition of Meadow Pipits (Mandema et al., 2014).



3.2.3.4 Other independent factors

There are numerous other independent factors besides the aforementioned ones of vegetation properties that can have an effect on the population of breeding bird species. One of them is the timing of the breeding itself. Tichit Durant & Kernéïs (2005) found that breeding success can be influenced by nest trampling if they are at the same time range. They found that the difference between lapwings' and redshanks' was that the lapwing nests approximately 1 month earlier.

In another study by Tichit Renault & Potter (2005), they explored vegetation management as a tool to assess its positive side effects on wading birds. Their results showed that the breeding success of redshanks was more sensitive to spring shortening of vegetation as they settle and nest later than lapwings. As such, they recommend that vegetation management should take into consideration the temporal scale if conservation at the community level were to be successful.

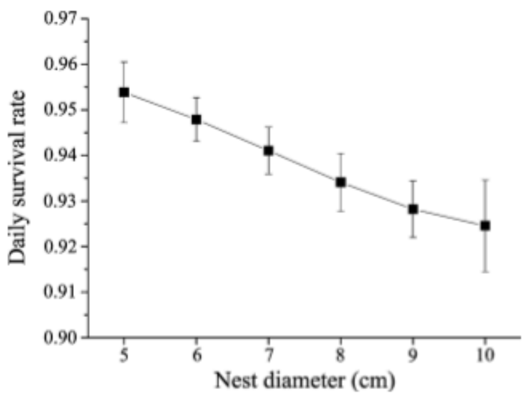
Vandenberghe et al. (2009) looked at the Influence of vegetation height management on meadow pipit foraging behaviour in upland grasslands. They also found that meadows foraged more in areas with preferred vegetation characteristics than in areas with a total of higher invertebrate biomass that were more present in foraging than random sites. The findings by Vandenberghe et al. (2009) supported their claim that resource- independent factors like food accessibility and forager mobility is capable of determining patch selection making them more vital in the selection criteria than food abundance. They found that food accessibility was a more vital factor when birds are selecting prey when vegetation is short and prey abundance as well as size are not abundant and small. As such, Vandenberghe et al. (2009) discovered clearly that an average height of vegetation created a more suitable selection of sward height, plant biodiversity, structural heterogeneity and adequate food supply for meadow pipits so that they can nest in tall vegetation and prey in short vegetation.

This means that the meadow pipits selected sites according a collection of different attributes.

With regard to invertebrate size, Vandenberghe et al. (2009) found that their biomass was more negatively affected by herbivores than their own abundance, suggesting that very short vegetation contain higher proportions of smaller sized invertebrates. This means that the distribution of invertebrates of different sizes can increase or reduce the sward's suitability as a resource for preying by birds. This can partly explain the phenomenon of meadow pipits preying on shorter vegetation as food accessibility was more of a priority than size of food.

Nest size can also be another factor that determines specie richness of birds. A study by Pakanen Luukkonen & Koivula (2011) looked at nest predation and trampling as management risks in grazed coastal meadows and they found that trampling rates were dependant on the nest size and timing of its production. Not only that but they also found that larger nests had lower survival rates (Fig. 3.2.3.4.1). The results of Pakanen Luukkonen & Koivula (2011) showed that nest sizes (10 cm) that represented northern lapwing (*Vanellus vanellus*) had on average a 0.075 daily probability of being trampled while smaller (6 cm) passerine nests had a daily trampling probability of 0.052.

Figure 3.2.3.4.1: Model averaged estimated of daily survival rates from trampling for different sized artificial nests (Pakanen Luukkonen & Koivula, 2011)



Mandema et al. (2013) looked at vegetation height and bird nest trampling through an experiment that used artificial nests. They looked at differences between 4 vegetation treatments on nest trampling and evaluated to what degree can nest trampling probability be higher. They found that artificial nests closer to freshwater tanks were more vulnerable to trampling (Fig. 3.2.3.4.3). Additionally, each herbaceous predator has a different behaviour, timing and trend in trampling artificial nests. Mandema et al. (2013) found that horses trample more artificial nests than cattle resulting in lower survival rates for these artificial nests due to the fact they are more mobile than cattle and are able to be further away from the tanks. Both horses and cattle however did trample more when they were at higher numbers (Fig. 3.2.3.4.2). As such, Mandema et al. (2013) concluded that the location of freshwater tanks has a profound effect on the distribution of herbaceous predators and in turn their capability to trample nests.

Figure 3.2.3.4.2: Fraction of artificial nests tramples in comparison to different treatments of herbaceous species (Mandema et al., 2013).

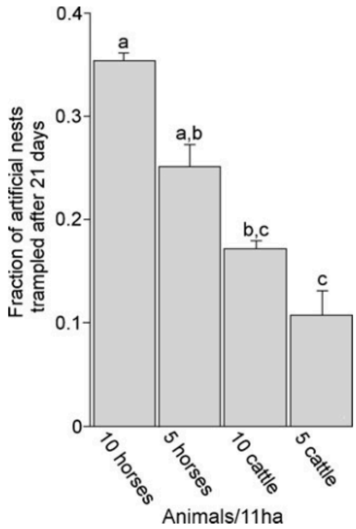
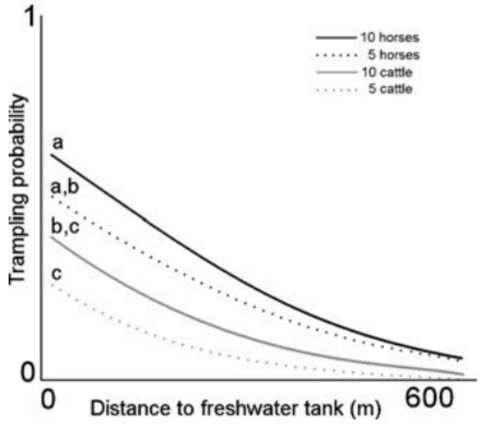


Figure 3.2.3.4.3: Probability of artificial nests being trampled within proximity of freshwater tanks (m) (Mandema et al., 2013)



It is important however to note the shortcomings artificial nests pose to the experimental setup. The difference between real nests and artificial is that for artificial nests birds do not breed there and provide protection for it, as such lacking the properties that it should have.

3.2.3.5 Geese

While most bird species in grasslands and saltmarshes use the habitat to prey on insects and breed and create nests, there is another type of bird species known as geese that exclusively feed on and graze the grassland itself.

Ydenberg & Prins (1981) studied spring grazing and the manipulation of food quality by barnacle geese and found that there is a relationship between spatial distribution of barnacle goose grazing and the rate at which food plants grow. They also found that the intensity of grazing keeps the standing crop at a constant height, and that due to grazing, the protein content of plants on grazed areas is significantly higher than un-grazed areas. Because geese migrate at very large distances and between seasons, Ydenberg & Prins (1981) also found that the breeding of Arctic nesting geese is largely attributed to the high availability of protein during the spring.

In another study, Vickery et al. (1997) looked at managing coastal grazing marshes for breeding waders and overwintering geese and whether there is a conflict. They looked at the winter grazing intensities of brent geese, pink-footed geese, white-fronted geese as well as the breeding densities of lapwings, redshanks, and snipes. These were related to the environmental characteristics of plots in coastal marshes in the north Norfolk coast. They found that Lapwings, redshanks and snipes were highest in breeding densities on the moistest and shortest fields.

Vickery et al. (1997) found in their study several trends in the factors that determine brent geese, grey geese, lapwing, redshank and snipe distribution in relation to other species. Generally speaking, high densities of breeding waders in the summer were mainly supported by geese who lightly grazed in the previous summer. On the other hand, lower densities of waders were supported by geese who heavily grazed. In the winter, plots that were least grazed by brent geese where most grazed by grey geese, while in the summer, high breeds of lapwings were also complemented with high breeds of redshanks but not with snipes. Vickery et al. (1997) also discovered that brent and grey geese preferred different characteristics when looking for fields to feed on. Grey geese preferred drier fields further away from the habitat while brent geese preferred moister fields with shorter swards. This puts things more into perspective as Vickery et al. (1997) also found that sward height was an important factor that influenced field choice for breeding birds as well and as such, Vickery et al. (1997) recommended that grass sward be kept short for the whole year in order to manage the area for both breeding waders and grazing geese. Overall, Vickery et al. (1997) explained that the negative relationship that exists between two bird communities could be attributed to field preference.

Van der Graaf et al. (2002) explored Short and long-term facilitation of goose grazing by herbivores in the Dutch Wadden Sea area. They found that geese clipping and removal of young lamina more frequently had elevated their protein levels by enhancing biomass production to the point of harvest at the end of the goose staging period which is already short. They found that repeated removal stimulated the plant tissue that is enhanced in nitrogen and favourable for geese. They also discovered that the geese preferred shorter and denser vegetation taller vegetation that was less dense. But also shorter vegetation assisted these geese in locomotion but also that of predators to detect them. Van der Graaf et al. (2002) also found that repeated grazing by geese helped maintain swards that are suitable. This was also confirmed by Davidson (2017) that geese abundance did indeed increase with shorter vegetation.

Bos et al. (2005) explored Utilising Wadden Sea salt marshes by geese in relation to vegetation management of other herbaceous predators. They found that there are differences in soil composition between artificial mainland marshes and natural ones as natural ones have thin clay layer on top of a sandy sub soil while artificial ones have thicker clay layer. In addition, salt marsh maturation is mediated largely by elevation due to sedimentation. Bos et al. (2005) also found that canopy height was correlated with geese grazing intensity as short stems were homogenous with favourable leaf/stem ratio who were considered high food quality for them. They also found that there was a positive relationship between geese communities in short canopy and their dropping density. As such, Bos et al. (2005) concluded that the absence of other herbivores that manage vegetation would cause a declining in the feeding suitability of the marshes for geese leading them to feed on alternative habitats like agricultural land that can cause economic consequences.

de Vlas et al. (2013) also confirmed that geese prefer to feed on nutrient rich grasses like Sea plantain and Arrowgrass found in older salt marshes that were in higher elevated areas.

Mandema et al. (2014) found that vegetation management by larger other bodied herbivores affected geese distribution at different temporal scales. Overall in the autumn, geese populations were highest when prevalence of herbivores were also highest and likewise geese populations were lowest when prevalence of herbivores were also low (Fig. 3.2.3.5.1a, Fig. 3.2.3.5.1b). They found also that differences in geese populations among different plots in autumn and spring were attributed more to availability of nutrient rich vegetation than canopy height. The reason for the presence of herbaceous predators at that time is because at the beginning of the autumn season, vegetation on salt marshes is tall, and plant digestibility is high for them but low for geese due to high fibre contents in the shoots.

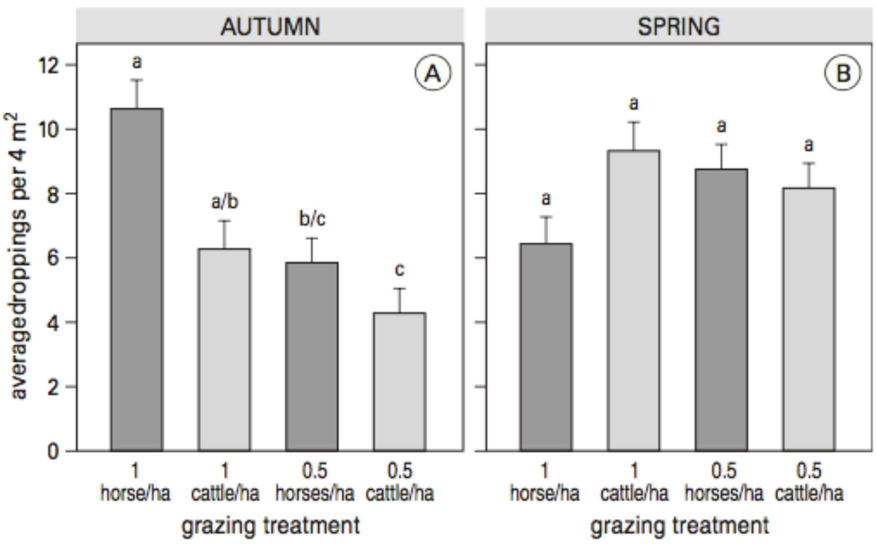


Figure 3.2.3.5.1: Grazing treatment in relation to average geese droppings (Mandema et al., 2014)

Moreover, Mandema et al. (2014) found that in spring, vegetation management by herbivores did not significantly affect the distribution of geese even though they did find geese to selectively forage at patches that had higher quality food. This means that they would spread over larger areas during this time of the year. In the summer, they found that management by herbivores at this time induces secondary shoot growth at an early age making the plants more nitrogen rich (Mandema et al., 2014).

3.2.4 Conclusion

In summary, based on the studies that were investigated and reviewed, there were numerous factors other than vegetation properties that were associated with biodiversity. The most notable of these factors is the temporal dynamics that can have an effect on the timing of species being present or absent in the case of birds or on the maturity of species in the case of plants. But there are also numerous other non-vegetative factors that are associated with biodiversity such as the spatial scale of the niche and the location of the vegetation within this niche. In addition to these factors, predator and prey interactions between plants, invertebrates and birds have a major role in biodiversity especially when it revolves around the functional roles of each of these species in both the predatory functions and maintaining the suitability of the niche. In terms of prey, its size, abundance, mobility, and location preference can have a major effect on its own biodiversity, its prey, and that of its predators. But for this chapter, much is focused on the properties of vegetation.

In terms of vegetation properties, it has been concluded that height is the most influential property that is associated with biodiversity. The reason being is that it affects and is affected by 5 different factors. Plant height was shown to have an effect on geese presence by acting as a food source for them and at the same time geese are agents in the management of vegetation height as well. This means that height was shown to also influence the suitability for invertebrates to live in that environment and as such, plant height did have an influence on their specie richness as well as being affected by some of these invertebrates who fed on their structures (Fig. 3.2.4.2). Moreover, the height of plants was also shown to have an effect on the specie richness of plants as well and it was demonstrated by multiple studies in the previous sections that too short or too long heights in vegetation compromised the diversity of plant species (Fig. 3.2.4.2). This meant also that the rate of growth of each plant had a role as well in maintaining diversity for plants. Finally, plant height also played a role in maintaining bird species diversity as height difference can both help keep a safe space for nests and also provide easier visibility for prey catchment. Likewise, birds like geese and others who are herbaceous are agents in maintaining the height of the plants (Fig. 3.2.4.3).

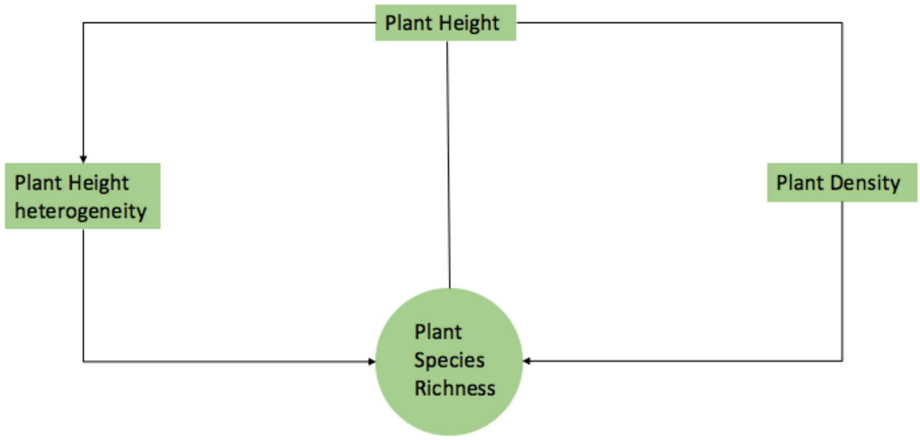


Figure 3.2.4.1: Vegetation properties associated with Plant Species richness. (→ = direct cause-effect; —— = reciprocal effect meaning they are affected by each other)

The second most influential property found to influence biodiversity was plant height heterogeneity. It was found overall that plant height heterogeneity acted more as a mediator and moderator of existing relationships. Plant height heterogeneity mediated the effects of plant height on plant species richness as different heights of plants in the same plot can cause different types of plant species to thrive while giving more area for over competitive species to thrive. Plant height heterogeneity was found to moderate the relationships between geese and plant height in that geese aid in the management of plant heterogeneity and likewise the heterogeneity of plant height can affect geese presence as a homogenous tall niche was found in the chapter not to support geese presence. Plant height heterogeneity was also found to moderate between plant height and invertebrate species richness as it helps create the required suitability needed for different invertebrate species who each of them have their own functional roles and their own diet (Fig. 3.2.4.2). Plant height heterogeneity also acted as a moderating effect between bird species richness and plant height as well in a similar manner as the geese in that different heights in vegetation was found to support nest protection at higher lengths and provide easier access to prey at shorter vegetation (Fig. 3.2.4.3).

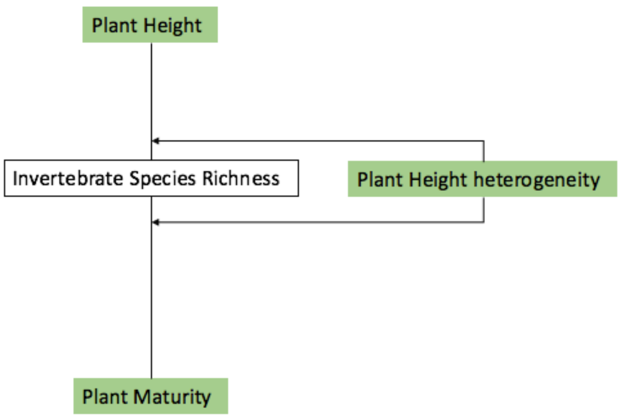


Figure 3.2.4.2: Vegetation properties associated with Invertebrate Species Richness. (→ = direct cause-effect; —— = reciprocal effect meaning they are affected by each other)

The third most influential property found to influence biodiversity was plant species richness. For this property it was found to affect and be affected by plant height in that height of vegetation was found that at a reasonable length to sustain high plant species richness in numerous studies (Fig. 3.2.4.1). Plant species richness was found to moderate the effects of plant height and geese populations as it was found that geese had dietary preferences for certain types of plant species. Moderating effects were also found to take place between plant height and other bird species richness too as different plant species had different structural properties that can be suitable to different types of birds to nest there (Fig. 3.2.4.3).

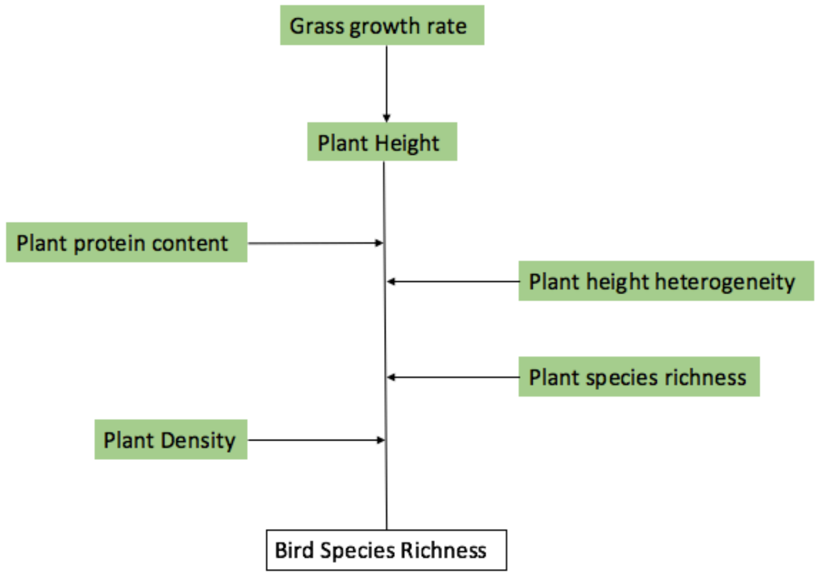


Figure 3.2.4.3: Vegetation properties associated with Bird Species Richness. (→ = direct cause-effect; — = reciprocal effect meaning they are affected by each other)

Other influential vegetation properties were also found to influence biodiversity such as the plant protein content and plant density. Plant protein content were found to moderate effects between Birds and Plant height in that some birds like geese were found to have preference for protein rich plant fibers (Fig. 3.2.4.3).

There are vegetation properties that had minimal influence on biodiversity but they cannot be ruled out. These properties were the grass growth rate, maturity and moisture of plants. Grass growth rate influenced the height of plants, while the maturity influenced insect species richness in that for some like hoverflies it was found that some plants that matured enough to produce flowers helped them pollinate them (Fig. 3.2.4.2, 3.2.4.3). As for plant moisture, they were found to moderate the effects between plant species richness and plant height in that vegetation with low moisture, plant species richness marginally increases with increasing height of vegetation partly because the lack of external nutrients does not help sustain the dominant highly competitive species who need considerable amount of nutrients and resources to be dominant making the less dominant species who are adapted to conserve resources thrive better and are more resistant to being overtaken by more aggressive species.

Overall this chapter has shown that there are certain key properties in vegetation of saltmarshes that have a role in the influence of bird species richness as well as invertebrate and plant species richness. It also has shown that there is a need for removal of plant biomass in order to prevent highly competitive plant species to be dominant and increasing plant species richness. It is important to note however that in some cases plant species richness can cause reductions in invertebrate species richness. This is why plant species richness alone cannot always be used to indicate biodiversity as responses can vary by taxa (Davidson et al., 2017).

3.3 Effect of different Grazing regimes on vegetation properties associated with wave attenuation and biodiversity

In this chapter, we looked at the vegetation properties that had the most effect on both wave attenuation and biodiversity that were explored in the previous two chapters. These vegetation properties were found to be the plant height and plant height heterogeneity structural heterogeneity). This chapter looked into past findings on how grazing contributed to plant height and structural heterogeneity and it was discovered that the grazing density, type of grazer as well as their spatial distribution across the plots and their dietary preferences were contributing factors in the creation of vegetation mosaics through plant height management. The results of the plant height data as well as the variance in height (for structural heterogeneity) were extracted from the Noord Friesland Buitendijks (NFB) and plotted for different months and at different grazing densities of high and low for both Cattle and Horse grazers.

3.3.1 Past Findings

Grazing species are notable to selectively graze when they are faced with distribution of vegetation that is patchy. They tend to focus more on shorter and leafier plants that have higher concentrations of nutrients. The reason being is that cattle intake of low quality plants can be constrained by their digestive system. As such, there is a possible trade-off that could exist between plant quality and quantity in a quest to maximize daily nutrient intake. In addition, selectivity in grazing is also determined by the scale of patchiness as much as the patch arrangement (WallisDeVries Laca & Demment, 1999). The question remains how patchiness can be determined by grazing in terms of scale but also arrangement? With regard to salt marshes which is the focus of this chapter and the research as a whole, numerous authors had recommended a variation in grazing densities but also grazer types in order to achieve high structural diversity. Such variation especially for livestock species is integral in influencing their diet behaviour, and their own distribution in a field that would inevitably influence vegetation structural heterogeneity (Nolte, 2014). In a meta-study by Davidson et al. (2017), they found that plant height, cover, biomass and litter under grazing were decreased where the trend was much stronger at higher grazing densities and longer duration further diminishing coastal defence capability and wave attenuation. As such, they have recommended a careful management of grazing that does not significantly impair coasts of this vital functional role.

3.3.1.1 Grazing Density

Grazers do not only react to the existing environmental properties through grazing. They also create environmental properties that have an effect on their grazing behaviour in the future. Grazers make these environmental properties through behavioural patterns that create variability in patch patterns in the case of the chapter concerned. For example, small-scale structural heterogeneity can occur if moderate continuous grazing takes place producing patches that are smaller and more heavily grazed complemented with un-grazed and/or light grazed patches. At a larger scale, grazers would cause larger scale structural heterogeneity as they would be more active near watering sources and much less active in more distant vegetation (Fig. 3.3.1.1.1) (Fuhlendorf 2001; Rietkerk et al., 2000).

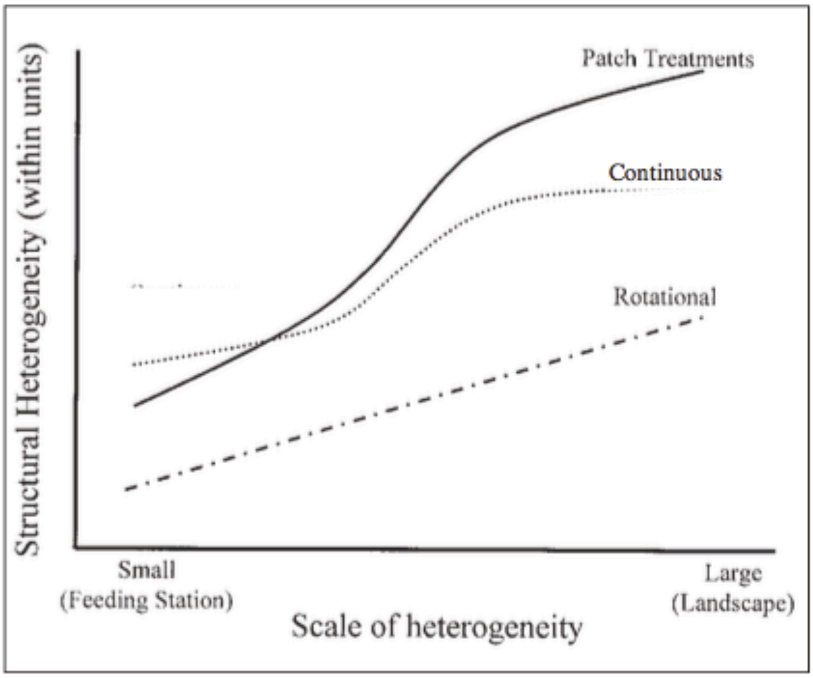


Figure 3.3.1.1.1: Relationship between Structural and Scale of heterogeneity in response to different grazing patterns (Fuhlendorf & Engle, 2001)

3.3.3.2 Plant height heterogeneity

With regard to plant height heterogeneity (structural heterogeneity), it can entail the variability of a variety of plant aspects from the stature, composition, density and biomass of vegetation. In this chapter, plant height heterogeneity refers mainly to patterns where taller vegetation alternate with shorter vegetation. Patches of this condition remain such as a result of a feedback process that involves the grazing of once grazed plants that end up reproducing shoots that are more nutritious than before. This makes them more attractive for grazers than less grazed ones. These nutritious shoots make these plants more palatable (eatable) for the grazers. Grazing density as well as the type of grazer plays an important role in plant height heterogeneity (de Vlas et al., 2013). In terms of grazing density, higher density entails the creation of larger patches of short plants than at lower densities. There are three types of structural spatial patterns: trends or gradients, patchiness and randomness. Trends or gradients can be found at larger scales (kilometres) and randomness can be found at smaller scales (centimetres). As such, average vegetation height depends on on the grazing density and plant biomass. It would also consist of short vegetation that is closer to freshwater resources and it would alternate with areas of taller vegetation that is far from freshwater resources. In addition, grazer spatial distribution also determines the density of grazing (Nolte, 2014).

de Vlas et al. (2013) found that at similar grazing density treatments of horses and cattle, horses caused a shorter average plant height than cattle. This could be the result of the high food demand horses need as well as their more enhanced trampling ability than that of cattle. In addition, the resulting mosaics of tall and short vegetation were twice larger under horse grazing than that of cattle (de Vlas et al., 2013). Nolte (2014) found that vegetation height increased the further away they were from the freshwater resources accompanied with decreasing stocking density. In addition, they found that the cattle and horses at different densities have different effects on plant height, patch size and structural heterogeneity. They found that patch differences between horses and cattle was attributed to the mouth anatomy. Horses are known to cut grass with their incisors while cattle use their tongue to rip off parts of the vegetation which results in a few centimetres of grass always remaining standing (Nolte, 2014; de Vlas et al., 2013). Nevertheless, according to Fig. 3.3.1.2.1A, there was no evidence that there was higher heterogeneity in cattle treatments compared to horse-grazed treatments and that heterogeneity was more affected by grazing density than species (Fig. 3.3.1.2.1) (Nolte, 2014).

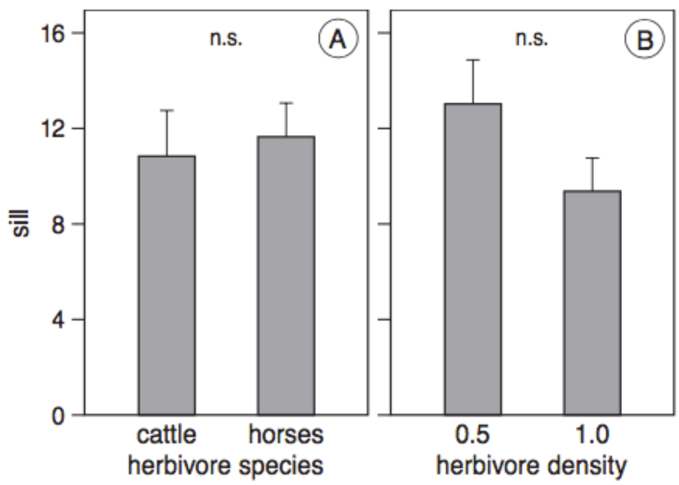


Figure 3.3.1.2.1: The mean sill heterogeneity compared between Cattle and Horse treatments (A) and grazing density (B) (Nolte, 2014).

One of the reasons as to why density was more important in determining structural heterogeneity is that biomass is removed more efficiently under higher numbers of grazers. The differences in structural heterogeneity between different types of grazers is small due to the minimal differences in palatability between the different plant species concerned. This means that the searching effort will not increase the gain and as such, it is not expected to find random grazing patterns. This is why it is important to acknowledge that information on the effects of different grazing species on vegetation-structure patchiness is not abundant. And it is important to note that grazing density and grazer type should be carefully chosen (Nolte, 2014).

3.3.1.3 Grazing behaviour

With regard to the grazing behaviour of different types of grazers, it is important to note that cattle and horses have different methods in how they graze and there are reasons to why it is as such (de Vlas et al., 2013).

For a start, patch selection as a behaviour plays an important role. The reason being is that grazers have preferences for patches that contain the highest digestible intakes as such making search patterns not random. This kind of selectivity increases when the selectivity in patch choice is integrated with selectivity of feeding areas. As such, selectivity is based on the feeding path of grazers and the feeding area (WallisDeVries Laca & Demment, 1999). It was found by WallisDeVries Laca & Demment (1999) in shorter patches grazing bites were smaller than in taller patches and that this was more of a factor in feeding selectivity.

For grazers, differences in the digestive systems between cattle and horses are factors that determine their grazing patterns. Cattle have a fermentation chamber in their foregut making food slower to digest but extract more nutrients than that of horses who ferment in the hind-gut fermenters and compensate by increasing their consumption. As a result, it can be self-explanatory that cattle were more clustered and stayed longer at the same area while horses due to their higher consumption patterns, they grazed longer and as such they were more distributed randomly **(**Nolte, 2014).

3.3.1.4 Preference for plants

Diet choice is an important factor that determines grazing patterns by grazers. Different species of grazers have different diet choices and what determines the diet is mostly the fibre content of the plant to be fed. With regard to grazing density, animals at higher grazing densities were found to include more plant types in their diet that would be avoided at lower grazing densities. This could be due to the fact that the more palatable plant species are scarcer at higher grazing densities. Higher grazing densities would mean there would be interference between individual grazers (Nolte, 2014).

For cattle, they tend to prefer plants with lower fibre content and unlike horses, they spend a considerable amount of their time searching and travel short distances (Nolte, 2014). In Figure 3.3.1.4.1 it can be seen that on average cattle for example ate more Sea aster than horses (de Vlas et al., 2013).

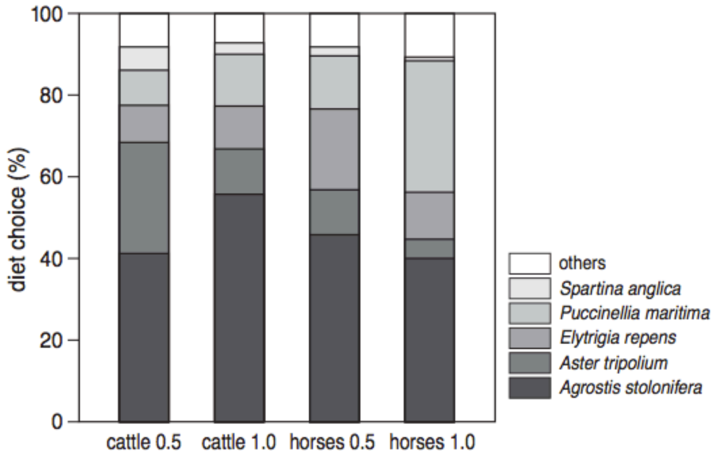


Figure 3.3.1.4.1: Average diet choice of cattle and horses at different grazing densities measured in percent time spent grazing on plant species (Nolte, 2014).

For horses, they tend to prefer plants with higher fibre content in addition to the fact that they are less capable to ingest secondary metabolites than cattle. Also, horse grazers graze for longer periods of time than cattle due to the fact that they ingest lower quality plants in their diet and as such they are much more active and cover greater distances (Nolte, 2014).

3.3.1.5 Overall

What can be taken from these findings is that there are a number of factors that affect grazing behaviour on the relevant vegetation properties in this chapter which are vegetation height and structural spatial heterogeneity. We have found from the literature that the relationship between grazing selectivity of plants and the arrangement of structurally heterogeneous patches was mediated by the digestive system properties of the grazer type. This relationship entailed that in both cases grazing selectivity causes a certain structural patch arrangement and vice versa. Certain structural patch arrangements can have an effect on grazers in selectively consuming the plants of their choice. This key relationship was found to be moderated by numerous factors, the type of grazer and the grazing density, as well as the spatial distribution of the grazers (Fig. 3.3.1.5.1).

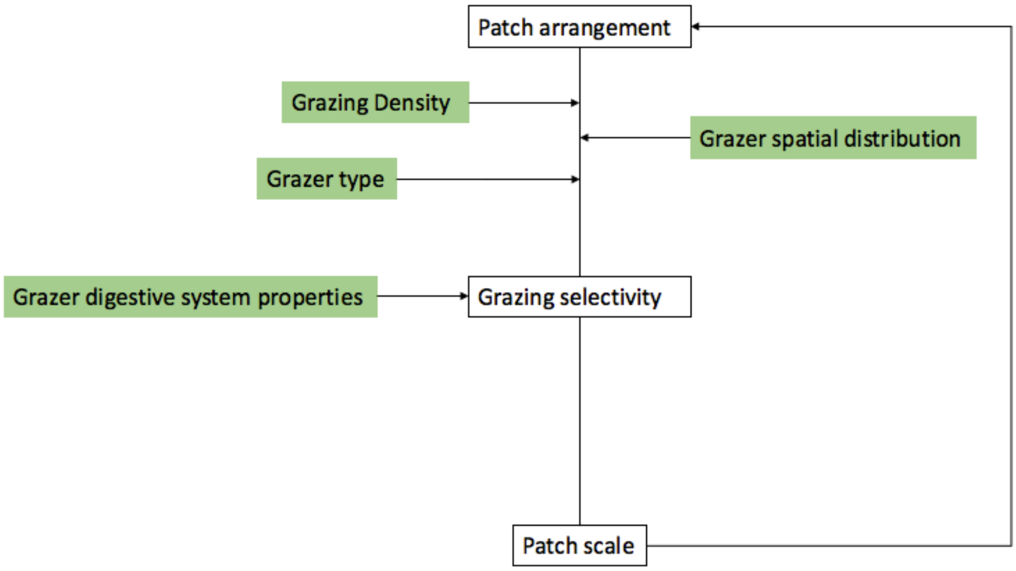


Figure 3.3.1.5.1: Overview of grazing behavioural phenomena. (→ = direct cause-effect; — = reciprocal effect meaning they are affected by each other)

3.3.2 Results

3.3.2.1 Kruskal Wallis Tests

The statistical tests performed on the data gathered from the NFB in order to know how effective are the different grouping variables (Grazing density, Grazer type, Plant Type, and Month) on the plant height have shown some predictable results. In the Kruskal Wallis statistical tests, any significance value that is below 0.05 would mean that there is a significant difference in the dependant variable when there is a change within the independent variable. While any significance value that is greater than 0.05 would mean that there is no significant difference in the dependant variable when there is a change within the independent variable.

Table 3.3.2.1.1: Kruskal Wallis significance test for the different variables that contribute to plant height

Grouping variable	*Plant height (cm) Asymp. Sig.*
Grazing density (head/ha)	.000
Type of Grazer	.000
Plant type	.298
Month	.000

Table 3.3.2.1.1 shows that Grazing density (head/ha) has a significance value of 0.000. This means that the Grazing density does have a very strong effect on height of the plants confirming results found in the literature. Moreover, the type of grazer, whether than is cattle or horses also have a significance value of 0.000. This indicates as well that the type of grazer has a very strong effect on height of plants. The time of the year is also a very important factor that determines also the peak growth of plants as well as the suitability of grazers to be present and as expected it was found to also have a very strong effect on the height of plants by having a significance value of 0.000 (Table 3.3.2.1.1). The type of plants on the other hand had a significance value of 0.298 thus indicating contrary to popular findings in the theoretical that it had very little effect on the height of plants considering that grazer types have certain plant species preferences in their diet especially under lower grazing densities (Table 3.3.2.1.1).

3.3.2.2 Grazing and Plant Height

Plant height is one of the vegetation properties involved in biodiversity conservation and wave attenuation that were found to be influenced by grazing in terms of both density and type of grazer. Results for the relationship between Plant Height and Grazing were extracted from NFB for both Cattle and Horses each at both low (0.5 head/ha) and high (1 head/ha) grazing densities. When observing the average plant height, the smaller in value means that the effect of the variable is greater. The results have shown overall that horses contribute more to decrease in plant height than cattle at both low and high grazing densities with the difference in effects being much more strong during the month of June than later in the year in November.

Table 3.3.2.2.1: Average Plant Height for different plant Species at different months in year 2016 at different grazing types and densities.

Month	*Species*	*LC*	*HC*	*LH*	*HH*
June	*PUC*	8,4	8,8	2,6	1,3
June	*FES*	7,9	6,1	3,0	1,9
June	*AGR*	9,0	5,0	3,1	2,3
Aug	*PUC*	16,8	13,5	7,6	6,5
Aug	*FES*	11,4	10,6	7,9	6,0
Aug	*AGR*	11,9	7,9	9,6	4,0
Nov	*PUC*	17,9	12,9	10,3	7,1
Nov	*FES*	12,1	13,8	11,1	8,0
Nov	*AGR*	15,0	11,9	13,0	5,6

For the month of June, it can be seen overall that horse grazing has a greater effect on plant height on average than cattle grazing at both low and high densities. When looking at both LH and HH across all plant species measured, it can be seen that in both cases average plant height did not exceed 3.1cm making it even lower than even lowest values of HC that is 5.0 cm (Table 3.3.2.2.1; Fig. 3.3.2.2.1).

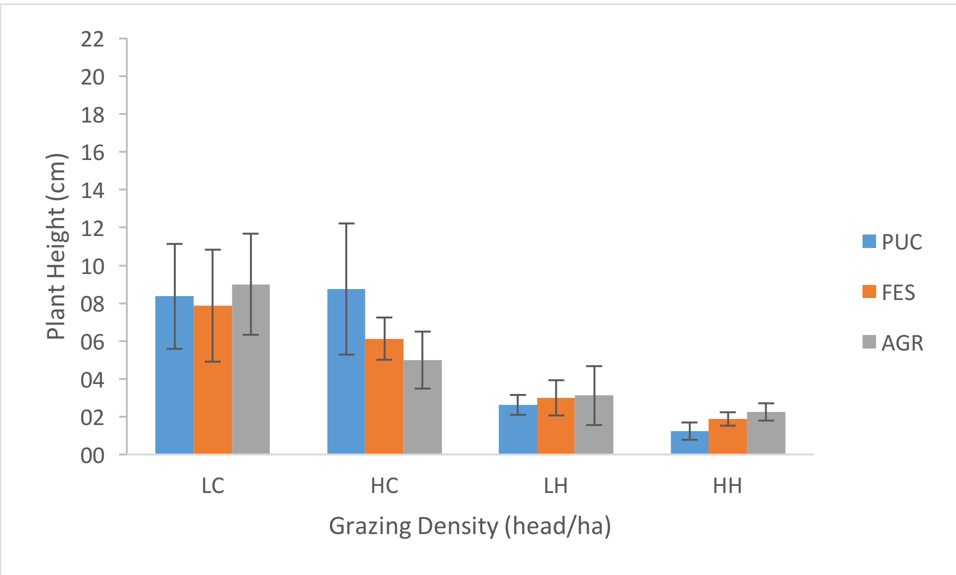


Figure 3.3.2.2.1: Average Plant Height (mean ± S.D.) for June (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing{1 head/ha})

For the month of August, it can also be seen just as in June that overall horse grazing had a greater effect on plant height than LC and HC. The reason being is that also for both LH and HH across all plant species measured, the average plant height did not exceed 9.6cm even though this value is higher than that June possibly due to multiple factors such as seasonal rain or the decrease in appetite of livestock over time of these particular plant types. And while this value exceeded the lowest plant height values HC it failed to exceed the other 6 values. The phenomenon of general plant height increase is also present for LC and HC as the lowest plant height values increased by 2.5cm from June to August while the highest values increased by 7.8cm (Table 3.3.2.2.1; Fig. 3.3.2.2.2).

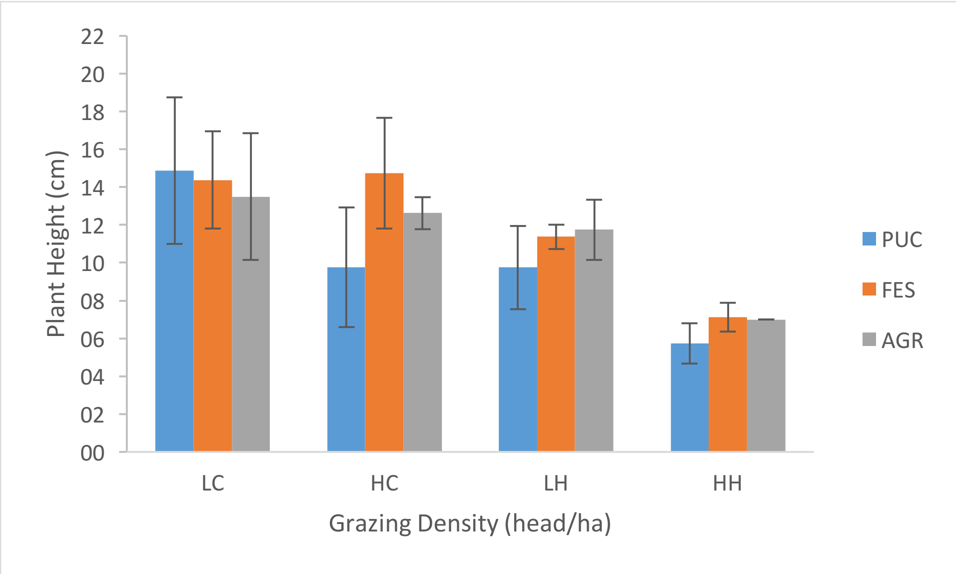


Figure 3.3.2.2.2: Average Plant Height (mean ± S.D.) for August (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing{1 head/ha})

For November, there is a slight shift in the results this time. Plant height in general had not increased as much between August and November as between June and August however, the highest horse grazing value had exceeded 3 of the 6 cattle grazing values one of them being at LC. Nevertheless, the results overall in November show the same conclusions as August and June but with a weaker trend or effect (Table 3.3.2.2.1; Fig. 3.3.2.2.3).

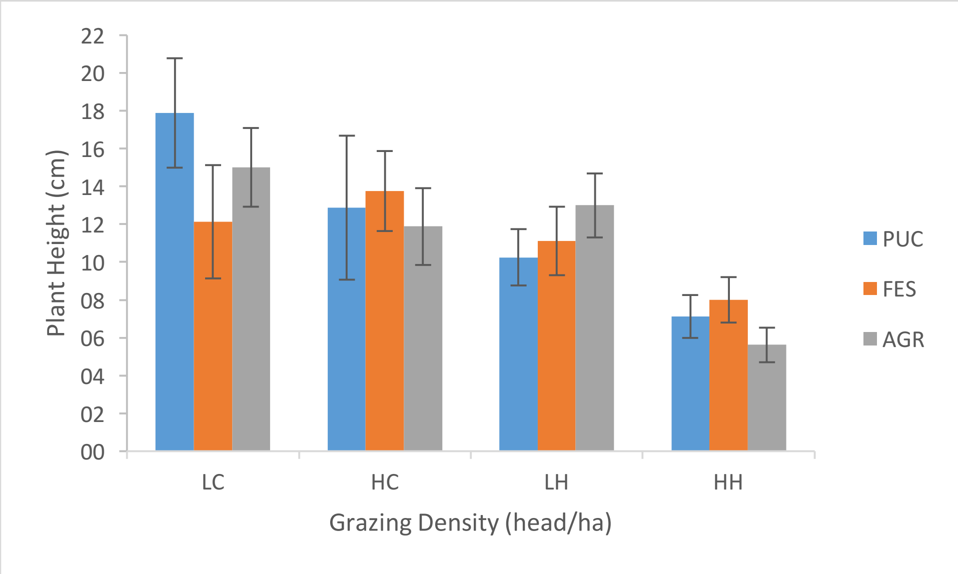


Figure 3.3.2.2.3: Average Plant Height (mean ± S.D.) for November (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing{1 head/ha})

3.3.2.3 Grazing and Structural Heterogeneity (Plant Height Heterogeneity)

Plant height heterogeneity (or Structural heterogeneity) is one of the vegetation properties involved in biodiversity conservation and wave attenuation that were found to be influenced by grazing in terms of both density and type of grazer. Results for the relationship between Structural heterogeneity and Grazing were extracted from NFB for both Cattle and Horses each at both low (0.5 head/ha) and high (1 head/ha) grazing densities. This was done by calculating the variance for all the measured plant species of PUC, FES and AGR at different grazing densities of LC, HC, LH, and HH. The higher the value of the variance meant that structural heterogeneity of plants was also high as it is assumed that heterogeneity refers to alternating mosaics of tall and short vegetation. The results have shown overall that cattle grazing creates more structural heterogeneity than horse grazing at both low and high densities.

Table 3.3.2.3.1: Variance for the plant height for different plant species at different months in year 2016 at different grazing types and densities.

Month	*Species*	*LC*	*HC*	*LH*	*HH*
June	*PUC*	7,7	11,9	0,3	0,2
June	*FES*	8,7	1,3	0,9	0,1
June	*AGR*	7,1	2,3	2,4	0,2
Aug	*PUC*	15,1	10,0	4,8	1,1
Aug	*FES*	6,6	8,6	0,4	0,6
Aug	*AGR*	11,3	0,7	2,6	0,0
Nov	*PUC*	8,4	14,4	2,2	1,3
Nov	*FES*	9,0	4,5	3,3	1,4
Nov	*AGR*	4,3	4,1	2,9	0,8

For the month of June, it can be seen overall that cattle grazing has had a greater effect on structural heterogeneity on average than horse grazing at both low and high densities. This is the case because the values for the variance in plant height are generally higher for cattle grazing than horse grazing overall (Table 3.3.2.3.1; Fig. 3.3.2.3.1).

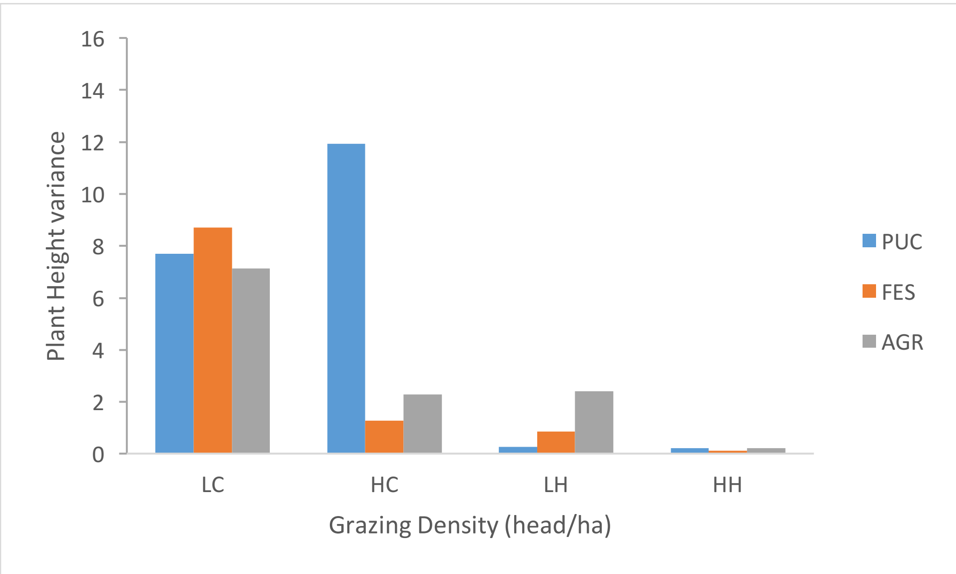


Figure 3.3.2.3.1: Plant height heterogeneity calculated by variance for June (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing {1 head/ha})

For August however, the results are slightly different. Cattle grazing overall still has more effect on structural heterogeneity than horse grazing but the strength of this effect is a bit weaker and values are a bit more even than in June. It can be seen that for LH, AGR values exceed that of those in HC. Moreover, PUC values in both LH and HH exceed AGR values of HC. Nevertheless, on a collective basis, LC and HC have higher variance values than LH and HH (Table 3.3.2.3.1; Fig. 3.3.2.3.2).

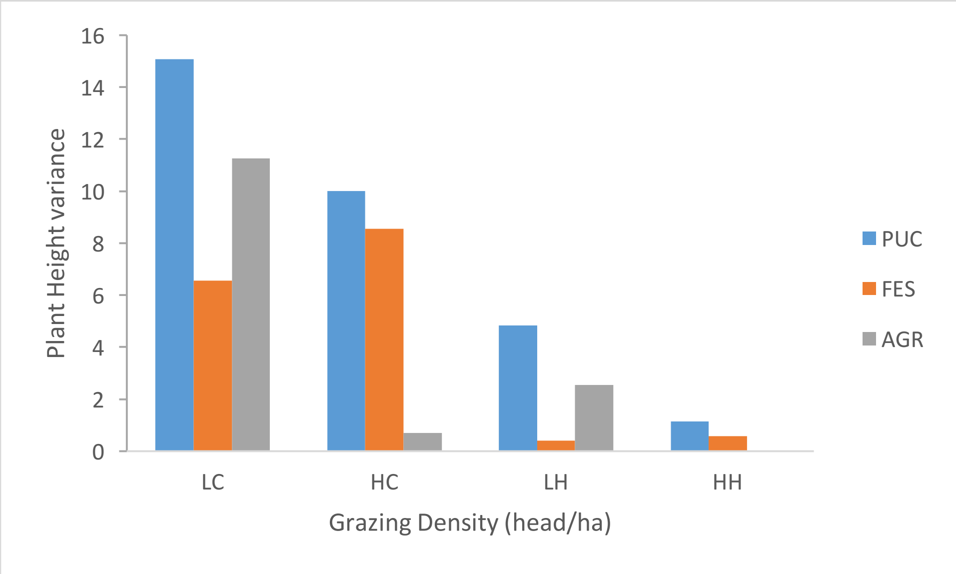


Figure 3.3.2.3.2: Plant height heterogeneity calculated by variance for August (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing {1 head/ha})

For November, we see a general decrease in heterogeneity for all types of grazing density with the exception of PUC at HC. This could be attributed to the fact that plant height mentioned in the previous subsection had increased overall between August and November. The variance had decreased for cattle grazing while it increased for horse grazing with FES and AGR. (Table 3.3.2.3.1; Fig. 3.3.2.3.3).

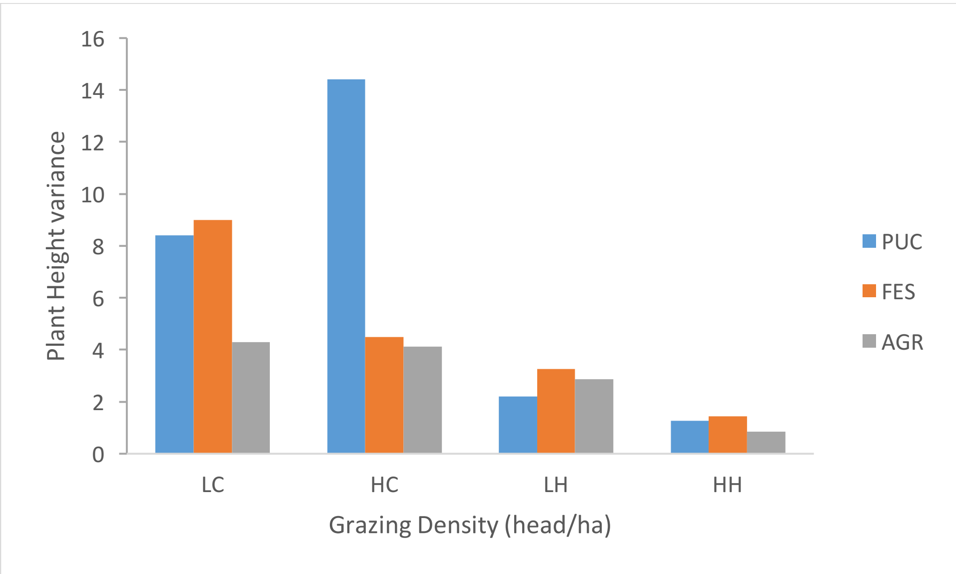


Figure 3.3.2.3.3: Plant height heterogeneity calculated by variance for November (LC = Low density cattle grazing {0.5 head/ha}, HC = High density cattle grazing {1 head/ha}, LH = Low density horse grazing {0.5 head/ha}, HH = High density horse grazing{1 head/ha})

3.3.6 Conclusion

The outcome of these results were that for plant height, horses contributed more to a decrease in plant height than cattle at both low and high grazing densities. For structural heterogeneity, cattle grazing was more effective in creating this phenomenon than horse grazing at both low and high densities but only in times where the rain period and plant growth is low. In addition, statistical tests were performed to test for significance of different grouping variables on plant height. It was found that the type and density of grazer as well as time of the year have a very strong effect on height of plants while the plant type did not have strong effects on plant height.

CHAPTER 4

DISCUSSION

4 Discussion

This thesis aimed to look at the effect of grazing on salt marsh vegetation patterns in relation to coastal safety and biodiversity by exploring three aspects. The first is finding out what are the most important vegetation properties that are associated with wave attenuation, the second is finding out the most important vegetation properties that are associated with biodiversity. And the third is exploring the effect different grazing regimes have on the selected vegetation properties that have the most effect in both wave attenuation and biodiversity. For the first aspect, it was predicted that plant height, plant diameter and plant stiffness would be the most important vegetation properties associated with wave attenuation. For the second aspect, it was predicted that plant height (structural) heterogeneity would be the most important vegetation property associated with biodiversity. And for the third aspect, it was predicted that a reasonable grazing density that is neither high or low accompanied with the use of cattle as a grazer will create the most structurally heterogeneous vegetation while low and high density horse grazing will create the least.

4.1 Back to the hypotheses

The outcome of this thesis had yielded that the most important vegetation properties associated with wave attenuation were the plant density, stiffness, height and size of the marsh. These results partly confirm the hypothesis made in that plant height and stiffness were predicted to be an important property associated with wave attenuation and this has proven to be true. However, the hypothesis was partly falsified as it predicted that plant diameter would be one of the more important vegetation properties associated with wave attenuation while the results from the literature had found that density of the plant was more important as well as the size of the marsh or in other words the size of the patch of structurally taller plants (heterogeneity).

In addition, the thesis had yielded that the most important vegetation properties that were associated with biodiversity were the plant height, plant height (structural) heterogeneity and plant species richness. These results also partly confirmed the hypothesis made in that plant height (structural) heterogeneity were predicted to be an important property associated with biodiversity and this has proven to be true. However, the hypothesis neglected the fact that plant height as well as plant species richness had a role too and hence the results of the literature proving otherwise had falsified the hypothesis in this aspect.

Finally, the thesis had yielded that for plant height, horses contributed more to a decrease in plant height than cattle at both low and high grazing densities while for structural heterogeneity, cattle grazing was more effective in creating this phenomenon than horse grazing at both low and high. These also mostly falsified the hypothesis made for this aspect. The hypothesis claimed that optimal density was the most suitable in creating structurally heterogeneous patterns of vegetation but when looking at the results it is clear that the type of grazer as well as the time of the year were the more determining of suitability to create a structurally heterogeneous vegetation pattern. This is the case despite the fact that in the statistical tests type and density of grazer as well as time of the year had a very strong effect on the height of plants. Moreover, because the previous hypothesis did not take plant height into consideration in the prediction, this hypothesis did not make a prediction on that basis and was left out. Nevertheless, credit should be given for the correct prediction in the type of grazer being the more effective agent creating structurally heterogeneous vegetation patterns. The hypothesis predicted cattle would be more effective and the results have proven this to be the case.

4.2 Comparisons of tested NFB data to findings and literature

The results of the 2016 plant height data and that of the plant height heterogeneity data found in the NFB with regard to different grazing regimes during different times of the year have shown some remarkable comparisons and contrasts to past findings with regard to different grazing regimes.

With regard to plant height, the fact that it was found from the data that horses contribute more to decrease in plant height than cattle at both low and high grazing densities gave two indications. First is that it confirms the findings by de Vlas et al. (2013) that horses caused a shorter average plant height than cattle, however it contradicted the findings by de Vlas et al. (2013) in that they claimed there was a significant difference of plant height in the grazing densities while this was not the case in the results mentioned. The lowest grazing density of horses did not yield higher height of plants than the highest grazing densities of cattle. This is the case despite the fact that the Kruskal-Wallis tests have shown that grazing density did have an effect on plant height. It is important to note that the Kruskal-Wallis tests showed the significance of grazing density on plant height within one grazer type and not between grazer types.

For plant height (structural) heterogeneity, the fact that it was found from the data that cattle grazing was more effective in creating this phenomenon than horse grazing at both low and high densities gave a few indications. These results contradicted a lot of what was mentioned in the past findings. Contrary to the results of the thesis, de Vlas et al. (2013) found that horse grazing created more structurally heterogeneous vegetation than that of cattle. In addition, it contradicted other findings that stated that there was no significant difference between cattle-grazed treatments and horse-grazed treatments and that structural heterogeneity was more affected by grazing density than species (Nolte, 2014). Nevertheless, when it comes to Nolte (2014) there are results that are partly corroborated with the results in the report. This can be observed with the plant heterogeneity results of August and November as there is also less significant difference.

Despite results gathered from NFB yielding contrasting results to what a lot of past findings have reported, they are still considered to be valid and consistent for a variety of reasons. Firstly, it is important to note that Nolte (2014) and de Vlas et al. (2013) gathered their data from multiple other plots aside from NFB and in other countries like Denmark and Germany and as such, the results will yield different conclusions due to the different location factors such as soil type, seasonal variation and elevation but also the temporal factors as global climatic variables change with time. These uncertainties actually solidify the consistency of these results as it further shows how despite the big uncertainties in the conditions that differ between this research and that of de Vlas et al. (2013) and Nolte (2014) there is still a common trend. For example, with regard to the contradictions found in Nolte (2014), it is important to keep in mind that an extended meta-study was conducted that lumped the values across all temporal variables. As such, it is plausible that there was no significant difference in plant height (structural) heterogeneity between types of grazers and it was more significant between grazing densities. If the temporal variables of June, August, and November were lumped together in one value it may have led to the same conclusion as Nolte (2014).

4.3 Unexpected findings

The unexpected findings were found for both plant height and plant height (structural) heterogeneity in isolated cases with specific plant types and at specific points in time. For the June average plant height, values for PUC were higher for HC than LC. This results goes against the natural trend proposed by many past works that at higher grazing densities, naturally average plant height should decrease as there are more grazers available at a limited space of resources. Even the explanation that PUC is less palatable for cattle does not suffice for this anomaly as AGR in LC maintains a higher value (Fig. 3.2.2.1).

Another set of anomalies were also found for the average plant height data for both August and November. The average plant height values for FES was found to be lower in LC than HC grazing regimes during both the months of August and November. Likewise, the results go against the natural trend proposed by many past works that at higher grazing densities, naturally average plant height should decrease as there are more grazers available at a limited space of resources. It seems plausible to assume that perhaps FES as well as PUC may be shorter in plant height during the indicated months as a result of differences in peak growth rates that could be different for other plant species like AGR.

Anomalies were not only found for average plant height data but also for plant height (structural) heterogeneity represented as variance of plant height. For June and November, PUC was found to have a smaller variance in LC than HC grazing regimes. This anomaly goes against most findings that under low grazing densities, structural heterogeneity is more apparent and provides the opposite results. Plausible explanations for this anomaly are inconclusive.

4.4 Limitations

This research did not take several factors into account which may have either further corroborated the hypothesis or further falsified it. For a start, the observation of rotational grazing regimes where there was an alternation between horse, cattle and no grazing at all was neglected. Testing for this factor statistically would have provided a reference and may have led to explanations to some of the existing unexplained findings and given an alternative approach to what is the optimal management strategy.

Moreover, the statistical Kruskal-Wallis tests were performed on very limited samples of data. The value of average plant height recorded was calculated for only 8 individual samples in every case. This raises concern about whether this small sample is representative enough of the whole plot that was selected since it is also not known how the samples were picked in the plots and where they were located. This limitation also affects the results of plant height (structural) heterogeneity of the different grazing regimes. Calculating the variance of plant height for the sampled individuals and using that as an indicator for structural heterogeneity can be an arbitrary approach that only looks at the varieties of lengths of the highest sampled plants and that of the lowest sampled plants not taking into consideration the spatial arrangments that have an effect on wave attenuation despite looking at the structural diversity. Furthermore, calculating a variance of a sample of only 8 individuals makes it even more subject to scepticism of how representative is this variance in reality.

In addition, one of the reasons there were anomalies especially in the later months of August and November is that the seasonal variability was not monitored or at the very least not taken into account. There could have been periods of intense rain that could have had an impact on some plant types over others thus resulting in the anomalies mentioned above. This is especially the case not only for the months that grazing activity were recorded but also the months between them. This is important also as the data that was taken for NFB in 2016 did not indicate if there were any grazing activities that took place between June and August and between August and November that could have had an effect on the plant height and structural heterogeneity results. Based on the overall results however, this seems not to be the case as the height values increased over time, but this is not certain as well as weather conditions were not closely monitored as well.

Finally, it would have been plausible to include more grazer types than just horses and cattle. In the NFB environment it is also possible to explore the grazing behaviour of sheep, geese and bison and see how different they are in comparison to horses and cattle. It could be possible that one of those three are more effective in their grazing strategies and hence provide the optimal conditions that maximize biodiversity and coastal protection goals. This is something that needs further research.

CHAPTER 5

CONCLUSION AND RECCOMENDATIONS

5 Conclusion

Overall this thesis found that the vegetation properties associated most with wave attenuations were the plant height, density and stiffness, while those associated most with biodiversity were plant height also as well plus plant height (structural) heterogeneity and plant species richness. The common properties that were extracted to be studied further were the plant height and structural heterogeneity. On that basis, the results of these studies found that horses contributed more to a decrease in plant height than cattle at both low and high grazing densities. For structural heterogeneity, cattle grazing was more effective in creating this phenomenon than horse grazing at both low and high densities but only in times where the rain period and plant growth is low. Moreover, the Kruskal-Wallis tests showed that the type and density of grazer as well as time of the year have a very strong effect on height of plants while the plant type did not have strong effects on plant height.

The results have partly corroborated the hypothesis made in that plant height and stiffness were predicted to be an important property associated with wave attenuation but was partly falsified when it came to considering plant diameter as one of the most important vegetation properties. The results also partly corroborated the hypothesis stating plant height (structural) heterogeneity were predicted to be an important property associated with biodiversity and this has proven to be true but neglecting plant height as well as plant species richness being major contributors. Moreover, the results falsified the hypothesis that optimal density was the most suitable in creating structurally heterogeneous patterns while in reality type of grazer as well as the time of the year can have more contribution.

Finally, the limitations can be found in the way the research questions were approached as it was the case with this research such as the absence of rotational grazing regime observation, limited data samples, lack of monitoring of weather conditions, and lack of inclusion of more types of grazers.

5.1 Implications

The results and conclusions of this research are important for several reasons. Firstly, they give more insight and opens the door for further research in how to minimize the existence of tradeoffs between nature protection and coastal protection that occur as a result of different grazing regimes under different densities The research had also demonstrated how different types of grazers can cause different effects on the height and structural heterogeneity of vegetation properties. This would in turn have an effect also on species richness of plants, birds and invertebrates as well as the wave attenuating properties of the resulting vegetation patterns. As such, this would encourage more insight for further research into more grazer types and more degrees of grazing densities during more prolonged periods and taking into consideration also the weather conditions. This way it can give us an understanding of what strategies are best taken in order to optimize plant height and structural heterogeneity in such a way that it both attenuates waves effectively and maintains plant biodiversity as well as that of other species that depend on them for shelter and food such as birds, insects and arthropods.

5.2 Recommendations

It is important to point out that many other authors before had offered recommendations based on their own findings and own meta-analyses. de Vlas et al (2013) recommended for example that multiple grazing regimes must be maintained next to each other in space where the use of cattle is predominant. Nolte (2014) recommended that a variation in grazing densities but also grazer types is essential to achieve high structural diversity and its preferable that there is knowledge of the livestock species' behaviour with respect to diet composition, activity and spatial distribution. In addition, Nolte (2014) preferred quantifying grazing intensities as average daily grazing hours/area or average distance travelled daily/ha instead of livestock units/area because animals of different species but similar size could differ in intake requirements. Finally, Davidson (2017) recommended that further research on the mechanisms and context-dependency of livestock impacts is needed.

The recommendations mentioned by the aforementioned authors are all plausible and reasonable. However, these recommendations can be very arbitrary for a variety of reasons. Firstly, in order to make more accurate recommendations, it is important to test as much variables as possible in the same conditions. The problem with making recommendations based on meta-studies like that of Davidson (2017) is that sometimes it is difficult to compare two cases from two different contextual conditions together as it can ignore important differences across the studies (Borenstein et al., 2009).

This is why it is important that more is required to be investigated with regard to the behavioural patterns of the grazers that was studied but also that of other types of grazers that thrive in a similar environment such as sheep and bison. But first, it is important however to acknowledge the context dependency of such phenomena and that the relationship explored in this environmental context might not necessarily be equivalent to that of other environmental contexts. This is why when undergoing grazing experiments that have to do with nature and wave attenuated properties it is important to have careful monitoring of weather conditions as well as other parameters that should be more carefully controlled like the grazing durations. The next step after that would be to start exploring the relationship between the produced vegetation patterns and the suggested type of grazers with respected density levels of low, moderate and high. This relationship would serve to explore how it affects biodiversity as well as wave attenuation. The results of which can be used to make an equation or a set of equations. These equations can be integrated to create a model that takes into consideration grazing behaviour, plant species richness, structural heterogeneity as well as parameter for bird and insect populations in addition to soil type and existing plant species in the selected niche. Such a model can be used to make a more plausible and optimized policy driven context dependant strategy that can be made for each coastal area to maximize both nature and coastal protection goals without compromising one at the expense of the other.

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APPENDIX

Appendix

Table 6.1: Normality Test for plant height data using Shapiro-Wilk test

Grouping Variable	*Plant Height*	*Shapiro-Wilk Sig.*
Month	*June*	.000
	August	.000
	November	.056
Plant Type	*PUC*	.007
	AGR	.001
	FES	.025
*Type of Grazer *lower bound of the true significance*	*Cattle*	.105
	Horses	.000
Grazing Density (head/ha)	*Low (0.5)*	.012
	High (1)	.000

Table 6.2: Transformation results of normalized plant height data

Grouping Variable	*Log Plant Height*	*Shapiro-Wilk Sig.*
Month	*June*	.000
	August	.027
	November	.005
Plant Type	*PUC*	.000
	AGR	.000
	FES	.000
Type of Grazer	*Cattle*	.000
	Horses	.000
Grazing Density (head/ha)	*Low (0.5)*	.000
	High (1)	.000