Indicator factors demonstrating the current transition between a salt and a fresh water ecosystem

Related biotic and abiotic indicator factors demonstrating the current transition from a fresh to a salt water ecosystem in the sub-areas of Hallumer-Ryt

Ella Bijkerk

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Preface

Before you lies the Final Thesis Report "Indicator factors demonstrating the current transition between a salt and a fresh water ecosystem", containing a research conducted in the saltmarsh of Hallumer-Ryt in Friesland, The Netherlands. This report is written as a result of the graduation assignment for the course Water Management. Independent research was conducted including executing field work and writing this report from March to July 2017.

The project was undertaken at the request of Jeroen Huisman, researcher at Van Hal Larenstein (VHL). This research was part of Wad'n Kennis, a long-term project. This project involves several parties, including Wetterskip Fryslân, It Fryske Gea, Altenburg & Wymenga, Vissers van de Kust, Program for a rich Wadden Sea, HZ University of Applied Sciences and Van Hall Larenstein.

The research question was formulated with the help of Geert Truijen, Astrid Valent. The research was challenging, but conducting extensive analysis has allowed me to answer the question that was identified. Fortunately, both Jeroen Huisman and my tutors from VHL were always available and willing to answer my questions. I would like to thank my supervisors for their guidance and support during this process.

The research was completed with collaboration of various parties. To Tristan da Graça and Marieke Krikke: I would like to thank you for making me acquainted to the research area. Japke van Assen, thank you for the additional bird monitoring in Hallumer-Ryt. Sandra and Ruth, thank you for identifying the phytoplankton samples. Henry Kuipers, thank you for the help with the statistical analysis. Furthermore, I would like to thank Jaap Vegter of Vissers van de Kust for making field operations possible on the tidal flats and It Fryske Gea for allowing access to the saltmarsh during breeding season.

And last, but definitely not least, I would like to thank my partner Tjitsen de Jong for the amazing collaboration during the execution of the project. Together, we managed to persevere as well as face every challenge that was thrown our way.

Enjoy reading,

Ella Bijkerk

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Summary

The Wadden Sea is the largest tidal area in the world and is of mayor importance in the sectors ecology, economy and culture. It was therefore added to UNESCO World Heritage Site in 2009. Hallumer-Ryt is an area in The Wadden Sea which is characterised by a saltmarsh. This habitat is considered to be a wetland type with a transitional character and has dynamic interactions between adjacent habitats in a natural state. A large spatial barrier is present in the landscape, in form of a dyke. This barrier is a factor which contributes to the reduction of the ecological potential of the saltmarsh and it adjacent habitats; the tidal flats and an inland area behind the dyke. A mayor consequence of the distinctive border between the saltmarsh and the inland area the appearance of hard boundaries between the previous gradual transition from a salt water to a fresh water ecosystem. In 2018, a pumping station and a fish ladder will be constructed in Hallumer-Ryt that may mitigate the transition between these ecosystems.

The goal of this research is to determine the current transition from a fresh water to a salt water ecosystem in Hallumer-Ryt. This is a necessary step before an assessment of ecological improvement can be made after the construction. Relations between the areas through biotic and abiotic indicator factors were researched in order to obtain knowledge on the current transition between the sub-areas: the tidal flats, saltmarshes and the inland area.

Biotic as well as abiotic factors were designated by literature and were studied in field and analysed subsequently. Fish and bird species distribution as well as physical parameters such as salinity, pH, oxygen temperature of surface water were key factors in this research. Other factors such as phytoplankton, benthos and chemical parameters were also included but not prioritised in the field operations and analysis. The distribution of the fish species was monitored using fish traps as well as fishing nets. Bird species, their location and their behaviour were monitored of four target species. Physical parameters were measured using the Hanna HI 9829 Multiparameter. The collected biotic data was analysed using Chi-Square Tests in IBM SPSS in order to find significant relations between factors and the sub-areas. This was done for abiotic data as well using One-way ANOVA Tests. Significance between a factor and the sub-areas is demonstrated when $p = <0.050$. The Jaccard Similarity Index was used on biotic factors in order to indicate the degree similarity between sub-areas. Finally, biotic and abiotic indicator factors were combined and analysed using the Chi-Square Test in order to find related indicator factors that are able to demonstrate the current transition from fresh to a salt water ecosystem between the sub-areas of Hallumer-Ryt.

Multiple biotic and abiotic factors were found to be indicators. Biotic factor such as species distribution of fish, birds, and benthos were found to be good indicators because they were found with a $p = 0.00$, which demonstrates a significant relation between the indicator factors and sub-areas of Hallumer-Ryt. The abiotic factors salinity, pH and surface water temperature were also found to be significant with a $p = 0.00$ according to the Oneway ANOVA Tests. Salinity and the distribution of fish species showed to have a direct relation because of the small variations in the sub-areas itself. pH and surface water temperature against the distribution of fish species showed a $p = 0.00$ in the Chi-Square Tests. These are all related indicator factors able to demonstrate the current transition from fresh to a salt water ecosystem between the sub-areas of Hallumer-Ryt.

Samenvatting

De Waddenzee het grootste getijdengebied ter wereld is en is van groot belang voor de ecologische, economische en culturele sector. Het gebied is daarom in 2009 aan het UNESCO World Heritage Site toegevoegd. Het Hallumer-Ryt is een gebied in het waddengebied, dat wordt gekenmerkt door kwelders. Deze habitat wordt beschouwd als een wetland-type met een tijdelijk karakter en in een natuurlijke staat dynamische interacties heeft tussen aangrenzende habitats. Een grote ruimtelijke barrière is aanwezig in het landschap, in de vorm van een dijk. Deze barrière is een factor die bijdraagt tot de vermindering van het ecologische potentieel van de kwelder en de aangrenzende habitats, het wad en het binnenland achter de dijk. Een gevolg van de burgemeester van de kenmerkende grens tussen de zoutmoerassen en het binnenland de verschijning van harde grenzen tussen de vorige geleidelijke overgang van een zout water naar een ecosysteem van zoet water. In 2018 zal er een gemaal en een vispassage worden gebouwd in het Hallumer-Ryt, dat de overgang tussen deze ecosystemen kan verzachten.

Het doel van dit onderzoek is het bepalen van de huidige overgang in het ecosysteem van het Hallumer-Ryt. Dit is een noodzakelijke stap, voordat een ecologische verbetering kan worden beoordeeld na de bouw. De relatie tussen de gebieden werden onderzocht door zowel biotische als abiotische indicatie factoren te meten met het oog op de kennis over de huidige overgang tussen de deelgebieden: het wad, de kwelder en het binnendijkse gebied.

Biotische en abiotische factoren waren gekozen door middel van literatuur, in het veld bestudeerd en vervolgens geanalyseerd. Distributie van vis en vogelsoorten evenals fysieke parameters zoals zoutgehalte, pH, zuurstof en temperatuur van oppervlaktewater waren de belangrijkste factoren in dit onderzoek. Andere factoren, zoals fytoplankton, benthos en chemische parameters, werden ook opgenomen, maar geen prioriteit gegeven in het veldwerk en analyse. De verdeling van de vissoorten werd gecontroleerd met behulp van fuiken en visnetten. De vogel soorten, hun vindplaats en hun gedrag werden gecontroleerd van vier doelsoorten. Fysieke parameters werden gemeten met behulp van de Hanna HI 9829 Multiparameter. De verzamelde gegevens van biotische factoren werden geanalyseerd met behulp van Chi-kwadraat Tests in IBM SPSS om van relaties tussen de factoren en de deelgebieden te vinden. Dit werd ook gedaan voor de abiotische gegevens met behulp van One-way ANOVA Test. Significantie tussen een factor en de deelgebieden werd aangetoond met $p = < 0.050$. De Jaccard Similarity Index werd gebruikt voor biotische factoren om de mate van gelijkenis tussen de deelgebieden aan te tonen. Ten slotte werden de biotische en abiotische indicatie factoren samengevoegd en geanalyseerd met behulp van de Chi-kwadraat-Test om gerelateerde indicatie factoren te vinden die de huidige overgang van een zoetwaterecosysteem naar een zoutwaterecosysteem tussen de deelgebieden van Hallumer-Ryt kunnen aantonen.

Meerdere biotische en abiotische factoren bleken geschikt te zijn als indicatoren. Biotische factor zoals de verdeling van de soorten van vissen, vogels, en benthos bleken goede indicatoren te zijn omdat ze een $p = 0{,}00$ scoorde, waaruit een significante relatie tussen de indicator factoren en deelgebieden van de Hallumer-Ryt blijkt. De abiotische factoren, zoutgehalte, pH en temperatuur van het oppervlaktewater bleken ook significant te zijn met een $p = 0{,}00$ score volgens Oneway ANOVA-Tests. Het zoutgehalte van het water en de distributie van vissoorten schijnt een directe relatie te hebben vanwege de kleine variaties in de deelgebieden zelf. De pH en temperatuur van het oppervlaktewater tegen de verspreiding van vissoorten toonde een $p = 0{,}00$ bij de tests van de Chi-kwadraat. Dit zijn allemaal gerelateerde indicatie factoren die de huidige overgang van een zoetwaterecosysteem naar een zoutwaterecosysteem tussen de deelgebieden van Hallumer-Ryt kunnen aantonen.

Contents

1. Introduction

1.1. Background and Motive

The Wadden Sea is largest tidal area in the world. It covers an area of 50.000 hectares and extends from Den Helder to the Danish peninsula Skallingen. It attracts 10 to 12 million migrating birds every year and it functions as an aquatic nursery in the reproduction system for fish from the North Sea (Reise, et al., 2010). The Wadden Sea is also an important area in the sectors economy and culture trough the tourism and fishing industry. For these reasons, the Dutch and German Wadden Sea was declared a UNESCO World Heritage Site in 2009. The Danish part was added in 2014 (UNESCO, 2017).

The Wadden Sea area is dependent on dynamic conditions, but is under pressure through active anthropogenic management for centuries. Examples are; habitat destruction though sand extraction, fisheries and beach replenishment as well as fragmentation through land reclamation, construction of dykes and separation from inland waters such as the Zuiderzee. These factors have contributed to reduction of the total ecological potential in the area. Other factors that put the area under pressure are increased water temperature, invasive alien species, increased predation, etc. (Walkers, 2015). The current Wadden Sea is estimated to be but a half of its original ecological potential when in a natural state (van Leeuwen, Bogaardt, & Wortelboer, 2008). Since the eighties a decline is present in fish stocks, particularly in marine juveniles of species such as European plaice (*Pleuronectes platessa*), common dab (*Limanda limanda*) and Atlantic cod (*Gadus morhua*) (Waddenvereniging, 2015). More than half of the 83 marine Natura 2000 species and habitats that are protected in the Netherlands have a poor or even a very unfavourable conservation (van Leeuwen, Bogaardt, & Wortelboer, 2008). Furthermore, the migratory birds are declining as well. From the 34 studied wader species 19 species were found to have increasing or stable numbers. Especially birds that eat shellfish, such as the Eurasian oystercatcher *(Haematopus ostralegus)*, common eider (*Somateria mollissima*) and spotted redshank (*Tringa erythropus*) are decreasing in numbers (Laursen, et al., 2009).

Currently, the Dutch, German and Danish authorities are collaborating through management of the Wadden Sea in order to preserve its cultural, economic and ecological value (CWSS, 1998 - 2013). The Netherlands is supporting projects to link the Wadden Sea with isolated water bodies (Common Wadden Sea Secretariat , 2012). These projects are executed in the Fish migration River Dam, the IJsselmeer, Holwerd aan Zee, Dokkumer Ee and Frisian lakes. Furthermore fish ladders at ground by rivers and canals are built in the inland landscape. These fish ladders are expected to contribute to a more gradual transition from a salt water ecosystem in the Wadden Seas to a fresh water ecosystem in the inland areas.

In this research the focus lies on an area in the Wadden Sea which is under pressure from one of the mentioned factors that contribute to the reduction of the ecological potential. Trough human intervention, a large spatial barrier is present in the landscape of Uytland, Northwest Fryslân, near the village Hallum, in the form of a dyke. This area is also known as Noarderleech or, how this area will be addressed in this report, Hallumer-Ryt. The research area Hallumer-Ryt is divided into three sub-areas: the tidal flats, a saltmarsh and an area behind the dyke also mentioned as the inland area (see Figure 1). The inland area is sparsely populated and is primarily used for agriculture. The water in this area is managed by ditches to create the right conditions for agriculture. The saltmarshes are part of the nature area Noard-Fryslân Bûtendyks. It stretches from Zwarte Haan to the pier of Holwerd and is managed by It Fryske Gea (It Fryske Gea, 2007). It is characterized by 'dobbes', puddles in the area on higher ground, and reclaimed land. Three tidal channels run through the saltmarshes to the tidal flats. It is an ideal resting place for all kind of bird species because of the vastness, peace and wide range of habitats. Cattle are grazing on the dyke and the fields. The tidal flats are part of the bigger Wadden Sea. The sub-areas do not have a gradual transition.

The dyke is a distinctive border between the saltmarsh and the inland area. This causes diadromous fish of the Waddenzee to be separated from domestic waters of Fryslân. Another consequence was the appearance of hard boundaries between the previous gradual transition from a salt water to a fresh water ecosystem. In 2018, a pumping station and a fish ladder will be constructed in the Hallumer-Ryt that may mitigate the transition between these ecosystems (Kommerie, 2017).

1.2. Problem Definition

A new pumping station and a fish ladder are scheduled for construction in the research area Hallumer-Ryt, which is planned in 2018. These are being constructed with the aim to restore the natural transition between salt and fresh water ecosystems of Northeast Friesland. The construction will pump fresh water into the tidal flats and will create a small estuary. Besides the pumping station a fish ladder will also be build which allows diadromous fish to travel from salt water to fresh water. These new conditions are expected to have a favourable effect on the ecology in the saltmarshes. Some parts of the ecosystem which are expected to be affected positively by these conditions are the distribution of fish through fish migration, the distribution of breeding birds and the water quality (Wetterskip Fryslân, 2017). Other parts of the ecosystem which were monitored before and might give an indication of a degree of change in the research area Hallumer-Ryt are phytoplankton, benthos as well as physical and chemical parameters (Da Graca & Huisman, 2014) (Keukens & Johan, 2017).

A determination of the current state of transition between a salt and fresh water ecosystem ought to be made before an assessment of ecological improvement of the Hallumer-Ryt can be made in the future. An assessment of this state has to be completed before the construction of the pumping station with fish ladder. Currently, little is known of the current state of biotic and abiotic factors that could be possible indicators to demonstrate current transition between the tidal flats of the Wadden Sea, the saltmarsh and the inland area. Some possible biotic and abiotic factors like fish, birds, benthos and chemical parameters were monitored before by Da Graca & Huisman (2014) and Keukens and Johan (2017). However, the amount of available data is insufficient in order to designate factors for the demonstration of the current state of transition between a salt and fresh water ecosystem.

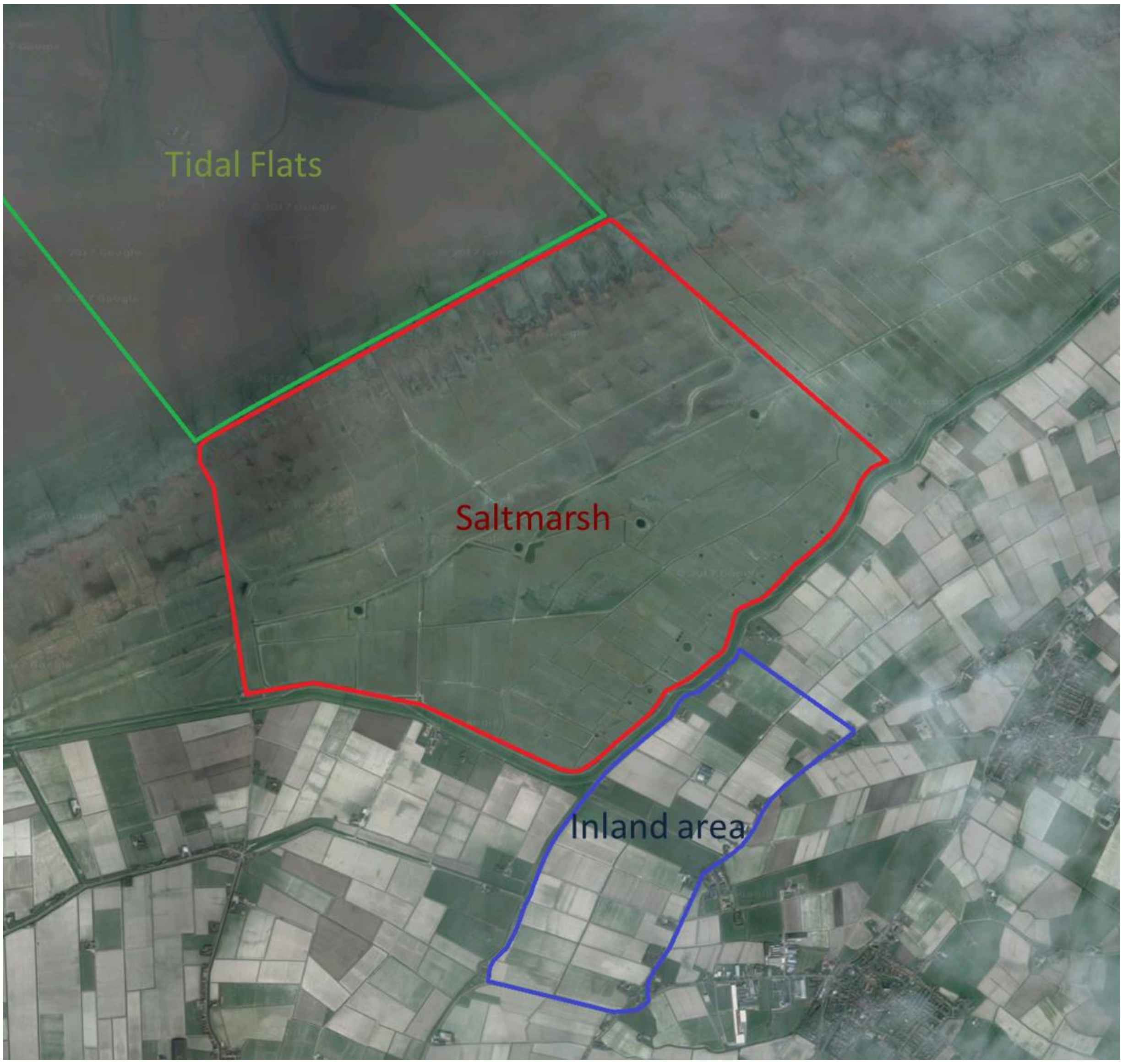

Figure 1: The layout of the sub-areas in Hallumer-Ryt.

This means a knowledge gap exists in the information that shows the transition between a salt and fresh water ecosystem in Hallumer-Ryt. Furthermore, there is no method to assess the ecological connection between the three sub-areas yet. Relations between the areas through biotic and abiotic indicator factors must be found in order to obtain knowledge on the current transition. This information is needed in order for a future estimation if an improvement in the ecosystem of the Hallumer-Ryt has occurred through construction of said pumping station with fish ladder. Research has to be done on biotic as well as abiotic factors to designate suitable factors for demonstrating a transition between research areas.

1.3. Objectives

There are no methods to determine the current transition in the ecosystem of the Hallumer-Ryt at the moment. Nor is there any regulation to measure a spatial relationship between a salt and fresh water environment through indicator factors such as fish species or salinity.

A determination of biotic and abiotic factors that demonstrate the current transition between the salt and fresh water ecosystem must be researched in order to assess the current transition of the sub-areas: the tidal flats, saltmarshes and the inland area in Hallumer-Ryt. Therefore, previous research on indicators for transition between salt and fresh water indicators is used in order to find proper factors which can be assessed in field. This literature research will aid the designation of suitable factors. Data of these biotic and abiotic factors is collected data through fieldwork. The data is then analysed in order to find related biotic and abiotic indicator factors. A factor is considered an indicator if they were analysed to have significant relation with the sub-areas of Hallumer-Ryt.

1.4. Research Question

The following research question was addressed during the course of the research work in order to find a solution for the stated problem:

Which related biotic and abiotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the transition from fresh to a salt water ecosystem?

This research question will be answered by answering the following sub-questions:

1a. Which biotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the current transition from fresh to a salt water ecosystem?

1b. Which abiotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the current transition from fresh to a salt water ecosystem?

2. Which found biotic abiotic indicator factors are related in order to demonstrate the current transition from fresh to a salt water ecosystem in Hallumer-Ryt?

1.5. Hypotheses

Physical parameters such as salinity as well as pH and oxygen are expected demonstrate a transition between the sub-areas in Hallumer-Ryt. The transition between the tidal flats and saltmarsh might be more gradual than the transition between the saltmarsh and the inland area. The gradual transition between the tidal flats and saltmarsh are caused by the tides which occur twice a day in the saltmarsh. Salt water is mixed with more brackish water in the gullies of the saltmarsh causing a gradual transition of abiotic factors between the areas. The hard transition between the saltmarsh and inland areas is caused by the presence of a dyke which prevents salt or brackish water from flowing into the ditches of the inland area.

This applies to biotic factors in the same way. Factors such as fish, birds as well as phytoplankton, benthos and chemical parameters may be indictors for demonstrating a transition between the sub areas in Hallumer-Ryt. Salt and fresh water fish species as well as diadromous fish may be factors to demonstrate a gradual transition between the tidal flats and saltmarsh. They could demonstrate the hard transition between the saltmarsh and inland area in a similar fashion. Bird species that feed on specific salt and fresh water species might also indicate the location of the ecosystems. Specific species found in the benthos and the phytoplankton found in the gullies may also be representative for the transition between a salt and fresh water ecosystem. Differences between chemical parameters between the ecosystems may demonstrate this as well.

Relations between biotic and abiotic indicator factors give a stronger picture of the current transition between salt and fresh water ecosystems as a whole. The salinity, pH and oxygen of the surface water can be linked to salt and fresh water fish species and show the niches of their ecosystem with the aid of these parameters. This can also be applied to the present phytoplankton and benthos in Hallumer-Ryt. Finally, bird species may have an indirect link with these abiotic indicators through their diet. If abiotic parameters and fish species are related in the shift from a salt to a fresh water ecosystem, links may also be made with the presence of certain bird species.

1.6. Boundaries and Conditions

Data collection of the biotic and abiotic factors in Hallumer-Ryt will be done in a timeframe of less than two months, starting from end of March to the first half of May. Because of this limited time, collecting data will only be done for biotic and abiotic indicator factors suitable for monitoring according to literature.

The focus of this study lies mainly on birds and fish, which are both biotic factors and physical parameters, which is an abiotic factor. These factors may be representative to obtain a degree of connection of the present biodiversity. Other factors such as phytoplankton, benthos and chemical parameters will be assessed in more detail and will be used for additional analysis if time permits. Four bird species will be monitored as indicator species and found diadromous fish will be examined. This means that not the total number of found species in Hallumer-Ryt will be assessed separately.

Field work on the tidal flats is executed once with aid of the partner 'Visser van de Kust', an integrated Fishery cooperation that strives for an active participation in projects of managements and research. An excursion of a few days is planned on the 11 and 12th of May to aid the fishers. This means that collected data from the tidal flats will be supplied with literature studies or information provided by partner organizations.

2. Theoretical Framework

2.1. Saltmarshes

2.1.1. Development of Saltmarshes

A saltmarsh is a type of wetland located in coastal areas. These particular kinds of wetlands are influenced by salt water brought in by the tides. The ideal conditions for the formation of the salt marches are a gently sloping shoreline with small wave energy and a sediment supply of sufficient size (Dijkema, 1983). The present size of the total area of saltmarshes in the north of the Netherlands (The Wadden Sea) is 7,300 ha; with a pioneer zone of 1,900 ha (Dijkema, Bossinade, Bouwsema, & De Glopper, 1990).

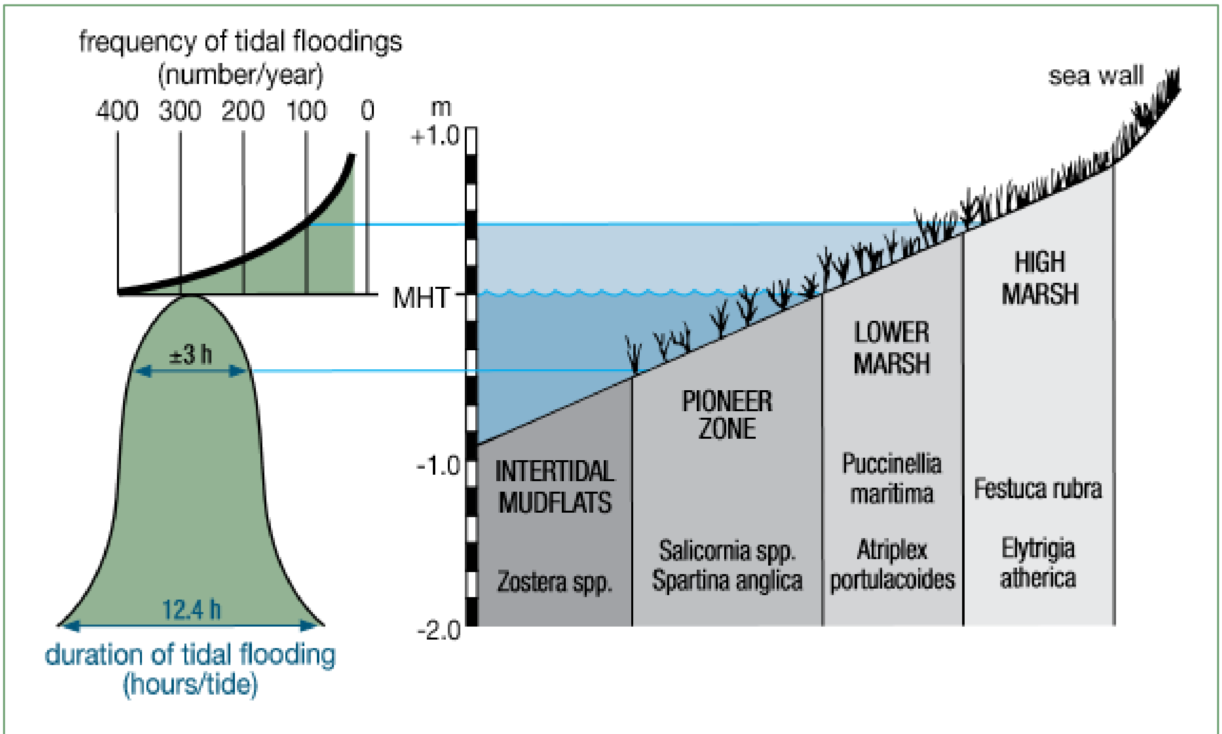

Figure 2: Schematic structure of a saltmarsh with vegetation zones in relation to inundation duration and inundation frequency

Natural saltmarshes are subdivided into three different zones, shown in Figure 2. Natural saltmarsh formation occurs if a mud or sand flat raises trough vertical accretion (It Fryske Gea, 2007). Primary plants, also known as pioneer plants, will start to colonise the pioneer zone which lies just below the mean high water level. This is caused by the mud flat being submerged by salt water twice a day through tidal influences. The second zone lies just above the mean high water level and is not submerged with every tidal cycle (Bakker, 2014). Further growth of the salt march results into a higher situated surface and is only flooded during storm tides. In natural estuaries, formation of saltmarshes is a cyclic process (Nienhuis & Gulati, 2013). The wetland silts up and erodes again after a certain height is reached. When erosion has occurred, the saltmarsh builds up again and the cycle repeats.

However, due to continuous embankments of saltmarshes in the Netherland a halt of salt march formation has occurred, and the present salt-marsh area is relatively small with respect to the tidal basins (Bakker, Esselink, Dijkema, van Duin, & de Jong, 2002). The saltmarshes along the northern coast were altered for the land reclamation and are still being sustained trough the maintained of the network of brushwood groynes, which enhances sedimentation and prevents salt-marsh erosion. They are characterised by their even manner in which drainage is distributed and their flat topography. Therefore, these areas contain less abiotic variation than back-barrier and estuarine saltmarshes in south west of the Netherlands.

2.1.2. Saltmarsh types in the Netherlands

Three main types of saltmarshes are distinguished in the Netherlands (Beeftink, 1977) (Westhoff, 1985). First, the sandy back-barrier marshes which are mainly found on the Wadden Sea islands. Second, the clayey estuarine saltmarshes, found in in the south west of the Netherlands. Third, the clayey artificial mainland saltmarshes which were developed from sedimentation works. These saltmarshes can mainly be found along the coasts of Groningen and Friesland. These saltmarshes in these areas, also known as the Wadden Sea, make up about 20% of the total area of saltmarshes along the European Atlantic and Baltic coasts (Esselink, et al., 2009).

2.1.3. Importance of Saltmarshes

Saltmarshes can be indicated as a type of wetland where fresh and salt water mix. Therefore they are an important transitional habitat between the ocean and land. Saltmarsh plants, also known as halophytes, are salt tolerant and are adapted to fluctuating water level brought on by the tides (Environmental Services, 2004). One of the common features in a saltmarsh is the zonation of different plant species in parallel zones with the elevation or distance from the sea (Beeftink, 1977), which means that some plant species may only thrive in specific habitat types. Many salt-marsh plant species and their associated plant communities are considered rare or even vulnerable to extinction, because the area between land and sea is proven to be narrow (Doody, Johnston, & Smith, 1993).

The vegetation found in salt marches is able to support a wide variety of animals of which many are found only in saline habitats (Doody, 1992; Adam, 1990). Not only bird species are dependent on saltmarshes, the decaying plants and microbes are an important food source for juvenile fish and crustaceans (Environmental Services, 2004). In short, saltmarshes are important for estuarine food chains and provide primary productivity and a support resource for estuarine food webs (Cappo, Alongi, Williams, & Duke, 1995).

Saltmarshes are also important as a natural flood control. They can mitigate flood damage as well as filter excess nutrients from surface runoff before this reaches the sea (EPA, 2016). Estimations were made by King & Lester (1995) for the amount of protection that salt marches can offer. They estimated that a six meter wide saltmarsh in front of a six meter high dyke would offer as much protection as a seawall of twelve meters high. This means that maintaining a saltmarsh in front of coastal structures would mean great economic advantages since building and maintaining structures to protect the inland areas are expensive (Wolters, 2006).

Finally, saltmarshes provide other ecosystem services such as services in the economic sector. They are used as grazing plots for cattle stock and their filtering provision, which lowers the cost for water treatment needed in certain areas. Other services are the ascetics and the recreation the saltmarshes provides as well as their contribution to intellectual wealth (Dale, Knight, Breitfuss, Radke, & Rogers, 2015). However, it is a challenge to assess the value of these services as they cannot be quantified.

2.2. Biodiversity in Saltmarshes

Saltmarshes provide habitat for a wide range of organisms. It is estimated that from 1,068 plant species that are found in the coastal habitats of Europe, around 200 species are solely found in saltmarsh habitat (van der Maarel & van der Maarel-Versluys, 1996). The area mostly vegetated by herbs, grasses or low shrubs.

Furthermore, saltmarshes are seen as important for a large number of migratory birds and aquatic birds, since they depend on these habitats for food, nesting and roosting sites (Dierschke & Bairlein, 2004). The area is used as a resting area as well as a breeding and feeding ground. The saltmarsh provide resting grounds for migratory birds such as the Brent goose (*Branta bernicla*) and barnacle goose (*B. leucopsis*), in order for them to reach their northern breeding grounds (Madsen, Cracknell, & Fox., 1999). Residents of the coastal area include waders which feed on the intertidal flats and use them as resting place during high tide (Koffijberg, et al., 2003).

The highest species diversity in saltmarshes is found among the invertebrate fauna. A considerable number of species found are restricted to this habitat and a total of around 1,500 arthropod species inhabit saltmarshes (Heydemann, 1981). Although a high number of species found are in saltmarshes, only a few numbers of resident species are able to spend their whole life cycle is the same area.

Fewer vertebrates are found to reside in saltmarshes but a relative high number of arthropods can be found in this area. The first contains mostly transient species, which means these species colonise these transition habitats temporarily, either during migrations or during a key period of their life cycle as migration stops, resting or feeding periods (Kneib, 1997). Most species come from adjacent terrestrial or aquatic environments. Time and space causes variation in the resulting specific richness of and transients. Especially when under influence from the seasons and tidal flooding. For some aquatic animals, and mainly for fish, the colonisation of the marshes is only possible during very short temporal windows, which correspond to flooding period (Laffaille, Feunteun, & Lefeuvre, 2000).

2.3. Saltmarsh Restoration

Sedimentation deficits were created due to the embankment of salt marches by summer dykes. These summer polders cover around 1,200 ha in the north of the Netherlands. By creating continuous embankments, the current saltmarsh area is relatively small in comparison to their adjacent fresh and salt water basins, the inland area and the Wadden Sea. The embankment also transforms communities in the saltmarsh from halophytic to glycophytic (Bakker, Esselink, Dijkema, van Duin, & de Jong, 2002).

The saltmarshes in the Netherlands are part of the area designated to have high values for fisheries, recreational and economical topics as well as conservational values. For these reasons The Netherlands, Denmark and Germany have been working together in order to restore and protect the Wadden Sea since 1978 (CWSS, 1998 - 2013). Current thoughts of restoration include the acceptance that grazing pressure and drainage need to be decreased in salt marches. The cultural value as well as the landscape is recognised to be an important asset in those areas. The saltmarshes will still contribute to flood control, although the primary aim is to conserve the current habitat (Alhorn & Kunz, 2002). The overall aim is to maintain and extent the area and enhance the natural development.

However, in reality these measures may not be enough because the embankment through dykes as well as summer dykes prevents the dynamic and natural development of intertidal habitats (Doody, 2007). More radical approaches in future prospects might be needed in addition to restoration and creating other forms of 'soft' sea defences. Approaches could include creating areas for floodwater storage or even moving structures such harbours offshore or raising houses above high tide sea levels (Reise K. , 2005).

2.4. Indicator Factors for Transitional Tidal Ecosystems

Saltmarshes are considered to be a wetland type with a transitional character because of their dynamic interactions between adjacent habitats, for example tidal flats or terrestrial habitats (Fulfrost, Marriot, Sloop, Thomson, & Valoppi, 2015). These interactions include estuarine to terrestrial processes and the other way around. Because these processes are dynamic, saltmarshes are dynamic habitats that can vary more than their adjacent habitat. These processes are a physical combination of soils, waters, and organisms, as well as combined processes that result from their interactions.

Wasson, Woolfolk, & Fresquez (2013) found that ecotones, the narrow transition zones between extensive ecological systems, may serve as sensitive indicators of climate change because they harbour species that are often near the limit of their physical and competitive tolerances. The ten year study shows that the higher marsh ecotones migrated rapidly in response to environmental change while maintaining stable plant community structure. This suggests that the high marsh ecotones can serve as a sensitive indicator of climate change.

Mapping ecological transitions has different approaches, as is the case with all dynamic ecological phenomena. A lot of variability in interactions between salt and fresh water have underlying biotic and abiotic factors and other ecological processes. If these habitats were to be mapped, research should concentrate on practical and mappable features that aid the determination of ecological transitions between salt and fresh water habitats (Fulfrost, Marriot, Sloop, Thomson, & Valoppi, 2015).

Indicators of local distinctions in biotic and abiotic factors in a saltmarsh are features which make it 'special' (JNCC, 2014). Target indicators that point at distinctive features include notable plant or animal species that are not yet features in their own right and associations between saltmarsh and other habitats. For example factors which show distinctions in transition from a brackish to a fresh water swamp.

Fulfrost (2017) has made an effort to describe and map estuarine transition zones in San Francisco Bay. The developed method called uses GIS based Decision Support System (DSS) to describe and map the distribution and extent of potential tidal transitional habitats. The DSS uses three mayor components, among which one of them is a report that describes transitional habitat based on how it can support the ecological functions of the tidal marsh ecosystem. A list of habitat indicators was developed based on the physical and biological properties of the tidal marsh ecosystem. These were utilized to map their distribution and assess their quality. These indicators were finally combined with threats in order to prioritizing potential transition habitats for protection or restoration.

2.5. Indicator Factors for Transitional Tidal Ecosystems in Hallumer-Ryt

In order to find a spatial ecological relationship in biotic factors and the sub-areas (tidal flat, saltmarsh and inland area), target species have to be designated. These biotic factors must represent the habitat based on prior knowledge. The following paragraphs are assessing this knowledge in order to designate target species which will be research during this project.

2.5.1. Food web for saltmarshes

Figure 3 shows the food web of a regular saltmarsh which can also be used as indication for Hallumer-Ryt. This food web will be affected by the project Vijfhuizen. It's still unknown how the project will affect the subareas in the upcoming years, but the environmental factors and the chemical composition of the water on the saltmarshes is going to change and is expected to have a positive influence on the fish and birds species in Hallumer-Ryt. The food webs of both the inland area and the tidal flats are expected to become more sustainable by the project (de Brujine, 2016).

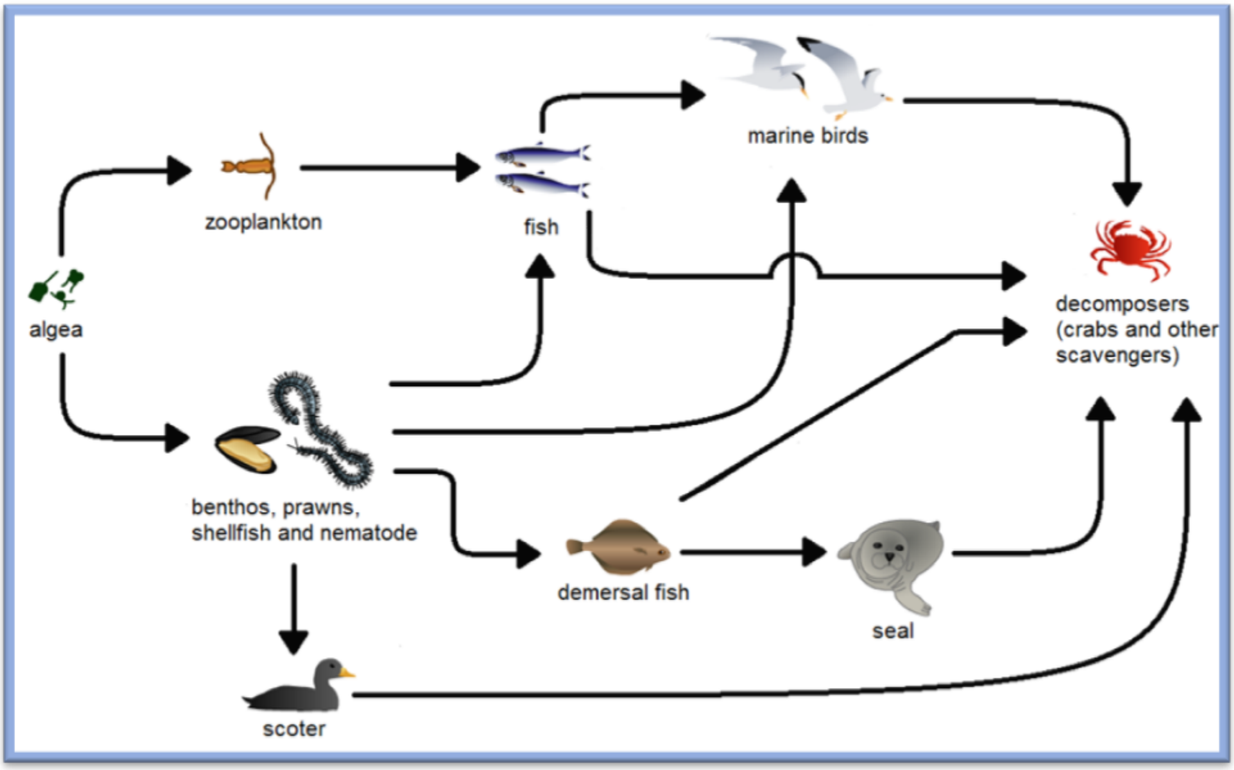

Figure 3: Food web of a saltmarsh (StudioVO, 2017)

2.5.2. Biotic Indicator Factors

Fish Monitoring

Active water management to ensure the safety of people has led to the isolation of inland waters. The dyke is a big barrier between the inland area and the saltmarshes and fish cannot cross it. The fish ladder that is constructed along with the pumping station will allow diadromous fish species like the three-spined stickleback, *Gasterosteus aculeatus* (RAVON, Driedoornige stekelbaars, 2015), or the European eel, *Anguilla Anguilla*, (RAVON, Aal, paling, 2015) to migrate between the freshwater and saltwater and is expected to reduce the isolation. The client wants to know if this is the case or not. Therefore, fish are the most important indicator of the transition between freshwater and saltwater ecosystems for this baseline measurement. Fish occur in every waterbody of the subareas and fish monitoring can be done in all seasons, although the spring could be most interesting for migrating species. The fish (including non-diadromous fish) could also give an indication of the biodiversity and species distribution of the subareas and if this is related to the transitions between the subareas. Previous research of other students in the area have created and tested the fish monitoring method (Da Graca & Huisman, 2014) (Keukens & Johan, 2017).

Bird Monitoring

Millions of migrating birds breed at Hallumer-Ryt every year and are a characteristic group of animals of Hallumer-Ryt (Vogelbescherming Nederland, 2017). It is expected that birds will be positively affected by the construction of the pumping station and the fish ladder. The pumping station will be connected to a gully and the water of the inland area that will be flushed out on the saltmarshes will create a small estuary in the West Gully. This new environment will most likely create a new feeding ground for bird species. Birds will also profit of an improved fish populations after the construction of the pumping station and fish ladder. Fish are a part of the diet of most bird species that occur in Hallumer-Ryt. Bird monitoring have been done by previous researches in the area. The spring is a good season to monitor bird species when they are breeding in Hallumer-Ryt (Marrum Online, 2017). Previous research of other students in the area have created and tested the bird monitoring method (Keukens & Johan, 2017).

Phytoplankton

Phytoplankton is at the base of the food chain and the variety of phytoplankton families can be found in freshwater ecosystems and saltwater ecosystems (National Geographic, 2017). Collecting phytoplankton samples, analyzing and determining the families and determining the distribution gives an indication over the transition of freshwater to saltwater. Furthermore, in order to determine the current state of transition it is important to take the base of the food chain into account because if change occurs in the fundament, it is expected it will affect the different levels of the food chain as well. Phytoplankton can be collected all year round this has not been done in Hallumer-Ryt.

Benthos

Benthos are also at the base of the food chain and like the phytoplankton (Housier River Watch, 2013), the variety of benthos families can be found in freshwater ecosystems and saltwater ecosystems. Collecting benthos samples, analyzing and determining the families and determining the distribution gives an indication of the transition of freshwater to saltwater. Furthermore, like the phytoplankton, it is important to take the base of the food chain into account because if change occurs in the fundament, it is expected it will affect the different levels of the food chain as well. Benthos however can be best collected at the end of the spring or in the summer. The method has been created and tested in previous research projects (Keukens & Johan, 2017) (Huigen, Brandt Wiersma, Keukens, & Draaijer, 2017).

2.5.3. Abiotic Indicator Factors

Chemical Parameters

Chemical parameters have not been collected as intensively by previous research, for these were mainly to test the method for biotic measurements for this baseline measurement. Chemical and physical parameters define the living conditions of the environment and therefore which species of animals live in this environment. The result is a food web of saltmarshes like Figure 3. They are also good indicators of the transition between freshwater ecosystems and saltwater ecosystems. The chemical parameter can also be collected all year round and sampling is not dependable on season, although different dates of sampling will give different result. Chemical parameters are also expected to change in the future after construction of the pumping station, because water of the inland area will be flushed out on the saltmarshes. The chemical composition of the waters of both subareas differs from each other.

Physical parameters

Physical parameters have been collected before by predecessors testing the fishing methods that were used for this research. Like chemical parameters, physical parameters are good indicators of the environment. They define the living conditions of the environment and therefore which species of animals live in this environment. This is shown in the food web of Figure 3. The physical surrounding of the West Gully in the saltmarshes will change after the construction of the pumping station which will result in an altered food web. Like the chemical parameters, physical parameter can also be collected all year round and sampling is not dependable on season although different dates of sampling will give different result.

2.5.4. Other Indicator Factors

Other indicators of transition between freshwater ecosystems and saltwater ecosystems are macro fauna and vegetation. The methods of sampling for the indicators have been created and tested by other students, but are depending of the season and good sampling can best be done in the summer. For this reason and limited time in general, these indicators are not taken into account in this baseline measurement.

3. Method

3.1. Site Description

Hallumer-Ryt is an area in the municipality of Ferwerderadeel with a surface area of 4200 hectares (It Fryske Gea, 2017). It consists of three sub-areas: the tidal flat, the saltmarshes and an inland area (see Figure 1). The inland area is primarily used for agriculture and the water in this area is managed by ditches to create the right conditions for agriculture. The saltmarshes stretches from Zwarte Haan to the pier of Holwerd and is managed by It Fryske Gea. The tidal flats are part of the bigger Wadden Sea.

3.2. Data Collection

Data collection of biotic factors consists of fish and bird monitoring, and collecting phytoplankton, benthos and chemical parameters samples.

Fish monitoring

Fish monitoring has been done in all of the subareas to determine which fish species live in these waters and possibly the ecological use of these environment by fish. The physical characteristics of the various types of bodies of water in each subarea and the material that was available made it clear that different methods of fish monitoring for every subarea. Data that was collected from the every caught fish were species and the body lengths. Also the number of caught individuals of every fish species was written down. For some fish species the gender and body morphology are also recorded.

Fish monitoring in the inland area were done in ditches surrounding the cultivated lands. Ten sampling locations were chosen for characteristics of the ditches that would make it more likely that fish occur in these waters. The fish were caught with the aid of a RAVON fishing net. Figure 4 shows the map of the inland area with the sample locations. The coordinates of the sampling locations are listed in Table 1.

Location label	Coordinates
E1	N 53 19.58, E 5 46.414
E2	N 53 19.525, E 5 46.097
E3	N 53 19.481, E 5 45.971
M1	N 53 19.076, E 5 46.059
M2	N 53 18.902, E 5 46.157
M3	N 53 19.045, E 5 45.629
M4	N 53 18.944, E 5 46.033
SW1	N 53 18.355, E 5 45.575
SW2	N 53 18.407, E 5 45.137
SW3	N 53 18.674, E 5 45.343

Table 1: Coordinates of the inland sample locations

Figure 4: Sample locations in the inland area.

There are several gullies crossing the saltmarshes of Hallumer-Ryt, but only two were suited for fish monitoring of this subarea. The gullies are referred as West Gully (WG) and East Gully (EG). Both gullies are connected with the Wadden Sea and are under influence of the tide cycle. During high tide water would flow in the gullies with fish carried along with the water. During low tide the water would withdraw back to the Wadden Sea. The West Gully, that will become connected with the future pumping station and is expected to change the most after the construction, was sampled by installing a fish trap with a mesh size of 1 cm under a culvert. The sampling location is called WG1. The East Gully was sampled by installing a fish trap with a mesh size of 5.5 mm under a wooden bridge. Using two fish traps with different mesh size will result in caught fish of all body sizes. The East Gully was also sampled with a shore operated lift net on a sluice to catch fish in larvae stadium. The sampling locations of the East Gully are EG2 for the fish trap and EG1 for the shore operated life

Figure 5: Locations of Fish monitoring and bird monitoring in the Saltmarsh. The yellow markings stand for the fish monitoring locations (WG1, EG1 and EG2).

net. Figure 5 shows the map of the saltmarshes which features the two gullies and the locations where the fish sampling occurred.

The accessibility of the tidal flats made it difficult to do field operations and initially it was planned to be a complete literature study. Thanks to the hospitality and assistance of fishermen of the 'Visser van de Kust', one day of fish monitoring could be done in this subarea on the 11th. The fishermen used a fish traps with varying mesh widths (from 25 to 2.5 mm) which stayed installed for a whole tide cycle. During low tide, the fish trap was emptied. This was done two tide cycles. The mean body weight of the caught European flounder (*Platichthys flesus*) was collected as additional data. The location of fish monitoring on the tidal flats are shown in Figure 6.

Figure 6: Location of the tidal flat sampling (TF1). The locations of the Saltmarsh monitoring are shown as well (WG and EG)

Additionally, the gender and type of Three-spined Stickleback were identified in all sub-areas. Female fish were identified on whether they looked pregnant. Male fish were identified by the red colour in their throat, which indicates territorial mating behaviour (Bakker & Millinski, 1900). The length of lateral armour plates of the fish indicate if a particular type of Three-spined Stickleback is found in fresh, brackish, or salt water. A stickleback was considered a salt water type if the plates were found on the whole body (leiurus) and a fresh water type if no plates (trachurus) were observed. A brackish water type has lateral armoured plates on half its body starting after the gills (semi-armata) (Hart, 1978).

Bird monitoring

Bird monitoring has also been done in all of the subareas, but primarily in the saltmarshes. Four indicative bird species have been chosen because they are expected to be positively affected by the construction of the pumping station. Data that was collected were the habitat of the birds, their behavior and number of individuals. With binoculars and a telescope the surroundings were observed for the four indicative bird species. These target species were Eurasian spoonbill (*Platalea leucorodia*), Common greenshank (*Tringa nebularia*), Spotted redschank (*Tringa erythropus*) and the

Curlew sandpiper (*Calidris ferruginea*). See also Appendix 4 for a more information on these species. Fish sampling locations WG1 (culvert) and EG1 (sluice) were used as observation locations as well as the bunker which is referred as WG2 (see Figure 5).

Phytoplankton

Water samples with phytoplankton have been collected in the saltmarshes on the 3th of May and in the inland area on 9th of May. The sampling locations of fish in the inland area (see Figure 4) were also used as sampling locations for phytoplankton. Sampling in the saltmarshes are done at the same time, during upcoming water of high tide and withdrawing water at low tide, in both the West Gully as the East Gully, roughly at the same distance in regard to the Wadden Sea. Fifty liters of water was filtered through a phytoplankton net and one sweep through the body of water to get the diversity of phytoplankton species. The samples have been analyzed in the lab of Van Hall Larenstein for number of species per sample point.

Benthos

Sediment samples with benthos have been collected in the saltmarshes on 8th of May which have been analyzed in the lab of Hogeschool Zeeland. Over the length of the East Gully four equally distributed locations were chosen from nearby the tidal flats till the dyke separating the saltmarshes with the inland area. The sediments of each location were triplet sampled with a benthos insertion tube. Figure 7 displays the locations of the East gully were sediment have been collected.

For a more detailed description of the methodology of collecting data of the biotic indication factors and the materials used see Appendix 2.

Figure 7: Benthos sample locations in the East Gully.

3.2.1. Abiotic factors

Physical parameters

Data for physical parameters have been collected in the inland area and in the saltmarshes. This was done with a Hanna HI 9829 Multiparameter. Measuring was done at the sampling locations of fish in the inland area (see Figure 4) and the sampling locations in the two gullies in the saltmarshes at WG1 and EG1 (see Figure 5). The physical parameters that have been analyzed are pH, salinity, conductivity, PSU, water temperature and dissolved oxygen. Data of the tidal flats was collected with the aid of Waterbase (Rijkswaterstaat, 2017). Two measurement points which were most close to the fish monitoring on 11-05-2017 were selected (see Figure 8).

F

Figure 8: Measurement point on the tidal flats. Data was collected by Rijkswaterstaat (2017)

Chemical parameters

Water samples with chemical parameters have been collected in the saltmarshes on the 3th of May and in the inland area on 9th of May at the same time as the phytoplankton sampling. The sampling locations of fish in the inland area (see Figure 4) were also used as for the water samples of chemical parameters. Sampling in the saltmarshes are done at the same time, during upcoming water of high tide and withdrawing water at low tide, in both the West Gully as the East Gully at roughly the same distance in regard to the Wadden Sea. The water was filtered two times, first by a paper filter and second by a membrane filter. These samples have also been analyzed in the lab of Van Hall Larenstein for chloride, nitrate, phosphate and sulfate. These chemicals have been chosen because they are also used as physical-chemical indicators of the quality of surface water by Kaderrichtlijn Water (2016).

For a more detailed description of the methodology of collecting data of the abiotic indication factors and the materials used see Appendix 2.

3.3. Data Processing

All monitored fish and birds were compiled in a list which showed all individuals monitored, on which day and time they were monitored and the area in which they were monitored. The monitored fish was also linked to the abiotic factors measured at the exact time the fish was caught in the data set.

3.3.1. Chi-Square and ANOVA Tests

During the execution of the tests in IBM SPSS, significant relations between all biotic factors and the sub-areas were considered as well as all significant differences of abiotic factors between the sub-areas. Significance is demonstrated when $p = <0.050$. A value of $p> 0.050$ and $p <0.1$ demonstrates a trend which tends to be significant.

First, significant relations between biotic factors and the sub-areas (inland area, saltmarsh and tidal flat) were considered using the Chi-Square Test. If significant relations were found in multiple factors, these factors were combined and considered for significance as well. For example, taking the combined related factors phytoplankton species and fish species and testing these on significant relation to the sub-areas in Hallumer-Ryt. Furthermore, similarities between populations of the sub-areas were calculated using the Jaccard Index.

Second, significance differences of abiotic factors in the sub-areas were considered using the One-way ANOVA Test. If significant relations were found in multiple factors, these factors were combined and considered for significance as well. For example, taking the combined related factors salinity and pH species and testing these on significant relation to the sub-areas in Hallumer-Ryt

Finally, tests were executed to find related biotic and abiotic indicator factors and if these combined factors have a significant relation to the three different sub-areas. These were tested using the Chi-Square Test. The found significant and thus related biotic and abiotic factors help demonstrate the current transition from fresh to a salt water ecosystem as well as degree of difference between the sub-areas of Hallumer-Ryt.

3.3.2. Jaccard Similarity Index

Additional tests were executed using the Jaccard Similarity Index. The number of observed species of the biotic factors in the subareas can be compared to each other with the Jaccard Similarity Index. If many or few species are found in all the subareas means there is a high or low similarity between them and indicates that the spatial transition between the subareas runs gradually or is quite abrupt. The Jaccard Similarity Index is easy to interpret, but is very sensitive to small sample size. Incomplete data or small numbers could give a wrong impression. Also it gives only an indication of how similar areas are, but does not explain what causes this similarity. Figure 9 shows the formula of the Jaccard Similarity Index.

$$\mathrm{CCj} = \frac{a}{a+b+c}$$

a = the number of species common to both communities
b = the number of species present in Community I only
c = the number of species present in Community I only

Figure 9: Formula used in the Jaccard Similarity Index

4. Results

4.1. Biotic Indicator Factors

4.1.1. Fish

Inland Monitoring

The ditches of the inland area were monitored on four days between 26-04-2017 and 19-05-2017. The ten sample locations (see Figure 4) were monitored for an added total of 27 times, with a sample time of half an hour per sample location. This means that the total monitoring time of inland area lasted for around 810 minutes. No fish was caught on locations M2, M4 and SW2 during all sampling occasions. This means that a total of 262 individuals were caught in seven different monitoring locations. These individuals are distributed amongst ten species. The largest number of species was found in M1. Here nine different species were caught and the lowest number was found in M3, here only one species was found.

Saltmarsh Monitoring

Three sample locations in the saltmarsh were monitored for a total 21 times (see Figure 5 for the sample locations) were between 20-04-2016 and 18-05-2017. Sampling time lasted 690 minutes in location EG1, 1330 minutes in location EG2 and 1060 minutes in location WG. A total of 959 individuals distributed amongst five species were caught on the monitoring locations. Four different species were found in location EG1 and EG2 and three species in location WG.

Tidal Flat Monitoring

The tidal flats were monitored twice. On 10-05-2017, a night monitoring, and 11-05-2017, a day monitoring was performed. Monitoring lasted for a total of 1440 minutes on location TF1 (see Figure 6). A total of numbers of 2657 individuals distributed amongst ten species were caught, from which eight different species were caught during the night monitoring and six different species during the day.

Caught Crustaceans and Ctenophora were not included in the analysis and are therefore not discussed in the results either. Appendix 5.I shows all the found species and their Latin names and Figures i, ii and iii in Appendix 5 show the distribution of the fish species in all sub-areas.

Relation between Fish Species and Sub-areas

The Chi-Square Test was performed using the distribution of fish species and sub-areas as variables. First, a test was performed using the complete database of found fish in Hallumer-Ryt which consists of a total number 3879 individuals distributed amongst 22 species. The output of this test can be found in Appendix 5.III. The test displayed a significance of $p = 0.00$, which demonstrates a significant relation between the distribution of fish and sub-areas of Hallumer-Ryt. However, 53.0% of the test displayed an expected count less than five. The requirement for this test requires more than 80.0% of all cells to have an expected count higher than five in each cell.

Therefore, this test was performed again using only fish species found with more than ten individuals found in all sub-areas. The test used a total number of 3571 fish distributed amongst eleven species. This time only 15.2% of cells had an expected count less than five. Furthermore, the test displayed a significance of $p = 0.00$, which demonstrates a significant relation between the distribution of fish and sub-areas of Hallumer-Ryt even if less species are considered suitable for the analysis.

Species * Sub-area Crosstabulation

			Sub-area			Total
			Inland	Saltmarsh	Tidal Flat	
Species * Sub-area Crosstabulation	Juv. Stickleback	Count	117	0	0	117
		Expected C...	7.6	22.8	86.6	117.0
		% within ...	50.4%	0.0%	0.0%	3.3%
	White bream	Count	42	0	0	42
		Expected C...	2.7	8.2	31.1	42.0
		% within ...	18.1%	0.0%	0.0%	1.2%
	Common roach	Count	38	0	0	38
		Expected C...	2.5	7.4	28.1	38.0
		% within ...	16.4%	0.0%	0.0%	1.1%
	Ten-spined stickleback	Count	25	0	0	25
		Expected C...	1.6	4.9	18.5	25.0
		% within ...	10.8%	0.0%	0.0%	.7%
	Three-spined stickleback	Count	10	278	18	306
		Expected C...	19.9	59.7	226.4	306.0
		% within ...	4.3%	39.9%	.7%	8.6%
	European Smelt	Count	0	175	13	188
		Expected C...	12.2	36.7	139.1	188.0
		% within ...	0.0%	25.1%	.5%	5.3%
	Juv. White Mullet	Count	0	164	0	164
		Expected C...	10.7	32.0	121.3	164.0
		% within ...	0.0%	23.5%	0.0%	4.6%
	Common goby	Count	0	80	0	80
		Expected C...	5.2	15.6	59.2	80.0
		% within ...	0.0%	11.5%	0.0%	2.2%
	Juv. Atlantic Herring	Count	0	0	2030	2030
		Expected C...	131.9	396.2	1501.9	2030.0
		% within ...	0.0%	0.0%	76.8%	56.8%
	Flounder	Count	0	0	552	552
		Expected C...	35.9	107.7	408.4	552.0
		% within ...	0.0%	0.0%	20.9%	15.5%
	Sand lance	Count	0	0	29	29
		Expected C...	1.9	5.7	21.5	29.0
		% within ...	0.0%	0.0%	1.1%	.8%
Total		Count	232	697	2642	3571
		Expected C...	232.0	697.0	2642.0	3571.0
		% within ...	100.0%	100.0%	100.0%	100.0%

Table 2: Distribution of fish species amongst the sub-areas in Hallumer-Ryt. Colours indicate the present fish species in the sub-area(s).

Table 2 displays the distribution of these eleven species over the sub-areas. The juvenile Stickleback was found to be most abundant in the inland area with 50.4%, the Three-spined Stickleback was most abundant in the saltmarsh with 39.9% and the juvenile Atlantic Herring was most abundant on the Tidal Flats. The Three-spined Stickleback was found in all sub-areas with percentages of 4.3 in the inland area and 0.7 on the tidal flats.

The inland area showed a distribution of different fish species in relation to the distance from the dyke. The inland area was therefore divided in three areas. These areas and their distance from the dyke and thus the saltmarsh are displayed in Table 3.

Sub-Area	Label Locations	Sample locations	Distance from Dyke
Inland Area	E	3	85-300
Inland Area	M	4	550-1200
Inland Area	SW	3	1300-2350

Table 3: Sub-areas of the inland areas.

For the analysis using the Chi-Square Test only fish species with more than ten individuals in total were used. The test used a total number 228 individuals and four species. The test displayed a significance of p = 0.00, which demonstrates a significant relation between the distribution of fish and sub-areas of the inland area. However, still 25% had an expected count of less than five individuals per cell.

Species * Locatie ID Crosstabulation

			Locatie ID E	Locatie ID M	Locatie ID SW	Total
Species	Ten-spined sticklebac	Count	22	3	0	25
		Expected	14.3	8.9	1.9	25.0
		% within	16.9%	3.7%	0.0%	11.0%
	Juv. Sticklebac k	Count	108	14	1	123
		Expected	70.1	43.7	9.2	123.0
		% within	83.1%	17.3%	5.9%	53.9%
	Common Roach	Count	0	31	7	38
		Expected	21.7	13.5	2.8	38.0
		% within	0.0%	38.3%	41.2%	16.7%
	White Bream	Count	0	33	9	42
		Expected	23.9	14.9	3.1	42.0
		% within	0.0%	40.7%	52.9%	18.4%
Total		Count	130	81	17	228
		Expected	130.0	81.0	17.0	228.0
		% within	100.0%	100.0%	100.0%	100.0%

Table 4: Distribution of fish species amongst the sub-areas in the inland area

Table 4 shows the distribution of fish species in the sub-areas of the inland area. The juvenile Stickleback was found most abundant in the area most close to the dyke (Location E). Moving further inland, juvenile Stickleback becomes less abundant in contrast to Common Roach and White Bream, which became most abundant in the areas M and SW. See Figure 4 for the locations labelled M, SW and E.

Three-spined Stickleback was found distributed over all sub-areas in Hallumer-Ryt. Therefore analysis was done considering this species as an indicator factor using the variables male/female and type against the sub-areas in the Chi-Square Analysis. Of these species total of 402 individuals were caught in the sub-areas. For a number of 245 fish the gender was identified and the scale type was identified in 359 individuals. Fish with unidentified genders and scale type were not used in the tests.

m/f * Subarea

			Sub-area			Total
			Inland	Saltmarsh	Tidal Flat	
m/f	Male	Count	0	88	0	88
		Expected	.7	83.7	3.6	88.0
		% within	0.0%	37.8%	0.0%	35.9%
	Female	Count	2	145	10	157
		Expected	1.3	149.3	6.4	157.0
		% within	100.0%	62.2%	100.0%	64.1%
Total		Count	2	233	10	245
		Expected	2.0	233.0	10.0	245.0
		% within	100.0%	100.0%	100.0%	100.0%

Table 5: Distribution of male and female Three-spined Stickleback amongst the sub-areas of Hallumer-Ryt

m/f * Subarea

			Sub-area			Total
			Inland	Saltmarsh	Tidal Flat	
Scales	Fresh	Count	7	16	0	23
		Expected	.4	21.4	1.2	23.0
		% within	100.0%	4.8%	0.0%	6.4%
	Brackish	Count	0	158	14	172
		Expected	3.4	160.0	8.6	172.0
		% within	0.0%	47.4%	77.8%	48.0%
	Salt	Count	0	159	4	163
		Expected	3.2	151.6	8.2	163.0
		% within	0.0%	47.7%	22.2%	45.5%
Total		Count	7	333	18	358
		Expected	7.0	333.0	18.0	358.0
		% within	100.0%	100.0%	100.0%	100.0%

Table 6: Distribution of scale type in Three-spined Stickleback amongst the sub-areas of Hallumer-Ryt

As seen in Table 5, pregnant female fish was found in all sub-areas of Hallumer-Ryt. Territorial male fish are found solely in the saltmarsh. Here 37.8% of the total number was identified as male. The Chi-Square showed a p = 0.03 which demonstrates a significant relation between the gender of Three-spined Stickleback and sub-areas of the inland area. The Chi-Square test for scale type showed a p = 0.00 and this also demonstrates a significant relation between the scale type of Three-spined Stickleback and sub-areas of the inland area. Only fresh water types were found in the inland area (see Table 6) and no fresh water types were found on the tidal flat. In the saltmarsh, the brackish type was found least abundant and the brackish and salt types were found almost equal in abundance with 47.4% and 47.7 % respectively. Brackish Three-spined Sticklebacks were found most abundant on the tidal flat with a percentage of 77.8.

Fish Population Similarity Estimates

For the similarity of the three subareas in regard to the fish species, the Jaccard Similarity Index has been used. The Jaccard Similarity Index gives an impression of the community similarity between two or more areas based on the species overlap. The result is a score between zero and one. A score closer to zero means less similarity between two communities and a number approaching one means a higher similarity between communities.

With the use of the analyses program Estimates, the three subareas have been compared for similarity with the Jaccard formula based on the caught fish species. Table 7 shows the result of the analyses, with the Jaccard Similarity Index in the last column.

The saltmarshes and tidal flats have the most similarity, 27.3% according to the test. The inland area and the salt marsh have a low similarity percentage (7.1%) and comparing the species of the tidal flats and the inland area resulted in a Jaccard Similarity of 5.6%. Shared species between all areas was the Three-spined Stickleback. The remaining two shared species in the saltmarshes as well as the tidal flats were the European Smelt and a fish of the family Gobiidae (Goby in the tidal flats and the Common Goby in the saltmarsh).

First Sample	Second Sample	Species observed in first sample	Species observed in second sample	Shared observed species	Jaccard Similarity
Inland area	Saltmarshes	10	5	1	0.071
Inland area	Tidal flats	10	9	1	0.056
Saltmarshes	Tidal flats	5	9	3	0.273

Table 7: Comparison between the subareas based on the caught fish species and the Jaccard Similarity score.

There have also been comparison for similarity made between the subareas based on the caught fish and the observed bird species, as well as a comparison between the inland area and the saltmarshes based on the caught fish species, observed bird species and analysed phytoplankton species. These comparisons can be found in Paragraph 4.1.5.

4.1.2. Birds

Inland area, Saltmarsh and Tidal Flat Monitoring

The monitoring data was collected along with collection of data for other biotic and abiotic factors in all three sub-areas. Therefore the bird monitoring of the four target species was done on seventeen days between 12-04-2017 and 19-05-2017. Additional monitoring was performed by Japke van Assen (2017) on nine days between 02-05-2017 and 01-06-2017. A total number of 125 birds were seen on twenty days of the total monitoring schedule.

A total number of 89 Eurasian spoonbills, which were not all individuals, were observed on the saltmarsh and 17 on the tidal flats. Three Common greenshanks were observed as well as seven Spotted redshank in the saltmarsh. The curlew sandpiper hasn't been seen in Hallumer-Ryt and none of the target bird species were observed in the inland area.

Behaviour

Four different types of behaviour were observed from the target species. All observed Common greenshanks and Spotted redshank were foraging. The European spoonbills showed a wide variety of the four behaviour types. The distribution of behaviour type in European spoonbills can be found in Appendix 6.II. Figure iii shows that 50.0 % of the observed spoonbills in the saltmarsh were foraging and about a quarter was resting. Only 5.26% was observed preening during the monitoring. Different types of behaviour were found along the East Gully in the saltmarsh. Figure iv shows that in the first region, which stretches from EG1 to the dike, behaviour is similar distributed to the overall observed behaviour in the saltmarsh. However the second region (See Figure v), which stretches from an area close to the tidal flats to the EG1, shows only two behaviour types. The spoonbills were either seen flying (66.6 %) or resting (33.3 %).

All monitored birds and the place, date and time of observation can be found on the maps in Appendix 6.I.

Significance of Factor

A Chi-Square test was performed using the distribution of the four target species and sub-areas as variables. A total of 125 individuals were used in the test. The test showed a $p = 0.171$ which means no significant relation is found between the distribution of the four target species and the sub-areas of the inland area.

Table 8 shows the distribution of the species amongst the sub-areas. A total number of 89 Eurasian spoonbills were observed on the saltmarsh and seventeen on the tidal flats. Three Common greenshanks were observed as well as seven Spotted redshank in the saltmarsh. The curlew sandpiper hasn't been seen in Hallumer-Ryt and none of the target bird species were observed in the inland area.

Species * Sub-area

			Sub-Area			
			Inland Area	Salt Marsh	Tidal Flats	Total
Soort	Eurasian Spoonbill	Count	0	89	17	106
		Expected	.0	91.6	14.4	106.0
		% within	0.0%	82.4%	100.0%	84.8%
	Spotted redshank	Count	0	16	0	16
		Expected	.0	13.8	2.2	16.0
		% within	0.0%	14.8%	0.0%	12.8%
	Common greenshank	Count	0	3	0	3
		Expected	.0	2.6	0.4	3.0
		% within	0.0%	2.8%	0.0%	2.4%
Total		Count	0	108	17	125
		Expected	0.0	108.0	17.0	125.0
		% within	0.0%	100.0%	100.0%	100.0%

Table 8: Distribution of target bird species amongst the sub-areas of Hallumer-Ryt

Bird Population Similarity Estimates

A Jaccard Similarity has also been done of the subareas based on bird species. Although the birds have been monitored in every subarea, none of the bird species were seen in the inland area. Therefor the similarity of inland area compared to the other subareas based on the birds is zero, as is shown in the last column in Table 9. Only the saltmarshes and tidal flats have some sort of similarity 33.3% according to the test. The inland area and the salt marsh as well as tidal flats and the inland area resulted in a Jaccard Similarity of 0.0% which means no similar species were observed in these areas.

First Sample	Second Sample	Species observed in first Sample	Species observed in second Sample	Shared observed Species	Jaccard Similarity
Inland area	Saltmarshes	0	3	0	0
Inland area	Tidal flats	0	1	0	0
Saltmarshes	Tidal flats	3	1	1	0.333

Table 9: Comparison between the subareas based on observed bird species and the Jaccard Similarity score.

For the comparison for similarity made between the subareas based on the caught fish and the observed bird species as well as the comparison between the inland area and the saltmarshes based on the caught fish species, observed bird species and analysed phytoplankton species see Paragraph 4.1.5.

4.1.3. Phytoplankton

Saltmarsh and Inland Area Monitoring

Phytoplankton was monitored for biodiversity on two days. The phytoplankton in the saltmarsh was collected on location EG2 and WG1 on 03-05-2017. The inland area was sampled on eight locations on 09-05-2017. These locations were E1, E2, M1, M2, M4, SW1, SW2 and SW3 (see Figure 4).

A total number of 37 species were found distributed amongst all sample locations. A total of 19 species were found in the saltmarsh and 21 in the inland area. Three species were found in both sub-areas; *Frustulia Rhomboides*, *Stichococcus bacillaris* and *Stauroneis Ancep.* The species *Frustulia Rhomboides* and *Stauroneis Ancep* are found in a fresh water environment, whereas *Stichococcus bacillaris* can be found in any environment but in typical marine habitats (AlgeaBase, 2017).

Phytoplankton Population Similarity Estimates

The tidal flats have been excluded for the Jaccard Similarity Index for phytoplankton, because no phytoplankton was monitored. Table 10 shows the similarity of the species observed in the inland area and the saltmarshes. The test resulted in a similarity of 8.1%.

First Sample	Second Sample	Species observed in first sample	Species observed in second Sample	Shared observed species	Jaccard Similarity
Inland area	Saltmarshes	20	20	3	0.081

Table 10: Comparison between the inland area and the saltmarshes based on the phytoplankton species and the Jaccard Similarity score

For the comparison between the inland area and the saltmarshes based on the caught fish species, observed bird species and analyzed phytoplankton species see Paragraph 4.1.5.

4.1.4. Benthos

Saltmarsh Monitoring

Benthos was collected on four sample points in the East Gully (see Figure 7) on 08-05-2017. Three samples from each sample point were taken not more than 0.5 m apart from each other. The group Oligochaeta was found with the largest abundance. From Polychaeta, two types of genus were found: Nereis and Nephtys. Nephtys was found to be lowest in abundance.

Significance of Factor

A Chi-Square test was performed using the variable distribution of the found group and genera against the locations in the East Gully (See Figure 7). A total number of 192 individuals were used in the execution of the test which showed a $p = 0.00$. This means a significant relation between the distribution of the four target species and the sub-areas of the inland area was found.

Species * Locatie ID Crosstabulation

			Locatie ID				Total
			1	2	3	4	
Species	Oligochaeta	Count	88	8	41	5	142
		Expected	80.6	14.1	37.7	9.6	142.0
		% within	80.7%	42.1%	80.4%	38.5%	74.0%
	polychaeta: Nereis	Count	18	9	8	1	36
		Expected	20.4	3.6	9.6	2.4	36.0
		% within	16.5%	47.4%	15.7%	7.7%	18.8%
	polychaeta: Nepthys	Count	3	2	2	7	14
		Expected	7.9	1.4	3.7	.9	14.0
		% within	2.8%	10.5%	3.9%	53.8%	7.3%
Total		Count	109	19	51	13	192
		Expected	109.0	19.0	51.0	13.0	192.0
		% within	100.0%	100.0%	100.0%	100.0%	100.0%

Table 11: Distribution of Oligochaeta, Polychaeta: Nereis and Polychaeta: Nepthys in the East Gully on the saltmarsh.

Location	Distance from dyke (m)
1	2250
2	1750
3	925
4	125

Table 12: Distance of sample locations from the dyke in m

Table 11 shows the distribution of the species along the East Gully in the saltmarsh and Table 12 shows the distance of each sample location from the dyke in meters. Nereis seems to be most abundant in Location 2 and this abundance decreases in the sample locations closer towards the dyke. Nephtys increases in number from Location 2 towards Location 4. Oligochaeta does not show a particular pattern in distance from the dyke. More individuals were found in Location 1 and 3.

Benthos Population Similarity Estimates

The benthos samples in the East Gully have also been tested with the Jaccard Similarity Index. All the three benthos species were found at all four sample points. The results of Jaccard similarity between every sampling point compared to each other an Index of 1. This means that all sampling points are completely similar and do not need to be shown and explained in a table.

4.1.5. Relations between Biotic Indicator Factors

Additional Jaccard Similarity tests were performed to compare multiple biotic factors on similarity between sub-areas in Hallumer-Ryt. This was done to give a more complete overview of the sub-areas as a whole in regards to the food web.

Fish and Bird Population Similarity Estimates

Table 13 shows the similarity of the subareas based on the two most important biotic factors of this research: fish and bird species. Shared species between all areas was the Three-spined Stickleback. The remaining two shared species in the saltmarshes as well as the tidal flats were the European Smelt and a fish of the family Gobiidae (Goby in the tidal flats and the Common Goby in the saltmarsh). Added is the monitored bird species Eurasian Spoonbill, which was found in both the saltmarsh and the tidal flats.

First Sample	Second Sample	Species observed in first sample	Species observed in second sample	Shared observed Species	Jaccard Similarity
Inland area	Saltmarshes	10	8	1	0.059
Inland area	Tidal flats	10	10	1	0.053
Saltmarshes	Tidal flats	8	10	4	0.286

Table 13: Comparison between the subareas based on the caught fish species and the observed bird species with the Jaccard Similarity score.

Notice the slightly lower similarity between the inland area and the saltmarshes and the slightly higher similarity between the saltmarshes and tidal flats compared to Table 7, where only the caught fish species in the subareas were compared to each other. Also here is there more similarity between the saltmarshes and tidal flats than both have with the inland area, which is in line with our expectations.

Fish, Bird and Phytoplankton Population Similarity Estimates

Table 14 shows the similarity of the in inland area and the saltmarshes based on the caught fish species, observed bird species and phytoplankton species. Similar to Table 10, no samples of phytoplankton were collected on the tidal flats and are not taken into account in this comparison. Notice the slightly higher score of the Jaccard Similarity Index compared to Table 7 in the results where the comparison only was made between the fish species in the subareas. Monitoring as much species as possibly can will give a more reliable comparison.

First Sample	Second Sample	Species observed in first sample	Species observed in second Sample	Shared observed species	Jaccard Similarity
Inland area	Saltmarshes	28	28	4	0.077

Table 14: Comparison between the inland area and the saltmarshes based on the caught fish species, the observed bird species and the phytoplankton species with the Jaccard Similarity score

4.2. Abiotic Indicator Factors

4.2.1. Physical Parameters

Significance of Factors

Biotic factors were monitored during the fish monitoring both in the inland area and saltmarsh. Results of the monitoring were analysed using the One-way ANOVA Test in order to find significance differences in the distribution of abiotic factors in the sub-areas.

Descriptives

		N	Mean	Std. Deviation
Salinity(ptt)	Inland	27.00	0.86	0.47
	Saltmarsh	72.00	15.46	2.77
	Tidal Flats	53.00	29.50	2.10
	Total	152.00	17.76	10.35
pH	Inland	27.00	8.25	0.36
	Saltmarsh	72.00	8.41	0.20
	Tidal Flats	77.00	7.95	0.29
	Total	176.00	8.18	0.34
Water Temp (°C)	Inland	27.00	13.77	2.24
	Saltmarsh	72.00	14.11	5.32
	Tidal Flats	23.00	11.06	1.92
	Total	122.00	13.46	4.44
Oxygen (mg/l)	Inland	27.00	7.59	2.89
	Saltmarsh	71.00	8.59	2.14
	Tidal Flats	24.00	7.90	3.19
	Total	122.00	8.23	2.56

Table 15: Means and standard deviation of the measured parameters in the sub-areas of Hallumer-Ryt

Table 15 shows the means and standard deviations for the parameters salinity, pH, water temperature and saturated oxygen measured in the inland area and saltmarsh. Parameters

The Levene Statistic for testing on Homogeneity of Variances showed that the variances measured in salinity, pH and temperature were not homogenous. Oxygen did have homogenous variances and the factor was considered to have no statistically significant differences in the distribution between subareas ($p = 0.176$).

For the other three parameters a Welch test was executed which compares means to see if they are equal. Salinity, pH and water temperature all showed a $p = 0.00$. This means all these factors were considered to have statistically significant differences in the distribution between subareas.

Because the means of salinity in the sub-areas were highly distinctive, scatter graphs were made of the parameters pH, salinity and oxygen as seen in Appendix 7. These were used for analysing related biotic and abiotic factors (see Paragraph 4.3)

The ANOVA test was used in in order to find significance differences in the distribution of abiotic factors in the sub-areas of the inland area. These sub-areas (E, M, SW) were based on the distance from the dyke as seen in Table 12. The measurement of the parameters in the inland area all had homogenous of variances. Salinity and pH were considered to have statistically significant differences in the distribution between subareas with a p = 0.00 and 0.001 respectively. Water temperature and saturated oxygen were not significantly different with a p = 0 .908 and 0.709.

4.2.2. Chemical Parameters

Collected Data

Water samples were collected from eight ditches of the inland area (see Figure 4) on 09-05-2017. The samples were analysed on Chloride, Nitrate, Phosphate, and Sulphate. The results of the analysis are showed in Table 16.

Sample location	Chloride (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Sulphate (mg/l)
ZW1	140.81	0.00	0.00	61.06
ZW2	144.58	0.00	0.00	60.65
ZW3	145.00	0.00	0.00	60.35
M1	294.83	0.12	1.89	103.32
M2	170.67	0.09	0.00	64.82
M4	192.55	0.00	3.60	43.34
E1	412.60	0.00	2.93	301.31
E2	420.18	0.00	4.02	31.03

Table 16: Chemical parameters in (mg/l) measured from samples taken in the inland area

Significance of Factor

The results shown in Table 16 were analysed using the One-way ANOVA Test in order to find significance differences in the distribution of abiotic factors in the sub-areas in the inland area. The sub-areas of inland area were again based on the distance from the dyke as seen in Table 3.

The Levene Statistic for testing on Homogeneity of Variances showed that the variances in the chemical parameters were not homogenous. Therefore the Welch test was executed which displayed a p = 0.00 for Chloride which means this factor is considered to have statistically significant differences in the distribution between subareas E, M and SW. Phosphate a p = 0.06 which demonstrates this parameter tends to be significant. However Nitrate had a p = 0.14 and Sulphate a p = 0.43. These factors were considered to have no statistically significant differences in the distribution between subareas in the inland area.

4.3. Related Biotic and Abiotic Indicator Factors

4.3.1. Salinity and Fish Species as Related Indictor Factors

The distribution of 11 fish species amongst the sub-areas of Hallumer-Ryt showed to have a significant relation. The fish species and thus also the subareas have a direct relation to the abiotic factor salinity. The means of salinity have not much variation inside sub-areas which causes this direct relation of salinity and fish species.

	Salinity (ptt)	Most abundant fish species
Inland	0.86 ± 0.47	Juv. Stickleback, White Bream, Common roach, Ten-spined Stickleback
Saltmarsh	15.46 ± 2.77	Three-spined Stickleback, European Smelt, Juv. White Mullet, Common Goby
Tidal Flat	29.50 ± 2.10	Juv. Atlantic Herring, Flounder, Sand lance

Table 17: Related Salinity and most abundant fish species in the sub-areas of Hallumer-Ryt

Table 17 displays which salinity and fish species are associated with the three sub-areas of Hallumer-Ryt. The fish species are sorted with descending abundance in the sub-area they are associated with. Juvenile Stickleback is most abundant in the inland area were a mean salinity of 0.86 ± 0.47 can be found. The juvenile fish could be considered both Ten-spined as well as Three-spined Sticklebacks. No distinction was made during the time of monitoring because the spines were too small to count. Ten Three-spined Sticklebacks are most abundant in the saltmarsh were a mean salinity of 15.46 ± 2.77 can be found. Finally, the Juvenile Atlantic Herring is most abundant in the tidal flats were a mean salinity of 29.50 ± 2.10 can be found.

4.3.2. pH and Fish Species as Related Indictor Factors

A Chi-Square test was performed using the distribution of fish species against pH as variables. Fish species and pH data measured in the inland area and the saltmarsh were taken into account for this test. From eight species more than ten individuals were monitored and were suitable for the test, which analysed a total number of 929 individuals from which the pH was measured when caught in field.

The collected pH results were divided into a group with low pH (<8) and a group with high pH (8>) using Figure vii in Appendix 7 as a guideline. The results of the Chi-Square test showed a $p = 0.00$ which means a significant relation between the distribution of the fish species and high and low pH values in Hallumer-Ryt was found.

Table 18 shows the distribution of the eight analysed fish species against monitored pH groups. According to this table, the juvenile Stickleback takes up large portion (86.0%) of the species distribution related to lower pH, followed by the Ten-spined Stickleback with a percentage of 8.3. Fish species that are found with higher pH are mainly species found in the saltmarsh. Highest percentages included species like Three-spined Stickleback (35.0%), European Smelt (21.7%) and Juvenile White Mullet (20.3%).

Species * pH Crosstabulation					
			pH		Total
			< 8,00	8,00 >	
Species	Juv. Stickleback	Count	104	13	117
		Expected	15.2	101.8	117.0
		% within	86.0%	1.6%	12.6%
	Ten-spined Stickleback	Count	10	15	25
		Expected	3.3	21.7	25.0
		% within	8.3%	1.9%	2.7%
	Three-spined Stickleback	Count	5	283	288
		Expected	37.5	250.5	288.0
		% within	4.1%	35.0%	31.0%
	European Smelt	Count	0	175	175
		Expected	22.8	152.2	175.0
		% within	0.0%	21.7%	18.8%
	Juv. White Mullet	Count	0	164	164
		Expected	21.4	142.6	164.0
		% within	0.0%	20.3%	17.7%
	Common Goby	Count	0	80	80
		Expected	10.4	69.6	80.0
		% within	0.0%	9.9%	8.6%
	White Bream	Count	0	42	42
		Expected	5.5	36.5	42.0
		% within	0.0%	5.2%	4.5%
	Common roach	Count	2	36	38
		Expected	4.9	33.1	38.0
		% within	1.7%	4.5%	4.1%
Total		Count	121	808	929
		Expected	121.0	808.0	929.0
		% within	100.0%	100.0%	100.0%

Table 18: Red coloured cells indicate the fish species was mainly found in the inland area. Yellow coloured cells indicate the species we found in the saltmarsh (see Table 2).

4.3.3. Temperature and Fish Species as Related Indictor Factors

A Chi-Square test was performed using the distribution of fish species against Surface water temperature as variables. Fish species and temperature data measured in the inland area and the saltmarsh were taken into account for this test. From eight species had more than ten individuals were monitored and were suitable for the test, which analysed a total number of 929 individuals from which the temperature was measured when caught in field.

The collected temperature results were divided into a three groups: low temperatures (<10.0 C°), high temperatures (15.0 C°>) and a group in between (10.0-15.0 C°). The results of the Chi-Square test showed a p = 0.00 which means a significant relation between the distribution of the fish species and high and low surface water temperature values in Hallumer-Ryt was found.

Table 19 shows the distribution of the eight analysed fish species against monitored surface water temperature groups. According to this table, the European Smelt takes up large portion (48.0%) of the species distribution related to lower temperature, followed by the juvenile White Mullet with a percentage of 42.1.Both species are mainly found in the saltmarsh.

Fish species that are found with higher pH is mainly the Three-spined Stickleback (77.6%) related to the saltmarsh. Temperatures between 10.0 and 15.0 C° are related a wide variation of species found both in the inland area. However, if those percentages are added, more fish species related the saltmarsh are found with these temperatures, which is 61.1% in total.

Species * Temperature Crosstabulation

			Temperature (C°)			Total
			<10.0	10.0 - 15.0	15.0 >	
Species	European Smelt	Count	130	45	0	175
		Expected	51.0	73.5	50.5	175.0
		% within	48.0%	11.5%	0.0%	18.8%
	Juv. White Mullet	Count	114	48	2	164
		Expected	47.8	68.8	47.3	164.0
		% within	42.1%	12.3%	.7%	17.7%
	Common Goby	Count	6	72	2	80
		Expected	23.3	33.6	23.1	80.0
		% within	2.2%	18.5%	.7%	8.6%
	Juv. Stickleback	Count	0	72	45	117
		Expected	34.1	49.1	33.8	117.0
		% within	0.0%	18.5%	16.8%	12.6%
	Three-spined Stickleback	Count	21	59	208	288
		Expected	84.0	120.9	83.1	288.0
		% within	7.7%	15.1%	77.6%	31.0%
	White Bream	Count	0	41	1	42
		Expected	12.3	17.6	12.1	42.0
		% within	0.0%	10.5%	.4%	4.5%
	Common roach	Count	0	35	3	38
		Expected	11.1	16.0	11.0	38.0
		% within	0.0%	9.0%	1.1%	4.1%
	Ten-spined Stickleback	Count	0	18	7	25
		Expected	7.3	10.5	7.2	25.0
		% within	0.0%	4.6%	2.6%	2.7%
Total		Count	271	390	268	929
		Expected	271.0	390.0	268.0	929.0
		% within	100.0%	100.0%	100.0%	100.0%

Table 19: Distribution of fish species with higher, mediocre and lower temperature groups. Red coloured cells indicate the fish species was mainly found in the inland area. Yellow coloured cells indicate the species we found in the saltmarsh (see Table 2).

5. Discussion

5.1. Research Site

The saltmarshes and the tidal flats are subareas that are not actively controlled by human management like the inland area. Both are under influence of the tide, season of the year or other heterogeneous environmental factors. Furthermore current projects in the inland area like the construction of the pumping station, the mowing of the ditches shore and digging of the nature-friendly shores in Hallumer-Ryt could have resulted in disturbance and a distorted picture of the total number of caught fish in some ditches, giving a false impression of a low biodiversity and distribution of the fish species in these waters. The current construction of the pumping station also causes disturbance in the saltmarshes, especially for the birds. The method was adjusted in order to adapt it to these circumstances, for example more fishing for higher change to catch fish, fishing from places further away from the influences and starting later with the field work in the inland area in order to give the ecosystem a change to adapt to the impact of the disturbance.

5.2. Method

In total twenty-five days were reserved for collecting data of the biotic and abiotic indication factors in the subareas. This was done from the end of April to the midst of May over a course of four weeks. Compared to the previous preparing research in the area which took ten weeks this is a small timeframe for a research with a lot of indicators (Keukens & Johan, 2017). Although the intensity of collecting data was high, four weeks is not enough little time to properly assess all biotic and abiotic factors that could be indicators for the current transition from a salt water to a fresh water environment in Hallumer-Ryt. However, further research will be undertaken in the future and will take the collected data of this research into account.

This limited time with divided attention to the subareas combined with the six different indication factors, all of them with an adjusted method suitable for each factor, resulted in some challenges. Although a lot of data was collected in total, the quantity in which different factor were monitored ranged significantly from each other. Four days where spend in the inland area, twelve on the saltmarshes and one day of data collecting was done on the tidal flats. It might have been easier to compare and analyze the collected data if the days in the field were equally scheduled over the subareas. This resulted in some data not being suitable for analysis of all sub-areas in Hallumer-Ryt. Four weeks of field work seemed not to be enough time to properly collect data from all the indicative factors. The season in which the data was collected in might have an influence on the collected data. However, the data that was collected was good enough in quality and quantity in order to perform proper analysis.

Other biotic and abiotic factors can be collected in order to indicate the transition between the fresh- and saltwater-ecosystem. Examples of biotic indication factors are vegetation or macro fauna, while an example of the abiotic factors is turbidity, suspended solids in the gullies water and the currents velocity of the inflowing water during high tide. These factors were not taken into account because of the limited time, materials and the season in which the fieldwork was planned. Additional data of unaccounted biotic and abiotic factors might give some interesting or relevant results to improve future management of the subareas.

5.2.1. Biotic Factors

Fish

Fish monitoring was done in all the subareas. However, because of the various bodies of water and limited materials, the method of every subarea was handled differently. The inland area was monitored using a RAVON fishnet, fish traps shore operated fish net were used in the saltmarshes and on the tidal flats a fish trap was installed for a full day. This all made it difficult to compare the results and use them in analysis and could result in the yield of the tests in SPSS being less reliable.

Furthermore, the total time of fishing differed in every sub-area. A similar fish monitoring research at the fish ladders of Zwarte Haan and Roptazijl that took place in 2014 at a fish ladder at Zwarte Haan and Rotapazijl, close by Hallumer-Ryt, caught a larger total number of fish. The reason for this is, besides more days of monitoring and a different method and materials, that the fish traps were installed for a longer period of time: six hours compared to the two and a half hours install time in this research. The total number of fish caught in this research was 124.013 individuals, which is more than the 3.878 individuals of fish in this research (Vries, 2014). This concludes that longer installation with the right material and methods results in more caught fish and this therefore results in more data to analyze and compare. The one day of fish monitoring on the tidal flats was also been done by installing the fish traps for a longer period of time which resulted in 2.657 caught individuals on this day. This meant a bigger chance of catching a larger number of individuals and a larger number of fish species that live in these areas.

The research at the Zwarte Haan and Rotapazijl regularly caught European eel. European eel are diadromous fish and was the main focus of the research together with the three-spined stickleback (Vries, 2014). During the field work in Hallumer-Ryt, European eel (in the form of glass eel) was caught five times using the shore operated lift net. At the research of Zwarte Haan and Rotapazijl, 29,027 eels have been caught by a shore operated lift net and larvae fish traps. This shows that using additional materials such as larvea fish traps better suited for catching European eel. Furthermore the timing suited better in this research because these fish are nocturnal. Also more three-spined sticklebacks were caught in total at Zwarte Haan (94,237) than in this one (1,164). Using a different method like the one of research of the fish ladder at Zwarte Haan and Rotapazijl seems to result in more caught fish species and more caught European eel in particular. This fish species could also be a biotic indicator species for Hallumer-Ryt because of its diadromous nature just like the Three-spined Stickleback.

The spatial condition of the gullies in the saltmarsh enquired a different approach in order to do create a good method. Different fish traps used in the two gullies. This resulted in different mesh sizes of the traps used. Fish traps were could not be installed at the same distance in regard to the distance to the inland area and tidal flats. The fish trap of the WG1 under the culvert covered the whole gully, in contrast to the fish trap in EG2, which covered around three-fourth of the gullies width. This means fish could have escaped the fish trap by swimming around. Additionally, a shore operated lift net in was used in the East Gully. This was not possible in the West Gully because of the lack of access and depth in the channel itself.

The difference in fishing methods of each subarea results in an altered representation of the caught fish. The pie charts in Appendix 5 might give an indication of the total number of fish and the proportion that use these waters, but should not be taken for a hundred percent accurate. However, species distribution can be seen as accurate, especially since large numbers in each sub-area were monitored.

Birds

Bird monitoring on the saltmarshes was done on the fish monitoring locations of both gullies. Additionally the bunker, seven hundred meters west of the West Gully, was used as a bird observation platform. Using binoculars and telescopes, a large area of the research area was observed. However, it was not possible to monitor the whole area, which was larger than the reach of these materials. Limiting the bird monitoring to four indication species resulted in observation of mainly one species and its behavior with addition of the species spotted redshank and common greenshank thanks to Japke van Assen (2017). These additional two species were monitored because of a specific walking route and explicitly dedicated field days solely for bird monitoring.

Although it is expected that these species will be positively influenced by the construction of the pumping station, it could also mean less data from other possible target species. If other possible target species that may also benefit from the pumping stations influence, like the common redshank (*Tringa totanus*), Eurasian oystercatcher (*Haematopus ostralegus*) and Pied Avocet (*Recurvirosta avosetta*) were observed it may have given additional information and more data to analyze.

5.2.2. Abiotic factors

Physical parameter monitoring was done in the inland area and the saltmarsh. However, no physical parameter data was collected on the tidal flats. Data from literature was be used to fill this gap and although the information about the physical state of the Wadden Sea is abundant, it would be preferred to use self-collected data. Furthermore, there was no opportunity to collect chemical parameters on the tidal flats and the saltmarsh.

In the inland area on the salt marshes, data was mostly collected on fixed sample points. Salinity was measured with large differences and small variations in sub-areas and could not be used for analysis to in order to find out a transition between sub-areas in relation to other data.

There was a larger variation of pH and surface water temperature in the sub-areas of Hallumer-Ryt which were both used in the analysis to find out if these abiotic indicator factors were related to the biotic indicator in the form of fish species. However, without relating the biotic indicator to the salinity it cannot be confirmed if the presence or absence of fish species in these waters is related to which abiotic factor or to multiple abiotic factors. Future research should analyze the influence of all the abiotic factors on the biotic indicators to find out which one is the defining factor. Whit this knowledge a more accurate prediction can be made over the future effect of the pumping station in the research area.

Benthos and Phytoplankton

There was no opportunity to collect benthos from the tidal flats and the inland area and three families have been identified on the saltmarshes, but during previous research four other benthos families had been identified (Keukens & Johan, 2017). This could mean that there might still be some benthos families that occur in the saltmarshes of Hallumer-Ryt that but were not identified. The benthos was classified by families and not by species. A better impression of the benthos community should be determined in the future by sampling all major gullies in Hallumer-Ryt and classifying the species. Furthermore, there was no opportunity to collect phytoplankton samples on the tidal flats. Two samplings of phytoplankton were executed in the salt marshes. One sample of each gully, both at the same distance in regard to the Wadden Sea. The inland area was sampled at eight locations. The difference in number of sample point might have made the results less reliable.

5.3. Results

The Jaccard Similarity Index is sensitive for small data sets and is likely to under-estimates the similarity in real life example. The similarity of the subareas will go up or down if all possible birds species seen in Hallumer-Ryt where taken into account and more fish, phytoplankton and benthos species were monitored. Also the species a proportion of areas is not taken into account by the Jaccard estimates (Clayton, 2005). The absences of monitored of the factors phytoplankton and benthos in the tidal flats prevented the comparison of all the subareas together using Jaccard Similarity test, with exception of birds and fish species.

6. Conclusion

6.1. Research question

The main research question as stated in Chapter 1 was:

Which related biotic and abiotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the current transition from a fresh to a salt water ecosystem?

This question can be answered by addressing the following sub-questions:

1a. Which biotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the current transition from fresh to a salt water ecosystem?

1b. Which abiotic indicator factors are found in the subareas of Hallumer-Ryt in order to demonstrate the current transition from a fresh to a salt water ecosystem?

2. Which found biotic abiotic indicator factors are related in order to demonstrate the current transition from fresh to a salt water ecosystem in Hallumer-Ryt?

6.2. Conclusions

Biotic and abiotic factors in Hallumer-Ryt haven't been used before as indicators to demonstrate a transition between a fresh and salt water ecosystem. However, multiple factors were expected to be suitable for this particular matter, according to literature from earlier conducted research in Hallumer-Ryt.

For example, fish species are expected to be an important indicator of the transition between fresh water and saltwater ecosystems because the barrier between the inland area and the saltmarshes is due to be removed and the fish ladder which is constructed along with the planned pumping station will allow diadromous fish species to migrate between the fresh water and saltwater. The new created environment is also expected to attract target bird species by the shift to healthier fish populations and species distributions. Other tested methods for collection of data of biotic factors in Hallumer-Ryt are phytoplankton and benthos. Abiotic factors such as physical and chemical parameters were selected for monitoring because they are suitable for all year round sampling and can be combined for analysis of the relation with abiotic factors if they were sampled at the same time.

Multiple biotic and abiotic factors designated by literature and monitored subsequently in Hallumer-Ryt were found to be indicators because they were able to demonstrate the current transition from fresh to a salt water ecosystem. Evidence for this statement is found in the output of multiple tests.

The Chi-Square test shows that biotic factors such as the species distribution of fish, birds, and benthos are good indicators to demonstrate the current transition from a fresh to a salt water ecosystem in Hallumer-Ryt. All mentioned factors were found with a $p = 0.00$, which demonstrates a significant relation between the indicator factors and sub-areas of Hallumer-Ryt; the inland area, the saltmarsh and the tidal flats. Furthermore, the Jaccard Similarity Index shows similarity between the three sub-areas using the found species in Hallumer-Ryt. The output of this test confirmed that the species distribution of fish, birds and benthos are proper indicators, because low percentages are displayed, which indicates the three sub-areas are not at all similar. Another factor which could be an indicator is phytoplankton, since the Jaccard Index shows almost no similarity (8.1%) between the inland area and the saltmarsh. Combining multiple biotic factors in the Index gives a more complete overview of the similarity between sub-areas.

Abiotic indicator factors were examined with the aid of the One-way ANOVA Test. The test demonstrated that, with an additional Welch test if necessary, multiple physical parameters are found with a $p = 0.00$. Salinity, pH and surface water temperature all show statistically significant differences in the distribution between the subareas of Hallumer-Ryt.

The found biotic and abiotic indicator factors were subsequently examined on significant association to the sub-areas using the Chi-Square test. Salinity and the distribution of fish species shows a direct relation because of the small variations in the sub-areas itself. Juvenile Atlantic Herring was most abundant in the tidal flats, with a mean salinity of 29.50 ± 2.10. Three-spined Stickleback was most abundant in the saltmarsh, with a mean salinity of 15.46 ± 2.77. Finally, Juvenile Stickleback was most abundant in the inland area, with a mean salinity of 0.86 ± 0.47.

Additionally, high and low pH (<8 and 8>) was examined against the distribution of fish species. Juvenile Stickleback, found in the inland area, was most abundant in areas with lower pH, while Three-spined Stickleback was mostly found in areas with high pH, according to the test. Surface water temperature was examined against the distribution of fish species as well. The abundance of European Smelt was highest in water with low temperatures (<10.0 C°), while the abundance of Three-spined Stickleback was highest in water with high temperatures (15.0> C°) which were both found in the salt marsh.

Both tests displayed a $p = 0.00$ and demonstrate a significant relation between the physical parameters pH and surface water temperature and sub-areas of Hallumer-Ryt.

7. Recommendations

The following recommendations are given, based on the performed field work and analysis of the results.

All indication factors, biotic and abiotic, should be monitored or sampled on more equally distanced locations in all of the subareas to get a better impression of the transition between a fresh water and a salt water ecosystem. If successors will collect data over a proportional distance from the inland area to the tidal flats, more links between biotic and abiotic factors could be made possible. All tested indicator factors could be monitored along the West Gully in future research. This will likely result in more species and individuals, whether fish species or phytoplankton. With a more complete and better picture of the biodiversity of the sub-areas, the results of analyses with the Jaccard Similarity Index, Chi-Square and Oneway ANOVA test will be more reliable.

Although the four target bird species (see Appendix 4) are expected to profit from the construction of the pumping station, it may be better to focus on other bird species, with the exception of the Eurasian spoonbill, whom likely will also profit from this change in the saltmarshes like Eurasian oystercatcher (*Haematopus ostralegus*), common redshank (*Tringa tetanus*) or black-tailed godwit (*Limosa limosa*). Walking a planned route through the saltmarshes and reserving days in the fieldwork schedule solely for bird monitoring are also strongly recommended.

The birds that were monitored were not marked by any indication, which could have resulted in double counting of individual birds at different occasions, even when special attention was given to prevent this problem. Marking the birds does not only prevent double counting, but can also be a great tool for behavior research, indicating the population size of the bird species in the research area or their home range (Juan arizaga, 2012). Trying to quantize the population size of all the bird species in Hallumer-Ryt might be helpful to demonstrate improvement in the future and whether this is because of the pumping station or because of other reasons. However, marking birds can result in disturbance of the population, especially in breeding seasons.

The use of the Jaccard Similarity Index was discussed in Chapter 5. The absence of monitored factors phytoplankton and benthos in the tidal flats prevented the comparison in all subareas. During future research all observed species of the organisms in all subareas should be recorded and compared with the Index and other more suitable indicators to make up for existing shortcomings.

Furthermore, a better impression of the benthos community can be achieved by sampling all major gullies and determining the abundance of more species in Hallumer-Ryt

Additional indication factors should be collected and monitored. Biotic factors like vegetation and macro fauna could be conducted during the summer season. Abiotic physical parameters like turbidity, abundance of dissolved solids and atmospheric pressure and additional chemical parameters could be measured as well. It is possible that these indication factors are relevant for the transition between the inland area, the saltmarshes and the tidal flats of the research area Hallumer-Ryt.

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Appendices

Contents

Appendix 1: Schedule and Products

I. Schedule

The research and other activities will take place over a time period of at least four months. The official starting date is on the 1st of March. The closure of the research, handing in the research papers will be on the 5^{th} of June. Whereas giving presentations and defending the thesis, will be scheduled on an unannounced date at the end of June.

February and March will be the starting months of the research. Students, teachers and supervisors will make each other's acquainted. Other activities are visiting the research area and starting a literature study and research proposal. Administration will be finished and a green light for the research will be given in March. The BMP-workshops will start in week 15.

In April will be making a start with collecting data. Students will spend three or four days of the week in the field. Meanwhile they still follow BMP-workshops and doing a literature study. They also start to think which analyses they can perform with their data and consulting with analysing-teachers.

Collecting data from the field will end in week 20, May. The data will also be analysed in this month and the students will follow the BMP-workshops. The BMP-workshops will be completed in week 24, June. The research will end with handing in the research papers and giving a presentation in the last 2 weeks of June. Depending on the amount of data, these dates can be postponed to the last week of August.

All the planned activities are included in a more detailed way in Table i. In addition, exact submission dates are given in Table ii.

II. Products

Collecting data from the field will end in week 20, May. The data will also be analysed in this month and the students will follow the BMP-workshops. The BMP-workshops will be completed in week 24, June. The research will end with handing in the final report and giving a presentation in the in the end of June. Depending on the amount of data, these dates can be postponed to the last week of August.

	March				April					May					June				
Activity	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Making acquaintance, approval and administration	■	■	■																
Research proposal			■	■															
Attending BMP-workshops				■			■	■	■	■	■	■	■	■	■	■			
Literature study		■	■	■	■	■	■												
Collecting data from the research area						■	■	■	■	■	■	■							
Analysing data											■	■	■	■	■	■	■		
Submitting research																		■	■
Presentation research																		■	■

Table i: Time schedule with planned activities needed to come to the desired end result.

Report to be handed in	Submission date
Research Proposal	10 April 2017
Draft Final Report	17 July 2017
Final Report	1 August 2017

Table ii: Submission dates given for every report that has to be handed in.

Appendix 2: Detailed Data Collection Description

I. Tides in Hallumer-Ryt

Doing research in the saltmarshes in Hallumer-Ryt, primarily fish monitoring in the gullies, meant working with the tide cycle. The tide cycle is the rise and fall of the sea levels because of the earth's rotation and the gravitational forces excreted by the sun and moon. The amplitude of the low and high water level is related to the alignment of the sun and moon which can result in extreme amplitudes of mean high water springs and mean low water springs. During low tide, the gullies fall blank and are unfit for fish monitoring. But with high tide the water flows from the Wadden Sea into the gullies of the saltmarshes and fish monitoring can be done. The tide is not a cycle with a fixed point during the day when its high water and when its low water. Because of this, a fieldwork schedule had to be made with the predictions of high water in Hallumer-Ryt.

The tide cycle consist of two times low water and two times high water in one full day. The water levels during both high tides differ from each other, as does the water levels of both low tides. This difference on water levels in both high and both low tides are depended on the sun and moons position related to the position of the earth. It is expected that when more water flows into the gullies more fish will be caught. For that reason every fish monitoring in the saltmarshes was preferably done during the predicted high tide with the highest water level.

Rijkswaterstaat (an executive agency of the Dutch Ministry of Infrastructure and Environment to manage water to ensure the safety of the inhabitants of The Netherlands) has put tables with predicted tide cycles for harbours on the internet so people can use them for activities which are influenced by the tide. Hallumer-Ryt does not have a harbour, so the predicted water levels of the nearby harbour of Harlingen were chosen as indication of the tide cycle.

The upcoming water of high tide took some time to flow into the gullies. It is expected that the entrance of the gullies are evaluated. When water is rising, it needs to go over this threshold before it flows into the gullies. The time it takes to reach the threshold is estimated to be roughly half an hour. High water levels in the gullies of Hallumer-Ryt were estimated to be half an hour on top of the expected water levels of Harlingen during high tide. Because the water levels is under influence of other factors (rain, wind direction and wind power), it was possible that the incoming water would flow in sooner (or later) than then expected time. Also installation of the fish traps needed to be done in time so the fish could be caught when the water flowed into the gullies. Therefor it was decided to arrive an hour at the locations before the incoming water in the gullies.

II. Data Collection

Data gathering of the assessment of the Hallumer-Ryt will be done in a timeframe of two months, starting from end of March to the first half of May. The method is split up in two parts; the biotic indicator factor, with all its sub-factors and the abiotic indicator factors.

a. Biotic Indicator Factors

Fish Monitoring

Fish monitoring is done in every subarea. The purpose of the fish monitoring is get an impression of which fish species occur in each areas. Fish species that are diadromous were chosen as indication species because they can give an indication of the gradual transition about the fresh water and saltwater ecosystems. Fish monitoring in the inland area also gives an indication if the biodiversity of this subarea is related to the spatial distance to the dyke.

Inland area

The inland area consists of cultivated land surrounded by ditches to manage the water for optimal farming conditions. The ditches are varied from width and depths. Ten locations have been chosen as sample points in this area to do fish monitoring (See Figure i). The location were chosen for characteristics that made it more likely that fish would occur in these places like aquatic plants or variable flow rates. Each location was sampled six times for fish.

Fish monitoring in the inland area was done by using a RAVON fishing net. The ditches were approached slowly to prevent chasing the fish away. With the overhand scooping method, the fish were caught and scooped out of the water (see Figure ii). Of every fish the body length were measured, the species were determined and the number of fish of each species were counted. In the case of the three-spined stickleback (*Gasterosteus aculeatus*), the variation of body morphology was determined and, if possible, the gender was determined. After the data collection the fish were thrown back in the water as quickly as possible to minimize the stress on every animal.

Figure i: Sample locations in the inland area.

Figure ii: Fishing with a RAVON fishing net from the side of the ditch (location M2).

Saltmarshes

The saltmarshes of Hallumer-Ryt have several gullies that are connected with the tidal flats. Two gullies were suitable for fish monitoring in the saltmarshes and are referred as West Gully and East Gully shown in Figure iii.

The West Gully was sampled by using a fish trap with a large mesh size of 1 cm. The trap was installed just before the upcoming tide so the fish that came with incoming water would be caught in time. It was placed under a culvert and covered the whole width of the gully (see Figure iv). When the water flowed back to the Wadden Sea the trap was taken out of the water. The total time of installation in the water was on average of 150 minutes. After retrieving the trap, the body length of the caught fish were measured, the species were determined and the number of each species were counted. In the case of the three-spined stickleback the variation of body morphology and, if possible, the gender were determined. After the data collection the fish were thrown back in the water as quickly as possible to minimize the stress on every animal.

Figure iii: Locations of Fish monitoring and bird monitoring in the Saltmarsh. The yellow markings stand for the fish monitoring locations (WG1, EG1 and EG2).

The East Gully was sampled by using a fish trap net with a small mesh size of 5.5 mm and a shore operated lift net. The trap was installed just before the upcoming tide so the fish that came with incoming water would be caught in time. It was placed under a wooden bridge but was not big enough to cover the whole width of the gully (see **Fout! Verwijzingsbron niet gevonden.**). After

Figure iv: Set up of the traps in the East Gully (left figure) and the West Gully (right figure).

installing, the fish monitoring continued with the shore operated lift net which samples the vertical dimension of the gully. The shore operated lift net has a surface of one square metre and a mesh size of 1 mm. These sampling were done on a sluice operated by It Fryske Gea and was located around a km southeast of the wooden bridge. When the water was retrieving back to the Wadden Sea, the trap was retrieved out of the water. The total time of installation in the water was again on an average of 150 minutes. With both the trap and the shore operated lift net, the body length of the caught fish were measured, the species were determined and the number of each species were counted. In the case of the three-spined stickleback, the variation of body morphology and, if possible, the gender were determined. After the data collection the fish were thrown back in the water as quickly as possible to minimize the stress on every animal.

Tidal flats

Fish monitoring on the tidal flats of the Wadden Sea were limited to one day. However with the help of the of the partner 'Visser van de Kust', an integrated Fishery cooperation that strive for an active participation in projects of managements and research, a fish monitoring could be done on the 11th of May. The sample location was located around two km north of a gully (not one of the two monitored Gullies) in Hallumer-Ryt (see Figure v). The fish were caught by a big fish trap that was installed before the upcoming tide and stayed installed for a whole tide cycle (12 hours). One during the night and one right after the first monitoring during the day. After retrieving the trap, the body length of the caught fish were measured, the species were determined and the number of each species were counted. For the caught European flounder (*Platichthys flesus*) also the mean weight was measured. In the case of the three-spined stickleback the variation of body morphology and, if possible, the gender were determined. After the data collection the fish that were not kept by the fisherman were thrown back in the water as quickly as possible to minimize the stress on every animal.

Figure 10: Location of the tidal flat sampling (TF1). The locations of the Saltmarsh monitoring are shown as well (WG and EG)


Figure vi: Set up of the fish traps on the tidal flat. The picture is facing towards the end of the trap setup and also the north. On the other side had a extended reach of 500 m to the west and to the east. This was done with the aid of long nets with a height around 50 cm (Huizinga, 2017).

i. Bird Monitoring

Bird monitoring was done in every subarea and was meant as additional activity during the fish monitoring. For this research, four species have been chosen because they are expected to be positively affected by the upcoming pumping station. These bird species are the Eurasian spoonbill (*Platalea leucorodia*), curlew sandpiper (*Calidris ferruginea*), common greenshank (*Tringa nebularia*) and the spotted redshank (*Tringa erythropus*). The purpose of the monitoring is get an impression where the four indicative bird species occur in the areas and what kind of behaviour they demonstrate. Some additional observations of the indicative species were given by Japke van Assen (2017), who was doing an internship by ecological consultancy Altenburg & Wybenga.

Inland area

The inland area is highly cultivated and not a suitable living place for the four indicative bird species. During the fish monitoring in the inland area, there was also paid attention if the four birds species were around during the activities of the fish monitoring in the inland area. However, no points of observation were chosen in the inland area to monitor the bird species. If one of the bird species was spotted, the location and demonstrated behaviour were written down. Special attention was given to try not to count the same animals twice.

Figure vii: Set up of the telescope on the EG1.

Saltmarshes

Bird monitoring were done on the saltmarshes during the activities of the fish monitoring. With binoculars and a telescope areas that could be interesting for the four indicative bird species were observed (see Figure vii). Observation locations for bird monitoring were the culvert in the West Gully and the sluice in the East Gully that are also used as fishing locations. An observation point that was used only for bird monitoring was the bunker, west of the West Gully The bunker was a great viewing platform for the saltmarshes of Hallumer-Ryt. If one of the bird species was spotted, the location and demonstrated behaviour were written down. Special attention was given to try not to count the same animals twice.

Tidal flats

Bird monitoring on the tidal flats were limited to one day of fish monitoring with the fishermen of Geintegreerde Visserij on the 11th of May. Because of the difficult accessibility of the tidal flats no materials could be taken to do bird monitoring. Observation was mostly done in the time outside of the fish monitoring activities. If one of the bird species was spotted, the location and demonstrated behaviour were written down. Special attention was given to try not to count the same animals twice.

ii. Phytoplankton

Phytoplankton was collected in the inland area and saltmarshes to get an impression of which phytoplankton families occur, where they occur and if there is a significant difference between the found phytoplankton families and the gradual transition between fresh water and saltwater ecosystems.

Inland area

On the 9th of May, phytoplankton samples were collected in the ditches of fish monitoring sample points (see Figure i). Fish monitoring in the inland area is also done on these locations. The water was filtered with a phytoplankton net with a mesh size of 55 µm. An amount of fifty litre was poured through the phytoplankton net to get a sample with enough amount of water to analyse. The net was also swept ones through the ditches to collect a variety of phytoplankton. This would give a better impression of the biodiversity of the phytoplankton of the sample points. The phytoplankton samples were analysed by interns at Van Hall Larenstein.

Saltmarshes

On the 3th of May, Phytoplankton samples were collected of the West Gully and the East Gully. The collection of the phytoplankton in both gullies were done at the roughly the same distance of the tidal flats and before the incoming water of high tide and after the water was withdrew back into the Wadden Sea. The water was filtered with a phytoplankton net with a mesh size of 55 µm. An amount of fifty litre was poured through the phytoplankton net to get a sample with enough amount of water to analyse. The net was also swept ones through the ditches to collect a variety of phytoplankton. This would give a better impression of the biodiversity of the phytoplankton of the sample points. The phytoplankton samples were analysed by Spanish interns at Van Hall Larenstein.

Tidal flats

No phytoplankton could be collected on the tidal flats because of lack of time, material and budget. Therefore, literature will be used as supporting information for this subarea.

iii. Benthos

Benthos was collected in the inland area and saltmarshes to get an impression of which benthos families occur, where they occur and if there is a noticeable difference between the found benthos families and the gradual transition between fresh water and saltwater ecosystems.

Inland area

Benthos samples were collected on the 8th of May by students of the Hogeschool Zeeland whom were doing a week of field operations nearby the subareas. Hogeschool Zeeland is a collaborative partner in WaD'N Kennis and were willing to help collecting data. Hogeschool Zeeland was also willing to analyse the benthos samples.

Saltmarshes

Benthos samples were collected in the East Gull on the 8th of May. Four sample points were chosen over the length of the gully with roughly the same distance between each sample point on every sample points, three subsamples were collected on each location (see Figure viii) An insertion tube was pushed thirty cm in the silt and taken out. The samples were given and analysed by Hogeschool Zeeland together with the benthos samples of the inland area.

Figure viii: Benthos sample locations in the East Gully.

Tidal flats

No benthos could be collected on the tidal flats because of lack of time, material and budget. Therefore, literature will be used as supporting information for this subarea.

b. Abiotic Indicator Factors

Abiotic parameters have been collected in the inland area and the saltmarshes to get an overall impression of the various types of water. It also indicates if the transition between the two subareas is gradually or not. With the assessment of the water in the Hallumer-Ryt, a prediction can be made how the physics parameter of the water will change after the construction of the pumping station.

i. Physical parameters

Inland area

During the days of fieldwork in the inland area, the waters of every sample point (see Figure ix) were analyzed with the Hanna HI 9829 Multiparameter. The parameters that were measured on these locations were the pH, salinity, conductivity, PSU, water temperature and dissolved oxygen. The multisensory probe measured thirty cm under the water surface if the depth of the waterbodies allowed it. After the analyzing the result were written down.

Figure ix: Used multiparameter suring the course of the field work (Hanna Instruments, Inc., 2017).

Saltmarshes

During the days of fish monitoring in the saltmarshes, both the West Gully and the East Gully were analyzed with the Hanna HI 9829 Multiparameter (see Figure ix). The parameters that were measured in the gullies were the pH, salinity, conductivity, PSU, water temperature and dissolved oxygen. The multisensory probe measured thirty cm under surface water if the upcoming water in the gullies was deep enough to allow this. Measuring the physics parameters were done every ten minutes from begin to end of the fish monitoring took (on average hundred fifty minutes). After every analyzing the result were written down.

Tidal flats

No physics parameters could be collected of the tidal flats. The tight fieldwork schedule only allowed one day of research on the tidal flats. Because of the inaccessibility and the harsh conditions of this area, no materials could be taken along to collect abiotic data. For this reason, literature will be used instead to get an indication of the physical quality of the water of the tidal flats.

ii. Chemical parameters

Chemical parameters have been collected of the inland area and the saltmarshes to get an overall impression of the quality of the various types of water. This also indicates if the transition between the two subareas is gradually or not. With the assessment of the water in the Hallumer-Ryt, a prediction can be made how the waters chemical composition will change after the construction of the pumping station.

Inland area

On the 9th of May, water samples were collected of the water of the fish monitoring sample points (see Figure i). 30 ml of water was first filtered with a paper filter and filtered again of 0.45 µm membrame filter. The samples were analyzed for chemical parameters in the lab of Van Hall Larenstein. The chemical parameters are chloride, nitrate, phosphate and sulfate.

Saltmarshes

On the 3th of May, water samples were collected of both the West gully and the East Gully. 30 ml of water was first filtered with a paper filter. This filtration was filtered again with a membrane filter of 0.45 µm. The collection of the chemical samples in both gullies were done before the upcoming water of high tide and after the water was withdrawing back into the Wadden Sea. The samples were analysed for chemical parameters in the lab of Van Hall Larenstein. The chemical parameters are chloride, nitrate, phosphate and sulfate.

Tidal flats

No chemical parameters could be collected of the tidal flats. The tight fieldwork schedule only allowed one day of research on the tidal flats. Because of the inaccessibility and the harsh conditions of this area, no materials could be taken along to collect abiotic data. For this reason, literature will be used instead to get an indication of the chemical quality of the water of the tidal flats.

Appendix 3: Day by day fieldwork planning

The tables below demonstrate all activities done in all sub-areas of Hallumer-Ryt. Collecting benthos from the saltmarsh was done on one occasion and mentioned specifically. Chemical parameters as well as phytoplankton were collected on two field days and fieldwork on the tidal flats were spread out on an excursion over two days.

Activities in the saltmarsh start an hour after low tide when setting up materials. For example, 11 April has a low tide at 6:00 in Harlingen. Low tide in Hallumer-Ryt expected to be around half an hour later, around 6:30. Another hour is added before the activity is started, which is 7:30.

April – Week 16					
Date	**Time**	**NAP**	**High - Lowtide**	**Research Area**	**Starting time 'Kweldercentrum'**
Wednesday April 19th 2017	02:14	64	HT		
Wednesday April 19th 2017	09:55	-104	LT	In Land Area	10:00
Wednesday April 19th 2017	14:55	84	HT	In Land Area	10:00
Wednesday April 19th 2017	22:36	-97	LT		
Thursday April 20th 2017	03:26	57	HT		
Thursday April 20th 2017	10:45	-99	LT		
Thursday April 20th 2017	15:54	79	HT	East Channel	11:54
Thursday April 20th 2017	23:30	-93	LT		
Friday April 21th 2017	04:45	51	HT		
Friday April 21th 2017	11:45	-91	LT		
Friday April 21th 2017	17:20	79	HT	West Channel	13:20

April – Week 17					
Date	**Time**	**NAP**	**High - Lowtide**	**Research Area**	**Starting time 'Kweldercentrum'**
Monday April 24th 2017	03:36	-117	LT		
Monday April 24th 2017	09:05	74	HT		
Monday April 24th 2017	15:56	-110	LT		
Monday April 24th 2017	21:26	104	HT	East Channel	17:26
Tuesday April 25th 2017	04:37	-123	LT		
Tuesday April 25th 2017	10:06	81	HT		
Tuesday April 25th 2017	16:56	-116	LT		
Tuesday April 25th 2017	22:04	108	HT	West Channel	18:04
Wednesday April 26th 2017	05:28	-125	LT		
Wednesday April 26th	10:50	85	HT	Inland Area	10:00

2017					
Wednesday April 26th 2017	17:45	-120	LT	In Land Area	10:00
Wednesday April 26th 2017	23:06	110	HT		
Thursday April 27th 2017	06:16	-123	LT	East Channel	
Thursday April 27th 2017	11:36	88	HT	East Channel	07:36
Thursday April 27th 2017	18:35	-125	LT		
Thursday April 27th 2017	23:56	109	HT		
Friday April 28th 2017	07:03	-122	LT		
Friday April 28th 2017	12:16	91	HT		
Friday April 28th 2017	19:22	-128	LT		

May – Week 18					
Date	**Time**	**NAP**	**High - Lowtide**	**Research Area**	**Starting time 'Kweldercentrum'**
Monday May 1th 2017	02:06	89	HT		
Monday May 1th 2017	09:00	-111	LT		
Monday May 1th 2017	14:10	94	HT		
Monday May 1th 2017	21:30	-124	LT		
Tuesday May 2nd 2017	02:44	76	HT		
Tuesday May 2nd 2017	09:40	-107	LT		
Tuesday May 2nd 2017	14:45	91	HT	West Channel	10:45
Tuesday May 2nd 2017	22:16	-119	LT		
Wednesday May 3nd 2017	03:45	65	HT		
Wednesday May 3nd 2017	10:29	-103	LT		
Wednesday May 3nd 2017	15:44	89	HT	East and West Channel	11:44 (+Chemical parameters and phytoplankton)
Wednesday May 3nd 2017	23:16	-114	LT		
Thursday May 4th 2017	04:55	58	HT		
Thursday May 4th 2017	11:27	-98	LT	Inland Area	
Thursday May 4th 2017	16:54	88	HT	Inland Area	
Friday May 5th 2017	00:26	-112	LT		
Friday May 5th 2017	06:00	58	HT		
Friday May 5th 2017	12:36	-97	LT		
Friday May 5th 2017	18:15	92	HT	East and West Channel	14:15

May – Week 19					
Date	**Time**	**NAP**	**High - Lowtide**	**Research Area**	**Starting time 'Kweldercentrum'**
Monday May 8th 2017	03:56	-128	LT		
Monday May 8th 2017	09:15	78	HT	East channel	09:00 (Benthos)
Monday May 8th 2017	16:16	-116	LT		
Monday May 8th 2017	21:26	104	HT	East Channel	18:26
Tuesday May 9th 2017	04:45	-125	LT		
Tuesday May 9th 2017	09:54	82	HT	Inland Area	10:00 (+Chemical parameters and phytoplankton)
Tuesday May 9th 2017	16:59	-114	LT	Inland Area	10:00
Tuesday May 9th 2017	22:15	102	HT	West Channel	19:16
Wednesday May 10th 2017	05:28	-117	LT		
Wednesday May 10th 2017	10:25	86	HT		
Wednesday May 10th 2017	17:46	-108	LT		
Wednesday May 10th 2017	22:35	99	HT		
Thursday May 11th 2017	06:06	-109	LT	Tidal Flats	5:00
Thursday May 11th 2017	11:05	92	HT	Tidal Flats	
Thursday May 11th 2017	18:21	-106	LT	Tidal Flats	
Thursday May 11th 2017	23:26	97	HT	Tidal Flats	
Friday May 12th 2017	06:36	-108	LT	Tidal Flats	
Friday May 12th 2017	11:46	98	HT	Tidal Flats	
Friday May 12th 2017	18:56	-107	LT	Tidal Flats	
Friday May 12th 2017	23:55	94	HT		

May – Week 20					
Date	**Time**	**NAP**	**High - Lowtide**	**Research Area**	**Starting time 'Kweldercentrum'**
Monday May 15th 2017	01:00	80	HT		
Monday May 15th 2017	07:58	-113	LT		
Monday May 15th 2017	13:05	95	HT		
Monday May 15th 2017	20:26	-103	LT		
Tuesday May 16th 2017	01:14	69	HT		
Tuesday May 16th 2017	08:26	-110	LT		
Tuesday May 16th 2017	13:35	90	HT	West Channel	09:35
Tuesday May 16th 2017	20:56	-100	LT		
Wednesday May 17th 2017	01:46	61	HT		
Wednesday May 17th 2017	08:56	-110	LT		
Wednesday May 17th 2017	13:54	87	HT	East Channel	10:54
Wednesday May 17th 2017	21:25	-100	LT		

Thursday May 18th 2017	01:55	56	HT		
Thursday May 18th 2017	09:36	-109	LT		
Thursday May 18th 2017	14:34	86	HT	West Channel	11:34
Thursday May 18th 2017	22:16	-100	LT		
Friday May 19th 2017	02:56	52	HT		
Friday May 19th 2017	10:26	-106	LT	Inland Area	10:00
Friday May 19th 2017	15:35	85	HT	Inland Area	10:00
Friday May 19th 2017	23:10	-99	LT		

Appendix 4: Background bird target species

Species description

Eurasian spoonbill

Species name: Eurasian spoonbill or common spoonbill
Latin Name: *Platalea leucorodia*

Scientific classification
Kingdom: Animalia
Phylum: Chordata
Class: Aves
Order: Pelecaniformes
Family: Threskiornithidae

Table i: Characteristics Eurasian spoonbill (BirdLife International, 2016).

Characteristic	
Length	Body: 70-95 cm wingspan: 115-135 cm
Weight	1130-1960 g
Range	Europe and West-Africa to the Red Sea, India and China
Habitat	Fresh and saltwater marshes, estuaries, deltas, tidal creeks, rivers, lakes, reservoirs and mangrove swamps
Diet	Small fish, aquatic insects, shrimps and other invertebrates
Reproductive age	3-4 years
Mean clutch size	3-5 eggs
IUCN Red List	Least concern

Ecology
The distinctively spatulate bill of the Eurasian spoonbill lends this tall, pure white water bird a slightly comical appearance. During the breeding season, adults develop a crest of pointed and drooping plumes, as well as patches of yellow on the upper breast and the tip of the bill. The rest of the bill is black, as are the long legs. The sexes are similar in overall appearance but the male is somewhat larger than the female, with a longer bill and longer legs . Juveniles resemble the non-breeding adults, but have pinkish bills and black tips to the wing feathers.

Species description

Curlew sandpiper

Species name: Curlew sandpiper
Latin Name: *Calidris ferruginea*

Scientific classification
Kingdom: Animalia
Phylum: Chordata
Class: Aves
Order: Charadriiformes
Family: Scolopacidae

Table ii: Characteristics curlew sandpiper (BirdLife International, 2017).

Characteristic	
Length	Body: 18-23 cm wingspan: 38-46 cm
Weight	44-117 g
Range	Siberia and Alaska to Western Europe, southern Africa, southern Africa and Oceania
Habitat	Tidal flats, beaches, wet grassy tundra, mudflats, ponds and lakes
Diet	Insects, crustaceans, mollusks, marine worms and some seeds
Reproductive age	1 year
Mean clutch size	4 eggs
IUCN Red List	Near threatened

Ecology

The curlew sandpiper is a medium-sized shorebird that has very distinctive breeding plumage and an extraordinary down-curved bill. Typically, this beautiful little bird has grey upper-plumage that is almost scaly in appearance, white plumage on the underparts, and a white rump that is noticeable in flight. It has slender, black legs and a prominent white eye stripe that extends back from the eye. However, during the breeding season the adult birds develop striking deep chestnut plumage on the underparts and speckles of red mixed with black and grey on the upperparts. Juvenile curlew sandpipers have a grey and brown body with a peach colouring to the breast.

Species description

Common greenshank

Species name: Common greenshank
Latin Name: *Tringa nebularia*

Scientific classification
Kingdom: Animalia
Phylum: Chordata
Class: Mammalia
Order: Charadriiformes
Family: Scolopacidae

Table iii: Characteristics common greenshank (BirdLife International, 2016).

Characteristic	
Length	Body: 30-35 cm wingspan: 68-70 cm
Weight	125-290 g
Distribution	Europe, Africa, Asia and Oceania
Habitat	estuaries and mudflats, mangrove swamps, lagoons, sewage farms and flooded crops
Diet	Insects, marine worms, mollusks, small fish, crustaceans and occasionally small rodents
Reproductive age	2 years
Mean clutch size	3-5 eggs
IUCN Red List	Least concern

Ecology
The common greenshank is an elegant wading bird with a long, stout, slightly upturned bill and long, yellowish- to greyish-green legs. It has a relatively long neck, and the bill is grey with a darker tip. Outside of the breeding season, the common greenshank is largely grey above and white below, with darker wings, grey streaks on the head and neck, and a whitish tail. Breeding adults have heavy dark streaking and spotting on the upperparts, head, neck and upper breast. At all times of year, this species has a white rump which extends into a distinctive white wedge up the back, visible in flight. The male and female common greenshank are similar in appearance, but females average slightly larger. Juveniles resemble the non-breeding adults, but have browner upperparts with buff edges to the feathers, and more streaking on the neck and breast.

Species description

Spotted redshank

Species name: Spotted redshank
Latin Name: *Tringa erythropus*

Scientific classification
Kingdom: Animalia
Phylum: Chordata
Class: Aves
Order: Charadriiformes
Family: Scolopacidae

Table iv: Characteristics spotted redshank (BirdLife International, 2016).

Characteristic	
Length	Body: 29-33 cm wingspan: 59-66 cm
Weight	125-160 g
Range	Northern Europe and northwestern Russia to eastern China, equatorial Africa and southeast Asia
Habitat	Wooded tundra, fresh and brackish wetlands, sheltered muddy shores, estuaries, lagoons
Diet	Insects, marine worms, mollusks, small fish, crustaceans and amphibians
Reproductive age	1 year
Mean clutch size	4 eggs
IUCN Red List	Least concern

Ecology
The spotted redshank is a medium-sized, elegant wading bird, slightly larger than a redshank. In summer plumage the adults are almost entirely black, save for some white `spotting' on the wings, a white `wedge' on the back showing clearly in flight, and a barred tail. In winter they have a grey back, and paler under parts, with a more prominent eye stripe than a redshank and lacking a redshank's white wing bars. Juveniles have a grey and brown back, a white belly and a peach-coloured breast.

Appendix 5: Monitored Fish Species and Distribution in Hallumer-Ryt

I. Found Fish Species

Species	Latin name	Found in
Ten-spined stickleback	*Pungitius pungitius*	Inland Area
Three-spined stickleback	*Gasterosteus aculeatus*	Inland Area Saltmarsh Tidal Flats
European perch	*Perca fluviatilis*	Inland Area
European bitterling	*Rhodeus amarus*	Inland Area
Common roach	*Rutilus rutilus*	Inland Area
Juvenile Atlantic herring	*Clupea harengus*	Tidal Flats
European flounder	*Platichthys flesus*	Tidal Flats
Common Goby	*Pomatoschistus microps*	Inland Area Saltmarsh
Garfish	*Belone belone*	Tidal Flats
Glass eel (Juvenile European eel)	*Anguilla anguilla*	Saltmarsh
Goby	*Gobiidae (Family)*	Tidal Flats
Squid	*Cephalopod (Class)*	Tidal Flats
Juvenile Stickleback	Gasterosteidae (Family)	Inland Area
Juvenile White mullet	Mugil curema	Saltmarsh
White bream	Blicca bjoerkna	Inland Area
Spined loach	*Cobitis taenia*	Inland Area
European eelpout	*Zoarces viviparus*	Tidal Flats
Common rudd	Scardinius erythrophthalmus	Inland Area
European smelt	*Osmerus eperlanus*	Saltmarsh Tidal Flats
Sand lance	Ammodytes tobianus	Tidal Flats
European bass	Dicentrarchus labrax	Tidal Flats
Tench	Tinca tinca	Inland Area

Table i: All found fish species in the subareas of Hallumer-Ryt and their Latin names

II. Distribution of Species in Sub-areas

Figure i: Distribution of fish species in the inland area

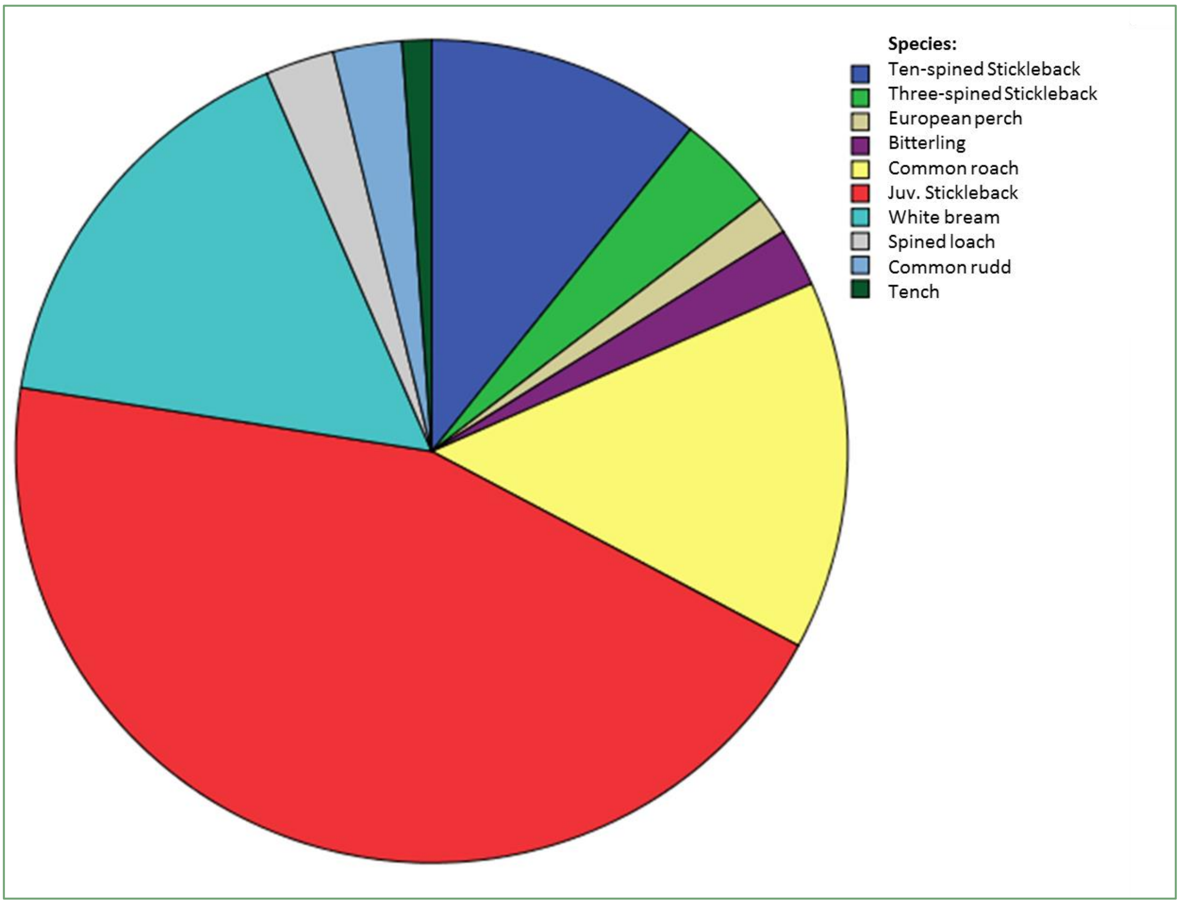


Figure i: Distribution of fish species in the inland area

Figure ii: Distribution of fish species in the saltmarsh

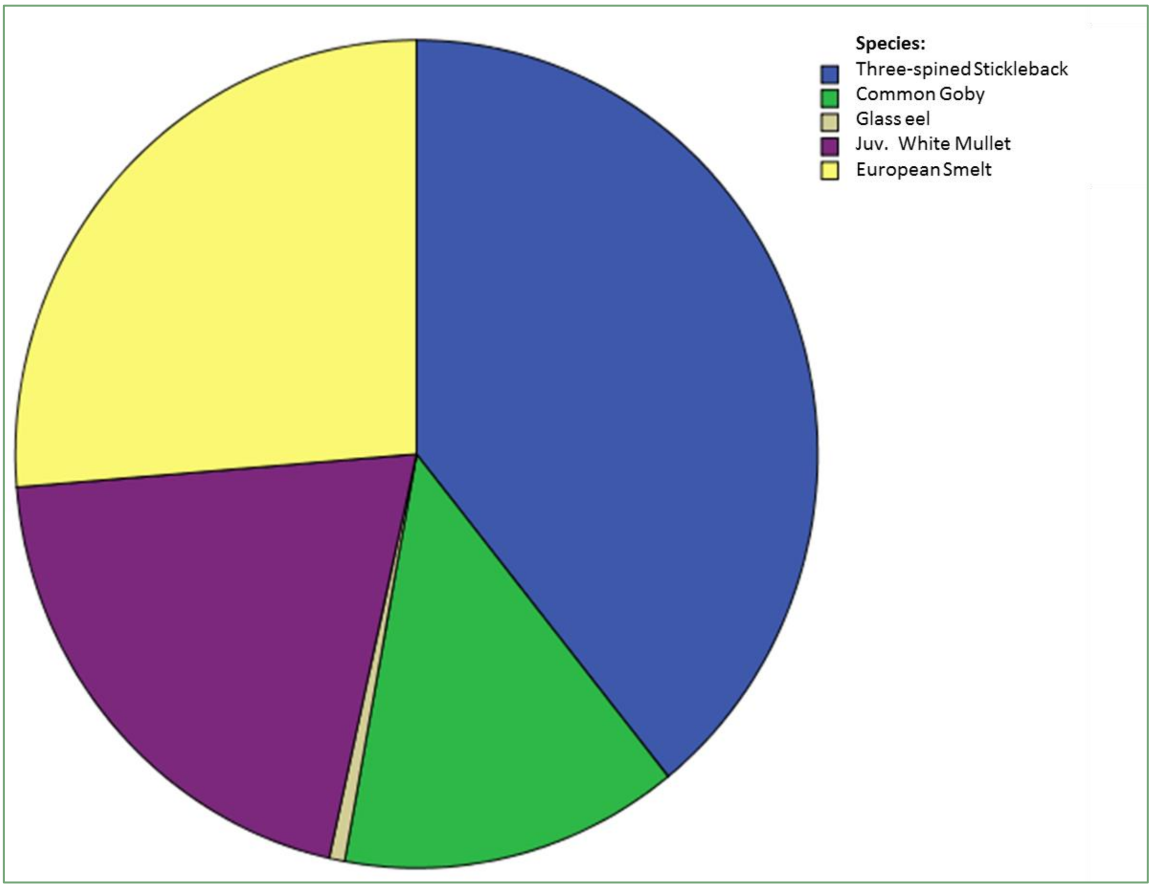


Figure ii: Distribution of fish species in the saltmarsh

Figure iii: Distribution of fish species in the tidal flats

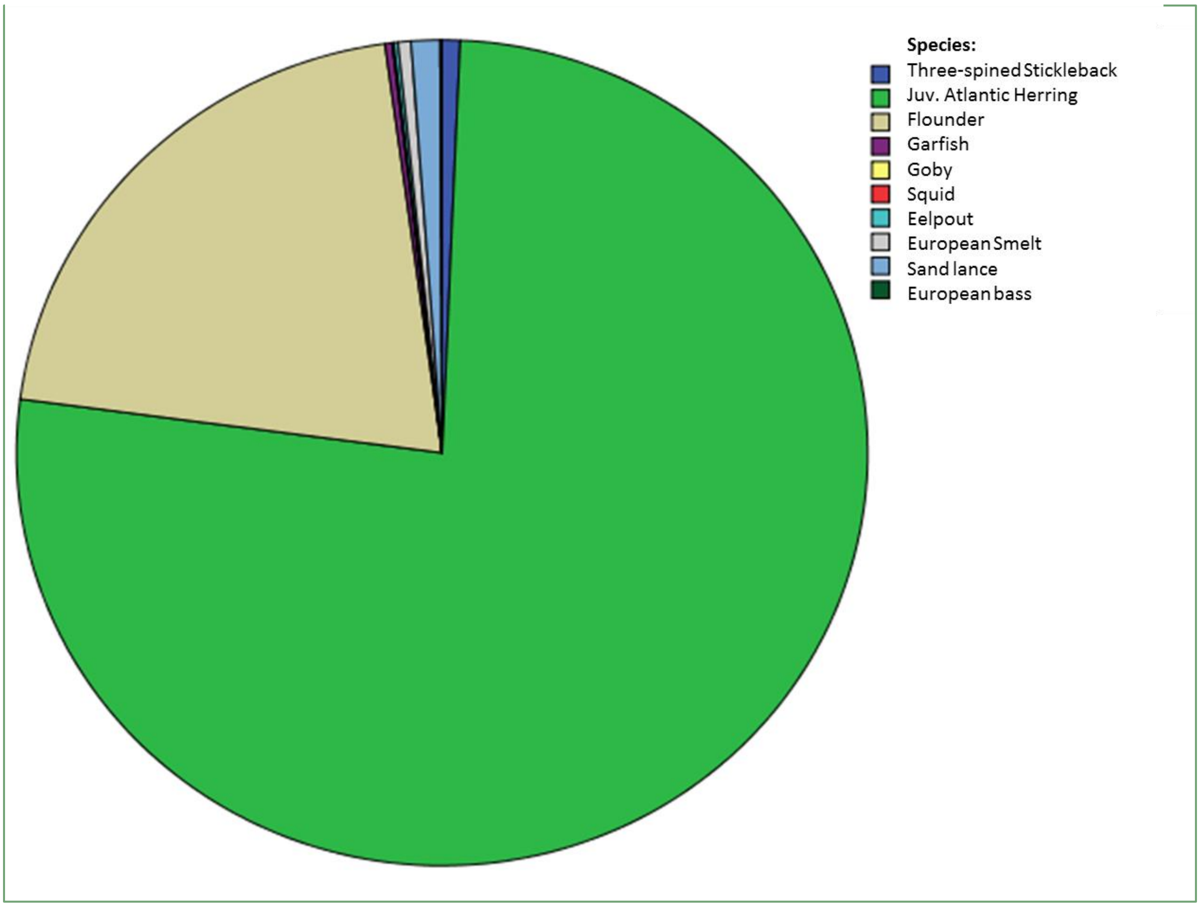


Figure iii: Distribution of fish species in the tidal flats

III. Chi-Square Test Distribution All Fish Species in Subareas

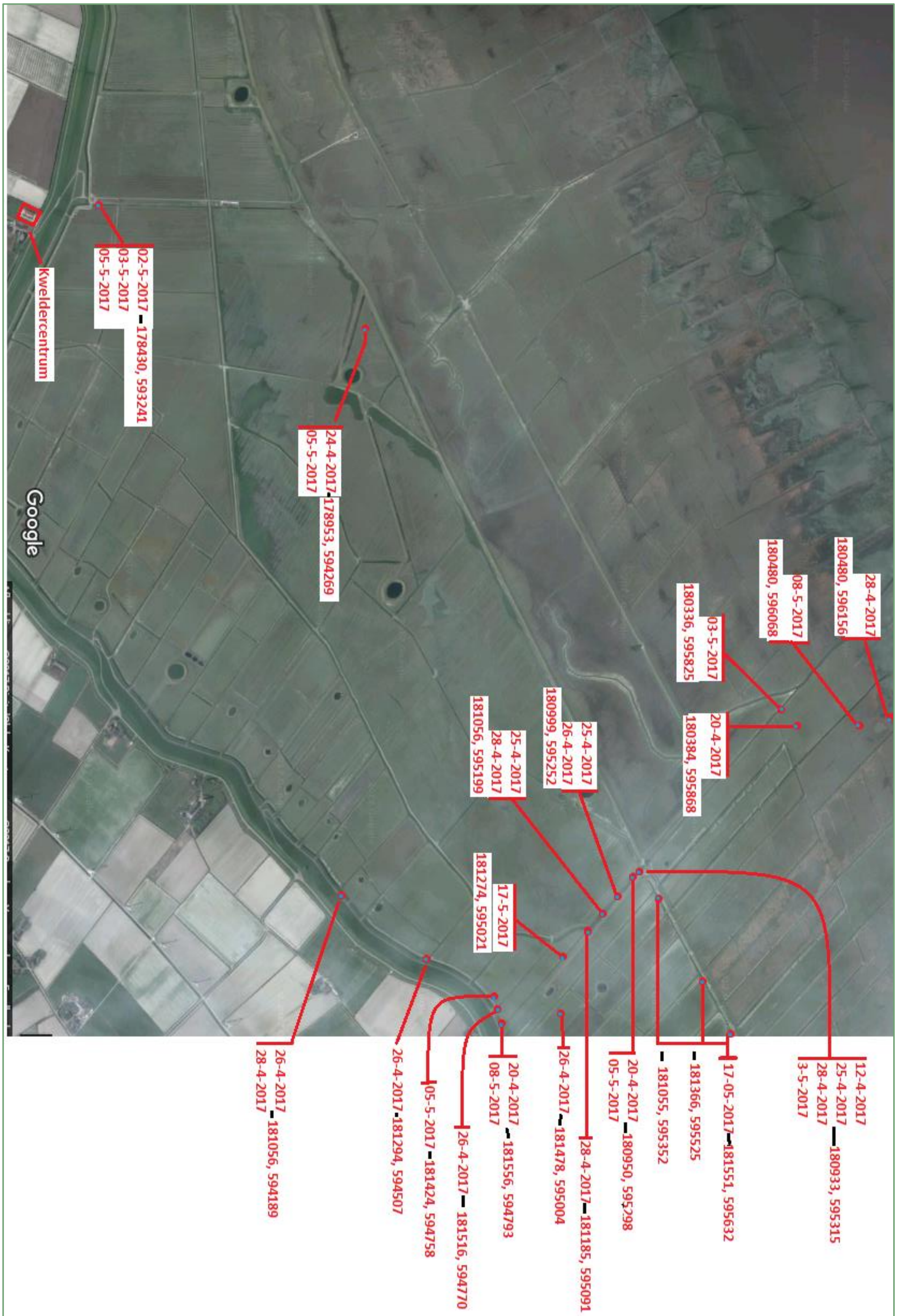
Species* sub-area

			Sub-area			Total
			Inland	Saltmarsh	Tidal Flats	
Species	Juv. Stickleback	Count	117	0	0	117
		% within Wad/Kwel	45.2%	0.0%	0.0%	3.2%
	Ehite Bream	Count	42	0	0	42
		% within Wad/Kwel	16.2%	0.0%	0.0%	1.2%
	Common roach	Count	38	0	0	38
		% within Wad/Kwel	14.7%	0.0%	0.0%	1.1%
	Ten-Spined Sticklebac	Count	25	0	0	25
		% within Wad/Kwel	9.7%	0.0%	0.0%	.7%
	Spined loach	Count	7	0	0	7
		% within Wad/Kwel	2.7%	0.0%	0.0%	.2%
	Common rudd	Count	7	0	0	7
		% within Wad/Kwel	2.7%	0.0%	0.0%	.2%
	Bitterling	Count	6	0	0	6
		% within Wad/Kwel	2.3%	0.0%	0.0%	.2%
	European perch	Count	4	0	0	4
		% within Wad/Kwel	1.5%	0.0%	0.0%	.1%
	Tench	Count	3	0	0	3
		% within Wad/Kwel	1.2%	0.0%	0.0%	.1%
	Three-spinde Sticklebac	Count	10	278	18	306
		% within Wad/Kwel	3.9%	39.5%	.7%	8.5%
	European Smelt	Count	0	175	13	188
		% within Wad/Kwel	0.0%	24.9%	.5%	5.2%
	Juv. White mullet	Count	0	164	0	164
		% within Wad/Kwel	0.0%	23.3%	0.0%	4.5%
	Common Goby	Count	0	80	0	80
		% within Wad/Kwel	0.0%	11.4%	0.0%	2.2%
	Glass eel	Count	0	6	0	6
		% within Wad/Kwel	0.0%	.9%	0.0%	.2%
	Juv. Atlantic Herring	Count	0	0	2030	2030
		% within Wad/Kwel	0.0%	0.0%	76.4%	56.1%
	Flounder	Count	0	0	552	552
		% within Wad/Kwel	0.0%	0.0%	20.8%	15.3%
	Sand lance	Count	0	0	29	29
		% within Wad/Kwel	0.0%	0.0%	1.1%	.8%
	Gar fish	Count	0	0	7	7
		% within Wad/Kwel	0.0%	0.0%	.3%	.2%
	European eelpout	Count	0	0	4	4
		% within Wad/Kwel	0.0%	0.0%	.2%	.1%
	European bass	Count	0	0	2	2
		% within Wad/Kwel	0.0%	0.0%	.1%	.1%
	Goby	Count	0	0	1	1
		% within Wad/Kwel	0.0%	0.0%	.0%	.0%
	Squid	Count	0	0	1	1
		% within Wad/Kwel	0.0%	0.0%	.0%	.0%
Total		Count	259	703	2657	3619
		% within Wad/Kwel	100.0%	100.0%	100.0%	100.0%

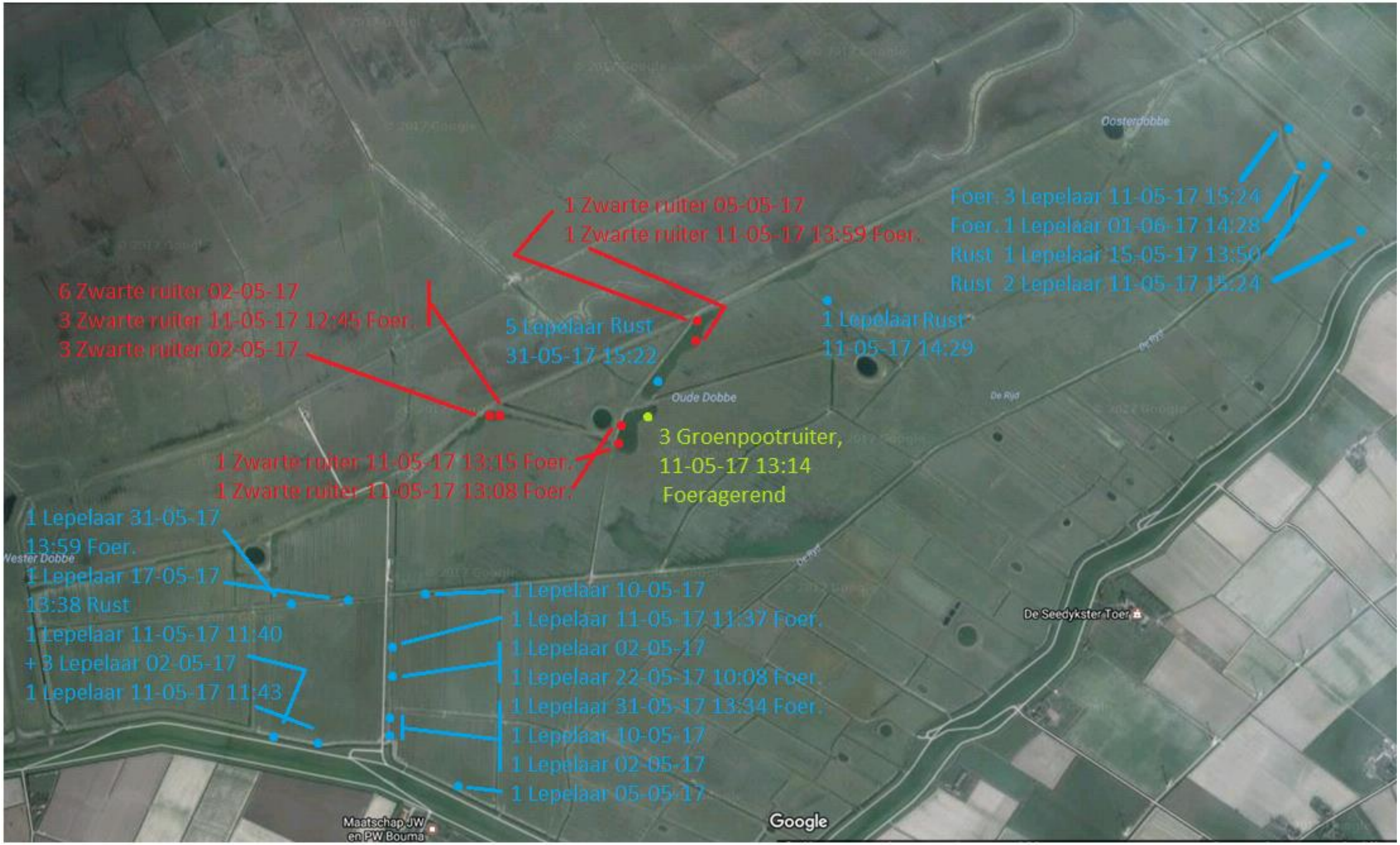
Table i: Distribution of all found fish species in the sub-areas of Hallumer-Ryt

Appendix 6: Monitored Bird species in Hallumer-Ryt

I. Distribution of Species in Saltmarsh



Map i: The first map displays the Eurasian Spoonbills monitored between 12-04-2017 and 19-05-2017.



Map ii: Birds monitored by Japke van Assen between 02-05-2017 and 01-06-2017 (van Assen, 2017)

II. Distribution of Behaviour in Species

Table ii shows the label locations of the two regions along the East Gully which relate Figure iv and v and the distance to dike. The first region is closer to the dike and the second region is closer to the tidal flats.

Sub-Area	Label Locations	North/South from Dyke	Distance from Dyke
Salt Marsh	EG First Region	North	2000-885
Salt Marsh	EG Second Region	North	885-0

Table ii: Distance to dike of the two regions along the East Gully

Figure iii: Behaviour Eurasian spoonbill in saltmarshes

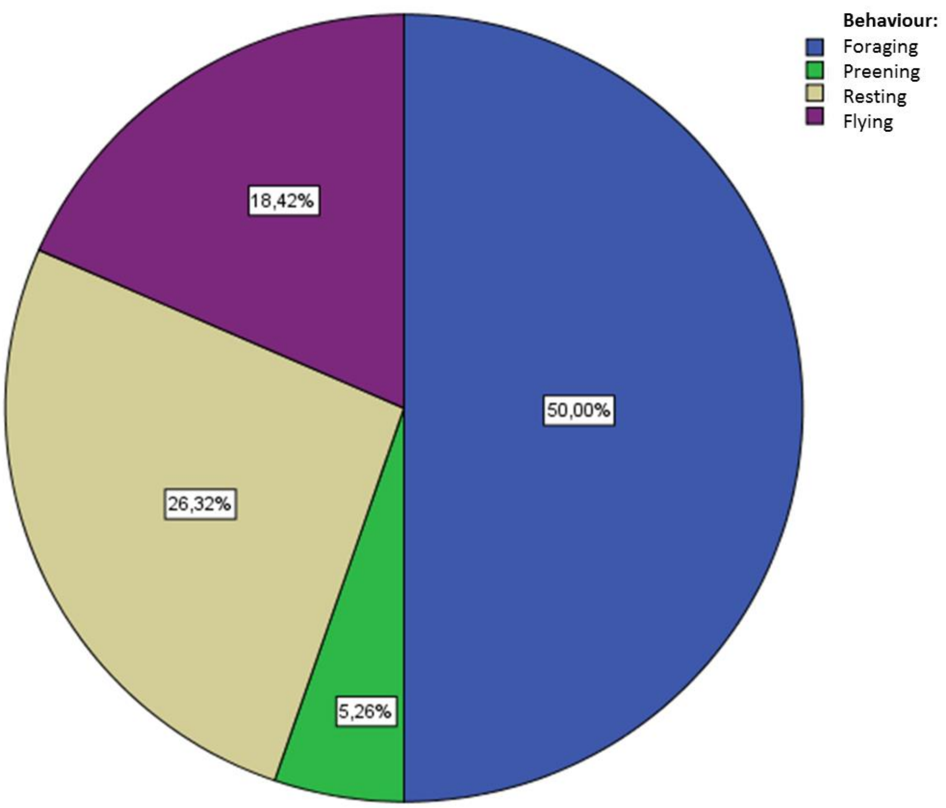


Figure iii: Behaviour Eurasian spoonbill in saltmarshes of a total of 89 individuals.

Figure iv: Behaviour Eurasian spoonbill in East Gully first region

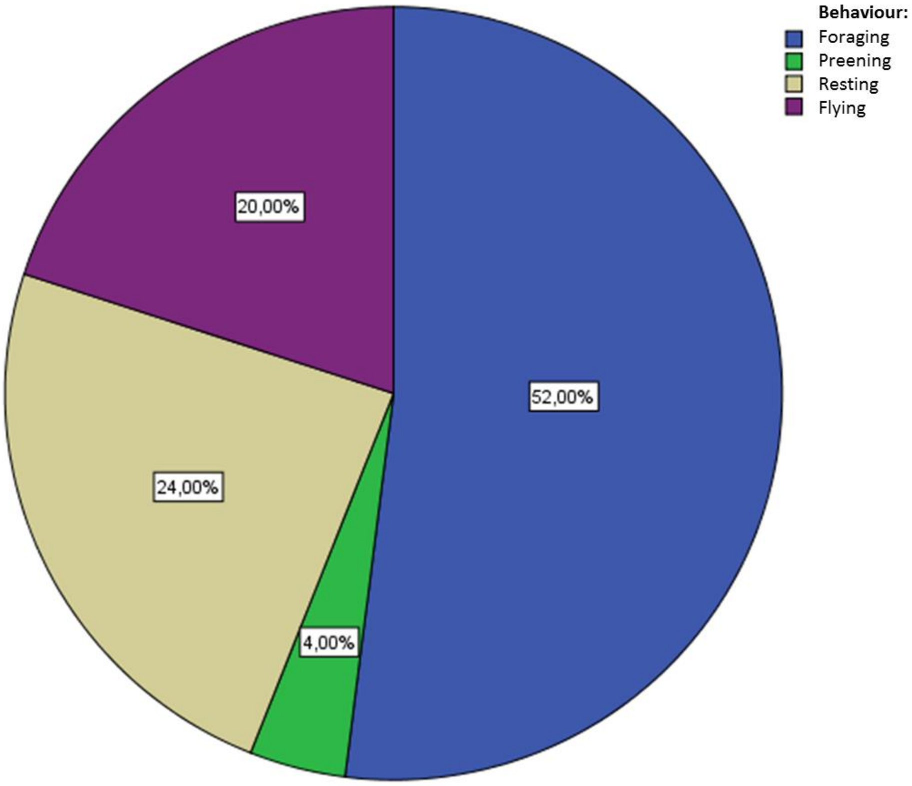


Figure iv: Behaviour Eurasian spoonbill in East Gully first region which stretches from EG1 to the dike of a total of 60 individuals.

Figure v: Behaviour Eurasian spoonbill in East Gully second region

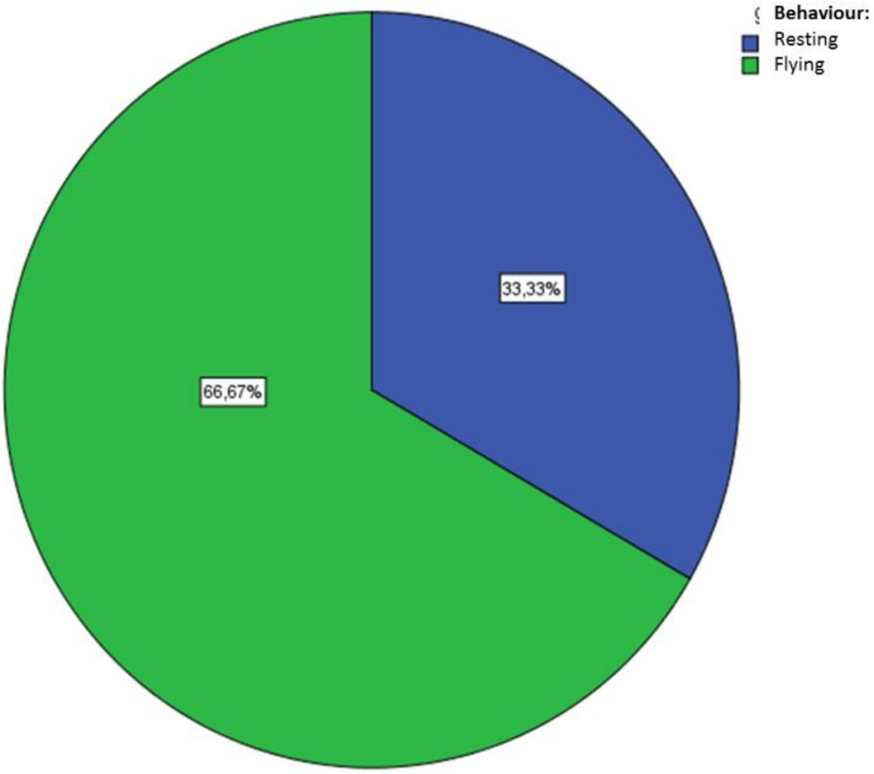


Figure v: Behaviour Eurasian spoonbill in East Gully first region which stretches from an area close to the tidal flats to the EG1 of a total of 9 individuals

Appendix 7: Monitored Abiotic Factors Hallumer-Ryt

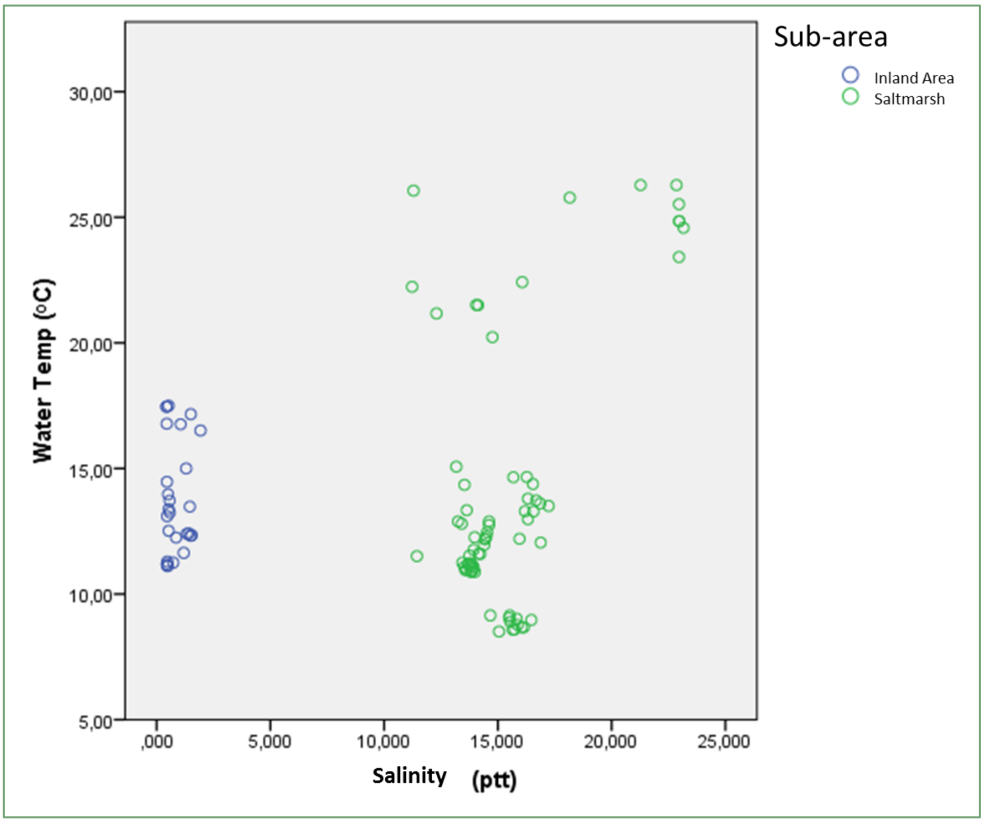


Figure vi: Measured water temperature against salinity. Subareas are indicated with colours in the graph.

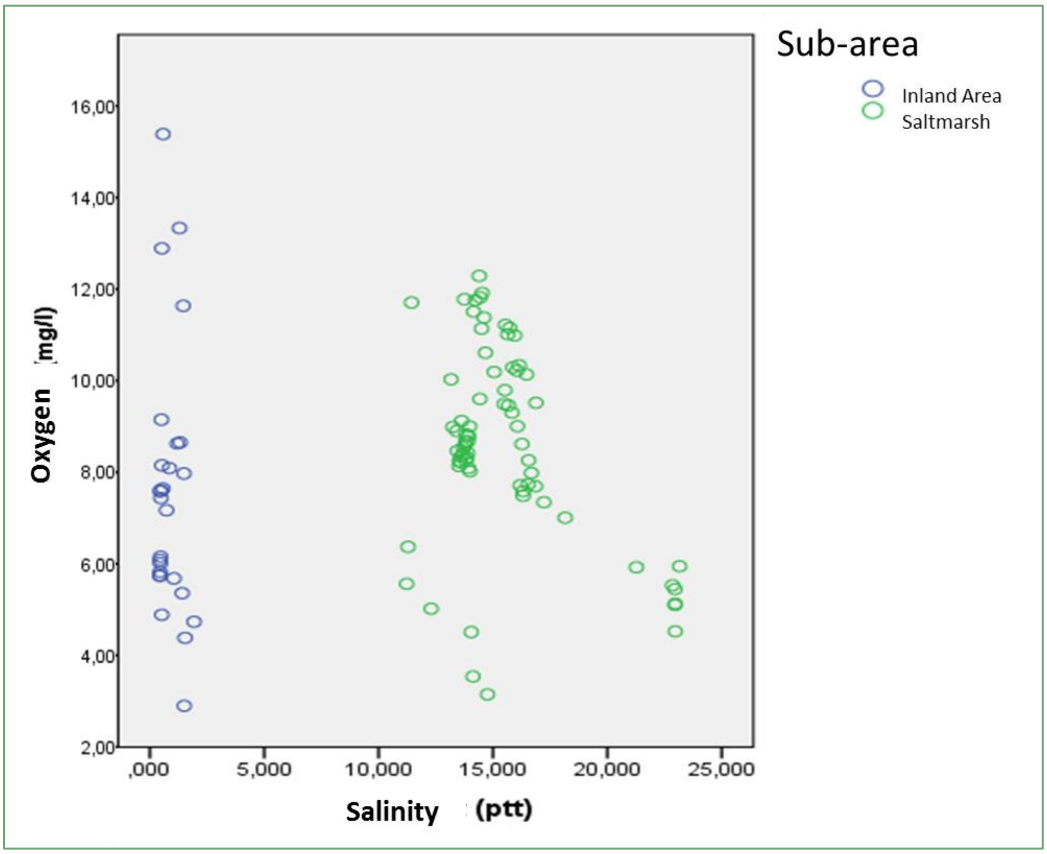


Figure vii: Measured oxygen against salinity. Subareas are indicated with colours in the graph.

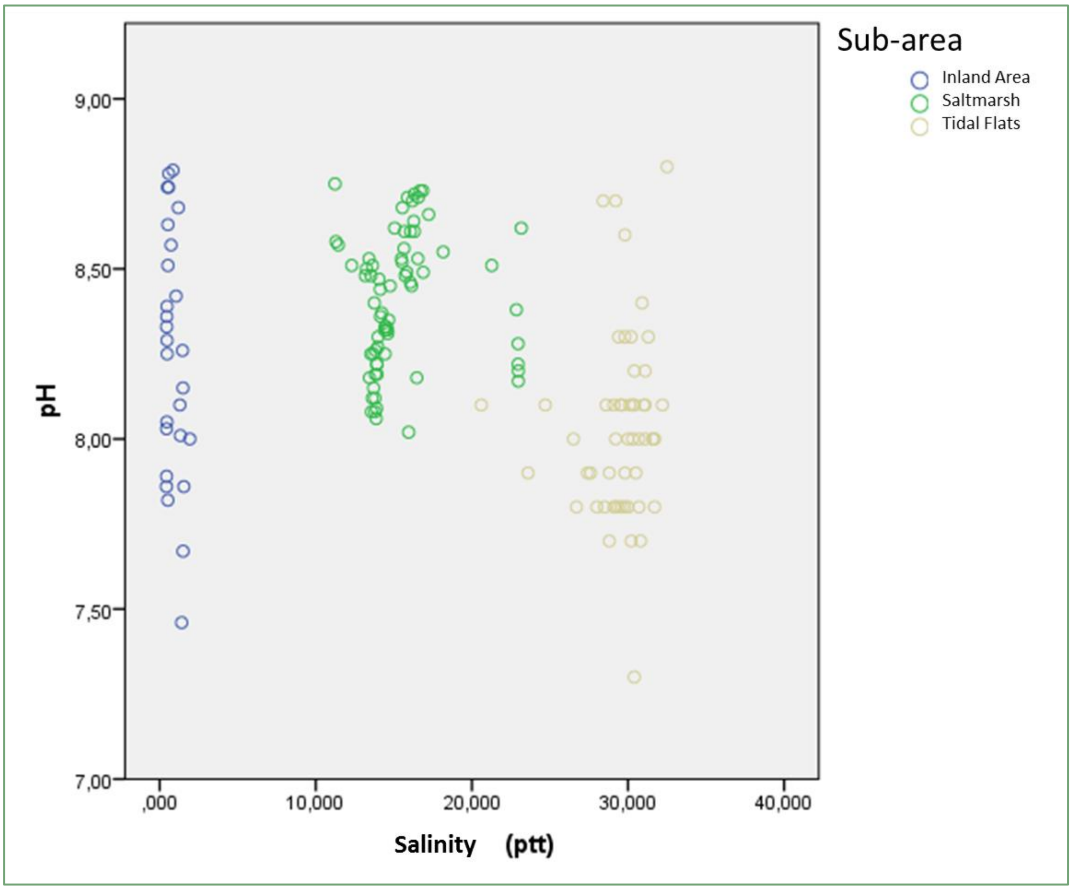


Figure vii: Measured oxygen against salinity. Subareas are indicated with colours in the graph.