Work Placement Report

"Monitoring of the ecological and morphological changes of the sand nourishment pilot on the Galgeplaat"

Aquatic Ecotechnology
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Work placement

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ABSTRACT

The construction of the storm surge barrier in the South delta of the Netherlands in order to protect land from flooding has impacted the estuarine dynamics. The water flow and the transport of sediments has notably decreased, leading to the phenomenon of “sand hunger” in the Eastern Scheldt. The main consequence of this high demand of sand is the disappearance of the intertidal areas, important zones for the ecology of the region (principally for benthic fauna and birds).

One of the short term experimental solutions to preserve these valuable habitats is to nourish them to compensate the loss of sand. Thus, a pilot sand nourishment was executed on the Galgeplaat in July 2008 by Rijkswaterstaat, in the framework of the Building with Nature program (BwN). An elaborate program was then set up to monitor impacts of the nourishment and assess its changes, in term of ecology and morphology. This monitoring program includes field measurements (sediments analysis, morphological survey) and the installation of an Argus video system, located on the South border of the suppletion. Based on a platform of 15 m high, the Argus station is composed of four fixed cameras, a moveable camera, a solar panel system, a computer and a wireless link, and a wave monitor.

Several hypothesis linked with morphological changes, birds and benthic fauna distributions need to be verified in order to determined if the test is, in a general way, successful. The study of these modifications and impacts is done by several organisations such as Rijkswaterstaat, IMARES and Deltares.

First, this report evaluates the performances of the Argus video system, specifically for the analysis of the nourishment. In this objective, a comparison of morphological results provided by the system and field measurements is performed. It shows that the monitoring of the morphology with Argus is possible by mapping waterlines, except for the North of the suppletion which is too far from the station.

Then, impacts of the nourishment and its modification have been assessed. Birds distribution was first studied thanks to the Argus system, in order to gauge the effects of the pilot nourishment on the birds population. The main conclusion is that the nourishment has impacted their distribution since a smaller number of birds is seen on the suppletion than on the undisturbed surroundings. It has also be seen that the nourishment as a function of resting place for birds when the area is the only zone discovered (before low and high tide) whereas the other zones of the Galgeplaat are used for feeding. Nevertheless, a lot of Argus pictures are blurred (three days per month have around 50% of blurred pictures), leading to a decrease of the quality of the results, although a stiffening of the platform has already improved the quality of the images. Some parameters of the Argus station need also to be modified to provide a more representative analysis of birds (increase of the number of pictures per day for instance).
Moreover, morphological changes of the nourishment have been studied with the Argus system since it has been previously validated. It enables to see the moving of the entire zone to the North, as well as the smoothening of the slope of the suppletion (the nourishment is becoming more uniform) but these changes appear slowly.
Finally, a link between the moisture level of the sand (wet, moist or dry) and the benthic fauna has been performed, to verify the hypothesis that wet areas are favourable for the benthic fauna growth. A

distinction within the different levels of moisture (dry-moist, moist and wet) is difficult but the analysis shows that dry areas seem not favourable for the development of benthic fauna.

The analyses that were carried out here do not show that the nourishment is currently valuable for the population of birds but the nourishment is too young to offer large place for feeding. The monitoring of the pilot needs to be continued to evaluate the long term impact on the ecological values of the Galgeplaat since nourishment could offer nice habitat for benthic fauna (notably on the wet areas) and consequently food for many birds.

A- INTRODUCTION

1. Background

The south-western part of the Netherlands is formed by the Rhine/Meuse/Scheldt estuary complex and consists of several islands and tidal areas. This delta area experienced a large flood in 1953 as a consequence of a severe storm in the North Sea basin. Human and economical damages were enormous (more than 1850 people drowned, equipment and infrastructure were damaged, the fertile land became salty) [B.J.A Huisman & A.P. Luijendijk (2009).]

In order to prevent future flooding, a special study group called 'delta commissie' was appointed. One of the solution advised by this committee was the closure of several tidal basins, under which the Eastern Scheldt. A serious debate concerning this closure opposed environmental groups, oysters and mussel industries and most of the inhabitants of the area. The construction of an open barrier formed by 63 gates appeared as a compromise to keep the Eastern Scheldt as a tidal and a salt water area while preserving the land from inundations. The realization of the Dutch Delta project was initiated in 1959 and ended in 1986 by the construction of the open storm surge barrier at the Eastern Scheldt inlet. The map in Figure 1 presents the barriers and the dams constructed as a part of the Dutch Delta work.

Figure 1: The Delta area since the Delta work

Nevertheless, the Eastern Scheldt project caused disturbance in the dynamic equilibrium of the tidal basin and a new equilibrium has to be reached. The characteristics of the tidal area have changed such as the diminution of the tidal prism and of flow velocities and the reduction in the import of sediments. As the tidal prism has decreased due to the construction, channels tend to trap sediments to decrease their cross-sectional area. Sediments are normally imported from the input water, but as the total amount of water has been really reduced, channels borrow sediments from shoals. This phenomenon can also be explained by the fact that the action of tides which builds up the intertidal areas (sedimentation) has really decreased since the Delta work whereas the impact of waves has remained the same (erosion). Sediments from the flats now fill up the channels of the estuary. One of the consequences of the dynamics modification is the disappearance of these intertidal zones, which play an important role in the Eastern Scheldt ecological values. Indeed, these places provide a habitat (food and environment) for many species. Their disappearance therefore impacts biodiversity in general and birds and seal population in particular.

The erosion of these flat areas concerns 50-100 ha each year, which is equivalent to a loss of 50 football fields. The volume of sand eroding per year is roughly of 1 million m^3. Furthermore, without human intervention, it has been estimated that only 1500 ha of intertidal area will remain in the Eastern Scheldt by 2075, which would induce a loss of more than 11,000 ha since 1986. Nevertheless, the total volume of sand needed to stop this eroding process would be approximately of 500 million m^3 [B.J.A Huisman & A.P. Luijendijk (2009).], which appears not feasible, in term of costs and technical means.

One of the experimented short term solutions to combat the loss of intertidal areas is to nourish them, in order to compensate sand lost in the channels and therefore achieve an equilibrium between sand import (sedimentation and nourishment) and export (erosion). A nourishment on the Galgeplaat in the Eastern Scheldt was executed by Rijkswaterstaat in 2008. An elaborate program of measurements has been set up in the sand nourishment to monitor ecological and morphological changes in the Galgeplaat. This program comprises two distinct parts: one composed of field measurements and another one linked with the installation of an Argus-Bio station. This latter has been installed after the building of the nourishment by the organization Ecoshape-Building with Nature. Thus, morphological surveys, birds censuses and sediments analysis are made regularly. Sediments analysis are made by IMARES and are mainly focused on the analysis of the benthic fauna whereas morphological studies are usually carried out by Rijkswaterstaat. In addition, the Argus-Bio station, composed of four fixed cameras and one moveable camera provide additional results by means of pictures taken every days. The different ways of monitoring are detailed later in this report (B- MONITORING OF THE SAND NOURISHMENT

Figure 2: The Eastern Scheldt, the Netherlands. In blue, the Galgeplaat or also called the Vondelingsplaat

2. The project

The project is part of the Dutch national programme of EcoShape-Building with Nature (BwN), which is an innovative programme aiming at "developing hydraulic engineering infrastructure while creating opportunities for nature at the same time". Starting in 2008, the programme BwN comprises several projects mainly in the Netherlands but also worldwide (Singapore for instance). One of the case studies of the BwN program considers the South-Western Delta area of the Netherlands. The present report is part of this case, notably with the project ZW 2 "Short and medium term solutions: stabilise intertidal areas", implemented to stabilise intertidal areas and gauge the effects of short and long term solutions executed in the Eastern Scheldt. The project is particularly part of the sub-program ZW 2.2 "Monitoring impact of nourishment Galgeplaat".
The project is lead in collaboration with Rijkswaterstaat (a department of the Dutch Ministry of Transport Public Work and Water Management), notably with the ANT project (Autonomous Negative Trend project). Several organizations such as IMARES (Institute for Marine Resources & Ecosystem Studies), NIOO-CEME (Netherlands Instituut voor Ecologie) and Deltares Institute are also involved at different phases of the project.

The monitoring of the sand nourishment aims at determining if the test is in a general way successful and point at discussing the possibility of extending the nourishment to a larger scale. One of the questions to be answered is the following: What have been the morphological changes on the Galgeplaat since the sand nourishment and how is the fauna of the area affected by this measure? Several sub-questions need to be studied to find an answer to this main question:

- ***1- What are the morphological changes of the nourishment?***
  - a- Does the sand stay in place ?
  - b- Does the nourishment keep its initial shape ?
  - c- Is there an extension of dry areas on the nourishment ?
  - d- What is the evolution of wet, moist and dry areas on the nourishment during a tidal phase / along one year ?

- ***2- How have the ecological values of the Galgeplaat been affected by the nourishment pilot?***
  - a- How is the birds population affected by the sand nourishment ?
  - b- Does the benthic fauna recover from the creation of the nourishment?
  - c- Is the benthic fauna distribution on the nourishment related to the wet and moist areas location ?
  - d- What is the impact of the nourishment on the mussels population of the Galgeplaat?

- ***3- How have the hydrodynamic characteristics been affected by the pilot ?***
  - a- Is there a decrease in wave height ?
  - b- Is there a change in water flow?

The first objective of this report is to evaluate the Argus-Bio system set-up to monitor specifically the pilot nourishment on the Galgeplaat and answer some of the previous questions. Thereby, the report will give recommendations to improve the system thanks notably to the comparison of both kind of measurements (Argus monitoring and field measurements).

Furthermore, some questions concerning the impacts of the suppletion and its modifications will be answered, but the present report will only target the sub-questions concerning birds and morphological modifications (1a, 1b, 1c, 1d, 2a and 2c). Several hypotheses connected to these aspects can be formulated. Verifying these assumptions will enable to know if the pilot is successful and how it has affected the fauna of the area. Morphological changes on the nourishment have then to be monitored in order to precisely determine the speed and the trends of modifications. Hypotheses about wet areas and ecology will check part of the chain reaction of an ecosystem: growth of benthic fauna and consumption of it by birds.

Studied hypotheses:

- The suppletion is constantly affected by morphological changes.
- The sand nourishment has affected bird numbers and birds spatial distribution.
- The location of wet, moist and dry areas on the nourishment affects benthic fauna (population and distribution): wet areas are more valuable for the benthic fauna growth.
- The distribution of birds is linked to the presence of macro-fauna.
- The presence of wet areas on the nourishment is beneficial for the presence of birds.

To verify these hypotheses, the pictures that have been taken so far by the Argus station cameras will be analysed. Firstly, birds will be studied by analyzing trends of occurrence and birds number. Secondly, morphological changes on the suppletion will be gauged, after the evaluation of the Argus technique for this use. Finally, a link with wet, moist and dry areas and benthic fauna will be studied. A connection with field measurements will be done when possible (link between benthic fauna and wet areas for instance).

B- MONITORING OF THE SAND NOURISHMENT

1. The sand nourishment

A pilot experiment was carried through on the Galgeplaat in July 2008 by the Rijkswaterstaat. First, a bank of clay has been built to maintain the sand in place. Then, 130 000 m^3 of sand (particles with a size of approximately 200 µm) were moved to form a disk of roughly 0.70 m high and thus a supplementation of around 15 ha. The finished suppletion has a diameter of around 500m. The sand used for the construction was extracted during the maintenance dredging of two adjoining shipping lanes: the White Tons Nestle and the Brabant fairway.

The following pictures show the creation of the new zone and its location on the Galgeplaat.

Figure 3: The sand nourishment creation and it location on the Galgeplaat

The following maps present the bed elevation of the Galgeplaat for two days, before and after the building of the nourishment.

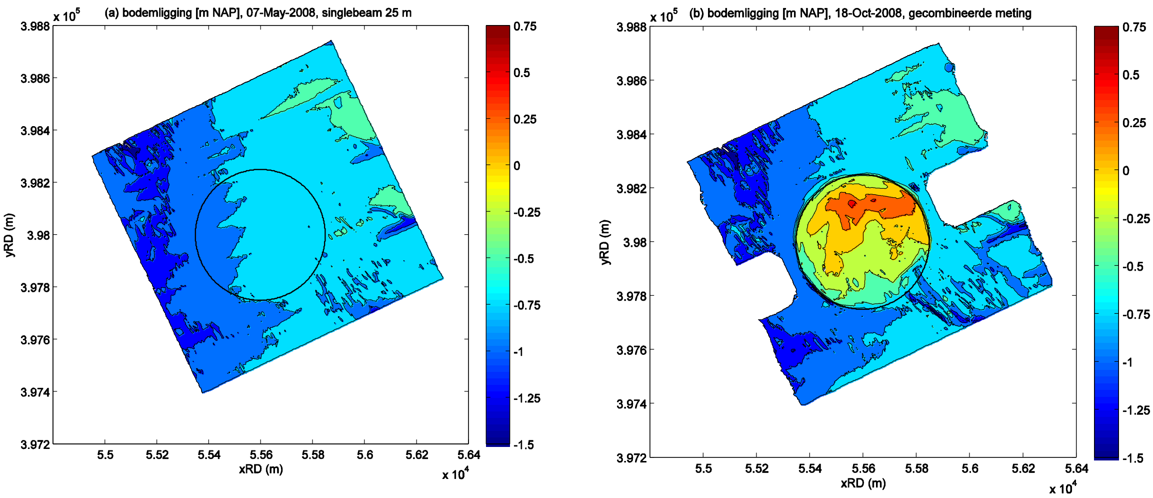


Figure 4: Bed elevation of the nourishment before (7/05/2009) and after (18/10/2009)

Bathymetry data show that the sand has not been spread uniformly since there is a higher zone on the North (in red on the map).

2. The Argus Video system

2. 1. The system in general

The Argus system is a video monitoring technique that enables the collection of information with the use of several cameras.

The Argus video systems were developed in 1992 thanks notably to the discovery of the time exposure technique. Video monitoring techniques are now commonly used to map and analyse coastal development since they provide data at low cost. By this way of monitoring, information is given at different scales ranging from days to weeks, and from meters to kilometres.

Coastal managers and engineers need to have information about coastal processes so as to adapt the variety of functions of the coast in a sustainable way. The video system aims at analyzing functions and aspects such as recreational activities, shipping function, safety against flooding and nature conservation.

An Argus Video system is typically composed of four or five cameras, allowing to monitor about 5 km of shorelines. They are situated, with a field computer and a wireless connection, on a high location along the coast. The cameras collect pictures regularly (every hours for instance) and the images are then send to the local system. All the data are saved in an archive computer.

The Argus cameras gather three types of images: a snapshot, a time exposure and a variance image. These images aim at a different functions since they do not indicate the same kind of information. The first kind of pictures, the snapshot images do not provide a lot of information and just serve for documentation for ambient conditions (weather for instance). Time exposure images are a average of ten minutes of the landscape and they are used to map shorelines and analyse changes in beach morphology. Indeed, they average natural modulations in waves breaking and show a smooth line of waves breaking. They also do not reveal temporarily and moving objects such as ship and people. Finally, variance images give information for the regions moving in time (like the sea surface) and this kind of images may help to identify moving regions from the unchanging zones (like dry sand for instance).

The three types of images are presented in Figure 5 (left to right: snapshot image, time exposure image and variance image).

Figure 5: The Argus system three types of images, station Egmond, The Netherlands (left to right: snapshot, time exposure and variance image)

2. 2. The Argus Bio station on the Galgeplaat

2.2.1. The station

To assess impacts of the sand nourishment pilot in the Eastern Scheldt, an Argus-Bio monitoring station has been installed in 2009 on the Galgeplaat. This station will be used in a integrated way, to analyse both ecological and morphodynamic aspects on the sand nourishment.

The station is based on a platform of 15 meters high, which is located on the south border of the sand nourishment. The system on the Galgeplaat is composed of four fixed cameras (C1, C2, C3 and C4) and one moveable camera (axis). To assure the energy supply, the connection with the archive system and the good functioning of the camera, the station also contains a solar panel system, a computer, a wireless data link, a wave monitor and a camera cleaning system.

The following pictures show the Galgeplaat Argus-Bio monitoring station (on the right photos) and its installation (left picture).

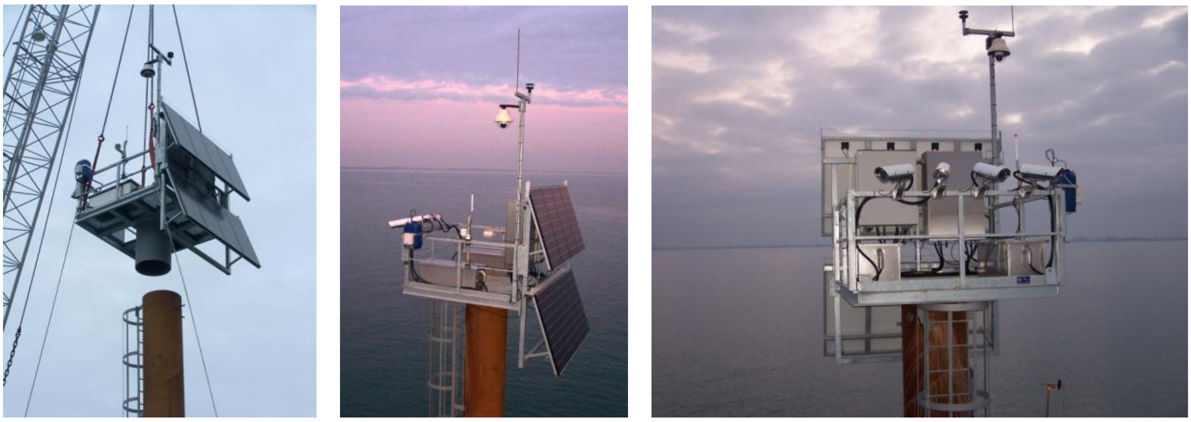


Figure 6: The Argus-Bio monitoring station

2.2.2. Setting and characteristics

Several parameters have been defined previously for the cameras:

- The moveable camera takes photos in four concentric circles, with a defined zoom and tilt (circle A: zoom 3700, tilt 45° ; circle B: zoom 5500, tilt 32.85 ; circle C: zoom 6500, tilt 23.40 ; circle D: zoom 7700, tilt 18). The circles contain each a different number of pictures (circle A: 16, circle B: 24, circle C: 36 and circle D: 48). [Ilse De Mesel & Tom Ysebaert (2009).]
- The moveable camera takes picture once a day, at low water level of a tidal period
- The fixed cameras take photos every day, with a step of 30 minutes (normal interval). Nevertheless, in order to gauge morphological changes of the suppletion, the fixed cameras can take pictures with a step of 5 minutes (just some days and only for a tidal period).

The following diagram shows the station location and the areas covered by the pictures for the different cameras.

The area covered by the axis camera is divided in four circles as explained above. Moreover, a distinction of three colours is made on the drawing, which indicates : in green the sand nourishment, in yellow: the landscape hidden by the platform, in red: other pictures on the Galgeplaat.

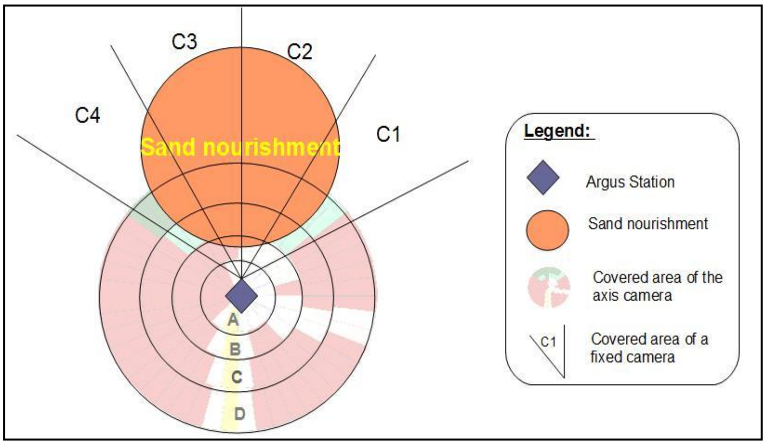


Figure 7: The monitoring area

The area covered by each picture of the moveable camera have been estimated: Circle A= 17m², Circle B: 20m², Circle C: 40m² and Circle D: 64m².

3. Field measurements

3. 1. Meteorological data and water level

Wind speed (dm/s), wind direction and water level (cm NAP) are all measured in Stavenisse every days since 1980. Results are stored in a database as an average of 10 minutes and they are available on the following website: *http://www.hmcz.nl*. Other meteorological parameters such as rainfall, sunshine duration and clouds cover are measured in the station of Wilhelminadorp. These data are found on the website *http://www.knmi.nl*

In addition of these national stations, the Argus station itself possess a wave monitor used to activate the cameras. The water level used for the analysis however is the one measured at Stavenisse because the level of the sensor of the Argus Bio station was not exactly known.

Figure 8: Measurements stations

Meteorological characteristics are used in this report in order to study if they are factors impacting birds occurrence. The water level is used to reference the pictures in Matlab to map morphological aspects of the nourishment. The Figure 8 shows the location of these monitoring stations.

3. 2. Morphology

The morphological evolution of the sand nourishment is monitored by the way of the RTK technique and completed by visual measurements.

The bed elevation is first monitored by using single-beam and RTK. This measurements are conducted every three months. The RTK (Real Time Kinematic) is part of the DGPS technique (Differential Global Positioning System). It is a method commonly used in land and hydrographical survey, based on the use of the GPS signal. A single reference station gives correction in real time, which provides accurate results. It has indeed been proved that the accuracy level of this method is about 0,3 metres.
These RTK measurements are compared later with the morphology analysis done with the Argus images.

Visual measurements are implemented in order to complete results from the RTK-measurements. Since the RTK method does not enable the analysis of small variations of bottom elevation (in the order of 10 cm changes), the monitoring of sedimentation and erosion is made according to measurements named SET (sedimentatie en erosie). They consist of comparing the bed elevation with a reference level, at 14 places on the Galgeplaat. On each spot, the sedimentation or the erosion is measured in a triangular zone.

The Figure 9 indicate the way of measurements: on the left photo, the three reference spots that form the triangular zone are viewed, as well as the scale sets for measurements. The orange arrows on the right picture indicate for each of the three lines, the five points where the bed elevation is measured.

Figure 9: Sedimentation-Erosion measurements

3. 3. Bird counting

Birds were counted in 2009 by Habitat Advies, an organisation specialized in ornithology and aquatic and estuarine ecology. The purpose of the count was to determine the number of foraging birds per hectare.

The birds censuses were performed at low tide on September 8 and 9, between two peaks of high water. The first census started when the first part of the studied surface area was completely dry and the last census was conducted throughout the quarter before the last zone of the studied area was flooded again. Between these two extreme censuses, counts were initiated every fifteen minutes for nine zones of the intertidal area (area of 100 x 100 meters each). Six of them were located on the sand nourishment and three others on the North of the pilot, as presented on the map named "Studied area for birds censuses" (Figure 10). The boundaries of the areas were marked with poles, previously set with a GPS.

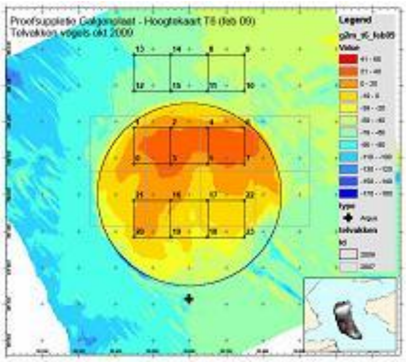


Figure 10: Studied area for birds censuses

Bird were counted from a ship, on a high location (around 3 meters high) to have a larger view of the nourishment and to see further. Telescopes and binoculars were also used to reach the same goal. During the count, the number of gulls was not assessed and a distinction between resting and foraging birds was made. [Drs. Rienk Geene & Jan Goedbloed (2009).]

Finally, three types of analysis were made:

- Maximal number of birds per area (100 x 100 m²) for both counted days
- Average of number of birds for 2 days per area
- Number of minutes spending for foraging per day (= Birds number per day x 15 minutes)

3. 4. Benthic fauna sampling

Sand for benthic fauna analysis was sampled at several date of 2008 and 2009 (including sampling before and after the nourishment) by NIOO and IMARES, two organisations involved in the Building with Nature program. Several measurements stations were chosen for the sampling, mainly according to their location: on the nourishment or on the reference site (outside of nourishment). At each station, three types of samples (different sizes) were taken, to analyse benthic fauna, grain size of sediments and pigments analysis.

In the part 3.1.2 of this report, a link between the benthic fauna and the level of moisture (wet, dry and moist areas) will be done, for one date only: July 14th 2009. At this date, the 25 stations of the nourishment were analysed, providing biomass and density results (see the opposite map for the location of these stations). The coordinates of the stations for this day are gathered in the table in Appendix 9.

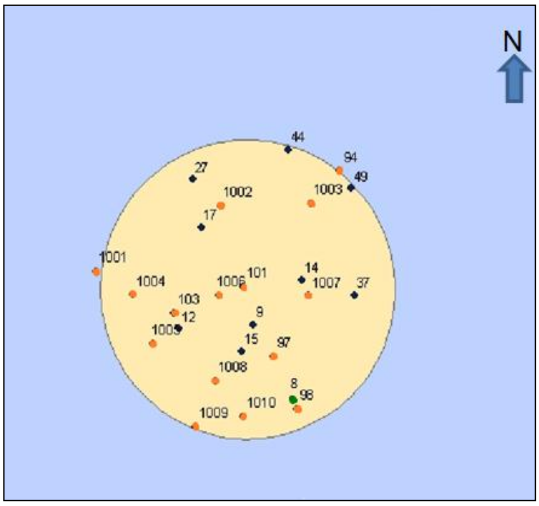


Figure 11: Field measurements station on the nourishment

C- ARGUS IMAGES ANALYSIS: METHOD

1. Birds analysis

The analysis of birds has been made for the moveable camera only (biggest zoom). Birds were counted and identified so far as possible for different periods of 2009. Results are available for the next dates (in 2009):

- Every days in August (excepted for the 27th of August),
- Every days in October (excepted for the 16th, 30th and 31st of October),
- 31st of July,
- 15th and 30th of September,
- 9th of November,
- 10th of December.

These days have been chosen by considering several criteria. An analysis throughout two entire months was done to get an overview of fluctuations of birds occurrence partly in function of meteorological conditions. The month of August was chosen to have data as soon as the station was installed whereas it has been decided to count birds in October because this is when birds population usually begin to increase in the Eastern Scheldt. The other days were chosen according to the quality of the Argus images only.

Furthermore, when the quality of the pictures was good, birds have been identified and classified in several groups:

- Cormorant (*Phalacrocorax sp*) (C)
- Oyster catcher (*Haematopus ostralegus)* (Oc)
- Eurasian spoonbill *(Platalea leucorodia)* (Es)
- Eurasian curlew (*Numenius arquata*) (Ec)
- Gull (G)
- Unknown (U)

Finally, in order to validate the analysis, blurred pictures were also counted and noted by the symbol "/". This character does not take into account pictures on which the landscape was hidden partly or entirely by the platform. These latter were defined respectively by the characters "*" and "**".

Results were gathered in a table in Excel with the following structure:

Data	Date	Hour	Circle	Pan	Measure	Bird	Specie	Oc	G	Es	Ec	C	U		*	**	/	WL	Wind
	31/07/2009	15/30	A	0,0281	no nourishment	0													
	31/07/2009	15:30	A	22,5422	no nourishment	1	G		1										
	31/07/2009	15:30	A	45,0563	no nourishment	*									1				
	31/07/2009	15:30	A	67,5704	no nourishment	2	Oc Oc	2											
	31/07/2009	15:30	A	90,0844	no nourishment	0													

Figure 12: Birds results in Excel

The function "filter" in Excel has been used, as proved by the first line of the picture above (data could be selected by one of the first line field).

2. Morphology and wet areas analysis

Although the nourishment is located in a zone relatively sheltered from strong waves and wind, it is still affected by erosion and sedimentation processes. It will in consequence be modified. Monitoring the morphology on the Galgeplaat is necessary to determine the time scale needed for changes to happen and to quantify erosion and sedimentation.

Field measurements are, as explained previously, conducted once a month and they are in these conditions not useful to show variations which appears in a small scale of time. A small scale of analysis is important since it has been demonstrated that the response of a beach affected by a storm appears in a few days. The analysis by the Argus system can be used as a complement to have information between two campaigns of measurement. Indeed, even though analysis by the Argus system depend on optical conditions and is less accurate than field measurements, it has been proved that the technique can be used to show trends in beach morphology.

2. 1. Use of the Matlab program

One of the techniques used to map morphology consists of mapping waterlines. Indeed, during a tidal period, the water is coming with a water level which is known and it follows the lines of bed elevation. Thus, drawing the contour of the water from low tide to high tide, with a small step of time (every five minutes for instance) enable to map changes in bed elevation.

Several applications are commonly used to analyse the Argus pictures. Among them, the IBM tool (Intertidal Beach Mapper) is applied to map waterlines. An image can be loaded from the video archive into the IBM interface and the tool automatically finds information from the database (hydrodynamic conditions such as the water level elevation).The user can then define a region of interest (also called ROI) that indicates where the program has to find shorelines. Within the ROI, the Matlab tool makes a distinction between wet pixels and dry pixels by clustering pixel intensities in Hue-Saturation colours space. Results are given by opening another window and by drawing the waterline on the picture. When the program does not succeed with the pixel comparison, manual waterlines can be drawn by using the tool 'manual click' and wrong waterlines can be deleted thanks to the button 'remove dots'.

The lines which have been drawn on the pictures are referenced according to a 2D dimension. In order to transform the image coordinates (2D) into world coordinates (3D), a technology called geometry solution is used. This technique relates each pixel of an Argus image with a X, Y and Z coordinate of the world, usually by referencing the third dimension (Z) with the Z-level measured from the water level. This geometry solution is essential to map correctly the bed elevation of a beach zone.

The images underneath show the functioning of the IBM tool of Matlab. The left picture indicates in red the region of interest and in blue the waterline found within the ROI. On the right, the scheme presents the result of the pixel comparison for the same waterline.

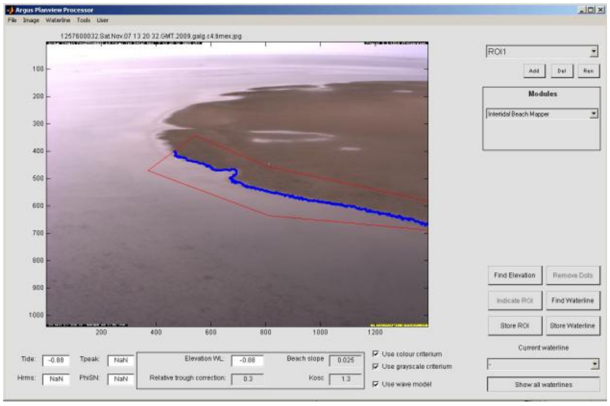


Figure 14: IBM tool

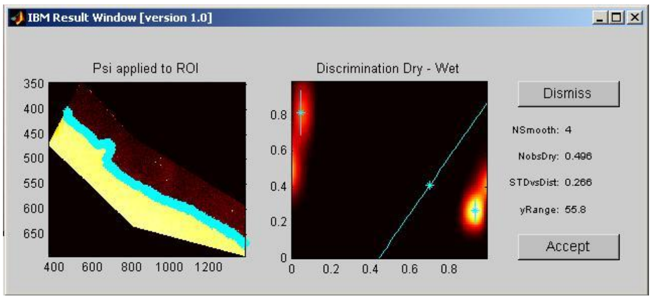


Figure 13: Pixel comparison

2. 2. Application to map the bed elevation of the suppletion

The analysis of morphology is made by mapping shorelines for the following days: 10-09-2009, 01-11-2009, 07-11-2009 and 01-12-2009. The function of this analysis is twofold. First of all, it aims at evaluating trends in morphology modifications, to show if the process of disappearance of intertidal areas has been slow down since the sand nourishment pilot. The second goal is to validate the Argus analysis in the case of the nourishment. Although waterlines mapping is a technique commonly used to assess changes on beaches, the technique has not really been validated for the application on the suppletion because the slope of the suppletion in not as important as in the cases of beaches. To check the reliability of the method, a comparison of results between field measurements and Argus analysis is done. If the technique is validated, it will be possible to analyse morphological changes more often in the future (every week instead of every month for instance).

2. 3. Application to map wet, moist and dry area on the suppletion

The analysis of wet, moist and dry areas aims at determining if a link between morphology and ecology exists. Indeed, it is interesting to see if the location of these morphological zones have an impact on birds population and distribution, and on benthic fauna distribution. Moreover, the analysis will enable to see the progression of the drying out of the nourishment at low tide.
To do so, the evolution of wet, moist and dry areas at two scales of times is studied. Thus, a short term evolution is considered by analysing one tidal period and a long term evolution is evaluated along the year. The study of the areas is made by taking into account to aspects: the area (in m²) and the location on the zones on the nourishment.

To compare changes that happen in one year, two days of the same period (March) have been chosen. Furthermore, in order to decrease the differences due to tidal cycle variation and to focus the analysis on areas changes in time, pictures with roughly the same water level and the same tidal cycle has to be used. This aspect justifies the choice of the studied days : the 15th of March 2009 and the 1st of March 2010. The curves for these days are given on the Figure 15. The curves at low tide have to follow a similar trend since this is when the analysis is done (represented by the blue circle). These both days are used to see the evolution of the areas.

Furthermore, another day has been mapped in order to make a comparison with benthic fauna. It has been decided to analyse the 14th of July 2009 since it is a day of which field measurements results are available.

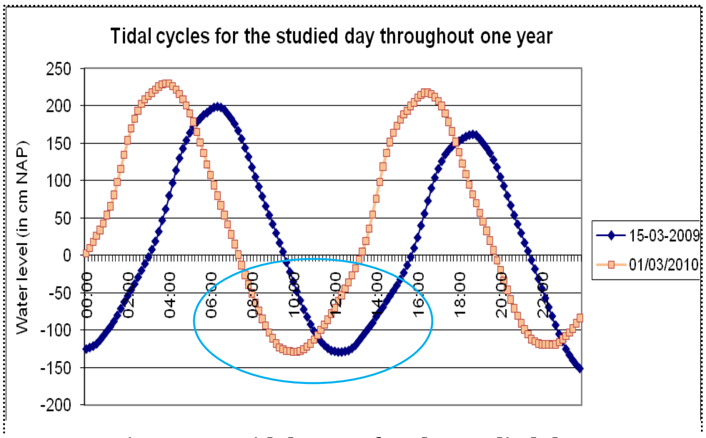


Figure 15: Tidal curve for the studied days

Again, Matlab is used here to map boundaries of zones. The edge of the nourishment (feature name "Anourishment-C1", "Anourishment-C2", "Anousihment-C3" and "Anourishment-C4" in Matlab) has been drawn once, and the same boundary was then used for each picture. Afterwards, to make the analysis easy, the features in Matlab have been named according to their characteristics and their location:

- Wet areas : "Aw " (wet area), "Awid " (wet area in dry) and "Awim"(wet area in moist)
- Dry areas : "Ad" (dry area), "Adim" (dry area in moist) and "Adiw" (dry area in wet)
- Moist areas: "Am" (moist area), "Amid" (moist area in dry) and "Amiw" (moist area in wet)

The border of each type of areas was drawn manually, depending of the moisture level that could be estimated on the pictures. Therefore, the quality of the images was an important factor for the quality of the results.

D- RESULTS AND DISCUSSION

1. Birds analysis

1. 1. Validation

1.1.1. Assessing image quality

Moreover, in the objective of assessing the system, the proportion of useful picture has been estimated. It is based on the analysis of "bad pictures", written down by the character "/". It is important to notice that this symbol does not include pictures for which the platform hide part or totality of the landscape. Usually, the number of bad pictures per day is around two or three pictures (as an average). Sometimes however, this number reaches critical value for the analysis. On the graphs below, the percentage of bad pictures is presented for both months of August and October.

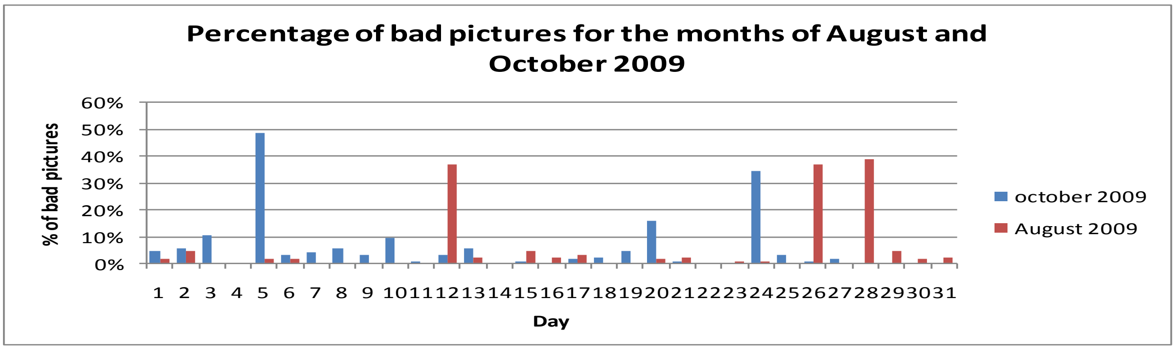


Figure 16: Validation of the system: percentage of bad pictures

On this figure, it is possible to see that six days have a percentage of bad pictures higher than 10%. Several meteorological factors can lead to explain these useless images: precipitation amount, sunshine intensity and wind speed. A combination of these parameters can also impact the quality of the Argus images negatively.

The Appendix 1 and Appendix 2 sums up the analysis of environmental parameters and some conclusions can be drawn:

- Generally, when the total amount of precipitation per day (in mm) is above 5 mm, the number of blurred pictures is high. This aspect is verified for the 12th and 28th of August and for the 5th and the 24th of October. For some days, the rainfall is higher than 4 mm a day, without any effect on the station, which means that the cameras have not taken photos during the rain.
- For the 26th of August and the 20th of October, a combination of wind speed and sunshine seems to explained the blurred pictures even if the sunshine intensity appears as a factor of which the effects are difficult to gauge.

The following graphs confirm that no correlation are clearly existing between one meteorological factor and the number of bad pictures since the R^2 (coefficient of determination of the linear regression analysis) is very low. Usually, the quality of the Argus Bio images was affected by a combination of several environmental aspects. The graphs for October are not presented since the same conclusion can be drawn.

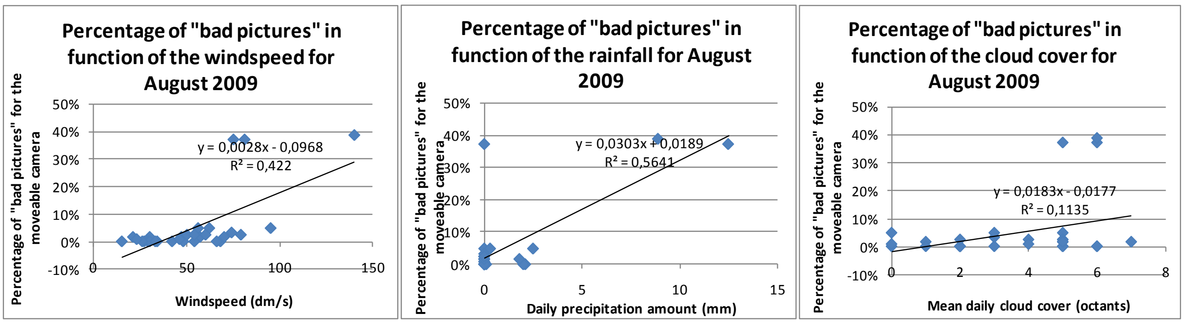


Figure 17: Interaction between bad pictures and meteorological data

However, to stabilise the platform and decrease the number of blurred pictures, a stiffening of the platform have been executed the 17th of November 2009. The quality of the Argus images has been really improved since this day, as proved by the following pictures, coming from the movable camera. These latter show a comparison of two windy days, the first one before the stiffening (2009, November 6 at 10:30, wind=71 dm/s) and the second one after it (2010, February 20, wind= 72dm/s).

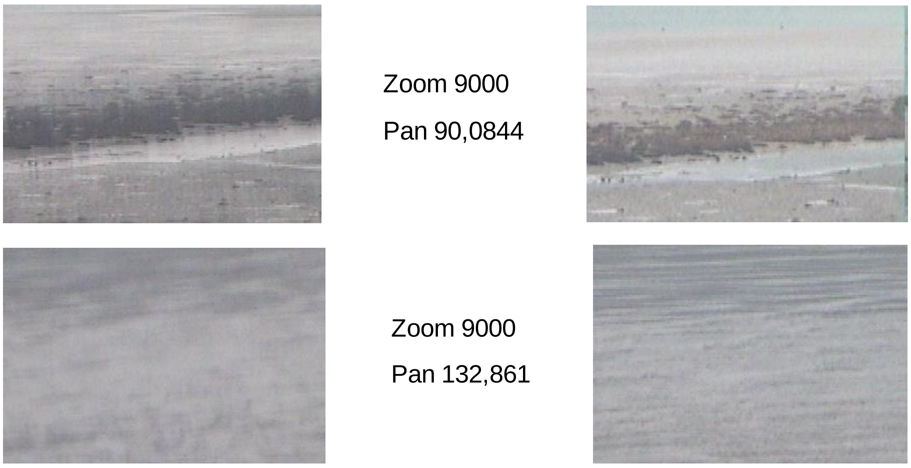


Figure 18: comparison of the quality of the pictures

However, if the impact of wind have been decrease since the stiffening measure, the platform is still subjected of other meteorological conditions (rainfall and sunshine intensity notably).

1.1.2. Comparison with birds censuses:

A comparison between field censuses and Argus counting has been tested. Nevertheless, it cannot be done correctly since :

- Areas defined for the field birds counting for the 8th and 9th October 2009 are not seen on the pictures from the moveable camera (for the four studied circles).
- The fixed cameras do not have taken pictures with a zoom big enough to provide pictures with a precise resolution.
- The censuses do not take gull into account and the fixed camera do not provide pictures on which the distinction between birds species is possible

Nevertheless, although no count were carried out with the pictures from the fixed camera since the covered areas are too large to enable it, their analysis can provide some conclusions confirming the birds censuses. Thereby, many birds can be seen on the pictures when the nourishment is the only discovered area (before ebb and flood tides) as proved by the pictures in Appendix 18, which show many birds before ebb tide (at 13:00 and 13:30) and no birds on the nourishment at low tide (11:30). It can be deduced that the nourishment has a function of resting place for birds during transition phases. Surroundings (that implicates where oysters grow) are on the contrary used by birds for feeding each time the water level is low enough.

1. 2. Results

- Distribution during a month

The following graphs present birds distribution in the Galgeplaat for both August and October 2009:

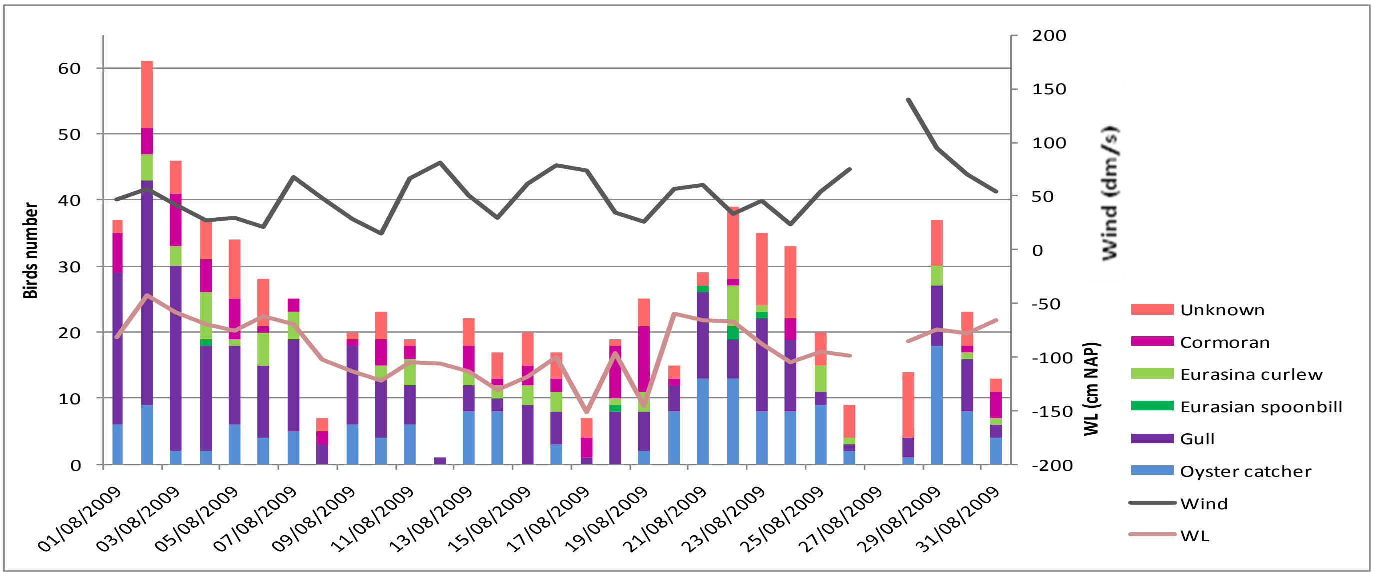


Figure 19: Birds distribution, August 2009.

Remark: No pictures were counted for the 27th of August

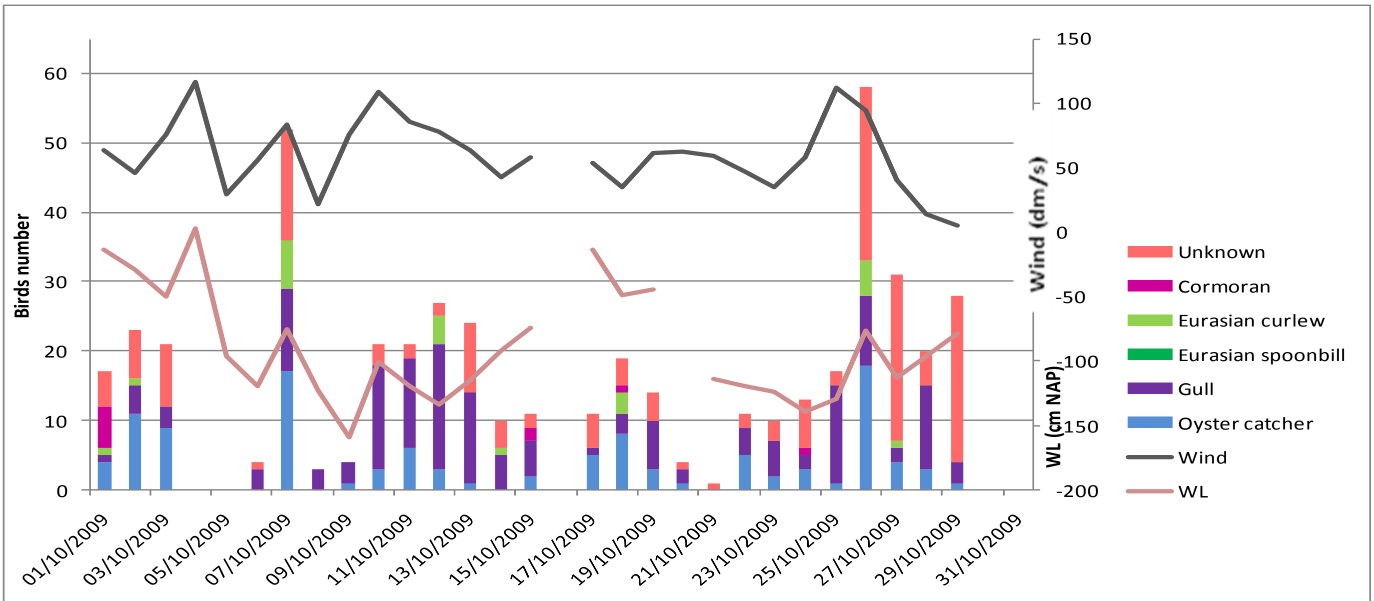


Figure 20: Birds distribution, October 2009.

Remark: No pictures were counted for the 16th , the 30th and the 31st of October

For both months, results present a high number of non-identified birds which can influence the quality of the analysis. Birds population is heterogeneous for both months, although the general trend is an lower number of birds for October than for August 2009. The heterogeneous distribution within a month implicates that the count of several days per month is necessary to have representative results

- ***Comparison of August / October***

A comparison between average for August and October has been performed, for the identified species to confirm the general trend seen on the previous graphs.

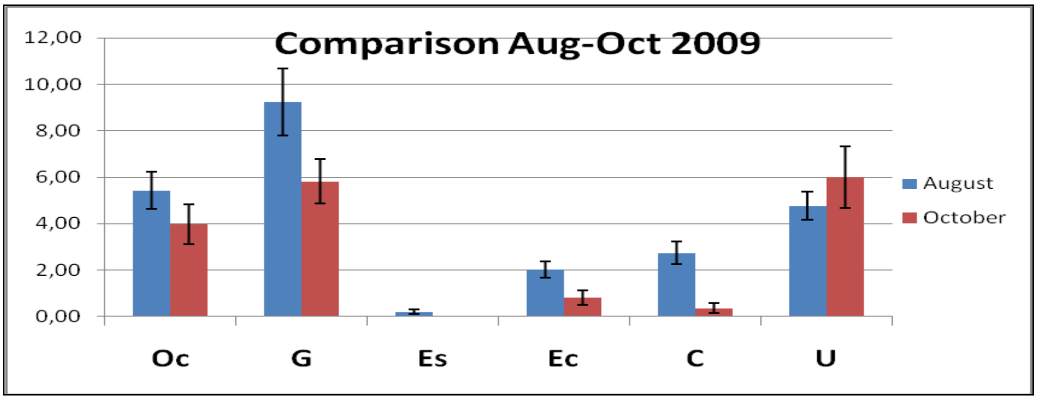


Figure 21: Comparison between August and October

Cormorants, Gulls and Eurasian curlews have an occurrence lower for October. The number of Oyster catchers remain roughly the same (by considering the error bars). The distribution of Eurasian curlew and Oyster catcher verifies seasonal trends of occurrence in the Eastern Scheldt for these two species. More information about birds occurrence in the Eastern Scheldt could be found in the following report [Tom Ysebaert, et al. (2009)].

Correlations have been tested within birds number and environmental parameters (wind and water level), by using R² value (coefficient of determination of the linear regression analysis). An example of graph is given underneath, analyzing the occurrence of oyster catchers as function of the water level (WL) .

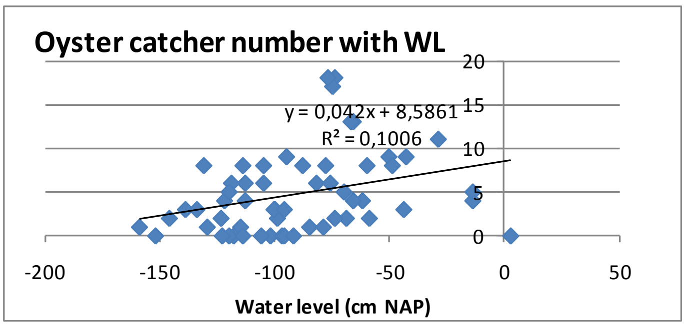


Figure 22: Correlation between oyster catcher number and water level

Other results of the correlations are presented in Appendix 4. For the graph above, as well as for graphs in appendix, R² values are low and indicate no clear correlation between the compared parameters.

- ***<u>Comparison nourishment/ reference site</u>***

The last analysis that has been done is a comparison between birds on the nourishment and on the reference site for the same area (1 ha). The 1 ha area has been defined according to the number of pictures analysed by circle and according to the area (in m²) covered by each picture.

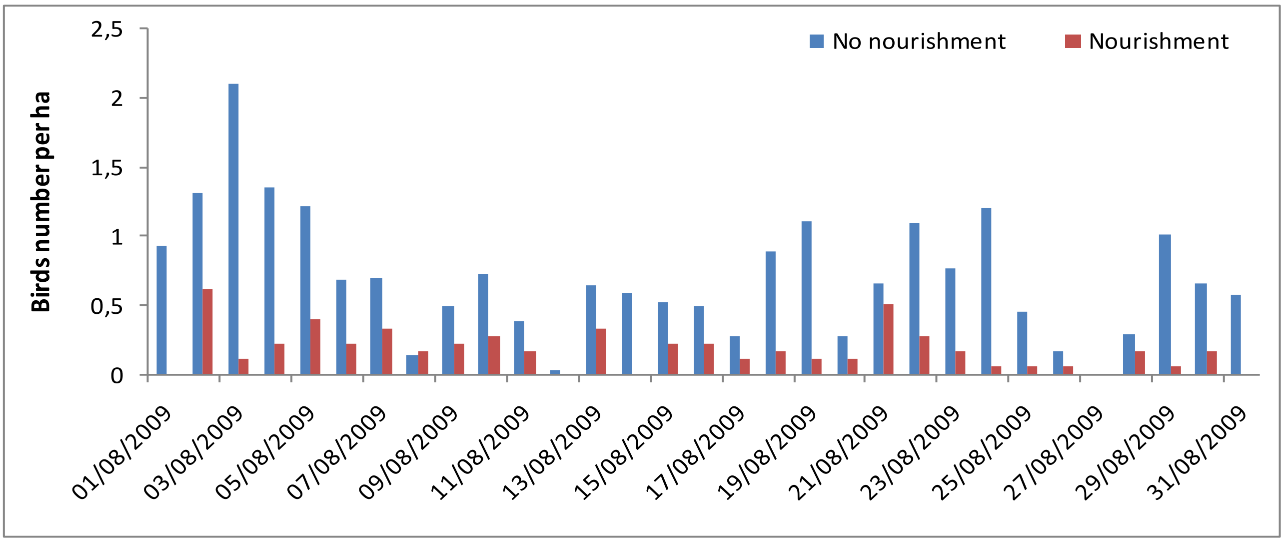


Figure 23: Birds number comparison between nourishment and reference site, Aug 2009

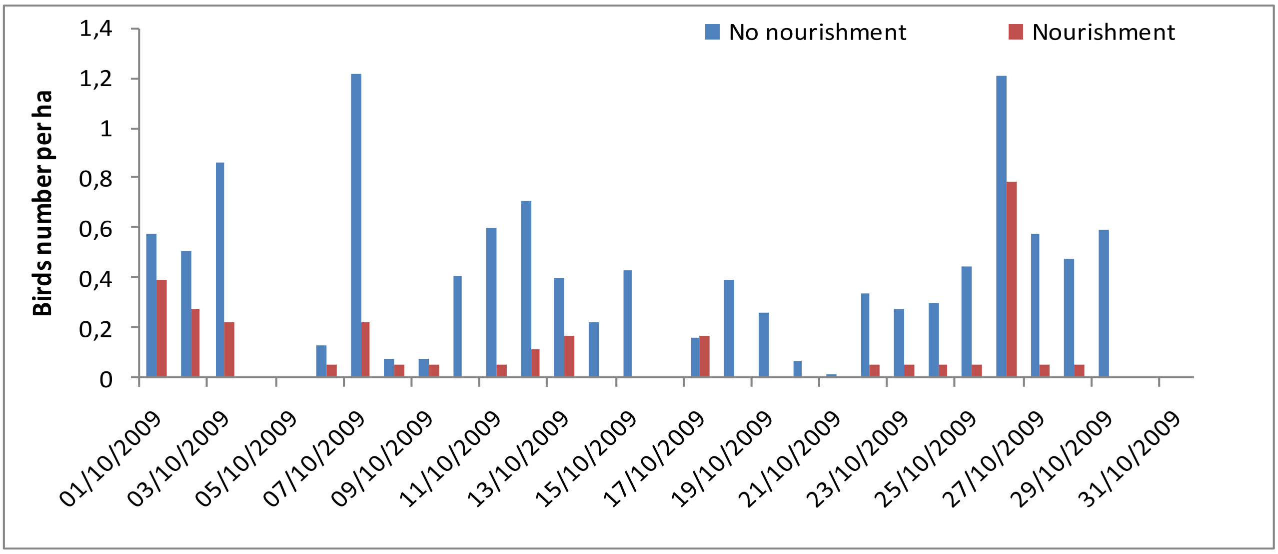


Figure 24: Birds number comparison between nourishment and reference site, Oct 2009

Graphs show a number of birds lower on the nourishment than on the reference site. As an average, less than 20% of the birds have been counted on the nourishment.

1. 3. Discussion

Regarding to the results, it is possible to assume that the birds distribution has been affected by the nourishment even if no analysis of birds had been performed for the period before the nourishment.

The analysis of birds distribution on the Galgeplaat clearly show a higher presence of birds on the reference site than on the nourishment.
This trend could be explained by the disappearance of benthic fauna on the nourishment after it creation whereas the fauna has remained present on the reference site for the same period (analysis of IMARES). The benthic fauna needs to recover from the nourishment so that birds can use the suppletion for feeding. Results show that benthic fauna began to recover from the construction since the density is increasing, but only small individuals are found on the site. There is a large difference in biomass between the nourishment and the reference site.

This is confirmed by the fact that the suppletion appears as a resting place for birds whereas the surroundings offer a large area for feeding, but these trends cannot be verified with the moveable camera since it covers the South part of the nourishment only once a day. Consequently, it is recommended to modify the parameters of the moveable camera:

- It should take pictures several times per day in order to have a better view of what happens during a tidal period.
- It should be more specific of the nourishment (a lot of pictures are currently taken on the South of the nourishment). For instance, an area on the West border of the suppletion should be covered since it is a zone where birds seem to rest before low and high tide. Additionally, an area in the middle of the nourishment should be monitored, to have an overview of birds occurrence on the nourishment.
- A camera with a better resolution could enable an increase of the quality of the results since the quality of the pictures will be improved. A camera with a wide-angle could also diminish the number of pictures and decrease the areas seen on two pictures.

Moreover, it appears that the identification of birds on the pictures was restricted by the quality of the Argus photos. Indeed, even for days for which the number of “bad pictures” was low, the identification was sometimes not possible because of problems related to zoom or to birds stance. Usually, when birds were seen from profile on the images, they were easier to recognize. On the contrary, when they face the station, the identification becomes complex since the particularities of one species are not well-seen (e.g. curved bill for the Eurasian curlew). The distinction was also more complicated for birds belonging to the same family. If the example of the Eurasian curlew is kept (Scolopacidae family), the identification of the species among other members of the taxon -such as the Red knot (*Calidris canutus*), the Common greenshank (*Tringa nebularia*) or the Dunlin (Calidris alpine)- was often not doable although they were smaller than the Eurasian curlew. Here, a confusion can also be made with the Grey Plover (*Pluvialis squatarola*, Charadriidae) which is, as the birds previously quoted, a wader. These four species are known as common species of the Eastern Scheldt which explain why their presence can be supposed.

In some cases, the identification was feasible thanks to the presence of another bird, by supposing they belong to the same species. An example of this “double” identification is given with the Figure 25. On this figure, one bird is identified easily as an Eurasian curlew. By extrapolation, it can be guessed that the other bird is also an Eurasian curlew. Without the first naming, the second bird should have been classified as “Unknown”. This leads to a very large

Figure 25: Double identification

incertitude of identification since even if the species name is not determined, the bird can still be classified as a wader (more accurate than categorize it as unknown).

One of the conclusion that can be drawn from these results is that the current Argus system is not accurate enough to enable a study per specie. In consequences, it is recommends for another analysis to considered birds in a different way.
This can lead to classify birds as follow:

- Gulls
- Waders
- Ducks or goose
- Oyster catchers
- Eurasian spoonbill
- Unknown (class kept for pictures with a bad quality)

In this categorization, two classes are specific -Oyster catchers and Eurasian spoonbill- because it is species easily discerned on the pictures. The other groups are not as precise as before (per specie) but they can lead to an overall identification better since it could decrease the number of unknown birds. Cormorants are here not taken into account since they are seen only on the station. In order to help a future analysis, some Argus pictures on which the identification has been made are presented in Appendix 5.

Moreover, besides difficulties related to the identification of birds, the quality of the results has been affected by the number of pictures. Indeed, as the moveable camera takes pictures in several partly overlapping circles, a lot of images could be superimposed, leading to count birds twice. As a consequence, although the results for some species present the same occurrence that the seasonal trends, a real comparison between birds survey and results from Argus should be done to verify the results.

2. Morphology analysis: Bed elevation

2. 1. Validation

The analysis of morphology by Argus picture is possible only when waterlines are visible from the camera. For a normal beach, this is almost always the case, except at night or in case of bad weather. However, as regards the suppletion, the station is based on the South edge of the suppletion which means that the North of the nourishment is not well-seen by the cameras. In these conditions, an accurate analysis is only possible for the South, as well as West and East part of the nourishment.

To validate the results given by the Argus images, a comparison of Argus results and field measurements data is done. Because such a comparison is complicated with a top view, the evaluation is accomplished for five transects on the nourishment called 54000, 55000, 56000, 57000 and 58000, as seen on the map besides (Figure 26: Analysed transects on the nourishment).

Three days for which both types of measurements are available are analysed:

- December 1, 2009
- November 1, 2009
- November 7, 2009

The graphs are presented in the appendix section.

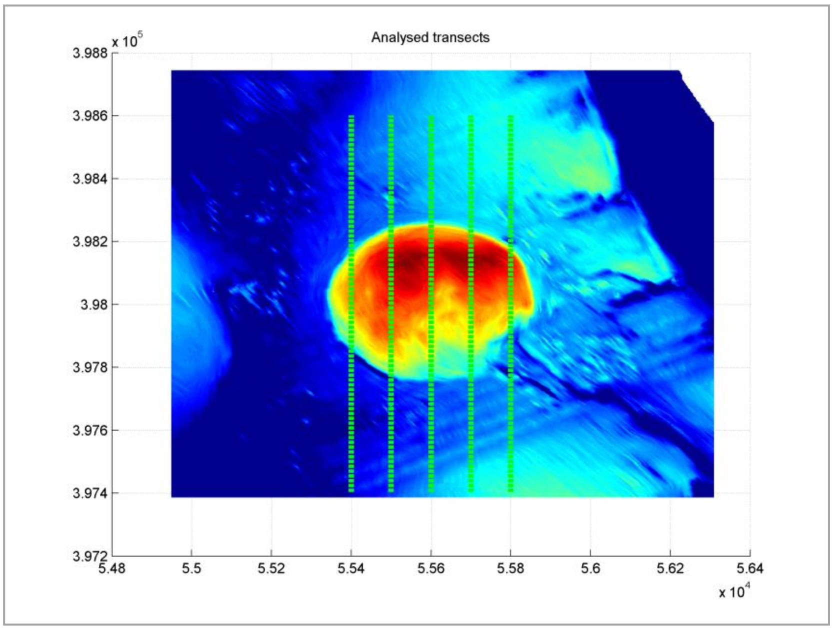


Figure 26: Analysed transects on the nourishment

The transects confirm the impossibility of mapping correctly the North part of the nourishment (on the right side on the graphs in Appendix 6, Appendix 7 andAppendix 8) with the Argus video system since the mapping of waterlines seems to overestimate the size of the nourishment. Furthermore, it appears that the slope on the front part of the nourishment is smoother with the waterlines mapping technique than with field measurements. These discrepancies can be explained by two aspects. The first one is that water level data used in Matlab to reference the bed elevation comes from the measured station located in Stavenisse. The second explanation concerns the geometry solution. Indeed, if the cameras move, the geometry solution changes and it can lead to a distortion of the profile unless the camera is referenced again.

It is possible to conclude that the Argus video technique can be easily improved, notably by using local water level measurement. However, the results are accurate enough to determine some trends in morphological changes on the Galgeplaat, for the South area of the nourishment.

2. 2. Changes analysis

Because the technique has been validated previously for the South zone of the nourishment, it is now possible to analyse curves to determine the evolution of the suppletion since its construction. The following graph has been made with the waterlines mapping of several days along the year 2009. The North part of the nourishment (above the arrow on the next figure) is not taking into consideration because of the bad quality of the results.

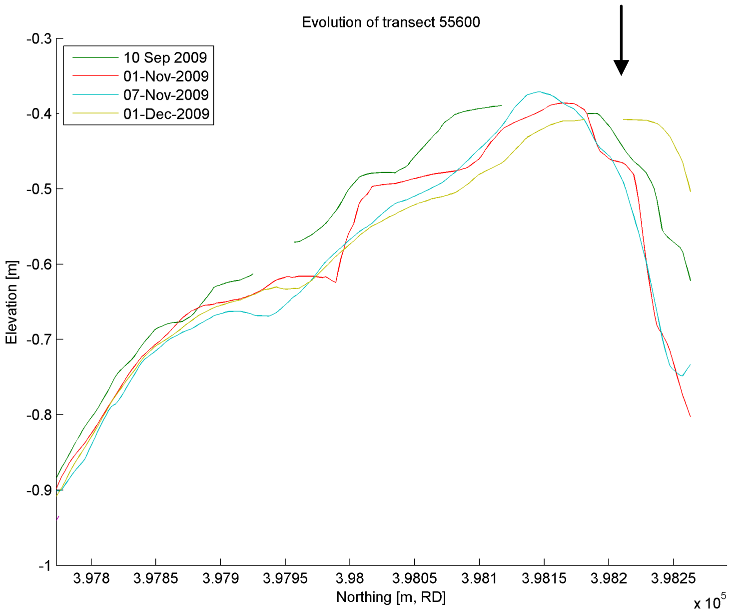


Figure 27: Evolution of the bed elevation of the nourishment, transect 55600

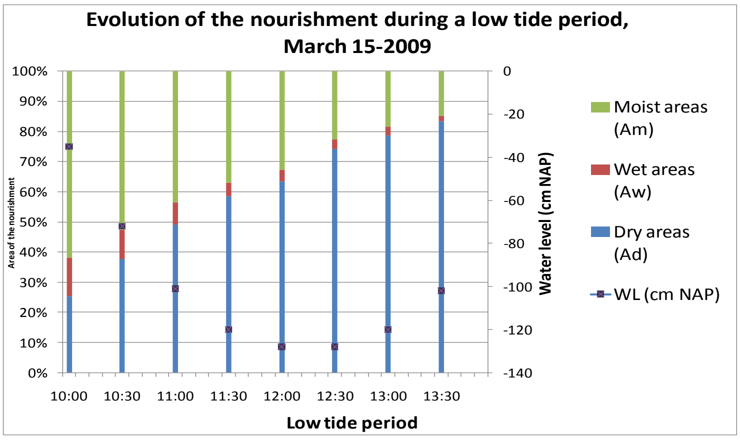
The diagram shows that the nourishment undergoes morphological changes slowly. The slope of the nourishment tends to be smoothed and the entire suppletion seems to move to the North, but this latter change is difficult to gauge since it concerns the part not well-seen with this monitoring technique. These observations have been confirmed by the analysis of by field measurements, but these aspects are not detailed in this report since the analysis is focused on the Argus video results.

3. Dry, moist and wet areas analysis

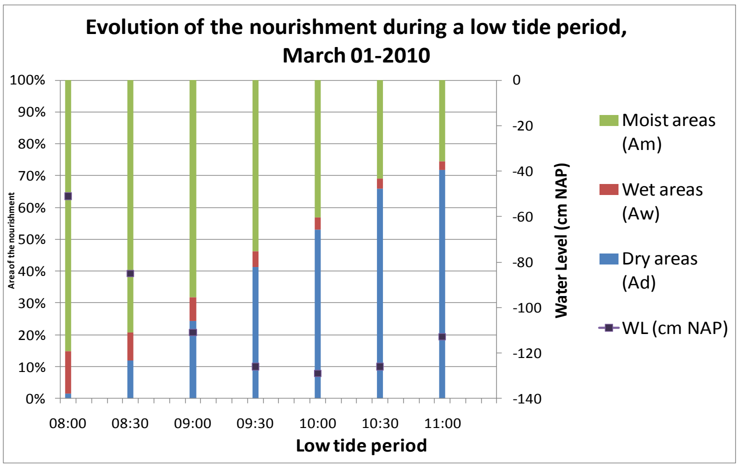
3. 1. Results

3.1.1. Evolution of the area (in m²) throughout a tidal period

The first type of results provides by the mapping of wet, dry and moist zones is the evolution of the areas in square meters. Results are plotted in the following graphs, for each day (March 15th 2009, March 1st 2010 and July 14th 2009).



Weather data of sunday 15 March 2009 in Wilhelminadorp	
Temperature : mean (in°C)	7.3
Sun, cloud cover & visibility	
Duration sunshine (hours)	9.5
Relative sunshine duration (%)	81
Relative atmospheric humidity: (%)	84
Precipitation	
24h sum (mm)	0
duration (hour)	0
Wind speed: (m/s)	5,3



Weather data of sunday 1 March 2010 in Wilhelminadorp	
Temperature : mean (in°C)	3,9
Sun, cloud cover & visibility	
Duration sunshine (hours)	7,7
Relative sunshine duration (%)	71%
Relative atmospheric humidity: (%)	85
Precipitation	
24h sum (mm)	0,9
duration (hour)	2,5
Wind speed: (m/s)	5,2

Remark : The 0.9mm of precipitation that was recorded for March 1st 2010 did not occur during the low water period, hence did not affect the results for this mapping.

The previous graphs indicate that the water seems to be drained away relatively fast since only a small percentage of the nourishment is defined as wet areas. For both dates, less than 30% of the nourishment remains moist or wet at the end of the low period.

Nevertheless, the water in March 2009 seems to be drained away faster than for March 2010 (more than 10% of dry areas for the first picture instead of 2% for March 2010). The Appendix 15 shows this trend clearly. It could be affected by several aspects, inluding meteorological parameters and morphological changes. First of all, it is important to notice that the mapping has been made for different hours (from 10:00 to 13:30 for 2009 and from 8:00 to 11:00 for 2010) which could have had an impact on the temperature, leading to more evaporation. The average temperature is also higher the 15th of March 2009 than the 1st of March 2010, a factor that could have reinforced the evaporation phenomenon. Secondly, the moisture seems to follow the morphology of the nourishment: the zones

where the bed elevation is higher have a bigger percentage of dry areas. It can be seen on the maps in Appendix 14 by comparing the morphology for the same period. Consequently, morphological changes of the nourishment (mainly the smoothing of the slope of the suppletion) could have impacted the drainage of the water. The maps in Appendix 13 can also confirm this hypothesis since they indicate that a majority of the areas dry in 2009 are moister in 2010, notably on the North where the main morphological changes have occurred.
A graph of the evolution of the moisture level of the nourishment for the 14th of July 2009 is presented in Appendix 16.

3.1.2. Spatial distribution of benthic fauna

Results from Matlab were plotted on three maps to have an overview of what happen throughout a low tidal phase: the combination of the three maps enable to cover the whole period. They were done according to the duration of a zone for each type of area. In addition, the location of measurement stations for the benthic fauna (on July 14th) has been indicated on the map.
Results can be seen in Appendix 10, Appendix 11, and Appendix 12.

Afterwards, these maps were used to define each station according to a type of area. They were classified thanks to the following scale:

- **Dry**: When it is dry during at least 2.3 hours (=2/3 of the time). It corresponds on the pictures to the areas where no trace of dampness were seen (Ad, Adim and Adiw in Matlbab).
- **Moist**: When it is moist during at least 2.3 hours. Visually on the pictures, both sand and water were presented in the area (Am, Amid and Amiw in Matlab).
- **Wet**: When it is wet during at least 2.3 hours. Visually on the pictures, it was when the sand was completely covered by water. (Aw, Awid and Awim in Matlab).

Nevertheless, some areas could not have been classified in these three categorizes since they were approximately evenly dry and moist during the same duration. A new class was then defined, the “dry-moist” category. The table in *Appendix 9* indicated for each station the type of area they correspond to.
Moreover, the station #1009 was excluded from the analysis because the level of moisture has been underestimated during the mapping.

Finally, graphs were performed, gathering the benthic fauna in function of the type of station. Both density and biomass were studied.

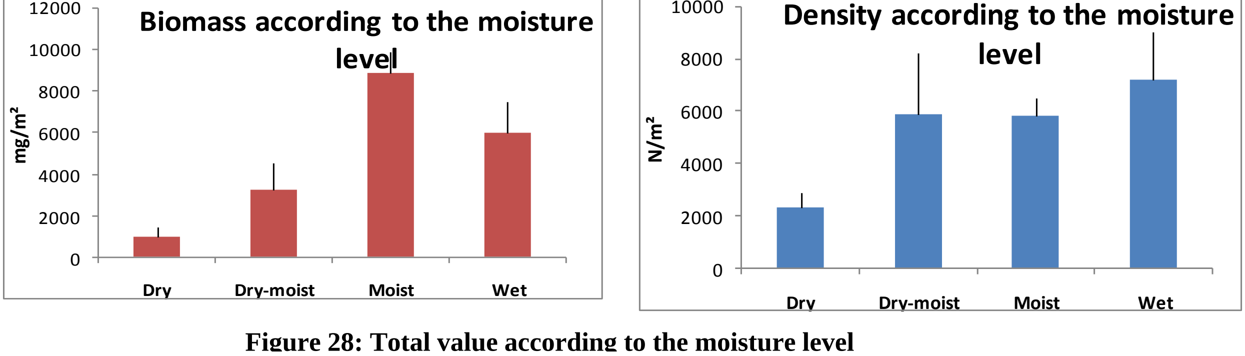


Figure 28: Total value according to the moisture level

The following graphs gather several taxonomic groups according to the type of area for both density and biomass (respectively left and right figures).

Figure 29: Density according to moisture level

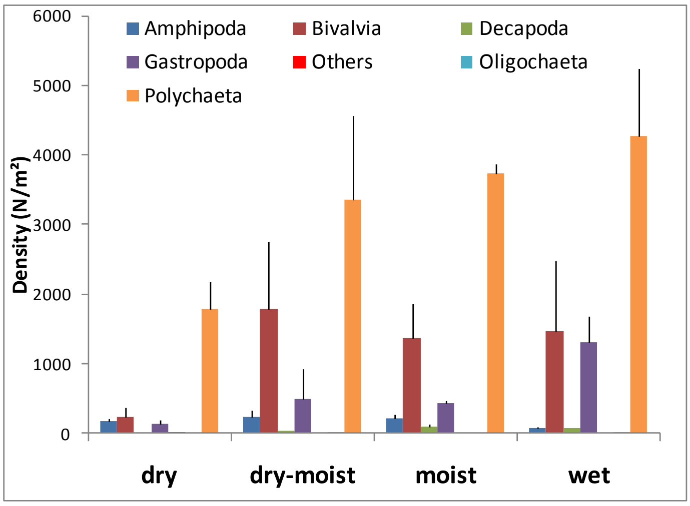
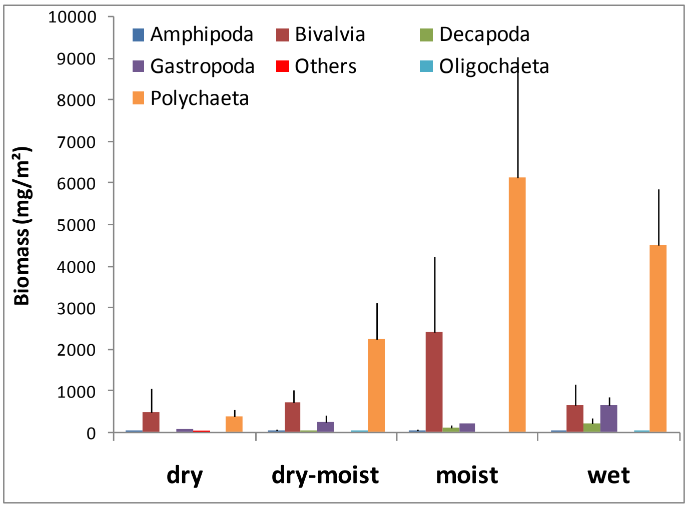


Figure 30: Biomass according to moisture level



Some representative species were also chosen to evaluate their occurrence according to the dampness level (*Arenicola marina*, *Capitella capita*, *Eteone sp*, *Hydrobia ulvae*, *Macoma balthica*, *Pygospio elegans* and *Scoloplos armiger*). Graphs with these species are the following:

Figure 31: Density according to moisture level

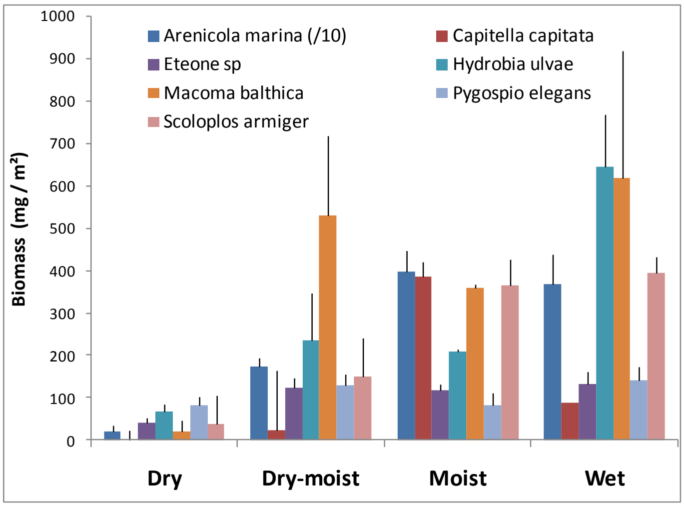
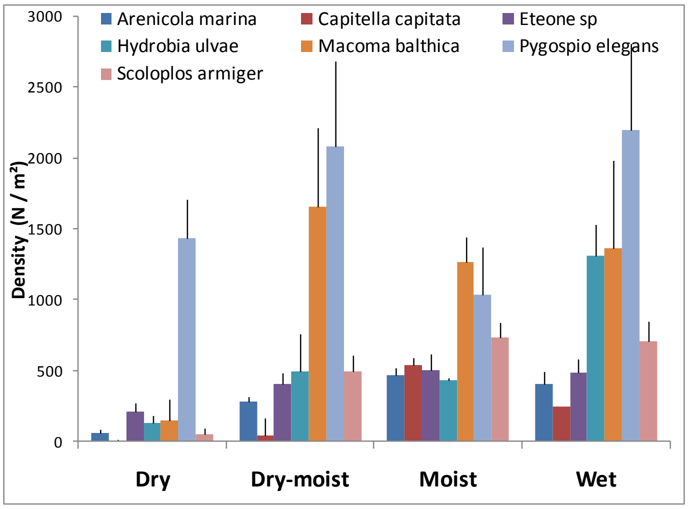


Figure 32: Biomass according to moisture level



Remark: To not overload graphs, only positive error bars were indicated on the previous figures although both negative and positive bars are significant for the results. Results proportion are available in Appendix 17.

The general conclusion that can be drawn from these results is that for both studied parameters (biomass and density), results for dry areas are usually lower than for other types: 16% of the total density and only 8% of the total biomass are found in stations located in dry areas. These low values contrast with the other proportions (29% in dry-moist, 23% in moist and 32% in wet stations for the density and 19% in dry moist, 41% in moist and 32% in wet stations for the biomass).

Some taxonomic groups such as Polychaeta and Gastropoda, seem to be really affected by the dampness level of the sand since the wetter it is, the more abundant they are (from 1778 for "dry

stations" to 4280 N/m² for Polychaeta for "wet stations" and from 128 for "dry stations" to 1307 N/m² for "wet stations").
For other groups, a distinction between wet, moist and dry-moist could not be done, but a separation between dry and other types of areas is possible. It is illustrated with the Bivalvia group, distributed preferably on dry-moist, moist and wet with roughly the same density. Other taxonomic groups (Decapoda and Oligochaeta) do not show a significant distribution on the level of moisture but it is species whose biomass and density was low (0 in dry, 27 in dry-moist, 99 in moist and 80 N/m² in wet for Decapoda and 0 in dry, 13 in dry-moist, 0 in moist and 13 N/m² in wet for Oligochaeta).

As well as for taxonomic groups, the analysis of species shows a poor abundance of benthic fauna for the dry areas. *Scoloplos armiger* and *Arenicola marina* are two species whose occurrence seems to be related to the dampness since they are present with a high density for moist and wet areas. *Hydrobia ulvae* also displays large number of individuals in wet areas (1307 N²/m that corresponds to 55% of the total density for this specie). *Capitella capita* is predominantly present in moist areas (66% of the density for this specie is found on moist stations). Furthermore, *Macoma balthica* and *Eteone sp* do not present a preference among dry-moist, moist and wet since they were observed in the same proportion in these categorizes (around 30% for both species).

Moreover, biomass and density do not evolved always in the same way. For the taxonomic groups Polychaeta and Bivalvia, wet and dry-moist areas seem to offer preferably an habitat for small individuals since the biomass is low for an high density. *Scoloplos armiger* is also a species presenting smaller individuals in moist and wet areas than in dryer zones.

3. 2. Discussion

Results show that dry areas are not favourable for the development of benthic fauna. The distinction between wet and moist areas is more difficult to assess, but it could be linked with the difficulties to make the separation of these areas on the pictures (visually not always significantly different). In general, the majority of the benthic fauna seems to be affected by the moisture level of the sand. The groups that are the most impacted are Polychaeta, Bivalvia and Gastropoda and every studied species show a preference for the moister areas except *Phygospio elegans*. Finally, moist areas offer an habitat for small individuals which could be linked with the moves of larvae thanks to water. However, this hypothesis needs to be verified, as well as a potential link existing between the species and their feeding mode in function of their favourable habitat.
Moreover, it could be supposed that the general increase of moist areas from 2009 and 2010 (as seen previously) has impacted positively the benthic fauna of the nourishment. Other environmental parameters could also have lead to the same conclusion.

E- CONCLUSION

The different analysis performed in this report can lead to answer the main objectives described previously. They are remembered briefly: evaluation of the Argus system, assessment of the morphological changes of the suppletion, analysis of the birds distribution on the nourishment and analysis of the potential link between benthic fauna and the level of moisture.

First of all, the main conclusion from the evaluation of the Argus system is that the system enable the analysis of the impacts of the nourishment and its changes.
It is indeed possible to monitor the morphological changes of the nourishment since the results follow the same trends than field measurements, except for the North of the suppletion (the distance leads to a loss in the quality of the pictures and in results accuracy). The system could be improved by updating the geometry solution of the cameras and by using the local water level.
Concerning the analysis of birds, it is possible with the moveable camera only, by using average of several days (to have representative results). The accuracy of the results could be improved by modifying parameters of the camera: it should take pictures several times per low tide period to give a better view of what happens throughout a tidal phase. Additionally, the camera should be more specific of the nourishment (a lot of pictures are currently taken on the South of the nourishment). Two areas of the suppletion should be covered with the moveable camera. One on the West border of the nourishment since it is an area where birds rest when the nourishment is the only zone discovered (before low and high tide). Another area in the middle of the nourishment should also be monitored to have an overview of the entire suppletion. Moreover, a camera with a higher resolution and a wide-angle could provide results with a better accuracy .

Moreover, hypotheses enounced previously (part C- 2) have been studied.
The first question was related to morphological changes of the nourishment. The general conclusion that can be drawn is that the suppletion is indeed affected by changes but they appear slowly. The slope of the nourishment seems to be smoothed and the entire suppletion is moving to the North (part not well-seen from the Argus station).
Concerning the population of birds, it appears that the pilot sand nourishment has affected birds distribution since only a low number of birds are seen on the nourishment whereas this number is higher on the reference site. The nourishment is used as a resting place for birds mainly during a specific period and the surroundings are used as a feeding area.
Finally, the link with benthic fauna occurrence and the type of areas (wet, moist and dry) was studied. The hypothesis that wet areas are more valuable for the presence of benthic fauna was difficult to verify, notably because of the distinction of the areas on the pictures. Nonetheless, it appears that dry areas are not beneficial for the benthic fauna growth. Moist and wet areas in general seem to offer a habitat for smaller individuals than dry areas, possibly because of the transport of larvae by water.

Some hypotheses have not been studied, because their assessment is restricted by the parameters of the Argus system. For instance, the spatial distribution of birds on the nourishment and its link with the benthic fauna has not been analysed because the fixed cameras do not provide pictures that enable the analysis of birds (insufficient zoom). For the same reasons, the hypothesis that connected birds with wet areas has not been studied.

Benthic fauna analysis clearly shows a disappearance of the benthic fauna after the creation of the nourishment whereas the fauna remain abundant on the reference site (analysis of IMARES). It leads to suppose that the re-colonisation of the nourishment by the benthic fauna will lead to a use of the nourishment by birds also for feeding. The suppletion could indeed provide food for birds, notably thanks to the wet and moist areas since it is zones that seem to be favourable for the development of benthic fauna.

The general conclusion of this report is that the nourishment is currently not valuable for birds as a feeding area, probably because of the modifications of the benthic fauna development. It implicates that the nourishment is actually too young to have a positive influence of the ecology of the Galgeplaat. However, the benthic fauna began to recover from the construction of the nourishment, and will consequently provide food for many birds. In these conditions, it could be supposed that the impacts on the long term will be rather positive. The monitoring of the area needs to be continued to really know the effects on birds and on the ecological values of the region.

List of figures

List of appendix

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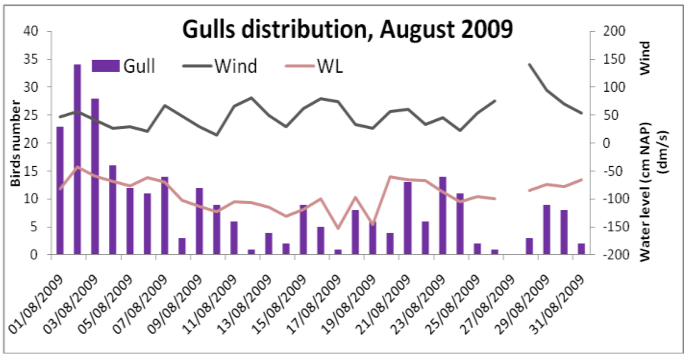
Appendix 1: Bad pictures analysis, August 2009

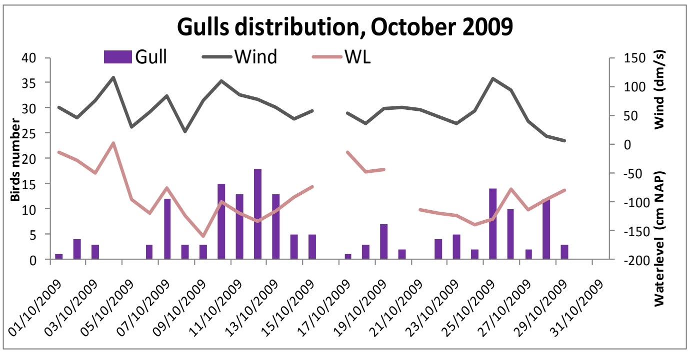
Date	Wind condition: Stavenisse (hmcz website)		Other weather conditions: Wilhelminadorp (knmi website)						
			SQ	SP	DR	RH	NG		
Date	Wind speed (dm/s)	Wind direction	Sunshine duration (hour)	% max potential sunshine duration	Precipitation duration (hour)	Daily precipitation amount (mm) (-1 for < 0,05 mm)	mean daily cloud cover (octants)	Number of bad pictures = "/"	%
01/08/2009	47	321	6,4	41	0	0	7	2	2%
02/08/2009	56	291	5,7	37	5,2	2,5	5	6	5%
03/08/2009	42	301	9,8	64	0	0	2	0	0%
04/08/2009	27	185	12,7	83	0	0	3	0	0%
05/08/2009	30	39	6,3	41	0	0	5	2	2%
06/08/2009	21	69	11,9	78	0	0	1	2	2%
07/08/2009	68	273	3,9	26	0,3	0,1	6	0	0%
08/08/2009	48	4	8,2	54	0	0	2	0	0%
09/08/2009	29	18	6,8	45	0	0	2	0	0%
10/08/2009	15	281,5	7,2	48	3,4	2,1	5	0	0%
11/08/2009	66	319	6,2	42	2,9	2	5	0	0%
12/08/2009	81	275	0,6	4	4	12,5	6	46	37%
13/08/2009	50	325	6,8	46	0	0	5	3	2%
14/08/2009	30	214	7,2	49	0	0	2	0	0%
15/08/2009	62	299	11,7	80	0	0	0	6	5%
16/08/2009	79	294	6,8	47	0	0	5	3	2%
17/08/2009	74	284	5,9	41	0	0	3	4	3%
18/08/2009	34	135	12,8	88	0	0	0	0	0%
19/08/2009	26	137	12,2	85	0	0	1	0	0%
20/08/2009	57	152	5,2	36	0,1	1,8	5	2	2%
21/08/2009	60	224	8,4	59	0	0	4	3	2%
22/08/2009	33	226	9,4	66	0	0	2	0	0%
23/08/2009	46	150	11,8	83	0	0	0	1	1%
24/08/2009	23	138	7,8	55	0	0	4	1	1%
25/08/2009	54	263	2,9	21	0	0	5	0	0%
26/08/2009	75	188	5,8	41	0	0	5	46	37%
27/08/2009			3,8	27	0	0	6	no count	no count
28/08/2009	140	251	8,8	63	1,8	8,9	6	48	39%
29/08/2009	95	284	10,5	76	0,9	0,3	3	6	5%
30/08/2009	70	250	6,3	46	0	0	5	2	2%
31/08/2009	54	163	11,2	82	0	0	2	3	2%

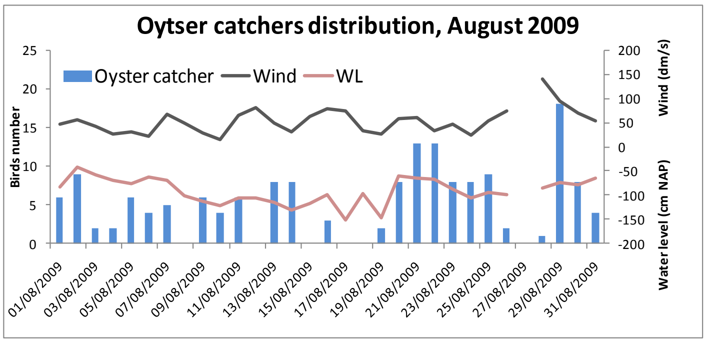
Appendix 2: Bad pictures analysis, October 2009

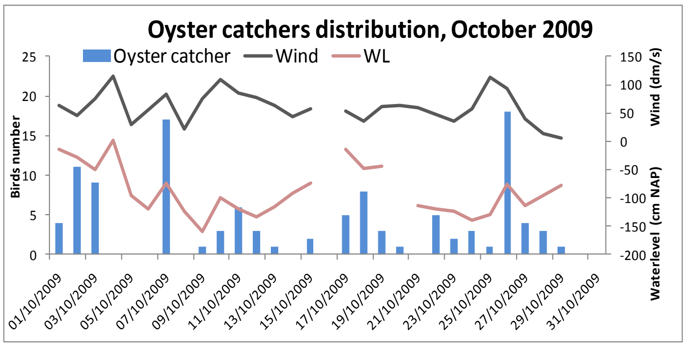
	Wind condition: Stavenisse (hmcz website)		Other weather conditions: Wilhelminadorp (knmi website)						
			SQ	SP	DR	RH	NG		
Date	Wind speed (dm/s)	Wind direction	Sunshine duration (hour)	% max potential sunshine duration	Precipitation duration (hour)	Daily precipitation amount (mm) (-1 for < 0,05 mm)	mean daily cloud cover (octants)	Number of bad pictures = "/"	%
01/10/2009	63	334	1,7	15	0,3	0,1	6	6	5%
02/10/2009	46	218	3,5	30	0	0	6	7	6%
03/10/2009	76	214	0,3	3	0,9	1,4	7	13	10%
04/10/2009	116	284	6	52	0	0	5	0	0%
05/10/2009	29	148	0	0	7,7	5,8	8	60	48%
06/10/2009	56	170	0,6	5	2,7	5,8	8	4	3%
07/10/2009	83	228	0,4	4	8,7	37	8	5	4%
08/10/2009	22	182	7,7	69	3	3,4	3	7	6%
09/10/2009	76	110	7,4	66	5,6	16,5	4	4	3%
10/10/2009	109	282	1,9	17	1,5	2,7	6	12	10%
11/10/2009	86	251	0,1	1	1	0,7	6	1	1%
12/10/2009	78	338	7	64	0,5	1,3	4	4	3%
13/10/2009	63	357	1,8	17	0,2	0,2	6	7	6%
14/10/2009	43	59	8,4	78	0	0	3	0	0%
15/10/2009	58	8	9,5	88	0	0	3	1	1%
16/10/2009			2,8	26	3,6	2,1	7	no count	no count
17/10/2009	53,5	348	5,5	52	0,5	0,4	3	2	2%
18/10/2009	35	249	0,9	9	2,3	0,6	6	3	2%
19/10/2009	61	198	1,9	18	0	0	7	6	5%
20/10/2009	62,5	118	5,1	49	0	0	7	20	16%
21/10/2009	59	127	1,2	12	4,2	1,9	8	1	1%
22/10/2009	47	208	0	0	2,7	0,9	6	0	0%
23/10/2009	35	186	4,6	45	0	0	4	0	0%
24/10/2009	58	163	0	0	7	5,9	6	43	35%
25/10/2009	112,5	235	7,5	74	0	0	2	4	3%
26/10/2009	94	271	0	0	0	0	7	1	1%
27/10/2009	40	190	2,2	22	0	0	6	2	2%
28/10/2009	14	234	6,5	65	0	0	4	0	0%
29/10/2009	5,5	302	2,5	25	0	0	7	0	0%
30/10/2009			3,1	32	0	0	5	no count	no count
31/10/2009			1,6	16	0,7	0,3	8	no count	no count

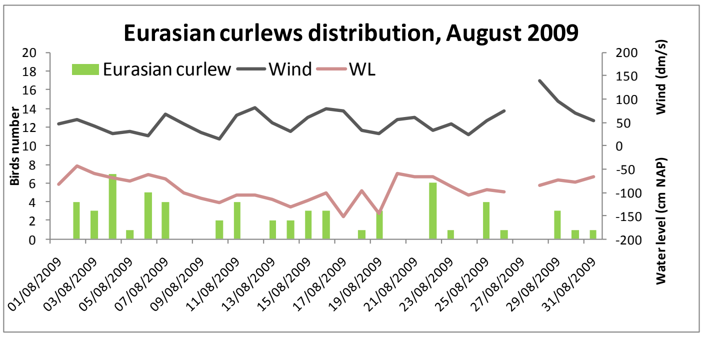
Appendix 3: Birds analysis, August and October 2009

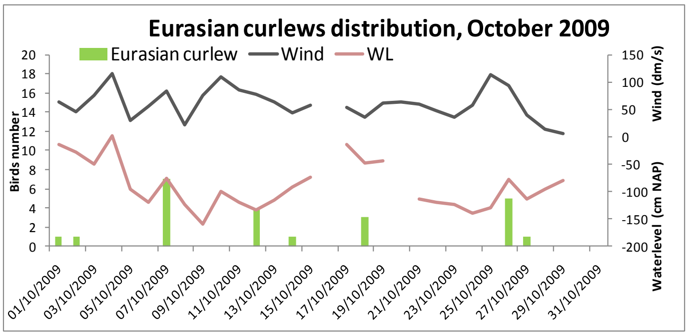




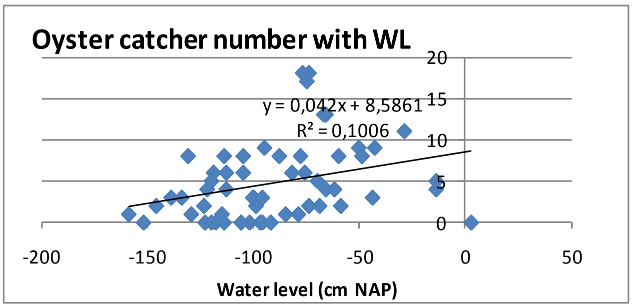


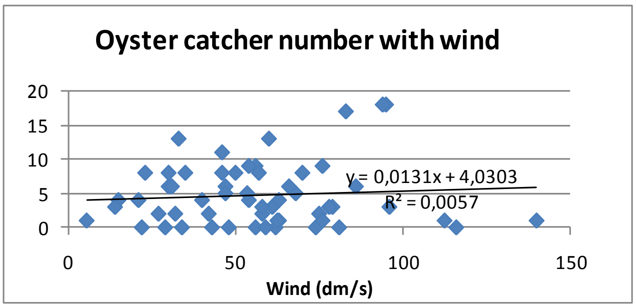


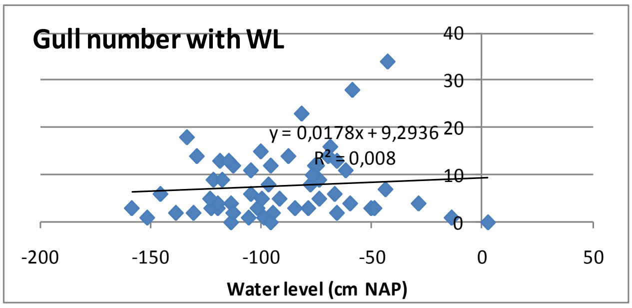


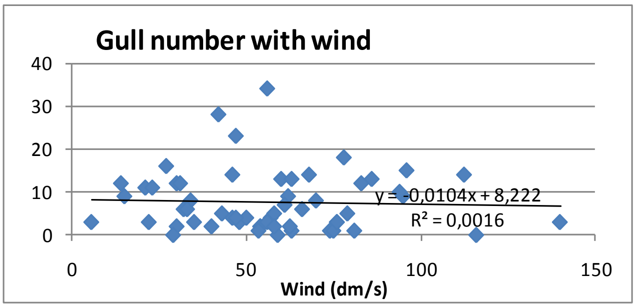


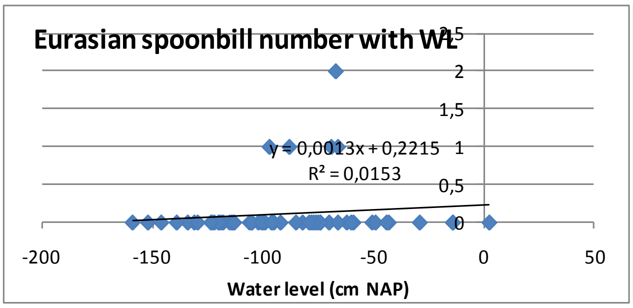
Appendix 4: Correlation between birds number and environmental parameters

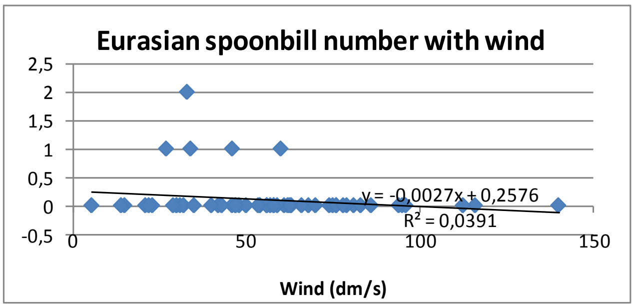


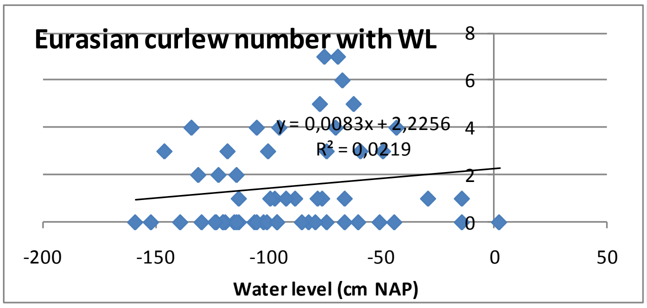


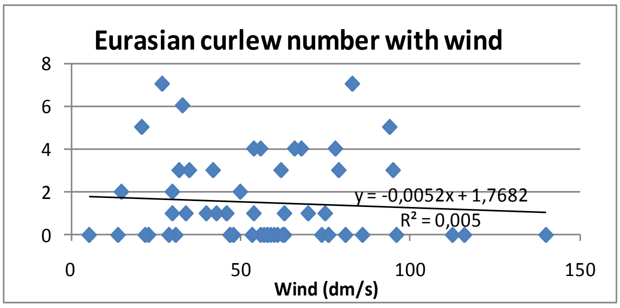












Appendix 5: Birds species in the Eastern Scheldt, Argus-Bio pictures

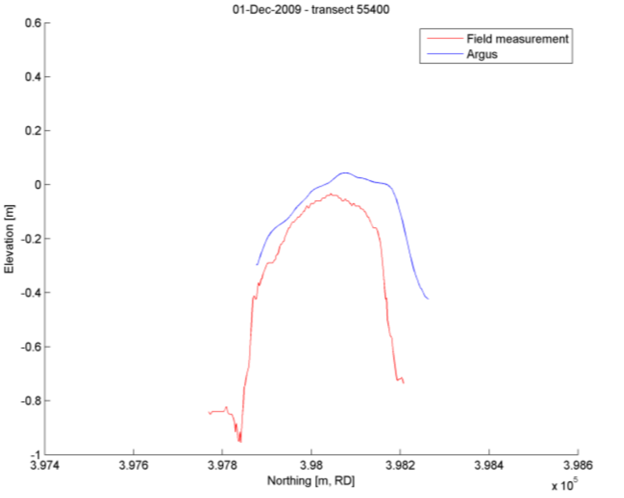
Cormorant **Eurasian spoonbill**

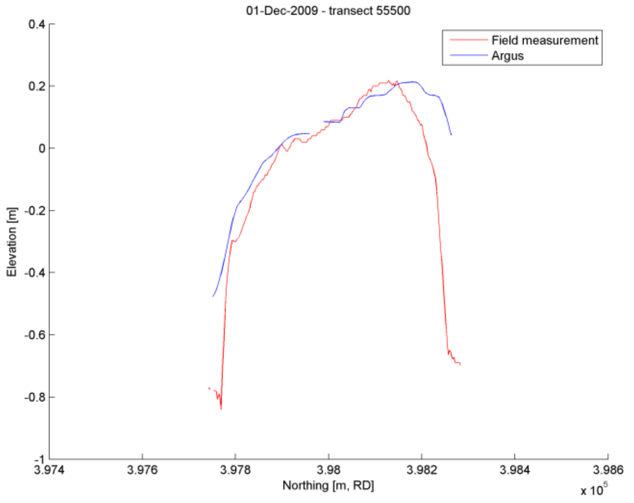
Oyster catcher

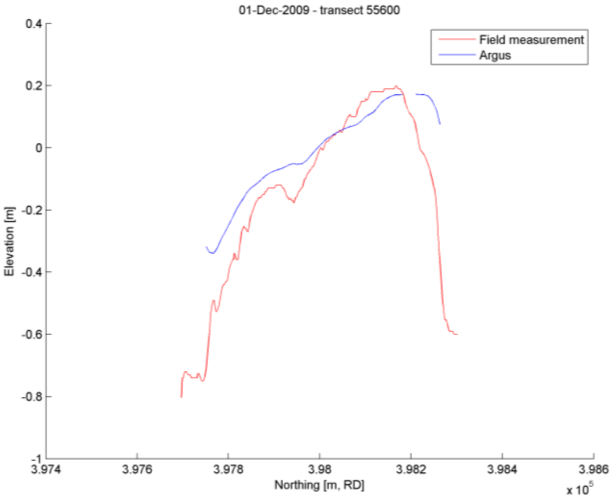
Gull **Duck**

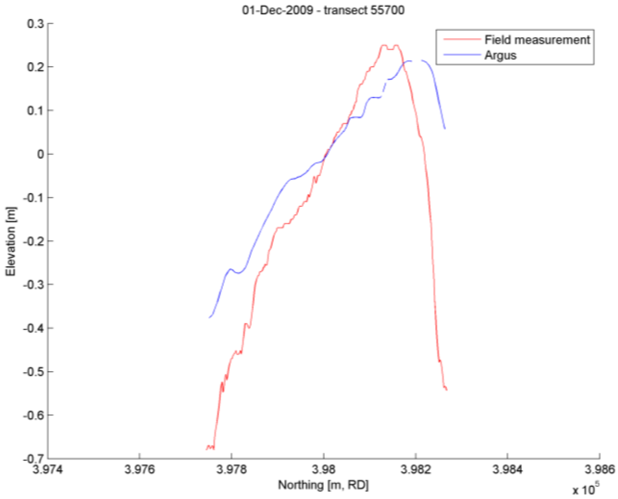
Eurasian curlew **Other waders**

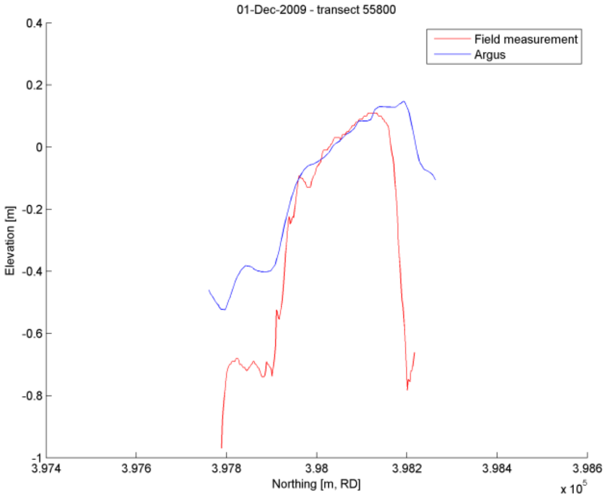
Appendix 6: Comparison for the 1st of December 2009, transects 55400, 55500, 55600, 55700 and 55800.



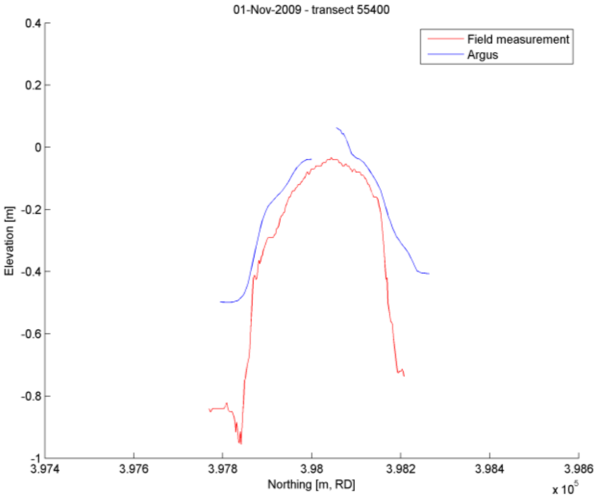


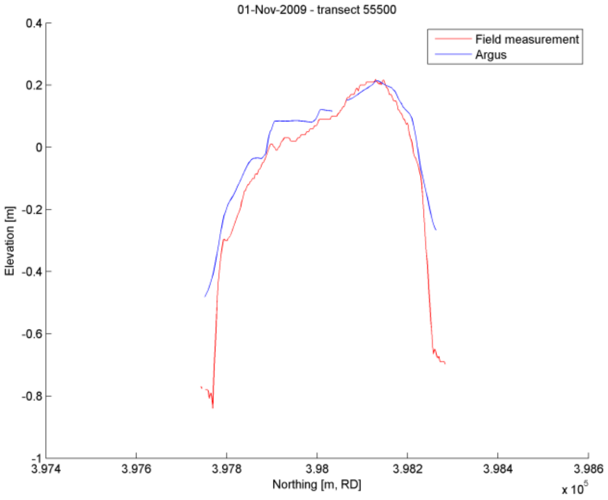


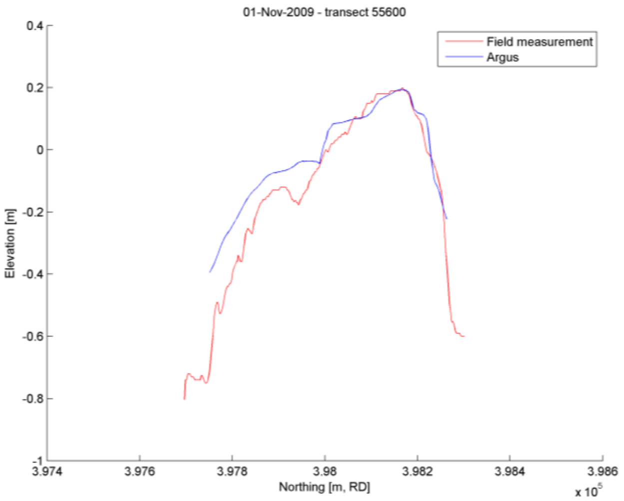


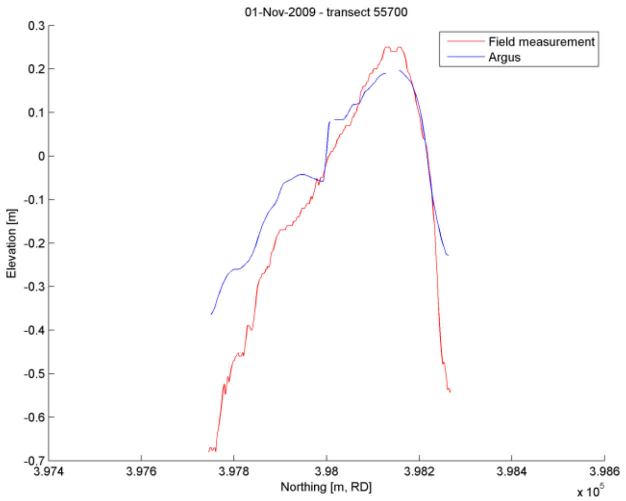


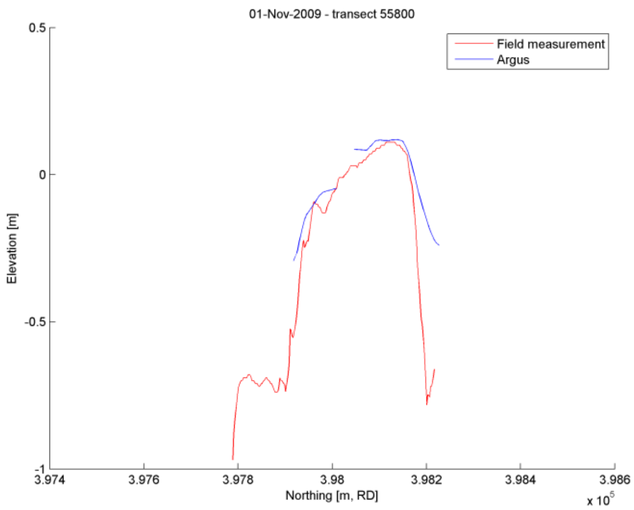
Appendix 7: Comparison for the 1st of November 2009, transects 55400, 55500, 55600, 55700 and 55800.



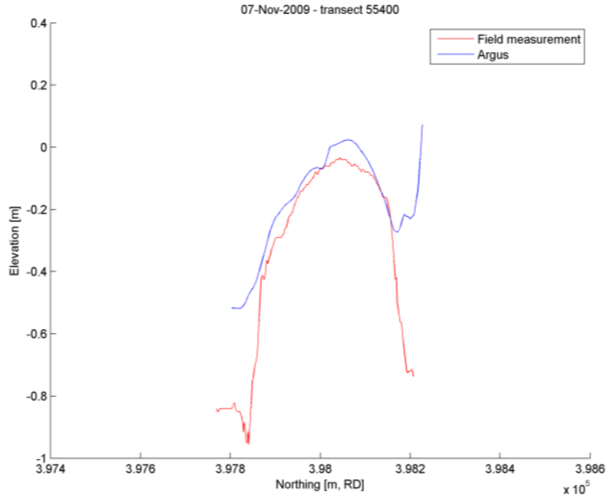


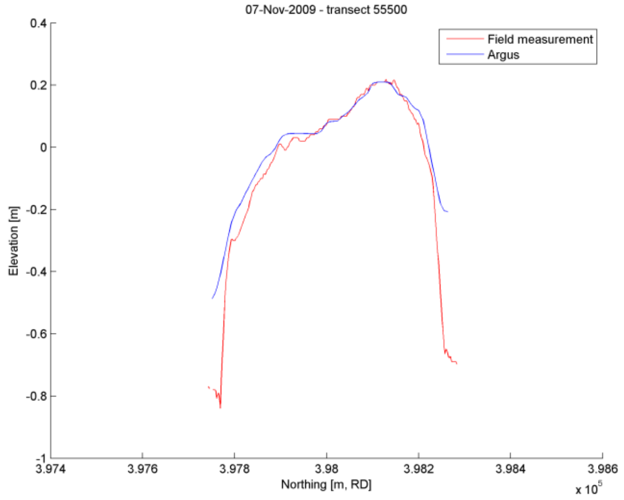


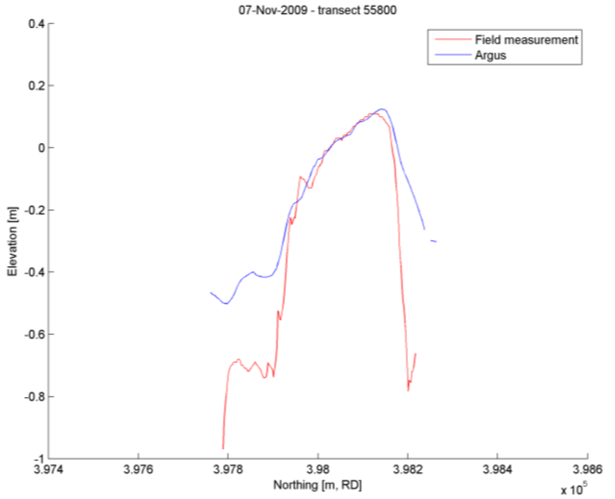


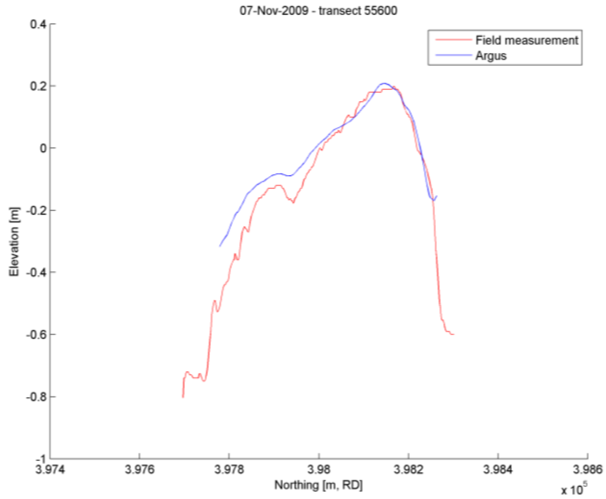


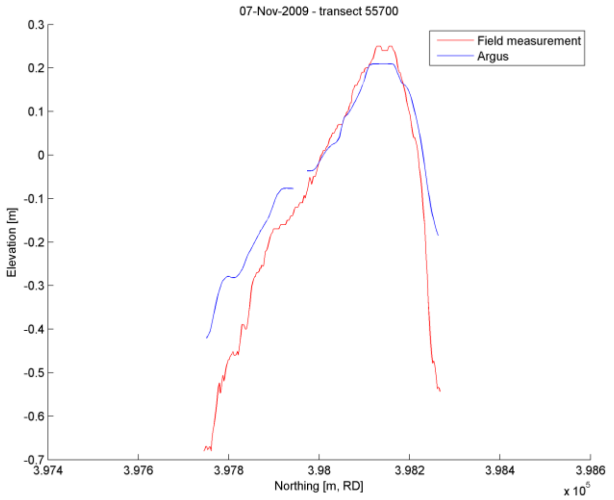
Appendix 8: Comparison for the 7th of November 2009, transects 55400, 55500, 55600, 55700 and 5800.







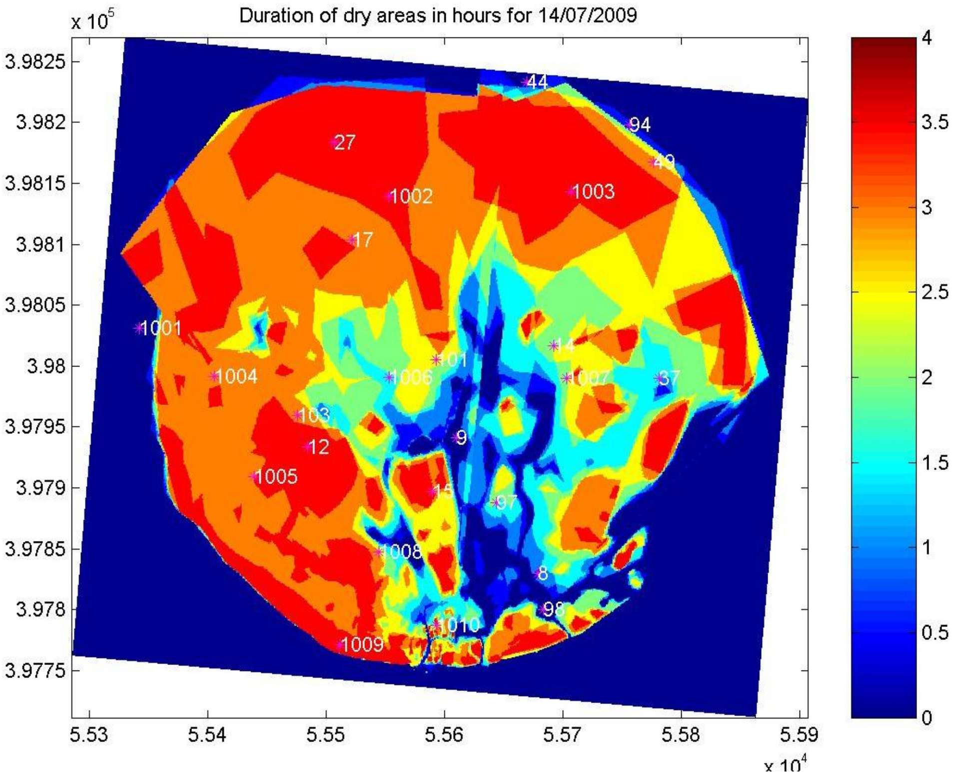




Appendix 9: Coordinates of the measurement stations, July 14th 2009

Stations	RD_X	RD_Y	Wet areas types
8	55679.184803	397830.007782	moist
9	55610.388334	397940.802506	wet
12	55484.69454	397933.639821	dry
14	55692.70811	398016.343152	dry-moist
15	55590.270542	397896.673063	dry
17	55521.7047149999	398103.366949	dry
27	55506.948644	398183.320396	dry
37	55781.230479	397990.146404	wet
44	55669.3170249999	398233.054341	wet
49	55776.419709	398167.861698	dry
94	55756.709429	398197.952319	dry-moist
97	55643.793278	397887.474811	moist
98	55683.687715	397799.891688	moist
101	55592.704805	398005.324255	dry
103	55475.977328	397959.772339	dry
1001	55342.138769	398031.405066	dry
1002	55553.0402699999	398139.641394	dry
1003	55707.08525	398143.287529	dry
1004	55405.156558	397991.213959	dry
1005	55438.915598	397909.313763	dry
1006	55552.878751	397990.528976	dry-moist
1007	55703.374175	397989.793793	dry-moist
1008	55544.506781	397847.142243	dry
1009	55511.794537	397771.00303	/
1010	55593.267427	397787.203876	dry-moist

Appendix 10: Dry areas results, for July 14th 2009



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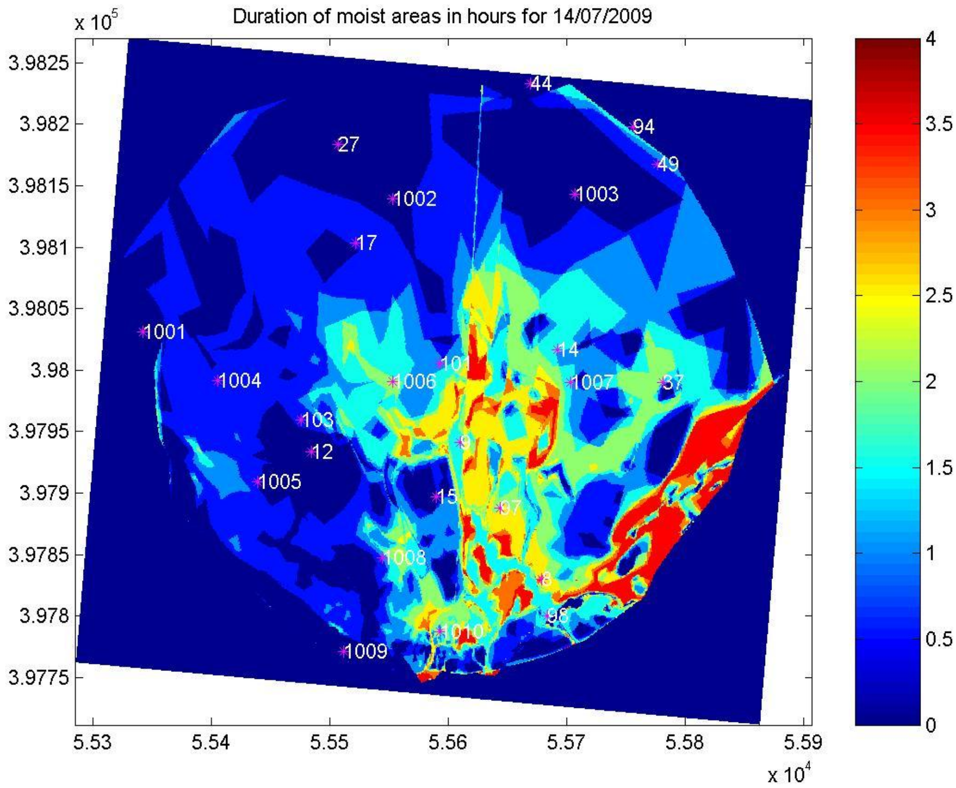
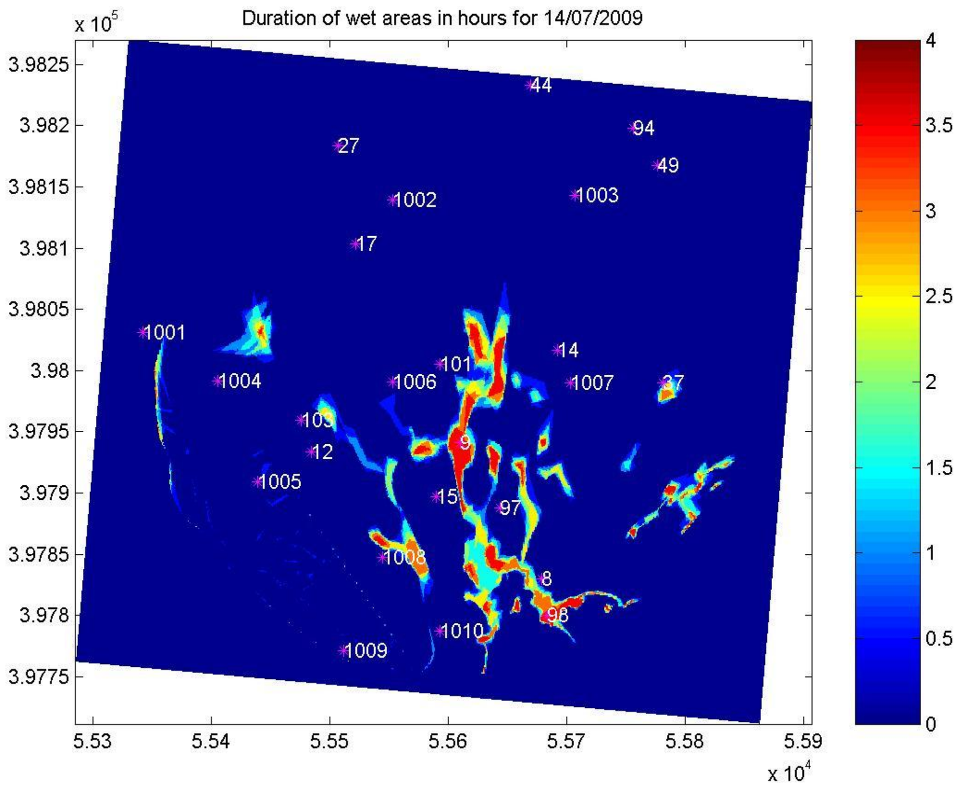
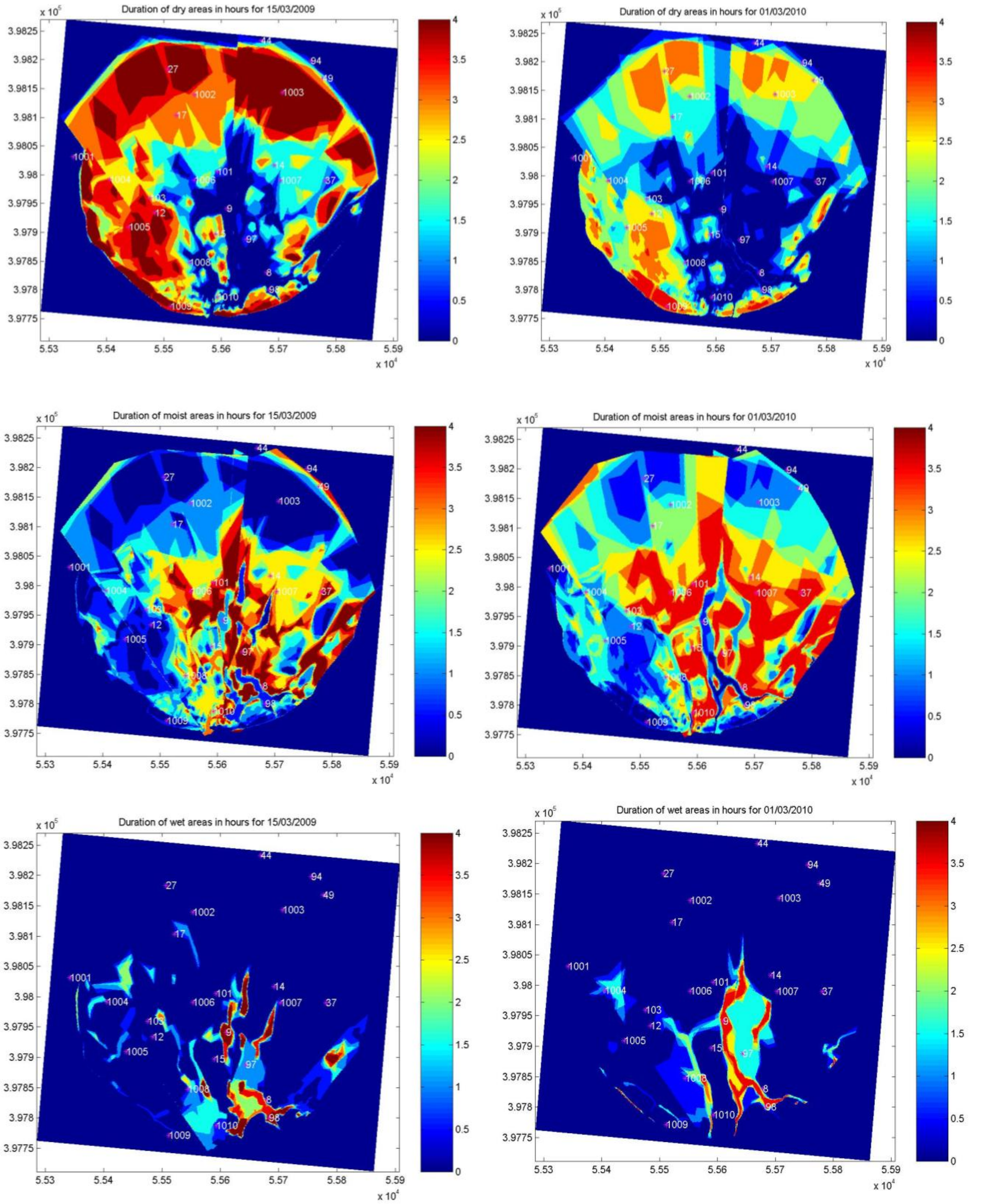
Appendix 11: Moist areas results, July 14th 2009



Appendix 12: Wet areas results, July 14th 2009

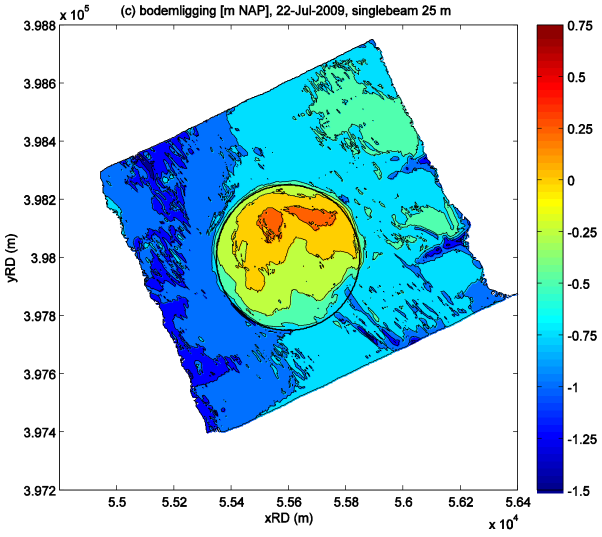


Appendix 13: wet, moist and dry areas results for March 15th, 2009 and March 1st, 2010 (respectively left and right)

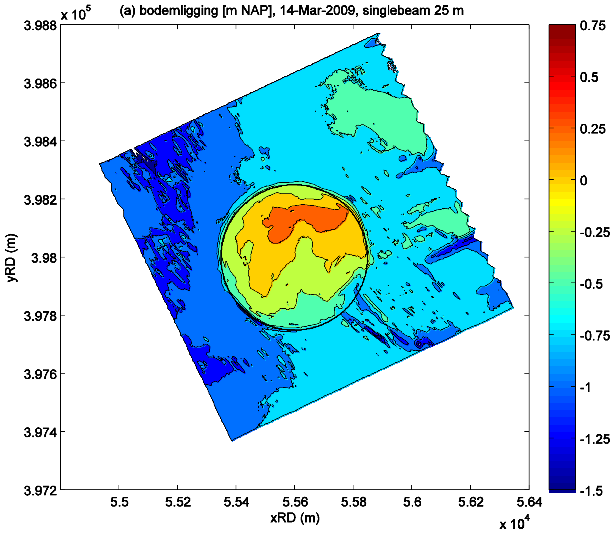


Appendix 14: Bed elevation of the nourishment

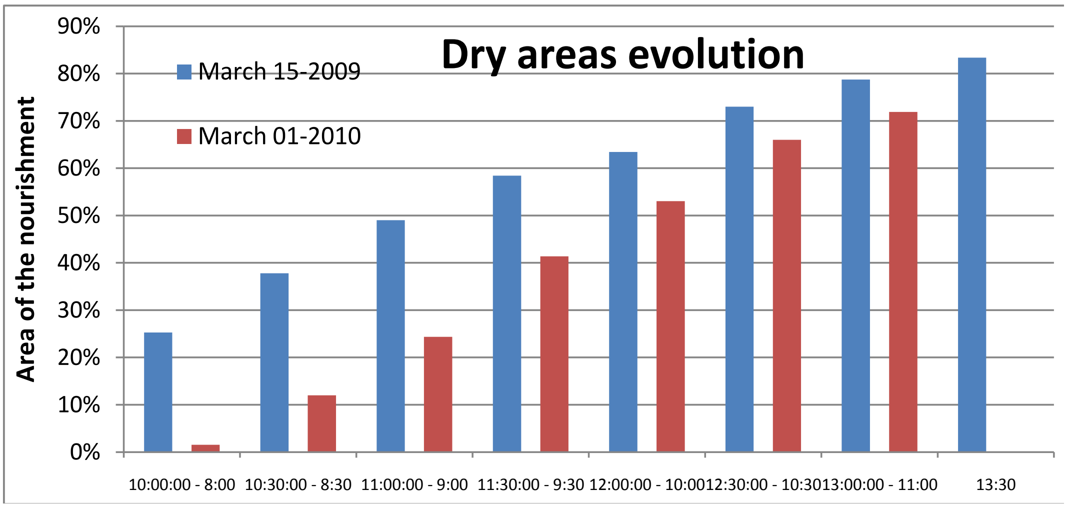
14-March 2009



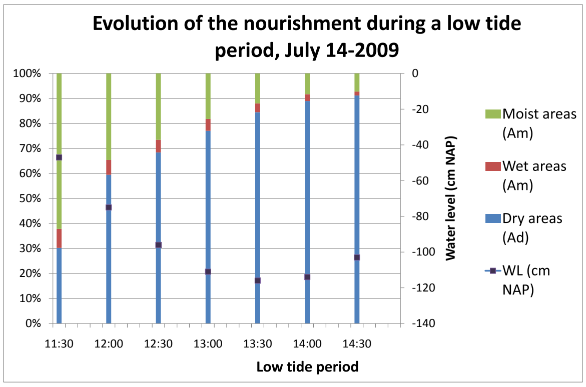
22-Jul-2009



Appendix 15: Evolution do the dry areas for march 2009 and march 2010



Appendix 16: Wet, moist and dry area analysis for the 14th of July 2009



Weather data of sunday 14 July 2009 in Wilhelminadorp	
Temperature : mean (in°C)	18,9
Sun, cloud cover & visibility	
Duration sunshine (hours)	6,6
Relative sunshine duration (%)	41%
Relative atmospheric humidity: (%)	81
Precipitation	
24h sum (mm)	0,8
duration (hour)	0,3

Appendix 17: Proportion of density and biomass according to the moisture level

Total value according to the moisture level:

Proportion	Density	biomass
dry	16%	8%
dry-moist	29%	19%
moist	23%	41%
wet	32%	32%

Value per specie according to the moisture level:

	proportion density	proportion biomass
Arenicola marina		
Dry	5%	2%
Dry-moist	23%	18%
Moist	39%	41%
Wet	33%	38%
Capitella capitata		
dry	0%	0%
dry-moist	5%	5%
moist	66%	78%
wet	30%	17%
Eteone sp		
dry	13%	10%
dry-moist	25%	30%
moist	31%	28%
wet	30%	32%
Hydrobia ulvae		
dry	5%	6%
dry-moist	21%	17%
moist	18%	18%
wet	55%	44%
Macoma balthica		
dry	3%	1%
dry-moist	37%	35%
moist	29%	23%
wet	31%	40%
Pygospio elegans		
dry	21%	19%
dry-moist	31%	25%
moist	15%	20%
wet	33%	29%
Scoloplos armiger		
dry	2%	4%
dry-moist	26%	16%
moist	51%	48%
wet	100%	100%

Appendix 18: Birds at low tide and during transition phases

C4, 08 Oct 2009, 11:30

C4, 08 Oct 2009, 13:00

C4, 08 Oct 2009, 13:30