Development of analysis techniques for the use of aerial photography in the monitoring of intertidal mussel beds and oyster beds

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Summary

The current method of mapping intertidal mussel beds is labour-intensive and potentially dangerous; it requires a field survey in which the circumference of mussel beds is determined by walking around them with a GPS. Therefore, in this project we investigated whether mussel beds can be recognized and mapped from aerial photography of the Dutch Wadden Sea taken by NAM/Arcadis. The aerial pictures were analysed by human eye and by recognition software (E-cognition). Both methods were compared in effectiveness and time efficiency.
The results show that both methods have their advantages and disadvantages. Although the success of human eye recognition was higher compared to software recognition, many structures were wrongly defined as mussel bed structures in both methods. Because of this, ground thruth will remain necessary to validate the analysis from aerial pictures, but can take place in a much smaller scale as only uncertainties have to be checked.
The use of aerial pictures, in combination with ground thruth, will result in a less labour-intensive and a more detailed and repeatable monitoring program.

Introduction

Within the framework of the WOT-tasks, IMARES monitors the area of intertidal mussel beds and the total biomass of mussels in the Dutch Wadden Sea twice a year. These measurements are carried out to monitor the development of mussel beds in the framework of NATURA 2000 and to facilitate policy making concerning mussel seed fishery. Next to this monitoring program IMARES carries out a detailed study on 7 individual mussel beds, concerning the parameters involved in the survival and development of mussel beds, within the framework of TMAP. These individual mussel beds are mapped every year to determine their exact location and size. In addition to these basic parameters, data is also collected on percentage cover, patch size, size-distribution, biomass and biodiversity within each individual bed. The current methods for monitoring mussel beds are labour-intensive, as it requires a field survey in which the contour of mussel beds is determined by walking around them with a GPS. The combination of working in a silted environment and working in a tight schedule in a dynamic area as the Wadden Sea results in a high work load, as the research vessel has to be reach before the next high tide. This tight schedule gives little time for more detailed measurements and observations.

In Germany ,TMAP monitoring of mussel beds is carried out by preliminary analysis (by human eye) of aerial photographs followed by field visits (Herlyn, 2005). From comparative analysis in Schleswig Holstein it is clear that relying on this analysis alone is not feasible (Stoddard, 2003).

From 2007 onwards aerial photographs of the Dutch Wadden Sea are taken by NAM at low tide in spring and autumn. On these photographs intertidal mussel beds and oyster reefs are visible. If detailed measurements are possible from these photographs, this will contribute to the analysis of the dynamics, as all beds can be monitored in greater detail. The development of individual patches in beds can be monitored and related to location within the bed, exposure to wind and waves, etc. This would contribute enormously to studies on stability of individual mussel beds and the parameters which are of importance for the survival of these structures. These are important variables for contributions to development of management plans for the ministries of LNV and V&W (RWS) Furthermore, the estimation of the total mussel bed area and total biomass of mussels in the WOT field inventory can be improved by analyzing photographs before the start of the survey. The photographs, in combination with maps of the previous year can be used to detect changes and thus improve efficiency of the survey. With this information not all beds may have to be visited and recorded by foot, but inspection of uncertainties may be sufficient. In combination with the ground truth data of the vessel survey on biomass, this will result in a less labour-intensive, and in specific areas, a more detailed monitoring program. More detail is required on mussel beds which are (partly) taken over by oysters and on oyster reefs in general, which are not included in the monitoring program at present.

To realize this improvement, the analysis techniques of aerial photography have to be further developed and tested. In first instance, aerial photographs will be compared with the data of the WOT- and TMAP-projects. The aerial photographs will be analysed by human eye and with the help of detection software Ecognition.

Problem analysis

Research questions:

- Can aerial pictures be used to recognise and map mussel beds in the Dutch Wadden Sea?
    - with detection by human eye
    - with detection software as E-Cognition

Method

The pictures were provided by the NAM and produced by Arcadis. They were aerial photographs of 5 km by 5 km with a pixel size of 0.5 x 0.5 meter. The pictures were taken on April 1, 2007.

The project consisted of 4 work packages;

A. Catalogue of the aerial pictures

The aerial pictures of spring 2007 were catalogued, so specific locations can be found easily and frequent and quick switching between picture-types (infra red or visible colours) was facilitated. For this purpose the pictures were categorized in such a way that they are available for Arc-info GIS where they can be combined with shape-files of former surveys.

B. Recognition and mapping of mussel bed contours by eye

First of all some “known” individual beds were checked to get an idea of the visibility of mussel beds on the pictures. It became clear that mussel beds were clearer on the infra-red pictures compared to the visible colour pictures. For this reason, for the recognition by eye only infra-red pictures were used.
Subsequently, two areas of almost 10 km x 10 km (9878 ha) were selected for the identification of mussel beds;

- Area Rottum, which was analysed with information on location and contours of beds in the previous year (spring 2006) that were copied as overlays over the aerial pictures and
- Area Schiermonnikoog, which was analysed without any previous knowledge or information.

The previous information on location and contours of the mussel beds in the Area Rottum came from the yearly spring survey of IMARES (WOT).
The recognition and the mapping of the beds by eye was done from the computer monitor as this makes it possible to “play” with contrast and other values to improve visibility.
The pictures were enlarged and with a drawing pad all structures were mapped which were recognized as mussel beds by human eye. The recognized beds were categorized according to “certainty”;
1= sure
2= pretty sure
3= pretty unsure
4= unsure
5= might be

Sometimes a mussel bed consisted of several categories of certainty.
For the analyses only category 1 and 2 were included.

The digitized contours of the mussel beds of categories 1 and 2 that were mapped by eye were compared with the WOT survey results of spring 2007, i.e. the same period as the photographs. Subsequently, the area of the beds that were recognized by human eye was grouped in several subgroups;

- "<u>missed</u>" means that the human eye did not map the structure as part of a mussel bed, but according to the WOT-survey of 2007 it was part of a mussel bed.
- "<u>correct</u>" means that the structure was recognised by the human eye and also was present in the WOT-survey of 2007.

- "wrong" means that the human eye recognised a mussel structure, but according to the WOT-survey this was no part of a mussel bed in 2007.

We then subdivided these categories in "old" and "new", according to existence of the beds in previous years.

- "missed-old" means that the human eye did not recognise a mussel structure, although it was visible in the WOT of 2006 (so although there was information of former presence, the human eye concluded that it was gone in 2007).
- "missed-new" means that the human eye did not recognise a mussel structure, but the mussel structure was also not present in the WOT 2006 (but was present in 2007).
- "correct-old" means that the human eye correctly recognised a mussel structure which was also present in 2006
- "correct-new" means that the human eye correctly recognised a mussel structure, although it was not there in 2006
- "wrong-old" means that the human eye wrongly recognised a mussel structure, but WOT recognised this as a bed in 2006 (that was no longer present in 2007).
- "wrong-new" means that the human eye wrongly recognised a mussel structure, and WOT did not identify this as a mussel bed in 2006.

C. Recognition and mapping of mussel bed contours with detection software

The processing of mussel bed mapping with detection software is based on images of 5 km by 5 km, which were subdivided in 4 subset images (as the software can not process larger pictures without special additions). The software (Ecognition) was “programmed” to recognize a certain combination of spectral and spatial characteristics. After the first session and comparison with WOT, the definitions were adjusted. For the recognition and mapping of mussel beds with detection software the same areas were selected as for the recognition by eye. The success was measured, after which some improvements were made. See for detailed methodology Appendix 1.
From both runs (before and after adjustment), the success and necessary time was recorded. The success was grouped in the same groups and subgroups as the success by human eye.

D. Analyses of both methods (human eye and software)

The total time and the success of each method is described in the analyses of the use of aerial pictures for the recognition and mapping of mussel beds in the Wadden Sea.

Results

A. Catalogue of the aerial pictures

The pictures were catalogued and made available for Arc-info GIS. The pictures were Geo-referenced. Both infra-red (fig. 1) as visible colour pictures were made easily accessible. The pictures can be combined in GIS with all historic survey data on mussel beds.

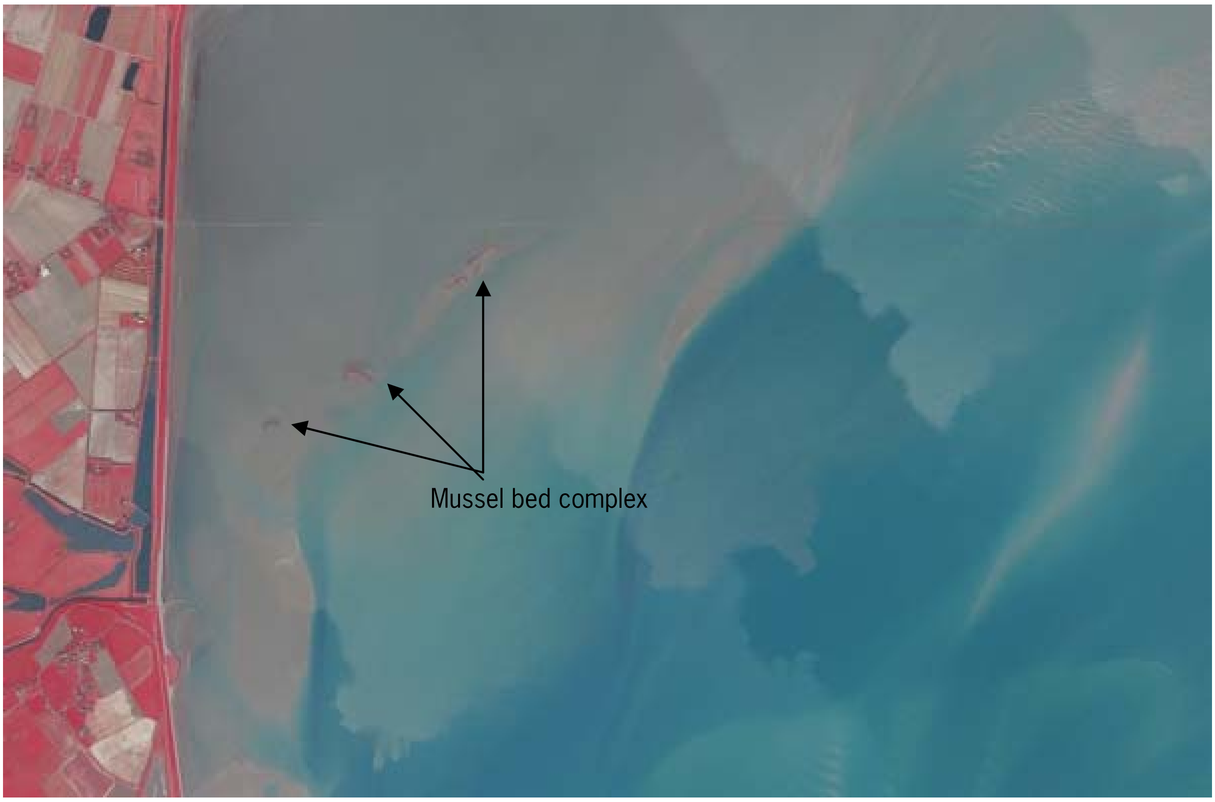


Fig. 1 Picture of area near Oost (Texel) where a mussel bed complex is clearly visible. The difference in colour in the area is the result of the different pictures which are combined for this area (picture: Arcadis).

B. Recognition and mapping of mussel bed contours by eye

Area Rottum (with locations and contours of WOT 2006):

When information was available on mussel bed location and contours of the previous year, the human eye considered an area of 267.74 ha to be mussel bed (in categories 1 and 2), while the WOT-survey (2007) mapped 172.9 ha (fig. 2). The human eye thus overestimated the area of mussel beds with 154% (if we assume that WOT mapped all mussel beds, which is not necessarily the case).

The human eye recognized (in certainty category 1 and 2) 84% of the area of the WOT-mussel beds correctly (table 2). From this percentage 11% was not present in the data of WOT 2006 ("correct-new") and 73% corresponded with the area recognized by WOT 2006 ("correct-old") (table 1).
With the human eye 12.7% of the WOT 2007 mussel beds were missed (table 2).
45.8% of the mussel bed area that was mapped by the human eye did not correspond with WOT 2007 ("wrong") (table 2). From this percentage 24% was mapped on locations where also in WOT 2006 no beds were found ("wrong-new") and 23% on locations that were mapped as mussel bed area in WOT 2006 ("wrong-old") (table 1).
The analyses of the area by human eye took 15 hours.

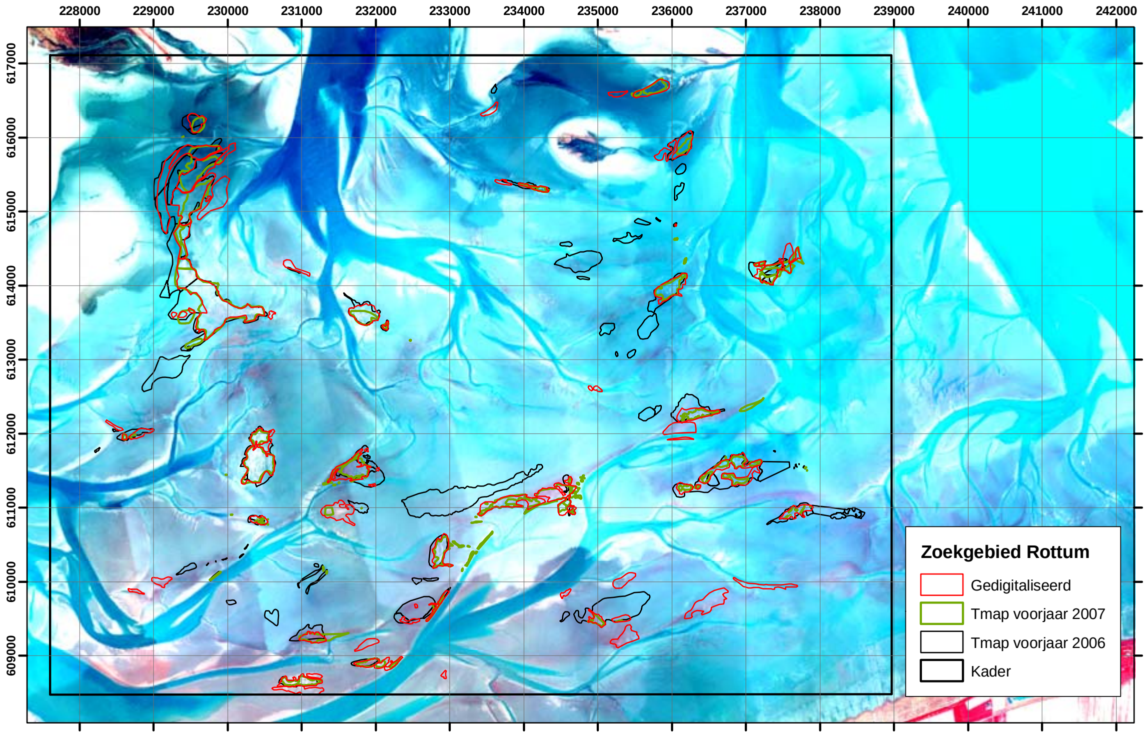


Fig. 2. Contours of mussel beds near Rottum recognized by human eye compared to WOT 2006 and WOT 2007 surveys (picture: Arcadis).

Table 1. Area (ha) of mussel bed structures recognized by human eye, subdivided in groups according to success

missed-old	missed-new	correct-new	correct-old	wrong-new	wrong-old
9.95	12.03	19.48	125.78	63.12	59.42

Tabel 2. Area (ha) and percentage of success of recognition by human eye with WOT 2006 available.

	Missed	Correct	Wrong
Hectare mapped by human eye	21.98	145.26	122.54
Percentage of WOT	12.7%	84%	-
Percentage of human eye estimate	-	54.3%	45.8%

Area Schiermonnikoog (without locations and contours of WOT 2006):

Without any previous knowledge on location or contours of mussel beds in the past, the human eye recognised 452.9 ha mussel bed, while the 2007 WOT-survey mapped 190.2 ha (fig. 3). The human eye thus overestimated the area of mussel beds with 237% (if we assume that WOT mapped all mussel beds, which is not necessarily the case).

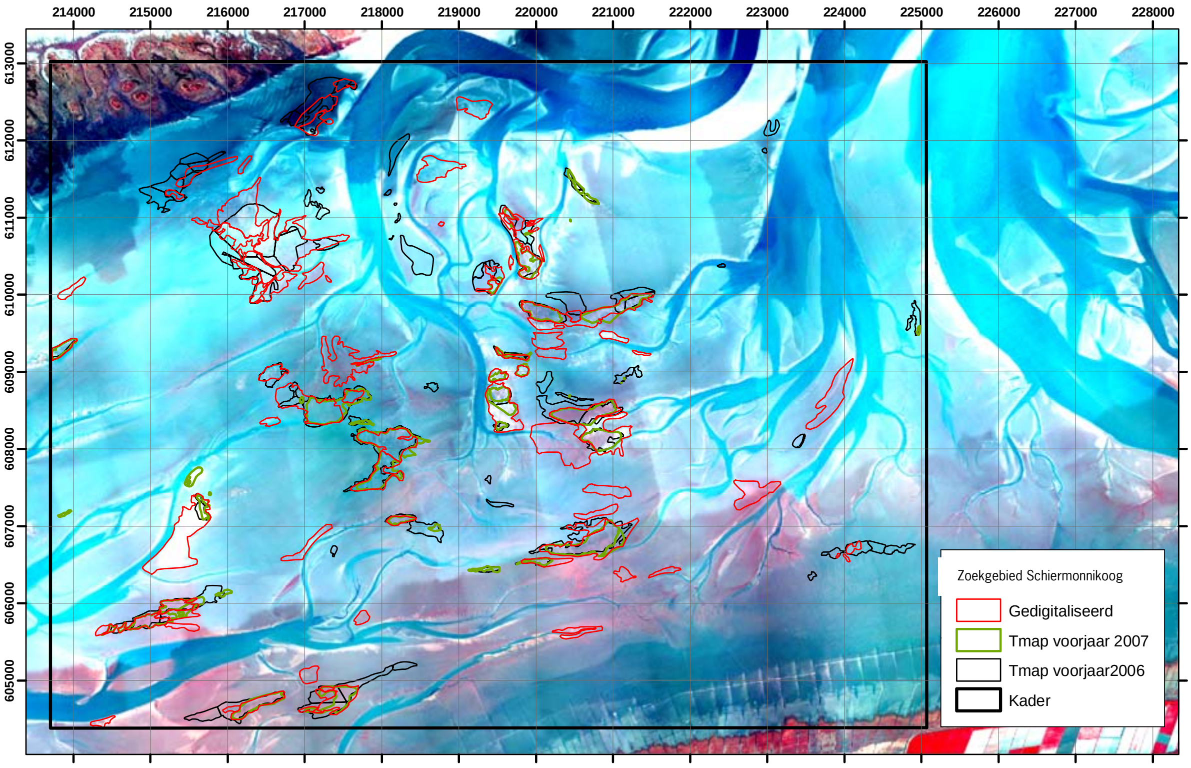


Fig. 3. Contours of mussel beds near Schiermonnikoog recognized by human eye compared to WOT 2006 and WOT 2007 surveys (picture: Arcadis).

The human eye recognized (in certainty category 1 and 2) 84.5 % of the area of the WOT-mussel beds correctly (table 3).
With the human eye 15.5% of the WOT 2007 mussel beds were missed ("missed") (table 3).
64.5% of the mussel bed area that was mapped by the human eye did not correspond with WOT 2007 (table 3).

The analysis of the area by human eye took 15 hours, trials included.

Table 3 Area (ha) and percentage of success of recognition by human eye without previous knowledge.

	Missed	Correct	Wrong
Hectare mapped by human eye	**29.56**	**160.59**	**292.33**
Percentage of WOT	**15.5%**	**84.5%**	**-**
Percentage of human eye estimate	**-**	**35.5%**	**64.5%**

C. Recognition an mapping of mussel bed contours with detection software

First trial

In the first trial the minimum bed size was set at 2 ha. In total (Rottum and Schiermonnikoog) E-cognition recognized and mapped 529.95 ha mussel structures, while the WOT-survey mapped 363 ha (table 4 en figure 4). E-cognition thus overestimated the area of mussel beds with 146% (if we assume that WOT mapped all mussel beds, which is not necessarily the case).

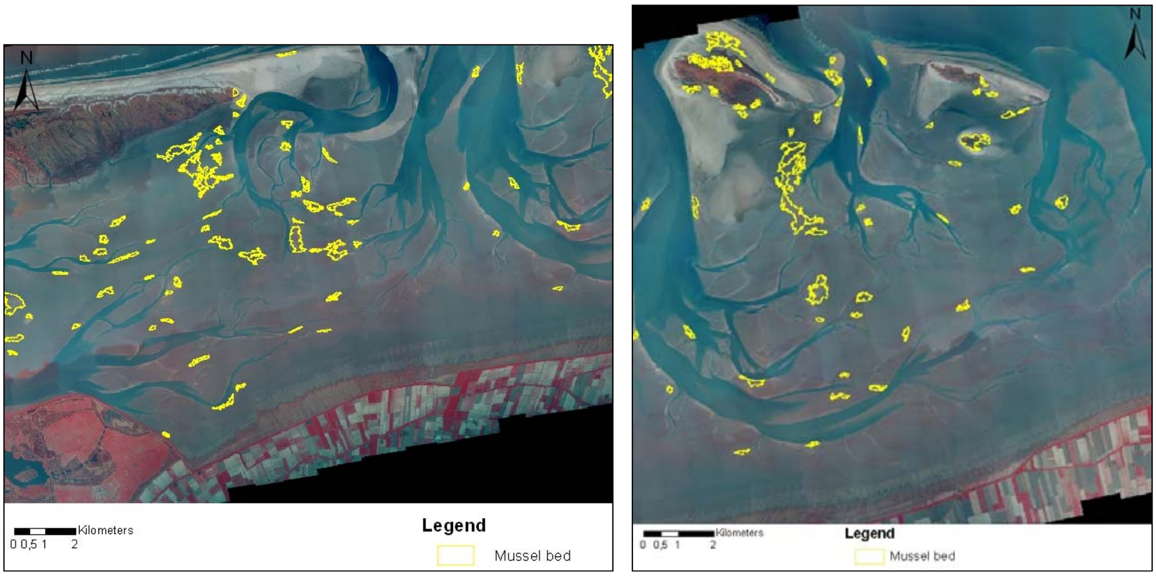


Fig. 4. Contours of mussel beds near Schiermonnikoog and Rottum recognized by E-cognition (picture: Arcadis).

In the first trial, E-cognition recognized 55 % of the area of the WOT-mussel beds correctly (table 4).
With E-cognition 48.4% of the WOT 2007 mussel beds were missed ("missed") (table 4).
62.3% of the mussel bed area which was mapped by E-cognition did not correspond with WOT 2007 (table 4).

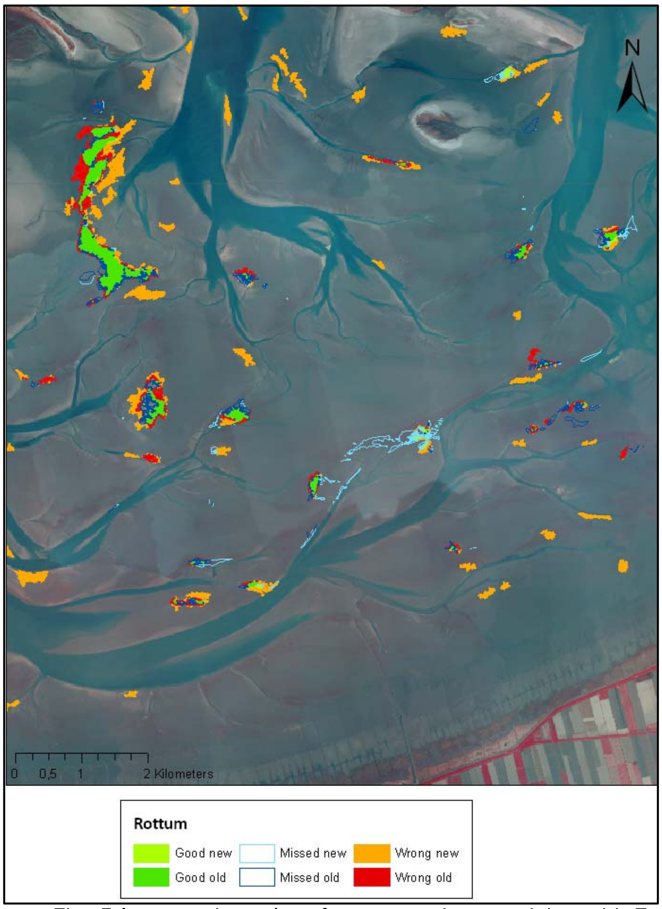
The analysis of the area by E-cognition took about 2 hours for each area.

Table 4. Results of first trial with automatic detection with Ecognition.

	Missed	Correct	Wrong
Hectare mapped by E-cognition	**175.67**	**199.69**	**330.26**
Percentage of WOT	**48.4%**	**55.0%**	**-**
Percentage of E-cognition estimate	**-**	**37.7%**	**62.3%**

Improved trial

In the improved trial some parameters for detection of the mussel structures were adjusted (appendix 1). One of the main adjustments concerned the size of the detected structures (now also < 2 ha). Besides those parameter adjustments, the most obvious wrongly detected elements located in deep water and in the dunes of the islands were manually removed.



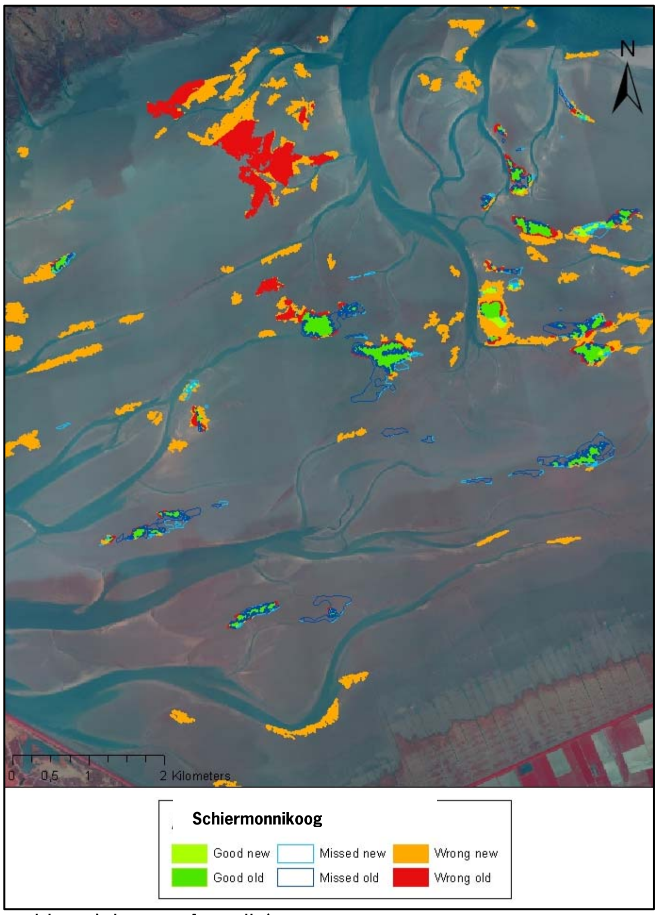


Fig. 5 Improved results of automated recognision with E-cognition. (picture: Arcadis)

In total (Rottum and Schiermonnikoog) E-cognition recognized and mapped 614.12 ha mussel structures, while the WOT-survey mapped 363 ha (table 5 en figure 5). E-cognition thus overestimated the area of mussel beds with 169% (if we assume that WOT mapped all mussel beds, which is not necessarily the case).

Table 5. Results of improved trial with automatic detection with Ecognition.

	Missed	Correct	Wrong
Hectare	**163.19**	**212.16**	**401.96**
Percentage of WOT	**44.9%**	**58.4%**	**-**
Percentage of E-cognition estimate	**-**	**34.5%**	**65.5%**

E-cognition recognized 58.4 % of the area of the WOT-mussel beds correctly (table 5).
With E-cognition 44.9 % of the WOT 2007 mussel beds were missed (“missed”) (table 5).
65.4% of the mussel bed area which was mapped by E-cognition did not correspond with WOT 2007 (table 5).

The analysis of the area by E-cognition took about 3 hours for each area.

Discussion and conclusion

This project aimed at improving the analysis techniques of aerial photography for mussel bed recognition and mapping. In this project two techniques were tested; recognition and mapping by human eye and recognition and mapping by automatic detection software.

The detection with the human eye was tested in two ways. The first test considered recognition of mussel beds in an area were contours of the previous year were available. The second test concerned a blind recognition test without any knowledge on previous locations of mussel beds.
In both cases the human eye overestimated the area of mussel beds. Surprisingly, the area of "correct" and "missed" recognitions did not differ much between the methods. The test with previous knowledge, however, resulted in less wrongly identified mussel bed area.
The "wrong-old" group in the human eye detection might be the result of structures of former mussel beds (shells, sediment, etc.) which are still visible on the picture, but were not mapped in the field (WOT 2007) because no living mussels were present. In addition it should be noted that also the WOT survey might miss mussel beds, as not every square meter of the tidal flats is visited, but only areas which are known to contain mussel beds or where mussel beds have been seen from the airplane.
The detection with the human eye might improve with practice.

Due to the process based on fixed rules, the software method seems more consistent, objective and repeatable than the human eye method. The detection with the recognition software resulted however in a much lower percentage of correctly recognized mussel beds. Also percentages of missed and wrongly detected mussel beds were higher. The first improvement did not result in higher performance, but other improvements might. Although success was lower with this method, the time costs were also much lower.

	Software	Human eye
Success	-	+
Accuracy	++	+
Time efficiency	+	-
Objectiveness	+	± (depending on interpreter)
Repeatability	++	± (depending on interpreter)
Consistency	++	± (depending on interpreter)

Although the success of human eye recognition was higher compared to software recognition, many structures were wrongly defined as mussel bed structures in both methods. Because of this, ground thruth will remain necessary to validate the analysis from aerial pictures, but can take place in a much smaller scale as only uncertainties have to be checked.

In conclusion it can be stated that software recognition is a powerful tool to help the human observer with the interpretation of the aerial pictures. A preliminary run with the software detection might draw the human eye to mussel bed like structures and in this way save time for the detection with human eye. In combination with information on locations and contours of mussel beds in previous years, this might improve human eye detection even more. When the human eye has detected a possible mussel bed, detection software is more accurate and consistent in drawing the actual contours.
As many structures were wrongly defined as mussel bed structures in both methods, ground thruth will remain necessary to validate the analysis

Besides advantages of analyses of mussel bed structures from aerial pictures as objectiveness, repeatability and consistency it is also possible to give a quantitative representation of the patterns which can be observed within mussel beds. Although this part of mussel bed mapping is not included in this project a first start has been made by using E-cognition (fig. 6). This technique might be helpful in classification of mussel bed patterns in studies on stability of structures, as patch sizes and patch size distribution can be easily calculated.

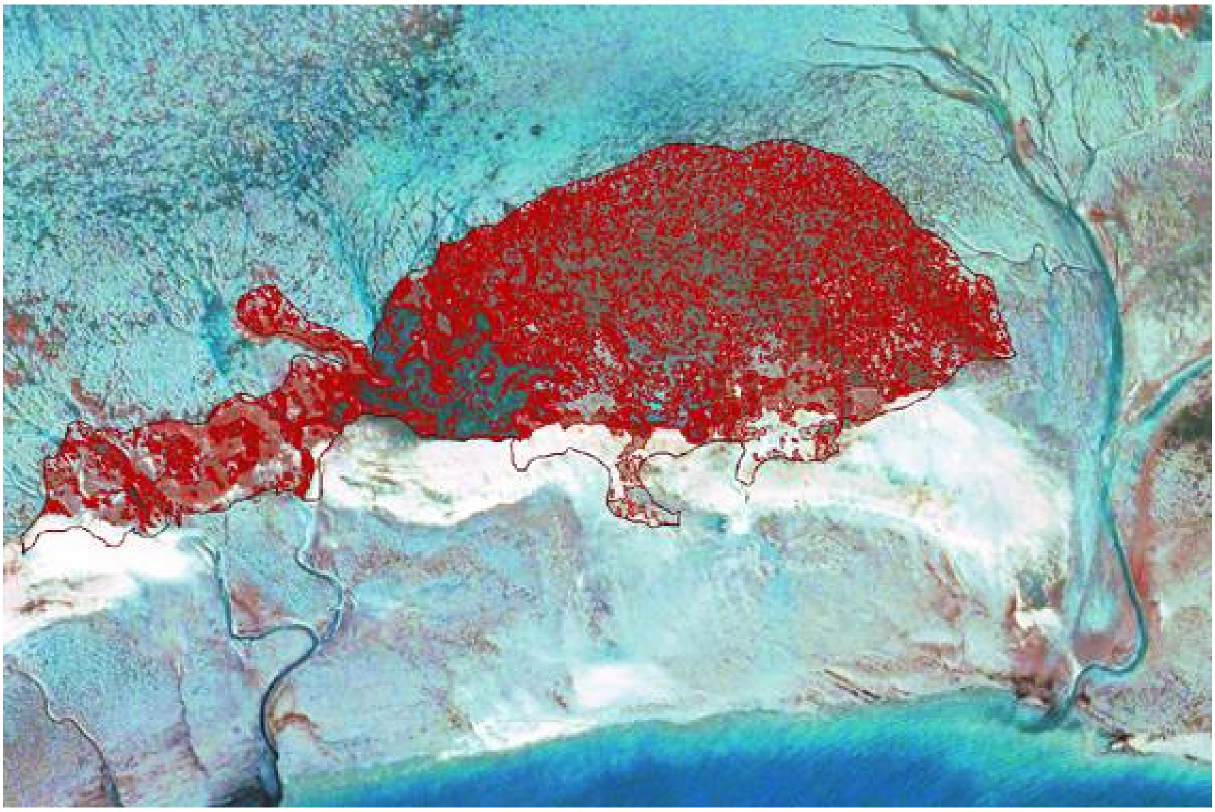


Fig. 6 Representation of structure on mussel/oyster bed near Ameland (picture: Arcadis). Probable shellfish patches were filled in by E-cognition within the contour of the GPS track (ground truth).

Quality Assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2009 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation, with the last inspection being held on the 5th of October 2007.

Referenties

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Justification

Report C004/09
Project Number: 4391900335

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen IMARES.

Approved: Dr. M.J. Baptist
Researcher

Signature: 09-12-'09

Date: 09-01-2009

Approved: Drs. F.C. Groenendijk
Head department Ecologie

Signature:

Date: 09-01-2009

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Appendix A. Mapping of mussel beds in the Wadden Sea based on automated detection on digital aerial photographs

Laure Roupioz, Anne Schmidt and Henk Kramer.

Introduction

As part of the Trilateral Monitoring and Assessment Program of the Wadden Sea, the detection and monitoring of the surface area and structure of mussel beds in the Wadden Sea is an important issue for environmental policies and management. Mussels are essential components of the Wadden sea fauna because of their influence on sediment dynamics and reef structure. They also form hot spots of biodiversity of associated species, as well as foraging grounds for birds.

Mussel beds show quite stable structures, but in dynamic environments such as the Wadden Sea, changes in their shape and structure occur frequently, and regular inventories are necessary to monitor them. These surveys are carried out by foot, collecting GPS coordinates by walking around the mussel beds on tidal flats field every year. This method is expensive, labour intensive and potentially risky. Moreover, these surveys are often limited by the weather and the site accessibility. In this context, the use of digital aerial photographs to detect the mussel beds is considered as a potential improvement that should be explored.

Digital aerial photographs are recently used as base information for the manual detection and delineation (mapping) of the mussel beds. However, this operation requires the participation of an expert with a sufficient knowledge of the area. Thus, it is still time consuming and can also be considered as subjective. Therefore, the objective of this study is to explore and assess the potential use of automated remote sensing methods to improve the mussel bed detection and mapping; in order to assess what automated methods add to manual methods in terms of efficiency (costs / benefits), accuracy, reliability, consistency and repeatability criteria. The question investigated in this study can be expressed as:

What do automated methods (image analysis tools for detection and delineation of mussel beds) add to manual methods in terms of efficiency, accuracy, reliability, consistency and repeatability?

Materials and methods

Both manual and automated methods for the detection and delineation of mussel beds on aerial photographs make use of different image characteristics, namely:

- Spectral characteristics, expressed as the spectral bands values, which refers to the colors of the image. Images are recorded on different wavelength ranges, corresponding to the different bands (in this case in blue, green, red and near infra red). According to its reflectance characteristics, an object will present specific spectral values in each band. For the human eyes, this appears as the difference in color between different objects. Only the visible wavelengths (blue, green and red) are perceptible by humans.
- Spatial characteristics which consist in the size, shape, texture and other physical values related to the feature other than color.

The difference between the manual and automated methods is that the latter can be performed consistently based on selected parameters, such as some spectral and spatial values quoted above. This makes the interpretation faster (depending on software performance), more consistent, transparent and repeatable due to the fact that the computation is based on a fixed rule set. The automated method is also more efficient in the distinction of elements thank to a more powerful detection in color changes and to the use of spectral value that are not visible for the human eyes, as near infra-red values. The question is how generic or specific the interpretation is, and whether this interpretation procedure can be translated into a set of rules?

In order to answer these questions, application of two software packages was tested:

- Envi Zoom, extension of Envi (www.ittvis.com/ENVI/)
- Ecognition (www.definiens.com)

Envi zoom quickly showed limitations related to its restricted availability of texture parameters. Indeed, we noticed during the first steps of the analyses that mussel beds were mainly distinguished from the other features by their typical texture, i.e. their spatial characteristics in the image. Ecognition software appeared to be more useful for its broader choice in texture parameters.

<u>Image processing procedure</u>

The processing of mussel beds mapping was based on aerial photographs of 5km by 5km with a pixel size of 0.5x0.5 meter. For practical reasons, the images were divided 4 parts (sub-image) before processing took place.

Each sub-image was processed as followed: First, it was segmented. During segmentation, the image, originally divided in regular pixels, is reclassified to other basic units called segments, according to the spectral pixel value: A pixel will be aggregated or not with its neighbours according to its spectral similarity. Thus, the created segments differ in size and shape but are homogeneous according to spectral value. Subsequently, the class "musselbed" is attributed to each segment corresponding to the rules set for this class. The other segments, that did not fulfil these requirements, remained unclassified. The result of this classification is optimized by some operations applied in order to improve the result.

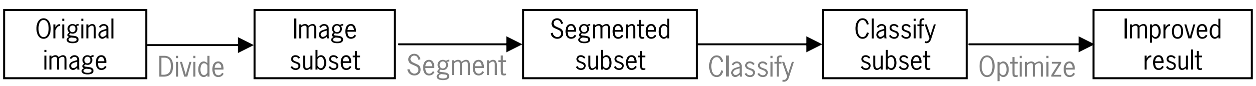

Figure 1: Image processing scheme.

Three kinds of parameters were selected for the identification of the mussel beds:

- the parameters referring to the spectral value (the color value of the segments),
- the parameters concerning the texture characteristics
- and the shape parameters, including the size of the elements.

All those parameters were chosen because of their capacities to extract the mussel bed features. To achieve this objective, the selected parameters act in a different way, complementing each other: While some identify directly the mussel beds, others allow to discriminate unwanted elements.

Spectral characteristics are not typical for the mussel beds. Indeed the color of those elements not clearly differs from their surrounding, which is mainly because they are often mixed with other elements such as sand or algae. Thus the distinction between those different elements can be difficult and lead to confusions. On the other hand, the textural characteristics are more specific to the mussel beds. Compared to mussel beds, their surrounding appears quite homogeneous in the pictures. This is translated by creating of a lot of small segments during the segmentation step, due to the high heterogeneity rates of those areas. Unfortunately these characteristics also identified water areas with small waves, as well as surface covered with vegetation or rocks (pebbles) elements.

Different tries were performed on one and subsequently two sub-images used as representative test areas (Annex 1). When a test result was considered as satisfying on these two sub-images, the identification process was applied on a larger geographic scale and some adjustments were done where necessary. Finally, the selected parameters to be analyzed were:

- The means value of the layer 1 and 3, which were used because of their capacity to exclude most of the water and vegetation/rocks features. Indeed, as explained before, the spectral values do not allow the direct detection of mussel beds.
- The standard deviation of the values of layer 1, used to improve the discrimination between mussel beds and water surface structure.
- The other parameters were selected on their ability to detect and delineate the mussel beds. The detection was mainly based on the texture and the shape of the object features: contrast, dissimilarity, homogeneity, length/width and area. The last two parameters were used especially to discriminate rough features that are not mussel beds and also small waves on the water.

Improvement:

After performing the methodology developed above, first results were produced and presented to the final users. According to the comments and expectations expressed during the presentation, the aim was to improve the automatic detection of the mussel beds. The objective was to make the methodology fit better with the requirements of the future users.

The main issue to deal with in the improvement phase was the size of the detected mussel bed. From the information given by the experts, most of the mussel beds measure between 2-3 and 10 hectares. The reasonable limit fixed for the detection of the features was that all the elements bigger than 0.5 hectare should be detected and smaller if possible. The main difference compared to the establishment of the first results was that in this step the adjustment of the methodology was carried out with the help of TMAP-survey of 2007 and 2006, as ground truth dataset to see if the adjusted method was effective or not.

Assessment of the methodology

In order to assess the quality of the results, the same survey data as used in the improvement step, was used as a reference dataset.

The surveys and imaging results were compared in ArcGIS. First the TMAP-survey datasets from 2006 and 2007 were combined and the polygons resulting from this union were reclassified as “New” (present only in 2007), “Old” (present in 2006 and 2007) or “Disappeared” (present only in 2006). The created dataset was combined with the dataset obtained as result of the automated detection. It led to the creation of a new polygon dataset divided in 6 classes:

- “Good new”, mussel beds appeared in 2007 that are correctly detected.
- “Good old”, mussel beds correctly detected that were already present in 2006.
- “Missed new”, undetected mussel beds appeared in 2007.
- “Missed old”, undetected mussel beds that were already present in 2006.
- “Wrong new”, all the elements recognized as mussel beds which are no identify in 2006 neither in 2007 TMAP-survey.
- “Wrong old”, detected mussel beds disappeared in 2007 but existing in 2006.

Finally, the area of each class was computed and summarized in tables.
The previous assessment, based on area computation, was completed by a counting the right and wrongly detected complete mussel beds. Counting complete beds allowed to assess when a mussel bed was correctly detected without taking into account the exact boundaries of the feature. During the counting the mussel beds were divided in 6 categories:

- “Good bigger”, mussel beds correctly detected with a size bigger than it appears in the reference dataset.
- “Good”, all the mussel beds detected correctly with almost the same size as the reference.
- “Good smaller”, mussel beds correctly detected with a size smaller than the one in the reference dataset.
- “Wrong old”, detected mussel beds present in 2006 and disappeared in 2007.
- “Wrong new”, all the non mussel bed elements wrongly detected.
- “Miss”, all the not detected mussel beds. For this category, information was added about the size of those “missed” mussel beds.

A last assessment was carried out to compare the result obtain using manual method (visual identification of mussel beds on aerial photographs) with the one obtained by automated detection. To do so, the two results datasets were combined in a new dataset. The latter allowed to compute the area common to the both datasets and the area specific to each for the detected mussel beds. This computation did not make a distinction between the correctly and wrongly detected features.

Results

<u>First results</u>

The overall result (figure 1) showed that the main mussel beds were detected. The elements which were not classified were mainly small beds, less than 2 hectares (table 3). This was the result of a decision rule set during the optimization step. This choice was made in order to obtain a clearer result; in other word to eliminate the small features wrongly detected which generated a lot of “noise” in the results.

During the test phase, the results obtained after the processing of one subset appeared to be more accurate than the general result obtained after processing the complete area (4 subsets). In order to improve the quality of recognition in other subsets, the accuracy of recognition had to be a bit degraded by enlarging the value ranges defined for the selected parameters. This resulted in a compromise in the defined value ranges to get the most satisfying result on the complete area. This compromise, was mostly required due to the fact that there are a lot of dissimilarities among the mussel beds, some are denser than other for example. Moreover, mussel beds are present in a large range of reflectance values and also texture values, although the later are more specific. That explains why a classification that is working correctly on one subset does not give a similar result on another one. The process, thus, had to take into consideration a large scale of values in order to detect as much mussel beds as possible. However by using a large range of values into account, more unwanted features with characteristics close to the ones of the mussel beds are wrongly identifying as mussel beds. To solve this problem, several parameters were selected for the classification in order to make the definition of the mussel bed as accurate as possible. Some decisions had to be made during the establishment of the methodology to find a good compromise between the detection of enough mussel beds and the exclusion of other elements.

In summary, the results show that automated detection of mussel beds is possible, but that a difference in terms of spectral and textural parameters between different mussel beds limit this method. To compensate for this shortcoming the automated detection should be combined with manual correction to improve the final result.

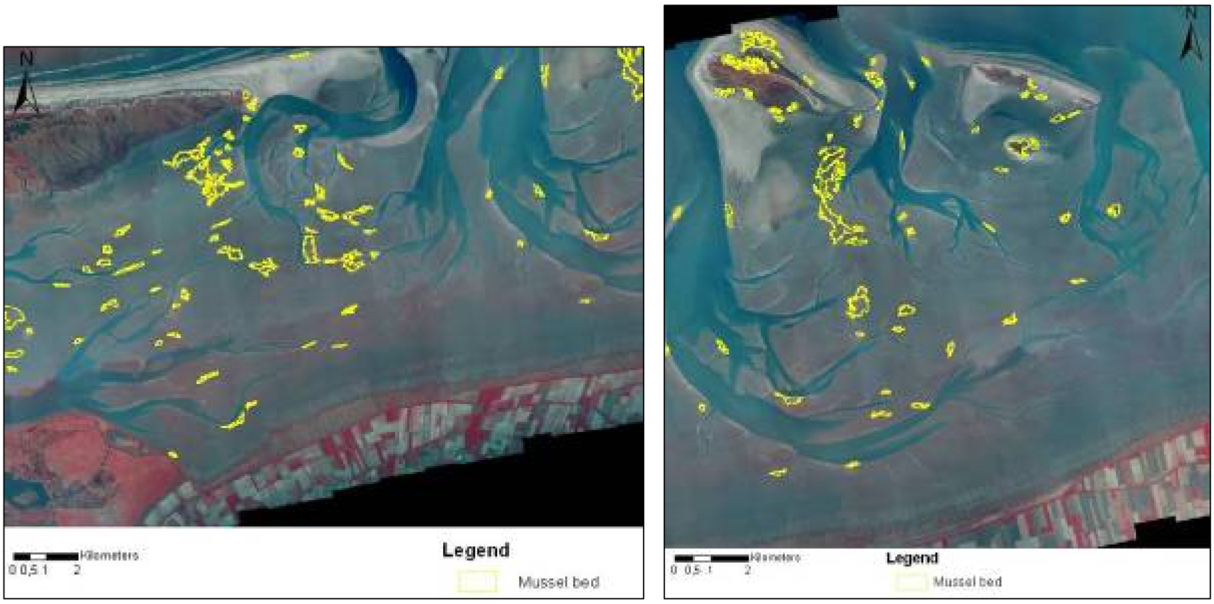

Figure 1: First automated detection results on Schiermonnikoog and Rottum

In figure 1, the result obtained after running all the steps developed in the methodology and a first cleaning by hand to remove the wrongly detected element located in water and land, can be seen. The detected mussel beds in the area of Rottum and Schiermonnikoog are delineated in yellow and displayed on the aerial photographs used for the processing.
With the rules set during the classification and the choices made for the optimization, the main mussel beds were detected. Only the smallest beds were missing and some errors occurred by confusion with water, vegetation or land elements. However these mistakes are easy and fast to identify and to correct afterwards.

The results were compared with the TMAP-surveys and the visual detection results (table 1 and 2).

	Missed		Good		Wrong	
	Old	New	New	Old	New	Old
Hectare	**120.80**	**54.87**	**25.49**	**174.20**	**248.03**	**82.23**
Hectare	**175.67**		**199.69**		**330.26**	
Percentage	**17.12%**	**7.78%**	**3.61%**	**24.69%**	**35.15%**	**11.65%**
Percentage	**24.90%**		**28.30%**		**46.80%**	

Table 1: Evaluation of the first result obtained for the automated detection of the mussel beds

	Hectare	Percentage
Common	**330.32**	**29.76%**
Only Visual	**579.96**	**52.25%**
Only Automated	**199.63**	**17.99%**

Table 2: Comparison between visual detection and first result of automated detection of the mussel beds.

The evaluation presented in table 1 and 2 were based on computation of the total area. This appeared to be a bit too restrictive when the automated detection method is considered as a help for the human user to find mussel beds on aerial photographs and not as a tool to delineate accurately the mussel beds. Therefore the comparison was also made with individual mussel beds instead of area (table 3).

	Good bigger	Good	Good smaller	Wrong old	Wrong new	Miss
Rottum	6	10	7	1	24	61 57 < 2 ha 39 < 0,3 ha
Ameland	3	9	8	11	34	26 23 < 2 ha 12 < 0,3 ha

Table 3: Assessment of the mussel beds detection through counting of individual mussel beds instead of area.

The automated detection method can be used as a useful tool to save time in the mapping of mussel beds. Indeed, most of the mussel beds bigger than 2 hectares are detected and the mistakes generated by wrongly detected elements are easy to correct for an expert. Most of the “wrong new” elements were located along canals and land/dunes areas.

Improvement

During the improvement phase, some changes were performed on the selected parameters to allow the detection of more mussel beds without generating too much mistakes.
The parameters which appeared to be relevant for the detection of the mussel beds were kept but some values were adjusted in order to detect as much mussel beds as possible, including small ones.

The result obtained after running the improved methodology and applying a first cleaning by hand to remove the wrongly detected elements located in water and land, can be seen in figure 2. The polygons representing the detected mussel beds are displayed in different colours according to the classification used in the assessment step (table 4).

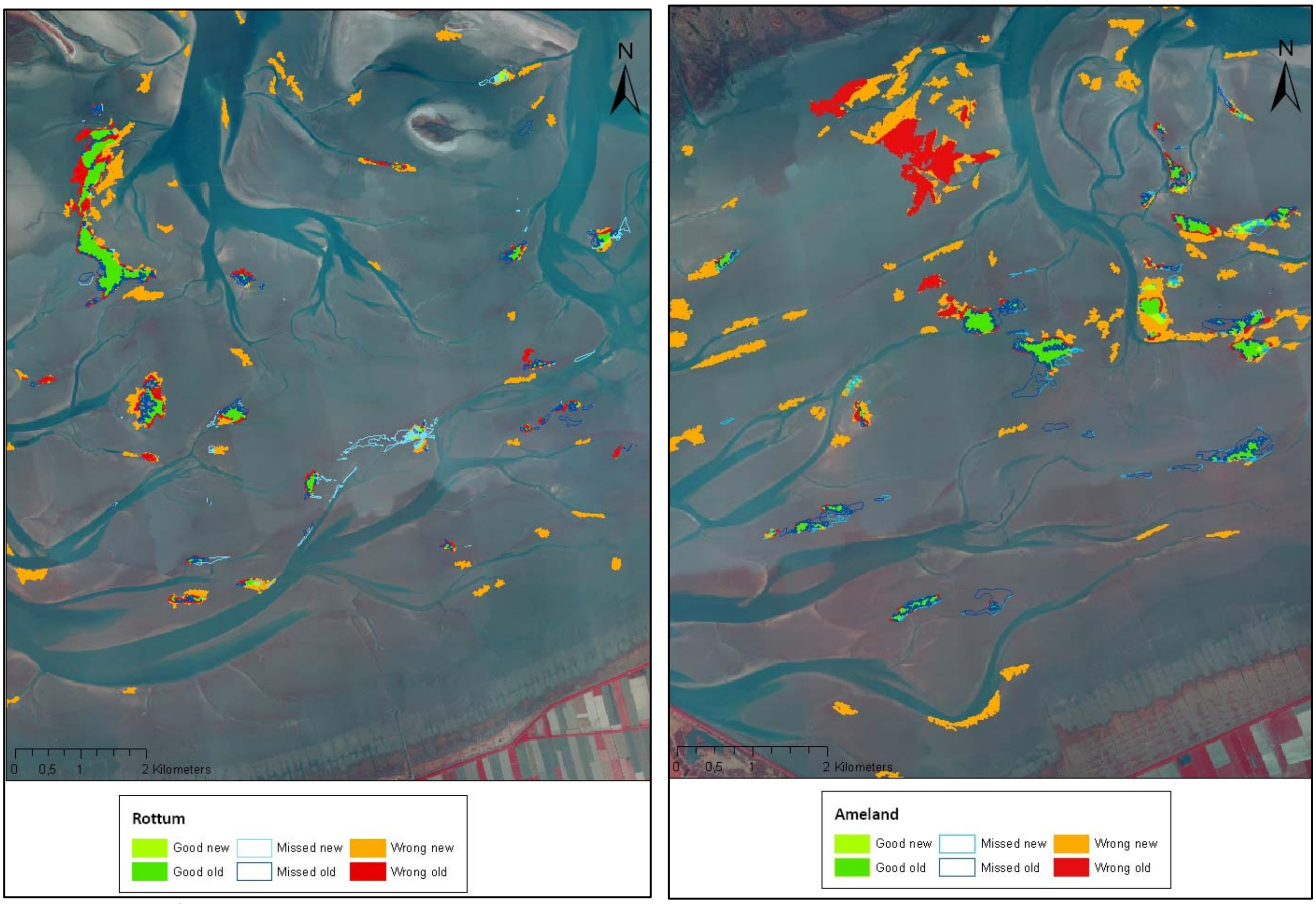

Figure 2: Improved results on Ameland and Rottum

The results were compared to the TMAP-surveys of 2006 and 2007 (table 4) and the visual detection results (table 5). In addition to the comparison of mussel bed area found by the different methods, a comparison of the number of beds (table 6) was also carried out.

	Missed		Good		Wrong	
	Old	New	New	Old	New	Old
Hectares	110.66	52.53	27.82	184.34	310.61	91.35
Hectares	163.19		212.16		401.96	
Percentages	14.24%	6.72%	3.58%	23.71%	39.95%	11.75%
Percentages	20.99%		27.29%		51.71%	

Table 4: Evaluation of the improved result obtained for the automated detection of the mussel beds

	Hectare	Percentage
Common	368.36	31.86%
Only Visual	541.91	46.88%
Only Automated	245.76	21.26%

Table 5: Comparison between visual results and improved results of automated detection of the mussel beds.

	Good bigger	Good	Good smaller	Wrong old	Wrong new	Miss
Rottum	13	11	14	5	51	46 43 < 2 ha 32 < 0,3 ha
Ameland	7	10	16	15	99	21 19 < 2 ha 11 < 0,3 ha

Table 6: Assessment of the improved mussel beds detection through counting of individual beds instead of mussel bed area.

The improvement of the automated detection method leads to a reduce in the number of “missed” mussel beds but also generated an increase of features wrongly detected. The “wrong” elements occurred along mainly along the canal and the land/dunes areas. This can be explained by the fact that those features are located in transition zones, between two land cover types, and present a high heterogeneity in structure which is the basic element used for the detection of mussel beds. This problem can partially be overcome by the use of masks to exclude the canals, land/dunes and all the others surfaces where the mussel beds can not occur.

The improvement step resulted in an increase in number of mussel beds detected but also the number of “wrong” detected mussel beds increased. A balance has to be found between the size limit for the detection of mussel beds and the number of wrong elements detected.

Processing time and cost estimation

The main steps of the processing are:

- To subset the images. This step is the fastest one, This operation can be easily carried out in Erdas and costs about 2 minutes per image. Envi or other software can also be used for this step.
- To process the subsets. This operation is the longest one. Ecognition is a powerful tool for the detection of the mussel beds but its processing time remains is main drawback. In this case, the process of one subset can take between 6 and 12 minutes, with an average of 7 minutes. A license for one year to use Ecognition costs about 13000 euro for the developer part and 16000 euro for the server (renting 1600 euro for 3 months).
- To improve the result in ArcGIS, about 5 minutes per images should be taken into account.

In total the process time of an image takes around 15 minutes. However, some operations can run simultaneously. When the classification process is running on one subset the user has the time to divide the other images into subsets, or to clean the results already obtained. Then, for an area like Rottum (9 images), the total processing time takes about 2 hours.

The total costs for this operation is about 13000 euro for the developer part and 16000 for the server (renting 1600 euro for 3 months).

Conclusion and recommendations

The objective was to explore and assess the potential use of automated remote sensing methods to improve the mussel beds detection and delineation in the Wadden sea based on aerial photographs.

According to the criteria quoted in the introduction, it is possible to evaluate the benefits of using an automated method.

	Automated	Manual
Efficiency (costs/benefits)	Average (depending on software performance and costs) Fast	Average (depending on interpreter) Time consuming
Accuracy	Satisfying to detect no to delineate	Satisfying (depending on interpreter)
Reliability	Need a manual correction	Satisfying (depending on interpreter)
Consistency	High (use of fixed rulesets)	Average (depending on interpreter)
Repeatability	High (use of fixed rulesets)	Average (depending on interpreter)

Due to the process based on rules, the automated method appears to be more consistent and repeatable than the manual method. The time of computation is also faster than the manual method. However, the automated method generates more mistakes.

The main conclusion is that the automated detection, by applying rules based on the selection of characteristic spectral and textural parameters, is a helpful tool in the monitoring of the mussel beds. Although it requires manual corrections to improve the result, this tool can already be considered as a help to catch the attention of the user on the interesting areas, thereby save analysis time. The automatic detection using Ecognition seems to give useful results for the identification of mussel beds. Automated methods, however, cannot completely replace manual methods; expert knowledge (+ field checks) is needed in the both methodologies.

The methodology can be improved by defining exactly the role that this tool will play in the monitoring of the mussel beds. Through this definition the best compromise between detecting enough mussel beds and not too much “wrong” elements can be found.

The comparison between the manual method results and the automated detection result can also be detailed by considering the classification in 6 categories used for the evaluation of the methodology.

The main drawbacks of this method lies in the fact that the software can not process large images so a preprocessing step to subset the aerial photographs is needed. The price of a software license is also rather high. However those points are compensated by a higher consistency and repeatability.

To conclude, the use of an automated method combined with the personal knowledge of an expert to improve the result is an efficient way to monitor, detect and delineate the mussel beds.

Annex 1

	Spectral parameters				Textural parameters				Shape parameters	
Try nº	Layer 1 mean	Layer 1 St dev	Layer 3 mean	Max diff.	GLCM Homogeneity	GLCM mean	GLCM contrast	GLCM dissimilarity	Area	Length/ width
1	>85	/	/	<= 0.13	0.1<x<0.32	>96	/	/	/	/
2	>85	/	/	<= 0.14	<0.4	>90	/	/	/	/
3	>85	/	/	<= 0.145	<0.46	/	/	/	/	/
4	>88	/	/	<= 0.17	<0.4	/	>4.5	/	<240	/
5	>75	/	/	/	<0.43	>94	>5.5	/	<350	/
6	75<x<145	/	/	/	<0.45	>94	>18	/	<350	/
7	75<x<150	/	/	/	<0.45	>94	>6.5	/	<350	<3
8	75<x<140	/	/	<= 0.165	<0.5	>105	>4	/	<400	<3
9	75<x<155	/	83<x<115	<= 0.2	<0.53	>94	>3	1.5<x<4	<450	<3
10	50<x<155	/	83<x<115	<= 0.4	<0.53	/	>5	1.5<x<5	<450	<3
11	50<x<150	/	83<x<140	/	<0.45	/	>5	1.5<x<6	<450	<3
12	45<x<150	2.5<x<7	83<x<140	/	<0.45	/	>5	1.5<x<6	<480	<3
13	55<x<152	2.5<x<6.5	85<x<126	/	<0.47	/	>4.1	1.35<x<5.2	<460	1.2<x<3.2
14	55<x<150	1.9<x<6.5	90<x<129	0.08<x<0.75	<0.47	87<x<131	>3.5	1.35<x<5	<480	1.1<x<3.2
15	53<x<150	2.2<x<7	84<x<133	/	<0.49	71<x<136	>3.6	1.35<x<5.2	<480	1.1<x<3.2

Table 1: Mussel bed detection tries (light grey are the first tries and dark grey are the improvement tries)

This table shows the main tries carried out during the studies, some small adjustments added in the middle are not reported here.

Parameters definition:

- **Layer 1 mean**: average of the spectral value for the band 1
- **Layer 1 St dev**: standard deviation of the spectral value for the band 1
- **Layer 3 mean**: average of the spectral value for the band 3
- **GLCM homogeneity**: GLCM stands for Gray Level Co-occurrence Matrix and in this case is used to measure the homogeneity between contiguous segments.
- **GLCM mean**: average value of the GLCM
- **Max diff.**: abbreviation for maximum difference
- **Area**: area of the segment
- **GLCM contrast**: GLCM used to measure the contrast between contiguous segments.
- **Length/width**: length of the segment compared to its width
- **GLCM dissimilarity**: GLCM used to measure the dissimilarity between contiguous segments.