Assessment of coastal Strandveld integrity using WorldView-2 imagery in False Bay, South Africa

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Keywords

Coast; ecosystem integrity; WorldView-2; remote sensing; Strandveld; False Bay

Highlights

- The Cape Flats Dune Strandveld is under heavy anthropogenic pressure
- Satellite imagery was used to assess ecosystem integrity in False Bay
- Factors impairing Strandveld integrity include vegetation loss and alien infestation
- Results provide valuable information for local environmental management

Abstract

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The coastal zone as interface between land and sea faces much pressure from human activities. These pressures make it difficult for the coastal zones to fulfil their natural functions, so threatening the state of coastal environments and making them vulnerable to coastal disasters and degradation. This study aimed to test whether high resolution remote sensing imagery can be used to assess the integrity of coastal Strandveld vegetation at the high spatial resolution required as baseline information for local environmental management. The study focused on the Cape Flats Dune Strandveld vegetation in northern False Bay near Cape Town, South Africa. The approach modifies and adopts a method developed by Lück-Vogel et al. (2013) for a remote sensing derived habitat intactness assessment for the Sandveld region at South Africa's west coast.

A regression analysis was performed on the eight spectral bands of two WorldView-2 images and five image derivatives to evaluate the most suitable bands for producing an ecosystem integrity index. Based on the results, only the RED and the NIR bands were required to perform a decision tree classification for the integrity classification, which significantly simplifies the application and opens the way for transfer to sensors with similar spectral bands.

The overall accuracy of the results was 80.5% with a kappa value of 0.75. This means that this approach provides results accurate enough for coastal management and conservation applications at a local scale. A further finding is the importance of seasonality to delineate natural and alien vegetation accurately.

1 Introduction

The coastal zone is the area where the land and sea meet (Leewis et al. 2012). Coastal habitats are highly productive areas supporting a variety of biodiversity (Costanza et al. 1997). Moreover, coastal habitats are important for shoreline stabilisation, as spawning grounds for marine life and buffers against natural hazards. They also provide coastal communities with a variety of natural resources and ecosystem services (Costanza et al. 1997).

The key pressures affecting the integrity of terrestrial coastal vegetation (i.e. vegetation above the high water mark) include unregulated public access and trampling, particularly close to urbanised areas (Nayak et al. 1989, Nayak & Bahuguna 2001), which can create pathways on dunes that eventually lead to vegetation loss (Moulis & Barbel 1999). Other pressures arise from sand mining, logging of firewood, littering and the introduction of invasive alien species that degrade coastal habitats (Nayak & Bahuguna 2001; Costanza et al. 1997).

One example of a vegetation type affected by these threats is the Cape Flats Dune Strandveld (in the following referred to as: Strandveld) which occurs in the greater Cape Town area at the southwestern tip of South Africa (Figure 1). Strandveld vegetation occupies habitats under the direct influence of salt spray and other factors associated with seawater (Mucina et al. 2006). It comprises of tall, evergreen, hard-leaved shrubland with abundant grasses and annual herbs growing on deep and well-drained sand along the coast (Mucina et al. 2006). Typical Strandveld plant species are *Searsia glauca, S. laevigata, Metalasia* *muricata, Phylica ericoides, Euclea racemosa, Pelargonium betulinum, Salvia africana-lutea, Ruschia macowanii, Ehrharta villosa, Zygophyllum flexuosum*.

A major handicap for coastal managers and conservationists in the region is the lack of appropriate data and information on the degree of integrity of the Strandveld ecosystem at a high spatial resolution suitable for local management.

According to Westra et al. (2013) in order to fully understand the degree to which ecosystems are disturbed, it is essential to first establish the "pristine" condition of the ecosystem as baseline. However, deriving information about the degree of non-pristineness or loss of integrity through detailed field surveys for mapping and monitoring of coastal environments is frequently unfeasible due to the vast extent of the coastline, physical inaccessibility and security issues or lack of funding and skilled staff. If we understand "ecosystem integrity" *sensu* Roche & Campagne (2017) and Westra et al. (2013) as the structural pristineness of a system (from which a functional intactness can be deducted to a certain extent), technical approaches for integrity assessment become more feasible. Ulanowics & Hannon (1988) postulate that integrity, as a measure of ecosystem intactness causes ecosystems to use incoming solar radiation more effectively than damaged ones. Damaged ecosystems in contrast generate latent heat (as the photosynthetic efficiency decreases). Therefore intact systems appear to be "cooler". Both, the photosynthetic efficiency and the temperature can be assessed using satellite imagery. In the last decades, this circumstance has been used for multispectral remote sensing assessments to derive information about regional scale land cover, ecosystem functional types and biodiversity (e.g. Turner et al. 2003; Kerr & Ostrovsky 2003; Fernández et al. 2010). However, the spatial resolution of these Landsat-type satellites was not sufficient to reflect small scale patterns of vegetation, biodiversity and degradation for use in local conservation (Rocchini 2007). It was only with the upcoming of high resolution satellites in the last decade that within-ecosystem analysis of local degradation gradients became feasible for ecosystems of narrow spatial extent, such as coast lines.

A similar lack of quantitative and spatially extensive information on vegetation intactness has been described e.g. for the Sandveld region on South Africa's west coast as input for spatial fine scale planning and restoration purposes. The vegetation in the Sandveld region composed of different Fynbos and western Strandveld types, resembling largely medium dense, up to 2m high fine-leaved, largely evergreen vegetation. The Strandveld elements are comparable to the Strandveld vegetation, the former however characterised by more succulent elements and the latter by more grasses and annual herbs (Rebelo et al. 2006).

Lück-Vogel et al. (2013) developed a remote sensing based approach using a pansharpened 15 m resolution Landsat-7 and a 20m resolution SPOT-5 image that integrated spectral, textural information and structural information derived from the imagery. The approach yielded an overall accuracy of 76.7% for the Landsat and 62.3% for the SPOT 5 imagery. However, as the approach was rolled out over the entire region composed of different vegetation types with naturally very different vegetation densities in the pristine climax condition, there was a vast over-estimation of degradation in naturally sparsely vegetated areas such as dune fields. Therefore, Lück-Vogel et al. (2013) recommended that further improvement of the results could be expected if the landscape were stratified prior to the intactness assessment, where clearly different vegetation types (e.g. reeds or open dune fields) were masked out or assessed individually.

The aim of this study was to test whether the technical approach presented by Lück-Vogel et al. (2013) but using high resolution satellite imagery can be used or adopted to derive reliable information for the Cape Flats Dune Strandveld vegetation in False Bay, on the southwestern tip of South Africa to provide fine-scale information on vegetation integrity for local management and conservation.

2 Material and Methods

2.1 Study area

False Bay is a large, partly protected bay (Figure 1), situated south of Cape Town in the Western Cape Province of South Africa (Theron & Schoones 2007). It extends between 34°04’and 34°23’ South and 18°26’ and 18°52’ East. False Bay is flanked by the Cape Peninsula mountain chain on the western and the Hottentots Holland Mountains on the eastern shore (Spargo 1991). The northern part of the Bay is relatively flat and protected from the ocean swell. The coast is therefore dominated by flat sandy beaches and dunes of tertiary or recent calcareous marine origin. However, in the eastern part of the northern bay, around Wolfgat and Macassar, cliffs and outcrops of underlying limestone rocks are present (Du Plessis & Glass 1991).

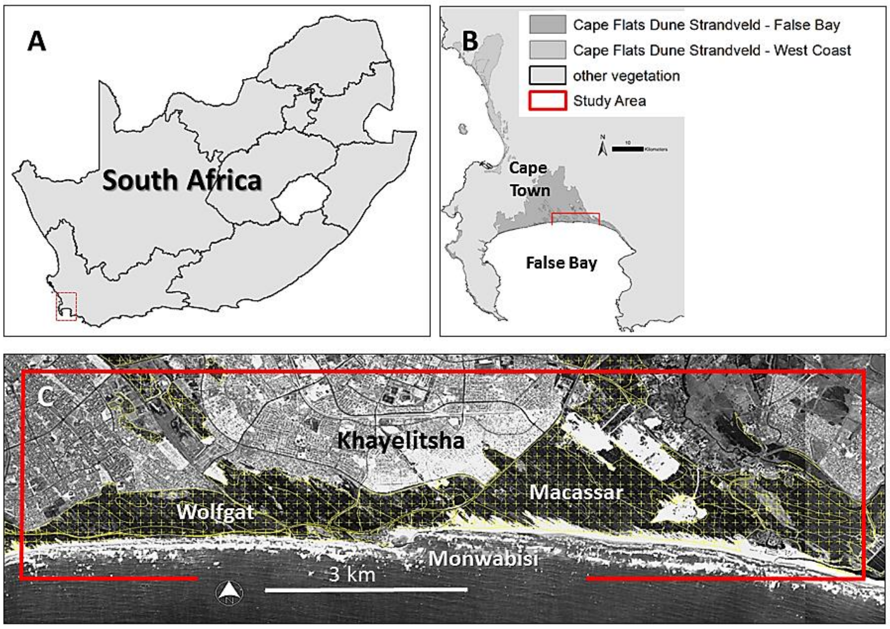

Figure 1: Map of Study area. A: Location of study site in South Africa, B: Natural distribution of Cape Flats Dune Strandveld in the greater Cape Town region, C: Map of Study area. Areas of remaining Strandveld are indicated in yellow checked.

False Bay has a Mediterranean climate with dry, hot summers from October to March and wet cold winters from April to September (Clark et al. 1996). The mean temperature is 26.7°C in summer and 7.5°C in winter.

The northern part of False Bay extending from Strand to Muizenburg is dominated by Cape Flats Dune Strandveld (Mucina et al. 2006). On the seaward side, this area borders on sandy beaches and limestone cliffs. In the north it borders on the township Kayelitsha.

According to Mucina et al. (2006) and Holmes et al. (2012), Cape Flats Dune Strandveld is highly endangered by the invasion of alien plants such as *Acacia cyclops* (Rooikrans) and *Acacia saligna* (Port Jackson wattle), informal footpaths (access to the beach), illegal logging (fire wood), illegal sand mining, livestock overgrazing and illegal waste disposal, pollution and urban sprawl, largely resulting from the close proximity of the dense low-to-medium income, formal and informal settlements of Kayelitsha that are heavily encroaching the Macassar-Monwabisi-Wolfgat dune area from the north (especially since 2014). The introduction of alien invasive plants also increased the susceptibility of the area to veld fires. In the Municipality of Cape Town where most of the Strandveld vegetation is located, about 55% of this vegetation is lost to transformation and about 36% of the remaining vegetation is formally protected as a Nature Reserve (City of Cape Town, no date).

This study focused on the remaining Strandveld occurring in the 12 x 3 km wide area between Macassar and Monwabisi. This area was selected as study area because it was accessible for collecting data in the field. Further, False Bay is a prime case of activities to be experienced on South Africa's coasts. Third, the processes impacting on vegetation integrity in the area are representative for the larger region.

2.2 Input data

2.2.1 WorldView-2 (WV-2) satellite data

Two partly overlapping WorldView-2 (WV-2) images acquired on 25 February 2014 and 11 October 2014 respectively were used for the assessment of vegetation integrity in the study area. The WV-2 sensor has eight spectral bands (a coastal band in the short-wave blue region, a "common" blue band, a green, yellow and red band, and bands in the red-edge, near-infrared1 (NIR1) and near-infrared2 (NIR2) range (http://www.landinfo.com/WorldView2.htm). The multispectral bands have a 2x2 m spatial resolution and a 16-bit data range which provides a high degree of spectral detail. The WV-2 level 3A data used in this study were acquired from the South African National Space Agency (SANSA). The projection of the images is Universal Transverse Mercator (UTM) zone 34 south. The satellite images were provided in a tile format.

2.2.2 Biodiversity Network data

The City of Cape Town, under whose government the study area falls, provided Biodiversity Network data in form of ESRI Shape (SHP) files that contained the natural vegetation types and subtypes in 2015. The distribution of the main vegetation type was largely identical with Mucina et al. (2006). At a subtype level the GIS layer further distinguished between Strandveld growing on sand or on lime stone. The data further contained information on built up or otherwise transformed areas. These data were used for masking out areas that were not of immediate interest to the study.

2.2.3 Ground reference data

Two field visits were conducted at the beginning of the project and at a later stage for the collection of ground reference data. During the first trip in August 2015, the collected and GPS-referenced information on vegetation integrity and factors impacting it was used for identification of the main impacting phenomena and the set up and validation of the integrity index approach.

In addition to the initial GPS-referenced field data, a further 100 points were collected on the screen, based on the general observations made in the field, resulting in a total of 130 reference points. They were used to set up a classification scheme and to perform an accuracy assessment of the results.

Given the continuous succession and recovery after disturbance, as well as fire events that occurred after the WV-2 image acquisitions, the judgement whether the classification for this point was correct or not, needed some "historical" information from the City of Cape Town's field rangers which have been working in the area over the whole period. Therefore, a second joint field validation was conducted in June 2016.

2.3 Image pre-processing

The WV-2 images acquired on 25 February 2014 and 11 October 2014 used in the study were delivered in 5 and 6 individual tiles respectively. In order to enhance further processing, all the tiles per date were mosaicked into one image per date using ERDAS IMAGINE (version 2014).

The mosaicked images were then radiometrically corrected to remove illumination and atmospheric effects to ensure the transferability of the classification rule set from one image to the other. The software used was ATCOR2 embedded in ENVI IDL. The output was top-of-canopy reflectance (Richter 2014).

Both images were subset to the extent of the coastal area of interest. Further all areas other than untransformed Strandveld (i.e. urban areas, water bodies, roads and other vegetation types) were masked out, using the Biodiversity Network data. These subsets were created to minimise computation time and to avoid biases in the accuracy of the integrity index as suggested by Lück-Vogel et al. (2013).

In order to derive textural and structural characteristics in addition to spectral parameters for spatial features in the satellite images, the images were segmented using eCognition Developer (version 9.0) software (Darwish et al. 2003; Definiens 2007). The result was a polygon vector layer outlining homogeneous areas in the image from which five image derivatives (i.e. Brightness, Compactness, Area, NDVI and NIR1 standard deviation) were generated from both images. Brightness and NDVI (Normalised Difference Vegetation Index) provide spectral information complementing the original 8 spectral WV-2 bands (Pettorelli et al. 2005). The compactness is an indicator of the "squareness" of a landscape feature. Natural landscape features appear more frayed/fractal than man-made features such as land use parcels or roads with straight boundaries. The polygon area adds structural information. According to Lück-Vogel et al. (2013) the NIR1 standard derivation can be used as proxy for the spectral within-polygon heterogeneity of the image object because natural vegetation, in contrast to e.g. agricultural crops and plantations, is characterised by a species- and age structure-diverse canopy that is expressed in the image objects in a higher local spectral variability. All five derivatives were calculated on both WV-2 images using ERDAS 2014 and eCognition software.

The segmented eight spectral bands and five image derivatives (Brightness, Compactness, Area, NDVI and NIR1 standard deviation) were exported from eCognition as smoothed polygon Shape files. They were then rasterised in ArcGIS (version 10.1) with a 2 m pixel size to match the original WV-2 resolution. All 13 bands were then unified in one multispectral layerstack for further processing in ERDAS.

2.4 Identification of processes impacting vegetation integrity

During the first field trip in August 2015, with the aid of GPS-referenced points, the condition of the Strandveld vegetation and its degree of integrity were established on the WV-2 imagery. Ecological integrity in this case was defined as "the state of being sound, unimpaired/unaltered by human activities and its complementary anthropogenic pressures and disturbances" (Roche & Campagne 2017; Westra et al. 2013). In contrast to the actual functional ecological intactness which is rather process-focussed (Roche & Campagne 2017), the integrity in terms of unimpairedness, expressed as natural density and diversity of the vegetation cover and deviations thereof, can more readily be assessed using remote sensing. The field trip helped to identify areas which are as close as possible (in a Metropolitan vicinity) to its undisturbed natural condition. Using these areas as baseline, the processes leading to an increasing impairment of integrity were identified.

Two types of largely intact woody climax Strandveld vegetation occurred in that area. On deep sandy soils, 2-4m high dense shrubby vegetation dominated, while on shallow soils on limestone rocks a heath-like, hardy shrub vegetation up to 2m height dominated. Both aspects were assumed to represent the "unimpaired" or intact condition.

Further, some areas were dominated by indigenous herbaceous vegetation. This vegetation is a natural community of the Strandveld vegetation on shallow soils and was thus considered as an intact aspect of Strandveld as well.

Apart from these largely undisturbed areas, various processes were observed that impacted the integrity of the Strandveld to various degrees. Patches of bare soil, i.e. areas that were depleted of all vegetation were considered the least intact state. Those areas included for instance footpaths and (illegal) drive ways.

The other extreme of impaired integrity were large areas where dense stands of alien *Acacia cyclops* and *Acacia saligna* had evicted most of the indigenous vegetation. Areas invaded by alien vegetation are also more prone to fires than intact Strandveld due to the higher degree of succulence of the latter (Rebelo et al. 2006).

Apart from these two extreme cases of impaired integrity, two forms of less extreme degradation were observed, both related however to the occurrence of alien vegetation. Firstly, scars in the (frequently previously alien infested) Strandveld from fires during years preceding the image acquisition presented various stages of biodiverse vegetation regrowth and were considered less impaired, as it was the indigenous vegetation recovering towards a higher degree of “unimpairedness”.

Secondly, areas that were cleared of alien vegetation recently consisted of some remaining larger indigenous shrubs with frequently unconsolidated open soil where acacias had been removed physically. Undergrowth was largely absent as the dense cover of aliens had impeded its development. Those areas were thus considered as heavily impaired or removed from the natural integrity of the system.

The vegetation categories that were observed are summarised in Table 1, ranked according to an integrity gradient from 1 (highly impaired) to 4 (largely undisturbed).

Table 1: Identified vegetation type relating to the level of integrity

Vegetation category	Assigned habitat integrity index	
Description	**Integrity Value**	**Description**
Bare Soil	1b	Highly impaired (bare)
Alien vegetation thickets	1a	Highly impaired (alien)
Recently cleared alien vegetation	2	Moderately impaired
Strandveld recovering from veld fires	3	Lightly impaired
Natural pristine herbaceous and woody Strandveld vegetation on limestone or sand	4	Largely unimpaired

All available 130 ground reference points were assigned the respective habitat integrity value. Two thirds of the points were used for training the decision tree classification, and the remaining one third was kept for later validation purposes.

2.5 Decision tree classification

For each of the training points, the values from all 13 spectral WV-2 bands and derivatives were extracted and exported to MS Excel. Then the correlation between the 13 bands and the respective integrity class was assessed using a 3rd-order polynomial regression analysis (coefficient of determination R^2). This procedure was performed on the 25 February 2014 WV-2 image only.

For the spectral bands, including NDVI and Brightness, two general patterns of relationship were visible. These are illustrated in the regression graphs in Figure 2 and Figure 3 which show the relationship between the five integrity classes on the X-axis and the mean reflectance values for the red band and the NIR1 respectively on the Y-axis. The integrity classes were sorted from highly degraded on the left with an increase in intactness to the right (with exception of class 1a: alien vegetation).

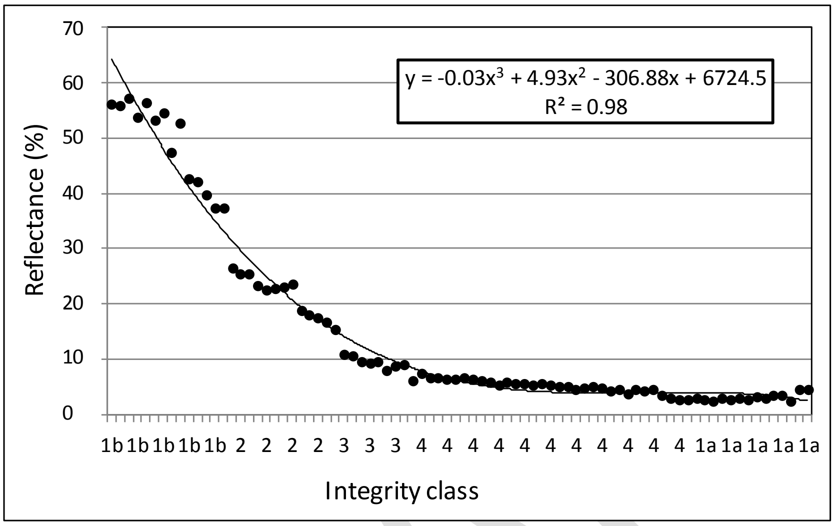

Figure 2: Relationship between levels of integrity and reflectance in the red band from the February 2014 image. For description of the integrity classes refer to Table 1.

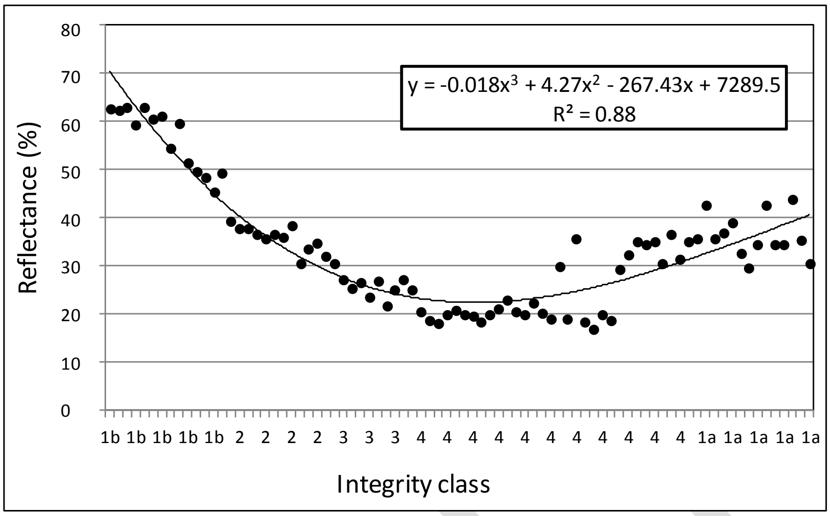

Figure 3: Relationship between levels of integrity and reflectance in the NIR1 band from the February 2014 image. For description of intactness class refer to Table 1.

For the WV-2 bands 1 – 5 in the visible range (coastal, blue, green, yellow and red), a continuous decrease in reflection from the classes of highest degradation (intactness class 1b) to highest integrity (and alien infestation as additional degradation class; integrity classes 4 and 1a respectively) similar to Figure 2 was observed. The Infrared bands 6 – 8 (red-edge, NIR1 and NIR2) and the brightness followed the trend visible in Figure 3 where the Alien infested areas (class 1a) can be distinguished from the most pristine class 4 by slightly higher reflectance.

As these two spectral patterns were the same in all spectral bands, for simplicity reasons it was decided to build the classification based on thresholding in the RED and the NIR1 bands only as these bands are available in most other earth observation sensors, should the transfer of the approach to another sensor be desired. The classification was applied on both the 25 February and 11 October 2014 image.

It was found that structural and textural derivatives, i.e. the compactness, Area and NIR1 Standard Deviation, in contrast to Lück-Vogel et al.'s (2013) work, did show no strong correlations to the integrity classes. The R^2 values for the 3rd order polynomial regression for these bands ranged between 0.09 and 0.18. The reason for this might be that the structural and textural derivatives are very useful to distinguish between different vegetation types but not within a vegetation type, as in this study all other vegetation and land cover was masked out from the beginning (see section **Error! Reference source not found.**). In the NDVI band, there was a positive linear relation visible between NDVI and integrity (apart from class 1a). However, given the extra processing step for calculating the NDVI, it was decided to use the original spectral input bands, red and NIR1 instead for the development of the decision tree.

2.6 Validation of results

Two approaches were used to assess the accuracy of the classification results. The first one made use of the 41 ground reference points described in section 2.2.3 to generate an error matrix and deducted accuracy parameters (Congalton & Green 2009) using ERDAS's classification accuracy tool. An error matrix is a comparison between remote sensing results and ground truth data (reference data). It identifies misclassification errors and their quantity.

Additionally, a further field trip was conducted in June 2016 to verify the results. The printed map results of both the February and October 2014 images were taken along for the selection of points of interest for validation. Investigated points were marked with GPS. A total of 18 field validation points was captured. The GPS points were later converted to a shapefile for further GIS analysis. Correspondence between appearance in the field and the classification output was analysed.

3 Results and Discussion

3.1 Derived integrity map for February 2014

Figure 4 shows the integrity map derived from the WV-2 image captured on 25 February 2014, representing the dry summer season. The classification identified areas ranging from highly degraded to high integrity. Highly degraded areas (red) are mainly bare areas of footpaths, and informal roads (could not be masked out initially) and other open patches without vegetation. Moderately degraded areas (yellow) indicate areas of cleared alien vegetation. Lightly degraded areas (light green) mainly represent regrowth of vegetation recovering from fires. Intact indigenous vegetation of the Strandveld is indicated in dark green. Purple indicates areas infested with alien invasive vegetation, mainly *Acacia cyclops*.

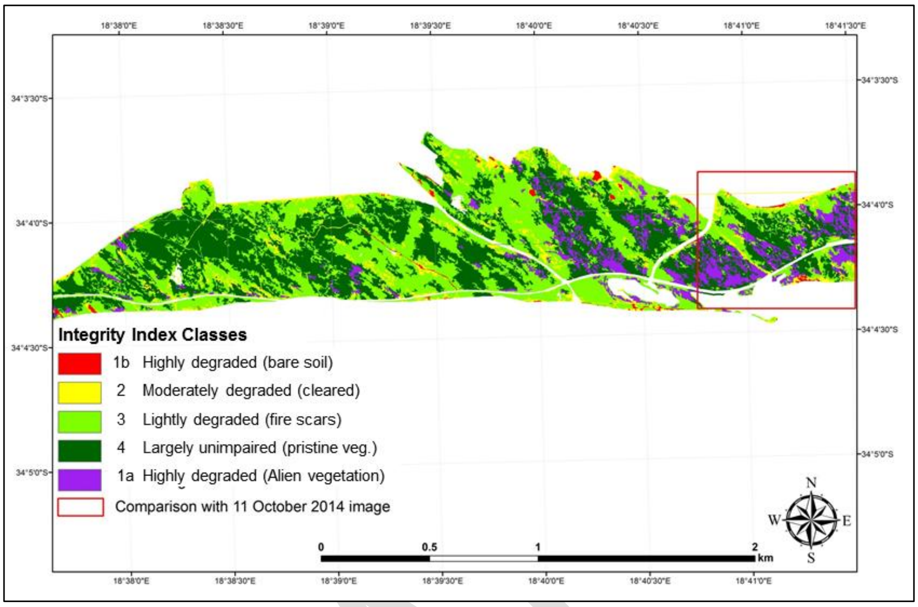

Figure 4 Integrity map derived from 25 February 2014 image (dry season).

3.1.1 Accuracy based on error matrix

Table 2 below shows the results of the accuracy assessment for the classification of the February image in form of an error matrix. From the error matrix several metrics were derived to assess the quality of the classification. The overall accuracy and the Kappa coefficient are measures of overall agreement between the remotely sensed classification and the reference data (Congalton & Green 2009). The producer's accuracy indicates how well the training points per class are classified, while the user's accuracy indicates the probability of a pixel being assigned the same class we actually find on the ground (Lillesand et al. 2004).

Table 2: Error matrix for the classification results of the 25 February 2014 WV-2 image based on field informed reference points. Shaded cells: correctly classified points.

Classified values	Ground truth reference: 1b	2	3	4	1a	classified total	User's Acc.
1b Highly degr. (bare)	4	0	0	0	0	4	100.0
2 Mod. degraded	2	4	0	0	0	6	66.7
3 Lightly degraded	0	1	6	0	0	7	85.7
4 Pristine	0	0	0	12	0	12	100.0
1a Highly degr. (alien)	0	0	0	5	7	12	58.3
Reference points total	6	5	6	17	7	41	
Producer's Accuracy	66.7	80.0	100.0	70.6	100.0		
Kappa	**0.75**						
Overall Accuracy	**80.5 %**						

Table 2 indicates that 33 points out of the total 41 reference points were classified correctly. Four out of 6 reference points for highly degraded (class 1b) were correctly classified; 4 out of 5 reference points for moderately degraded (class 2) were correctly classified; all 6 reference points for lightly degraded (class 3) were correctly classified; 12 out of 17 reference points for pristine vegetation (class 4) were correctly classified; and all 7 alien reference points (class 1a) were correctly classified in the WV-2 image for 25 February 2014.

Of the 6 reference points for highly degraded two were incorrectly classified as moderately degraded. A main reason for this error is probably the similarity of the spectral properties of the two classes in cases where alien clearing was conducted just prior to the image acquisition hence leaving the ground largely bare. Furthermore, confusion between moderately and lightly degraded occurred, probably due to the continuous gradient of degradation severity between both classes. However, about 30% of the pristine vegetation reference points were wrongly classified as alien vegetation. This means, the occurrence of alien vegetation was over-estimated. This confusion might have occurred in cases where pristine vegetation appeared on exceptionally moist places (leading to above-average vegetation vigour) or in places where patches of milkwood forest (*Sideroxylon inerme*) occurred which are not classified separately for that area in the Biodiversity Network data. Milkwood would have a higher vegetation density and would thus appear more like alien vegetation in the classification.

The best producer's accuracy was achieved for alien vegetation and lightly degraded at 100%, with intact vegetation scoring 70.6%. The least producer's accuracy was registered for highly degraded at 66.7%. Satisfactory user's accuracies were achieved for pristine vegetation at 100%. This means that pristine vegetation should be found in 100% of the cases where it is indicated in the map. The second highest user's accuracy was found for lightly degraded at 85.7%. The minimum user's accuracy was achieved for alien vegetation at 58.33% which is considered to be below the desired level for satisfactory accuracy. However, the experienced over-estimation of alien vegetation is still preferable to an underestimation, as the over-estimation still has merit for the land manager has a pre-screening tool.

The high overall accuracy of 80.5% and a kappa of 0.75 for the February classification indicate substantial agreement (Congalton & Green 2009; Landis & Koch 1997) between the classification results and the reference data. The high overall accuracy is ascribable to the high spatial resolution of 2 metres and the high spectral resolution of the bands of the WV-2 image, as well as the exclusion of transformed areas and non-Strandveld vegetation as per recommendation by Lück-Vogel et al. (2013).

3.2 Derived integrity map for October 2014

Figure 5 shows the integrity map derived from the WV-2 image of 11 October 2014, representing the wet winter season. The general occurrence and description of the classes is the same as in the February image. However, in the October map naturally bare coastal areas on the coast (southern fringe of map), such as dunes are (wrongly) classified as highly degraded (red), too. Apparently here the masking of non-Strandveld vegetation was inaccurate.

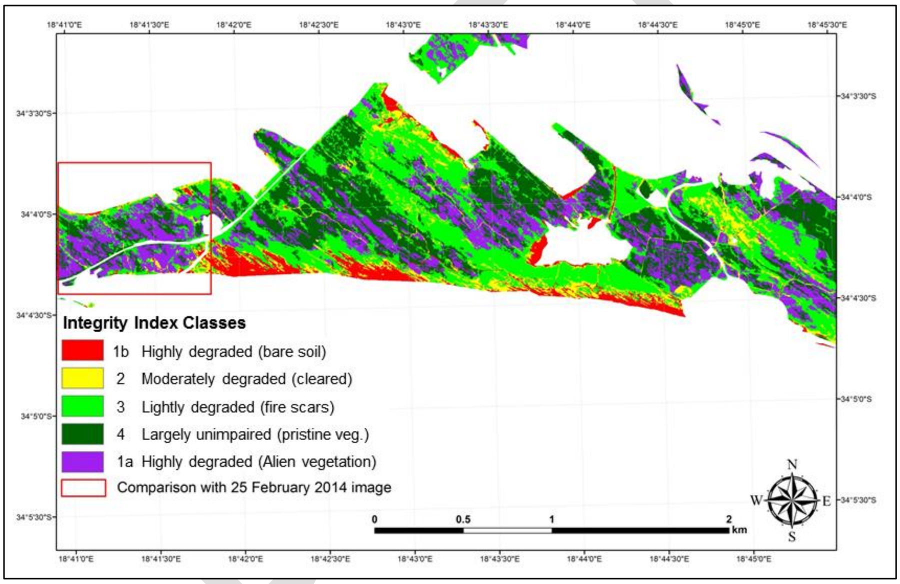

Figure 5: Integrity map derived from 11 October 2014 image (wet season).

3.3 Comparison between February and October integrity maps

Figure 6 compares the area where the February and the October maps overlap (indicated by the red frames in Figure 4 and Figure 5).

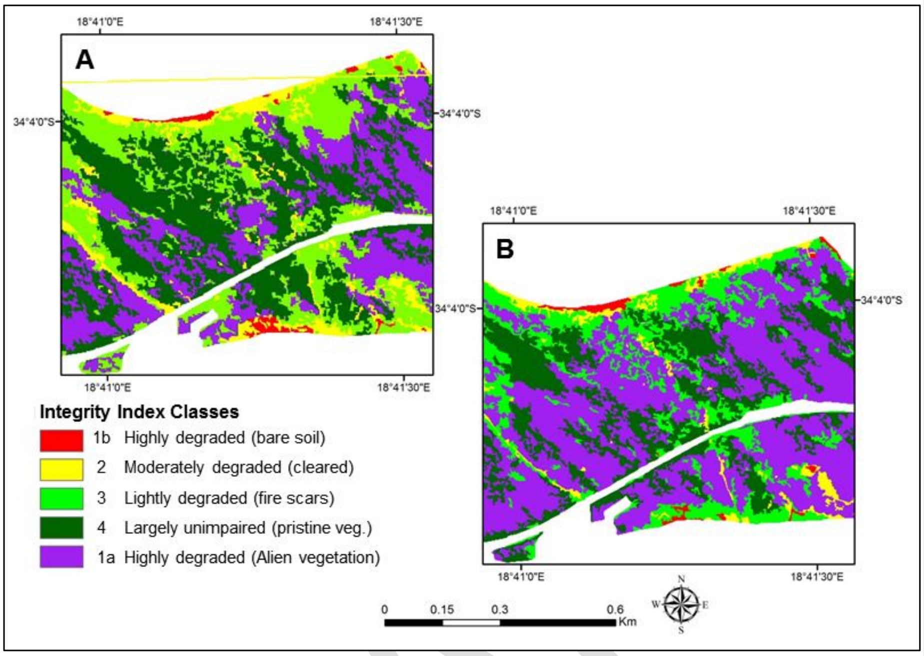

Figure 6: A) Integrity map for the 25 February 2014 image; B) for the same area for the 11 October 2014 image.

The October classification shows a significant increase in alien vegetation compared to the classification from February. However, field validation (see below) showed that this apparent increase is not caused by a true increase in alien vegetation but a phenological effect of vegetation growth given different seasons in which the images were taken. It appears that during the dry season, indigenous vegetation reduces their photosynthetic activity to a minimum, while the alien vegetation still remained highly photosynthetic active. In the rainy season, the indigenous vegetation is highly photosynthetically active too, thus wrongly being classified as alien vegetation. These results give important insights on how the seasonality influences the accuracy of alien vegetation detection in a Strandveld environment.

3.4 Field validation

As mentioned in section 2.2.3, one additional field trip was conducted in June 2016 in order to gain “historical” information about the dynamics and changes that took place in the area during the time between the WV-2 image acquisition and the conduction of this project in 2016. Based on the information provided by the Nature Reserve staff, the mapping results conducted for both 25 February 2014 and 11 October 2014 images were interpreted. Out of the 18 investigated points, for 13 points field observation and classification coincided.

Out of the wrongly classified 5 points, three confused pristine vegetation with alien vegetation. This happened either in areas where alien vegetation did not come to complete dominance yet, or on areas which were only classified as alien in the October image (phenological effects, see above). For one point, a moderate degradation was confused with a light degradation where a fire occurred just prior to the image acquisition, and in one place, azonal, dense riverine vegetation was confused with pristine vegetation. This non-Strandveld vegetation patch should have been masked out in the initial phase of the analysis. For a detailed description of the field observations refer to Mbolambi (2016).

4 Conclusions and recommendations

The presented paper aimed at identifying degrees of vegetation integrity within the Cape Flats Dune Strandveld vegetation in the north-eastern part of False Bay, Cape Town, South Africa using WorldView-2 multispectral satellite imagery. Partly overlapping imagery from

February and October 2014 with a spatial resolution of 2x2m was used. Based on field observations, a decision tree classification for both images was conducted. Regression analysis between the individual spectral bands and the degradation classes allowed to identify the two most suitable spectral bands for the decision tree classification, i.e. the red and the NIR1 band. Accuracy assessment was conducted based on additional field data. The overall accuracy of the results was 80.5% with kappa statistical value of 0.75. The accuracies thus show that the masking of all other vegetation or land cover types prior to image classification does increase the classification accuracy, as stipulated by Lück-Vogel et al. (2013). The results showed that with satisfactory accuracy it was possible to distinguish areas with high vegetation integrity from areas which are highly, moderately and lightly degraded. The distinction between intact vegetation and dense alien *Acacia* vegetation turned out to be less accurate and highly influenced by the actual acquisition date of the satellite imagery. The study results revealed that Images sensed in the dry, summer season better detected alien invasive vegetation because then the signal from the indigenous vegetation is significantly lower than the alien vegetation signal. During the wet season however, indigenous vegetation is more active and easily confused with alien vegetation. For future approaches, it is also advised to conduct field work as closely to the image acquisition date as possible, to avoid inconsistencies between field and image data due to natural vegetation succession and human impact such as de-bushing or fires happening in the interim.

The high spatial resolution of the WorldView-2 image allowed for the detection of very small scale degradation patterns, e.g. caused by illegal footpaths. The highly detailed maps therefore provide a suitable tool for environmental managers to put in place local management actions and to monitor their success.

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