CATHERINE T. KELLY

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Master in Marine and Coastal Systems

Work performed under the supervision of:

Dr. Óscar Ferreira (Universidade do Algarve)

Dr. Lara Talavera (Universidade do Algarve)

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Declaro ser o(a) autor(a) deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

Declaration of Authorship of work

I declare to be the author of this work, which is original and unpublished. Authors and works consulted are duly cited in the text and are included in the list of references.

✕

Catherine Therese Kelly

ACKNOWLEDGMENTS

Foremost, I would like to thank Dr. Óscar Ferreira and Dr. Lara Talavera. For their supervision, dedication and knowledge of the area of study and for allowing me to devleop a deeper understanding of the techniques used. I would like to thank the Universiade do Algarve for my MSc. studies here in the Algarve and its many enthusiastic professors that I have encountered. I would like to acknowledge Direção-Geral do Território (DGT) for providing the orthophotography used for this study. I would like to extend a sincere thank-you to Joshua Sugars for his knowledge, help and support with ArcMap.

I would like to thank each and every person in the Marine and Coastal Systems Masters for their friendship and laughter during the two years (especially on the oceanographic cruise). I would like to mention my gratefulness for the friendship of “The French gang” especially Gabrielle Descamps and Anicet Petillon. A thank-you for the love, care and friendship from Ana-Laura Dias, Rachel Acker and Tayna Nascimento. A heart-felt thank-you to Jacqueline Santos for her friendship and motivation throughout this study. A special thank-you for the love and support from my friends and family afar in Ireland and France, especially to my parents who have supported my hopes and dreams throughout my life. Finally, a big thank you to my partner Ben Mosley for his humor, constant moral support, and love.

RESUMO

As dunas do sistemas de ilhas barreira suportam uma grande variedade de vegetação que estabilizam e promovem o crescimento das dunas protegendo as zonas costeiras. Os habitats de vegetação diferem entre dunas frontal, interdunar e posterior de acordo com a sucessão evolutiva e a exposição da vegetação a fatores naturais como o vento e ondas. Esses fatores podem ter um efeito significativo sobre a geomorfologia das dunas. Além disso, a geomorfologia das dunas pode influenciar a ecologia, devido a evolução eco geomorfológicos que existem nas dunas costeiras, tais como os fatores reguladores "top down", como a areia eólica, e "bottom up", como as condições para um crescimento ótimo de sucessão comunitária. O sistema de ilhas barreira da Ria Formosa é uma reserva natural protegida desde 1987, esse sistema é constituído por uma lagoa protegida por cinco ilhas barreira e duas penínsulas separadas canais de marés, denominados como barras. Dentro deste sistema de ilhas barreira, a Ilha da Culatra contém uma importante comunidade pesqueira, presença de trilhas e colônias locais da gaivota-de-patas-amarelas (*Larus Michahellis*). Visto que a Ilha da Culatra contém “dunas cinzentas” que estão listadas como um tipo de habitat prioritário, de acordo com a diretiva europeia, foi necessário realizar um estudo rentável sobre o estado da vegetação. Foram investigados fatores que possam contribuir para a perturbação do sistema de vegetação das dunas da ilha da Culatra. O estudo na presente dissertação, desenvolveu um índice para calcular a perturbação da vegetação dunar dentro da Ilha da Culatra utilizando técnicas de detecção remota com a utilização de Sistemas de Informação Geográfica (SIG). Os materiais utilizados para a análise foram ortofotografias e imagens do Google Earth. Estes materiais e ferramentas permitiram classificar a vegetação para completar um índice de perturbação da vegetação. O índice foi realizado através da composição colorida de ortofotografias a cores verdadeiras. Para complementar os dados, foi também utilizada a imagem do Google Earth. As fontes de perturbação foram identificadas pela sobreposição de elementos antropogénicos digitalizados. Este estudo identificou a mudança no estado da vegetação de 2005 para 2017, envolvendo o aumento da perturbação. Constatou-se que a principal causa desta perturbação estava relacionada com marcas causadas por veículos na ilha. O índice e os métodos destacaram a necessidade da utilizar imagens de melhor qualidade, que podem ser de grande utilidade para estudos futuros devido à simplicidade dos métodos e à sua abordagem rentável. Além disso, este método e índice pode ser altamente transferível para outros sistemas dunares e pode ser utilizado como base de referência para o estudo posterior da vegetação dunar na ilha da Culatra, chamando a atenção e importância para a conservação do sistema dunar.

Palavras-chave: Perturbação da vegetação dunar; Índice de vegetação dunar; Classificação da Vegetação; Imagens a cores verdadeiras; Ortofotografia; Sistemas de Informação Geográfica.

ABSTRACT

Barrier island sand dune systems support a high variety of plant communities, which stabilise and promote growth of dunes protecting inland areas. According to plant succession and exposure, to natural factors such as wind and ocean, vegetation habitats differ between foredune, interdune and backdunes. This can have a significant effect on the geomorphology of the dunes. Moreover, the geomorphology of dunes can influence the ecology, due to the eco-geomorphological feedbacks that exist in coastal dunes such as "top down" (for example aeolian sand) and "bottom up" (such as the conditions for optimal growth of community succession) regulating factors. A protected natural reserve since 1987, the Ria Formosa consists of a lagoon protected by five barrier islands and two peninsulas supported by tidal inlets. Within this barrier system, Culatra Island contains a significant fishing communities, the presence of local footpaths and colonies of the Yellow legged gull (*Larus Michahellis*). Since Culatra Island contains "grey dunes" which are listed as a priority habitat type according to the EU habitats directive, it was therefore necessary to conduct a cost-effective study on the state of the vegetation and whether any factors are contributing to the perturbation of the Culatra Island dune vegetation system. This study developed an index to calculate dune vegetation perturbation within Culatra island using remote sensing techniques within a Geographical Information Systems environment (GIS). The materials used for the analysis were orthophotos and Google Earth imagery. These materials and tools enabled the ability to classify vegetation to complete a vegetation perturbance index. The index was carried out by the classification of orthomosaicked true colour images. To complement the data, Google Earth imagery was also used. Sources of perturbation were identified by the superimposition of digitized anthropogenic elements. This study identified the change in vegetation state from 2005 to 2017 involving the increase of perturbation. It was found that the main cause of this perturbation was related to track marks caused by vehicles on the island. The index and methods highlighted the need to use better quality imagery but can be of great use for further studies due to the simplicity of the methods and its cost-effective approach. Furthermore, this method and index can be highly transferable to other dune systems and can be utilized as a baseline for further study of dune vegetation on Culatra island, drawing attention and importance to the conservation of the system.

Key-words: Dune vegetation mapping; Dune vegetation index; Vegetation Classification; True colour images; Orthophotography, Geographical Information Systems.

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1. INTRODUCTION

Coastal dunes are landforms with great value, due to their ability to provide coastal defence, support biodiversity, agricultural use, water catchment, housing and tourism (Carter, 1991). Dunes have a morphological relevance due to their ability to provide a physical resistance to erosion events by wave action, Dune vegetation has the ability to stabilize and bind the dune sediment, allowing the trapping of sand, increasing dune height and volume (Goldstein et al. 2017). The growth and stabilization of the ecology of these ecosystems, play a major role in the mediation of the functions and health of dunes (Njseagrant, 2016). Moreover, the geomorphology of dunes can influence the ecology, due to the eco-geomorphological feedbacks that exist in coastal dunes such as "top down" (for example aeolian sand) and "bottom up" (such as the conditions for optimal growth of community succession) regulating factors. However, due to expansion of populations, growth of industry, and the exploitation of natural resources, there has been a significant degradation of coastal dunes (Carter, 1991).

Due to the combination of anthropogenic and natural processes, there has been changes within the dune vegetation, affecting alterations of the length and the seasonal growth (Jackson and Cooper, 2011). Tourism particularly threatens Mediterranean coastal dunes, causing severe modifications to vegetation and causing a widespread disturbance and disappearance of endemic species. The climate and biomes that develop on coastal dunes are very diverse, and consist of a highly diverse ecology, since they are found in almost all latitudes (Snead,1972). Moreover, this stresses the importance of dune vegetation monitoring, identification of changes and the associated causes (Martinez and Psuty, 2005).

Ria Formosa, South Portugal (**Fig.1**.) is a multi-barrier system with extensive fields of grey dunes. The dune vegetation is however, threatened at some places within the system, both by natural and anthropic factors. Since Grey dunes are considered a priority habitat under the EU habitats directive, it is necessary to calculate the current state of dune vegetation health. The island of Culatra contains one significant community (Culatra village) which is tied to extensive fishing activities. The other two villages of Farol and Hangares do not have a permanent living population. Since this system is a protected area, they contain well developed dunes, however, in some areas near inlets there are scarcities of vegetation, due to their associations of inlet migration (Vila-

Concejo, 2004). Vegetation is evidently non-existent near the occupied areas of Farol, Hangares and Culatra at Culatra **I**sland. The presence of yellow legged gulls (*Larus Michahellis*) has also been noted on this island., and possibly linked to an impact on vegetation changes. Multi-temporal datasets are useful materials when identifying and detecting spatial change (Vinet and Zhedanov, 2011). Therefore, it was necessary to compute a vegetation perturbation index based on these datasets to identify the state of vegetation and if any causes of perturbation are related to human activities and/or natural factors.

1.1 OBJECTIVES

The aim of this research is to assess the state of dune vegetation in Culatra island, Ria Formosa, Algarve, Southern Portugal. This will be carried out by monitoring changes using orthophotos and Google Earth imagery and to identify areas with perturbed vegetation by applying a vegetation perturbation index. This will be carried out to find the possible cause of perturbation (natural or anthropogenic) by relating the perturbed areas that were identified by the index with human/natural processes.

2 STATE OF THE ART

2.1 BARRIER ISLANDS AND ASSOCIATED DUNE SYSTEMS

Sandy coasts can be recognized for their propensity to self-organise and for their sensitivity to geomorphic, biological, and meteorological inputs (Riggs, 1976). A barrier island is an elongated and unconsolidated body of sandy or gravelly sediments lying above high tide level, separated by a lagoon or marsh from the mainland (Komar, 1986). Often composed of siliciclastic sediments, the depositional history of these islands is a result of rising local sea level variations and coastal processes (Schnicder and Kruse, 2003). Barrier islands are crucial geomorphological features representing 10% of the world's coastlines (Pilkey et al. 2011). These landforms may defend low lying coastal lands against storms, whilst protecting the extensive rich natural resources of estuaries and marshes (Komar, 1986; Deng et al. 2017). However, barrier islands are dynamic and sensitive features of the coastal environment (Concejo et al. 2002). They are an example of an extreme dynamic system coinciding with fast long-shore and cross-shore variations in relation to tidal and wave processes (Dias et al.2013). Barrier islands can be difficult to manage due to lack of knowledge (Dias et al. 2013)

Oertel (1985) defined the different major elements of a barrier island system including (1) the main island, (2) Backbarrier lagoon, (3) inlet and inlet deltas, (4) backbarrier island, (5) backbarrier platform and (6) shoreface. Coastal dunes (located in the backbarrier island) can be described as aeolian landforms developed because of ample loose sediment, which is transported inland by ambient winds (Martinez and Psuty, 2005). According to Jungerius (1990) a decrease in aeolian activity and the stabilization of vegetation moulds the fixation of dune landscapes. Changes in vegetation can link to the transformation of geomorphological features of dunes through a change in dynamics and type of landform (Hernandez- Cordero et al. 2017; Hilton et al. 2006). Dune landscapes can sustain high biodiversity, due to their ability to function as physical support systems of a variety of natural habitats (Martinez et al. 2008). Vegetation cover is the most used factor in characterization of the stabilization process of dunes (Garcia and Romero, 2016). Vegetation allows a compilation of sediment, causing a decrease in transport, due to the increase of roughness created by plants, reducing wind speed and therefore, decreasing aeolian transport (Hesp, 1981; Levin et al. 1998). Dune vegetation can provide further physical resistance to wave erosion events due to its ability to stabilise and bind the dune sediment, trapping additional wind-deposited sand, supplementing the rise in dune height and volume (Goldstein et al. 2017).

Grey dunes are considered a priority habitat according to the EU habitats directive. Fixed coastal dunes or "grey dunes" contain herbaceous vegetation according to the CORINE biotype classification. These fixed and semi-fixed dunes are stabilized by an abundance of lichens, mosses, and closed perennial grasslands and bushes, but vary from system to system (Natura, 2000). According to Bonte et al. (2004) the succession of grey dunes commences with fixation and is driven by the complexity of dune formation of soil. Grey dunes display a dynamic biological community succession between "top down" regulating factors such as; sand blowing, producing a dynamic landscape, whereas "bottom up" community succession leads to the development of scrub and woodland (Prooovost, 2004).

Vegetation cover has increased globally between 1987 and 2017 due to changes in climate, according to Jackson et al. (2019). A mixture of anthropogenic and natural processes has been linked as potential drivers for vegetation cover changes, including alterations of the length and the growing season (Jackson and Cooper, 2011). Environmental modifications such as dune stabilization, erosion or remobilisation may be caused by human activities or natural changes (Garcia- Romero, 2020). Large volumes of sand can be easily mobilised by high velocity winds, rapidly transporting the sands and allowing blowouts, changing stable dunes to more mobile dunes. These blowouts can cause the drifting sand to smother vegetation and allow dune erosion (Narayanasamy et al. 2020). Other natural disturbances of dunes include overwash and animal grazing (e.g. seagulls). The ability of dune plant species to mould physiography can be replaced by overwash distribution along the shoreline (Stallins, 2003). Overwash processes occur usually as tongue-shaped penetrations, that lead to a depositional fan, producing a surface of bare sand, with the addition of a source of windtransport, with vegetation stopping this erosion of sediment along the perimeter of the sand flat (Schwartz, 2005). Coarse material may be deposited on salt marshes during these high energy conditions (Wheeler et al. 1999). Vegetation and drag from creek banks may cause the velocity of flood waters to decrease resulting from lateral spreading (Groot et al. 2011). There is a strong geographic contrast in the interaction between extrinsic disturbance from storm overwash and intrinsic recovery of biogeographic processes within barrier island dune systems (Stallin, 2003). Morton et al. (2000) describes washovers as morphological features that are generated by overwash, occurring during sea level elevation. In the Ria Formosa barrier islands, the dominant mechanism formations of washovers are inlet dynamics (57% of the washovers) (Matias et al. 2008).

Seabirds can also transform terrestrialvegetation by altering edaphic conditions (Ellis, 2005). Sand dune vegetation lies beneath leached heath and guano rich soils, which leads to toxicity in summer creating more specialized flora, therefore, limiting the total number of species of vegetation (Gillham,1960). It has been noted that dispersal of seeds by gulls leads to a high invasion rate by more cosmopolitan plants species, producing a decline in native species (Ellis, 2005). In a previous study by Vidal et al. (1999), it was found that a disturbance of high severity induced by the activities of seabirds, tends to select and favour plant species that are more adapted to the expense of indigenous island taxa. A high retention of water capacity can be found in soils due to the presence of organic matter from bird colonies (Garcia et al.2002). Negative effects of trampling on tree seedlings by gulls can be found to cause a mortality in the seeds. (Maesako, 1999).

Coastal dune habitats may be particularly vulnerable to the impact of recreational activities and tourism. Vehicles can cause a considerable amount of damage on coastal dunes. (Westhoff,1967). Kindermann and Gormley (2010) found that movement of vehicles by recreational visits have damaged the habitats of dunes where the overall area of track marks increased threefold from 1978 to 2007. In South Africa, a decreasing trend in vegetation height was found in relation to track mark effects on dune vegetation (Rickard et al. 1994).

2.1 DUNE VEGETATION MONITORING USING AERIAL IMAGERY

Remote sensing offers the ability to detect changes on the Earth's surface through satellite sensors. It is a powerful tool in providing valuable assistance to allow scientists to monitor temporal and spatial changes on the earth's surface (Alqurashi and Kumar, 2013). Remote Sensing and Geographical Information Systems (GIS) are important tools to efficiently monitor landscape changes (Gartzia et al 2013). These changes in landscape can be monitored with Aerial photos, which are useful airborne information sources for the study of vegetation dynamics in dune systems (Okeke and Karneli, 2006). In the past, studies of vegetation with the use of aerial imagery have been utilised to efficiently monitor changes following a visual qualitative analysis (Garcia et al. 2001). This type of analysis can be complemented with a simple series of analytical techniques (Curr et al. 2000). Moreover, it is possible to carry out and improve this analysis of aerial imagery through a GIS environment (Paganet al. 2019; Shanmuga and Barnsley, 2002). GIS is useful in measuring the spatiotemporal changes of different environmental variables, with the capability to include numerous sources of different data into the platform (e.g., aerial images, orthophotos and satellite imagery), and the ability to use multiple tools (e.g., orthomosaic stitching map georeferencing, classification of images (Mausel and Moran, 2004).

With regards to monitoring, it is possible to identify vegetation with a simple index used to analyse the vegetation from remote sensing equipment. The use of satellites and airborne sensors may be used to capture hyperspectral and multi-spectral images, which entails the development of vegetation indices (Garcia et al. 2020). A common method to apply to vegetation analysis employs the use of automatic classifications using near infra-red bands (Hugenholtz et al. 2012). A popular vegetation index used is called the Normalized Difference Vegetation Index (NDVI) (Rouse Jr et al. 1974). It is a normalised ratio of near infrared and red spectral bands (Jensen. 2005). NDVI is an index computed from multi-spectral imagery and issued to assess vegetation health or to distinguish between different land uses, land cover classification, water bodies, open area, and scrub areas for example (Gandhi et al. 2015).

Using indices to study dune vegetation from remotely sensed imagery requires the application of different image classification techniques. Many authors have used different vegetation classification methods for different purposes. For example, Fernandez et al. 2019 developed a semi- quantitively/qualitative index approach to determine coastal dune vegetation on the Sefton coast, UK. Calculated expected mobility (M) of dunes was used to estimate expected dune vegetation cover to qualitatively calculate the observed mobility/vegetation cover (Fernandez et al. 2019). This was calculated using the percentage of vegetation or bare sand, then quantified by digitising all the areas of bare sand in each mosaic in ArcGIS (Fernande et al. 2019). Jackson et al. (2019) used NDVI index derived from Landsat images to quantify changes in dune vegetation cover over a 30-year period globally. The study was conducted using clipped areas classified in ArcGIS using an interactive supervised classification, which was then classified using samples that were previously trained to represent vegetated areas and bare sand. (Jackson et al. 2019). Another study (Laporte- Fauret et al. 2020) used a normalised vegetation difference index and random forest classifier based on a twostep classification approach using vegetation and sand pixels compiled from a NDVI filter to detect coastal dune vegetation change in Aquitaine, southwest France. Other studies such as Valentini et al. (2020) discovered that by using LiDAR with hyperspectral it created the ease of using already existing processes which simplified the production of thematic maps and coastal metrics, allowing a discrete pixel analysis to explore the system as a whole using FHyL (Field spectral libraries, airborne Hyperspectral images and LiDAR altimetry..

2.3 STUDY AREA

The Ria Formosa is a large coastal sheltered lagoon (Fig.1.) bordered by a multi-barrier system and has been classified as a natural park since 1987. The barrier system currently has five islands (Barreta,Culatra, Armona, Tavira and Cabanas) and two peninsulas (Cacela and Ancão), which are separated by six tidal inlets (Ancão, Faro – Olhão, Fuzeta, Tavira and Cacela) and is roughly triangular-shaped with a total extension of 55 km and is up to 6 km from the mainland (Ferreira et al. 2016). The tidal regime within this system is semi-diurnal, with a mean tidal rage of 2.2 m and spring tides reaching around 3.4 m (Matias et al. 2006).

FIGURE 1 - RIA FORMOSA IN SOUTH PORTUGAL, ALGARVE AND INSIGHT (RECTANGLE) WITH CULATRA ISLAND. (SOURCE ARCMAP BASE MAPS).

The offshore wave climate is characterised by W-SW waves of 71% occurrence and SE waves that aregenerated by local frequent winds, about 23% occurrences (Costas et al. 2001). The more energetic side of the Ria Formosa is the western side exposed to the WSW conditions while the eastern side is directly exposed to the E-SE (“*Levante”*) conditions (Costas, 1994). Dominant winds are from the west and north-west, with south-west also being frequent, while eastern are less frequent, however, the latter may dominate throughout short periods between spring and autumn seasons (Andrade, 1990). Net longshore sediment transport carries an eastward trend, estimating from 6 x 10^3 up to 3 X 10^5 m^3yr^{-1} for the west flank, and for the east flank from 10^4 to 1.5 x 10^5 m^3 yr^{-1} (Ferreira et al. 2016; Vila-Concejo et al. 2004).

The evolutionary trend Ria Formosa displays is a landward displacement of the back barrier with a decrease in the extent of the barrier coastline (Kombiadou et al. 2016). This has caused a coastal squeeze action, i.e., a shrinking of the lagoon (Carrasco et al. 2008; Ferreira et al. 2016). The Ria Formosa displays a similar pattern in comparison with other transgressive barrier island systems according to Nave and Rebelo (2021). Due to a rise in sea level, the Ria Formosa is actively transgressing, is in an active phase of landward migration, including the rebuilding and island erosion. However, Kombiadou et al. (2019) found that shoal attachment was the main mechanism for growth in in the Ria Formosa (70% + 5.8%). According to Kombiadou et al. (2019) there are four evolution regimes within the Ria Formosa system; enhanced growth through artificial means, promotion of stability by artificial and natural factors, decay triggered by artificial means causing inland migration and natural growth. The barrier islands' formation process vegetation growth can be summarised into three stages, according to the studies of Ferreira et al. (2016) (Table 1). Eastern Culatra can be categorised into stage 3 as it presents a more stable barrier development with recurved spits (Ferreira et al. 2016).

TABLE 5:DESCRIPTION OF BARRIER ISLAND STAGES IN RIA FORMOSA, ACCORDING TO FERREIRA ET AL. (2016).

Stage	*Physical Process and vegetation*
1	Low crest Elevation Frequent overwash Flat surface with sparse pioneer vegetation
2	Growth in island crest elevation High interaction between aeolian sand transport and vegetation expansion Distal overwash fans
3	Stable barrier development Dense vegetation cover

Due to the loss of the tidal prism at the Armona inlet, there has been a change in the hydrodynamic circulation caused by Faro-Olhao stabilisation (Pacheco et al. 2008; Pacheco et al. 2010; Kombiadou et al. 2019). Apart from Armona, the inlets which are non-stabilised move eastwards due to longshore drift (Kombiadou et al. 2019). The position of the inlet is forced to move in a similar direction as the dominant longshore transport, from west to east which is a result of sediment accumulation on the western part of the barrier island, allowing the migratory pattern of the opening to move eastward, until a limiting position is reached, followed by an infilling, and restarting the whole process again (Vila-Concejo et al. 2003; Pacheco et al. 2005). This reduction at the Armona inlet caused the shoreline to retreat the west end of Culatra and is responsible for the growth of the spit to the east (Ferreira et al. 2016). According to Garcia et al. (2002) between 1958 and 1976, there was a 5.8 m/year shoreline retreat on the Western shoreline of Culatra island. The eastern part, however, is dominated by longshore growth caused by the domination of recurved spits, due to the narrowing of the Armona inlet, shoal attachment by Culatra and Armona W (60% +2.3%) and its vulnerability to overwash processes (Ceia et al. 2010; Ferreira et al. 2016; Matias et al. 2008; Kombiadou et al.2019).

As proposed by the European Habitats Directive (EEA), there are (2110) Embryonic shifting dunes, (2120) shifting dunes which occur along the shoreline with Ammophila arenaria (white dunes) and (2130) fixed coastal dunes consisting of herbaceous vegetation located within Culatra island Ria Formosa system. The EEA reported that all three of these dune habitats have a conservation status of B, with a representivity of C for both shifting dunes and Embryonic shifting dunes and A for fixed coastal dunes. Within the Ria Formosa, the capacity of dune growth can be dominantly controlled by local wind or limiting factors in supply, with a recent study by Costas et al. (2020) stating that the presence of spatially random growth patterns, may be correlated with non-uniform distributions, for example, the characteristics of sediments, and anthropogenic influence. Optimal conditions for the growth of dunes occur during storm periods take place with high run-up (Costas et al. 2020).

Overwash is a common occurrence within the Ria Formosa system, which is associated with the retreat of shoreline and breaching of barriers, it is also contributing to the lowering of the foredune and loss of vegetation (Garcia et al. 2002; Garcia et al. 2010). Other factors which may contribute to loss of vegetation are seabirds such as the yellow-legged gull (*Larus Michaellis*) with two distinct colonies, (Mendes et al. 2017). These seabirds are known for their foraging methods,which may disrupt vegetation, as most species of gulls have an opportunistic behaviour (Christel et al. 2012). The Audouin's gull (located within the Ria Formosa) takes advantage on fishing rejects (SPEA,2021). This Indicates that their reason to nest on these islands is due to the close location of the harbours, fishermen, sea and land, and the fact that this is a protected area. The LIFE project located in Ria Formosa, aims to characterise the local ecological requirements andconservation threats of Audoin's gull (*Larus Aeudouinii*) (LIFE 18 NAT, 2019). Other examples of degradation factors include occupied areas (Ceia et al. 2010). Culatra Island contains three main communities, Farol, Hangares and Culatura (Fig.1.). Human occupation in these villages has increased within the last few decades, as well as the presence of footpaths and tractor derived track marks (Fig.2). The eastern side is unoccupied. Culatra contains 612 permanent residents, as the occupation of the Culatra settlement is related to fishing. Whereas the communities of Farol and Armona have more seasonal residents, related to the summer season (Bernardo et al. 2002) Another source degradation factor could be the formation and presence of the pipeline located on the Eastern end of Culatra, which was built in 2008.

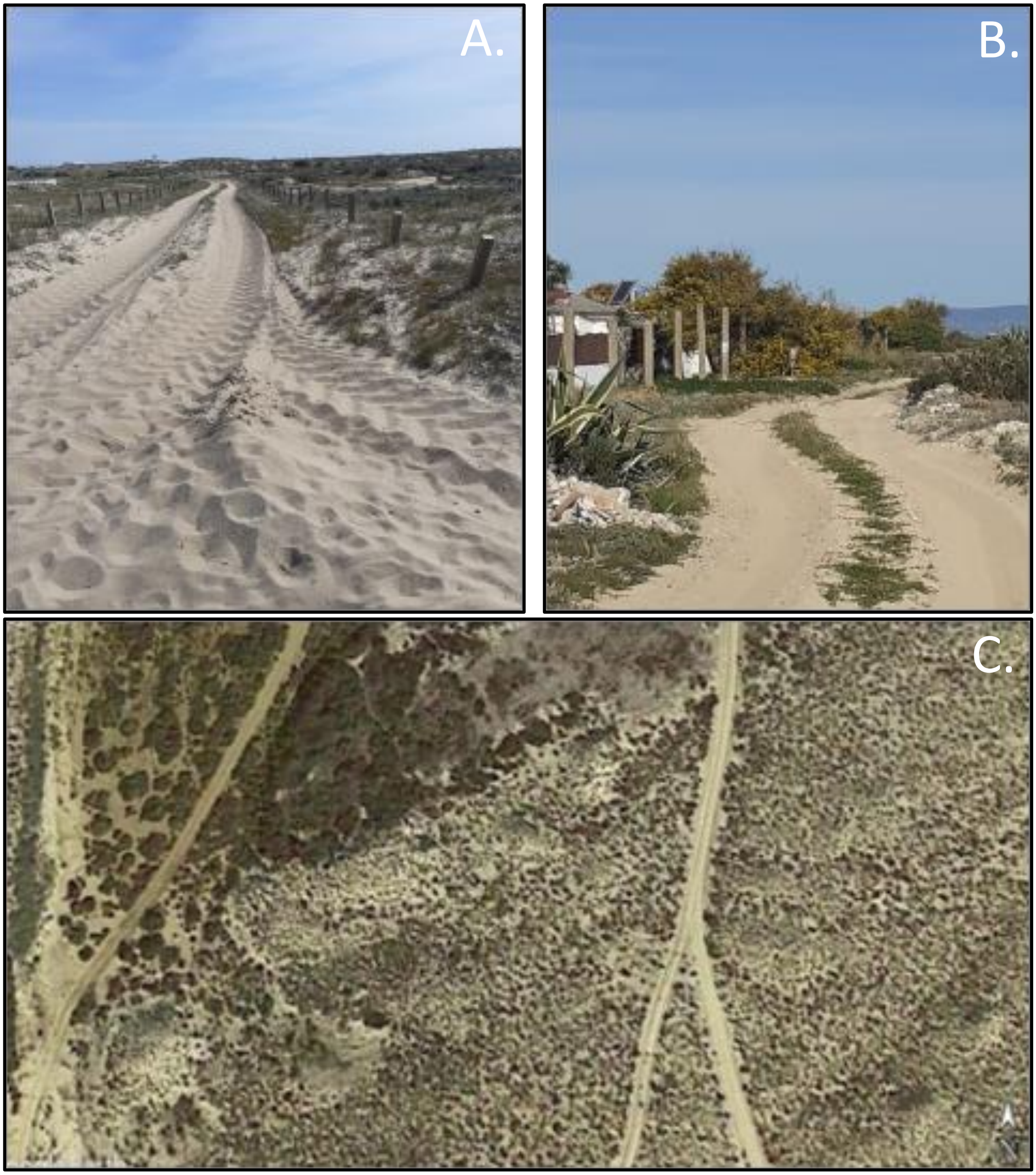

FIGURE 2 - TRACK MARKS LOCATED IN CULATRA ISLAND. WHERE (A) IS A PERSONAL PHOTO OF A RECENT TRACK MARKS ON A FIELD VISIT (B) A PERSONAL PHOTO TAKEN OF A LESS RECENT TRACK MARKS ON A FIELD VISIT AND (C) IS SATELLITE IMAGERY OF A TRACK MARK. (SOURCE: GOOGLE EARTH

2 MATERIALS AND METHODS

2.1 DATA COLLECTION AND PREPARATION

The dune vegetation analysis was investigated using different remote sensing orthophotography images from Direção-Geral do Território (DGT) for years 2005, 2008, and 2014 (Table 2). A Google Earth image from 2017 was used. Both the orthophotos and Google Earth images were spatially referenced to ETRS_1989_Portugal_TM06 (Fig. 4).

Once collected, the orthophotos were mosaicked together into a unique orthomosaic dataset. This was done to merge different orthophotos of the same year into a single image for better handling. The shift tool was used to correctly align the 2005 mosaicked orthophoto which was slightly displaced.

TABLE 6: DETAILS OF THE IMAGERY USED, RESOLUTION AND SOURCE.

Aerial Imagery details

Year	*Horizontal Resolution*	*Source*
2005	0.5 x 0.5 m	DGT
2008	0.1 x 0.1 m	DGT
2014	0.1 x 0.1 m	DGT
2017	0.45x0.45m	Google Earth

(*Measured pixel size*)

To complement the orthophotos and expand the spatial temporal scale of the analysis, a 2017 Google Earth image (Table 2) was downloaded using a 2.02 km view altitude and no tilting was ensured during the download process. The image was spatially georeferenced having the 2014 orthophoto as baseline reference. The 2017 Google Earth images were stitched together (Fig. 4). Once the imagery was prepared, it was masked using a polygon shapefile that was digitized carefully around the outline of the barrier island, ensuring that all elements of interest (e.g., beach, foredunes) were included. The previous steps were performed using different tools of ArcMap (®ESRI) GIS software.

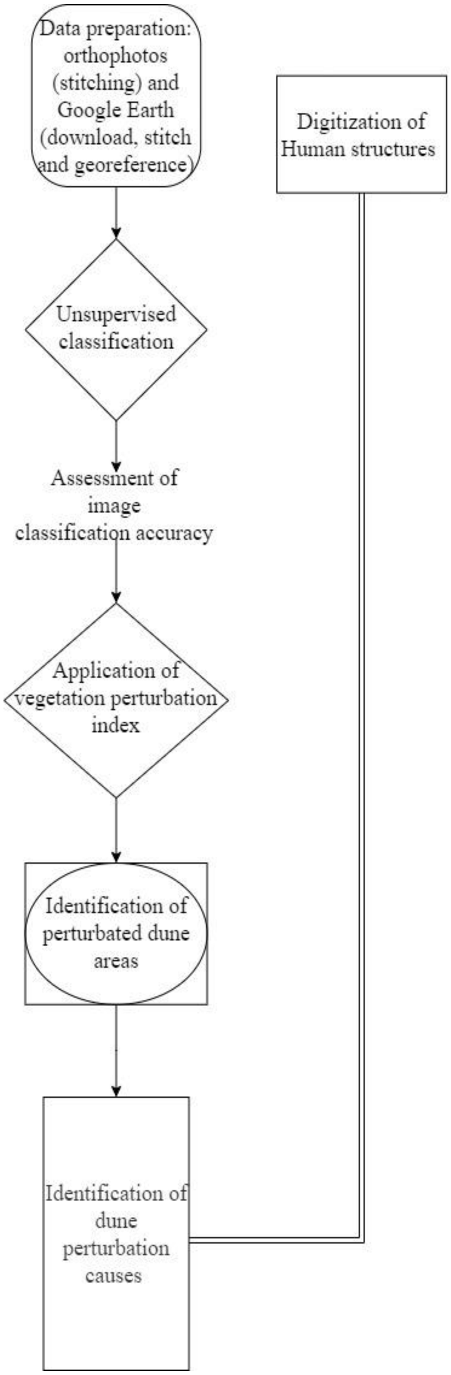

FIGURE 3 - GENERAL WORKFLOW FOR THE COMPUTATION OF THE PERTURBATION INDEX

2.2 IMAGE CLASSIFICATION

The masked images within the outline of Culatra Island were classified (Annexes, pg.66+67) using an unsupervised classification method into three classes: shrubs, herbaceous vegetation, and sand (classes 1, 2 and 3, respectively) (Fig.4).

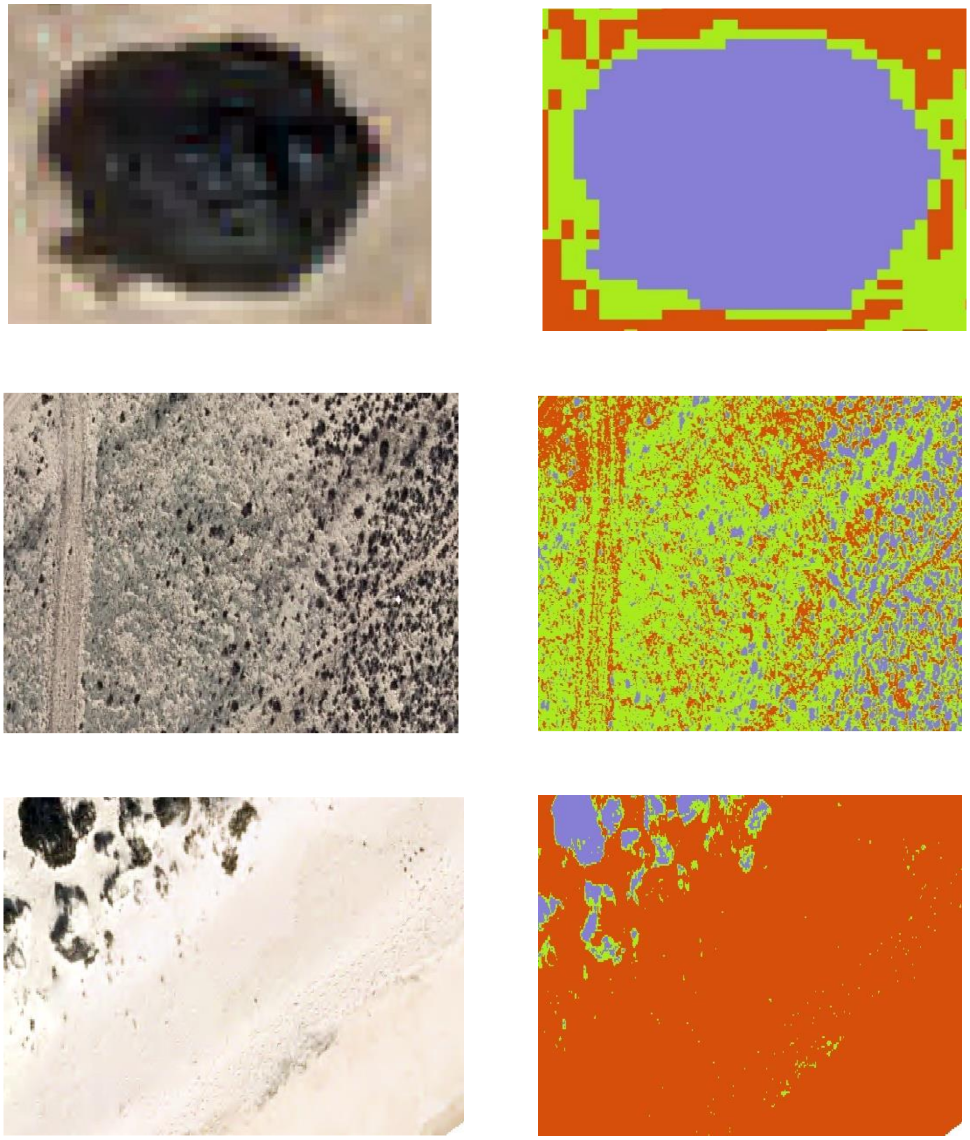

FIGURE 4 - EXAMPLES OF RGB IMAGES AND CLASSIFIED IMAGES SHOWING SHRUBS (MAGENTA), HERBACEOUS VEGETATION (LIGHT GREEN) AND SAND (RED) BASED ON THE 2014 ORTHOPHOTOS

An evaluation of the classification accuracy was carried out using a reference point cloud (30 points) and an error matrix was built comparing the classified values in each point of every dataset to the classification criteria of an observer in the same points (reference data), thus determining the degree of discrepancy among classes. This error matrix approach allowed the calculation of several statistics used to assess the classification accuracy: the agreement accuracy, overall classification, commission error, omission error and Kappa coefficient (Sen, 1968; Cohen, 1960). The agreement accuracy is the probability that an image pixel was labelled correctly by the classifier, whereas the overall classification accuracy represents the sum of the classified samples divided by the sum of the reference samples (Jackson et al. 2019). The error of omission parallels the producer accuracy which gives the accuracy of a specific class, which equivalates to the error of commission (Jackson et al. 2019). Kappa coefficient is a discrete and multi-variate technique, which can be used in an accuracy assessment (Jackson et al.2019). Kappa values range from 0 to 1; those that are below or equal to 0.40 may indicate a poor agreement, Kappa values between 0.40 and 0.75 indicate a good extent of agreement, whilst Kappa values above 0.75 indicate an excellent agreement (Jackson et al. 2019).

2.3 APPLICATION OF DUNE VEGETATION STATE

The classified images were re-sampled to have an equal cell size of 1x1 m and were then converted to points. A regular grid (10 x 10 m cell size) was built and used to intersect the previous points created. This allowed the counting of points corresponding to sand (class 3) in areas of 10 x10 m, and the obtention of maps showing the percent cover of sand in Culatra Island for every year analysed. Class 3 (sand or bare soil) was selected to indicate the percentage cover of sand assumed to be representative of the dune state. To identify thresholds for optimal or perturbed dune vegetation, the frequency distribution of sand in areas recognised as having a healthy dune vegetation composition were computed for every sand percent cover map obtained (Fig.5). The most frequent values in the histograms were assumed to represent optimal grey dune composition, while the less frequent ones were assigned a certain degree of perturbation. (Table3).

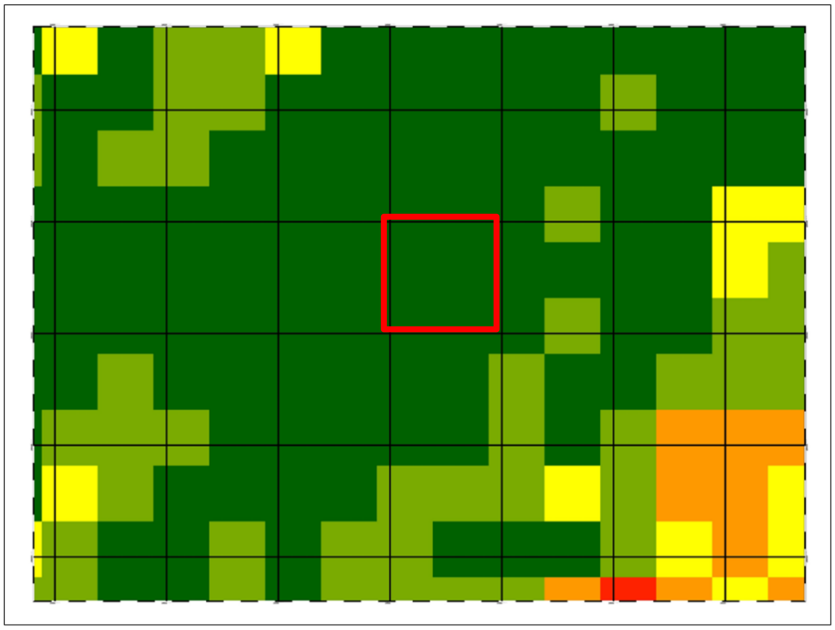

FIGURE 5 - HEALTHY DUNE VEGETATION PIXEL IN 100M 2 REPRESENTED BY RED POLYGON

TABLE 7: THRESHOLDS OF PERTURBATION FOR EVERY IMAGE ACCORDING TO PERCENTAGE OF SAND COVER. WHERE SC= SAND COVER~

	Optimal	Partial	Perturbed
2005	%Sc ≤23	%Sc 23 - 37	%Sc ≥ 37
2008	%Sc ≤47	%Sc 47 -62	%Sc ≥62
2014	%Sc ≤44	%Sc 44 - 56	%Sc ≥56
2017	%Sc ≤18	%Sc18 - 26	%Sc ≥ 26

3.4 ANALYSIS OF SPATIO TEMPORAL CHANGES OF SAND COVER AND ANALYSIS OF DUNE STATES

Once sand maps were computed, they were exported and analysed. The attribute table was exported. The percentage sand coverage area was calculated (*100) and the percentage amount of sand was analysed using MATLAB to plot a bar graph representing the different classes of sand coverage percentage within the total area counts. Dune state of vegetation maps were also exported and analysed. The attribute tables were exported and the percentage cover of area was calculated (*100) as this allowed a comparison due to the extraction of changing natural/human elements such as saltmarsh and human occupation. This was then analysed with Bar graphs produced in MATLAB.

3.5 DIGITISATIONS

Human occupation and artificial structures were digitised within the orthophotos and the Google Earth imagery. To understand whether human factors were inducing dune vegetation perturbation, infrastructures and human related elements were digitised as polylines and polygons in ArcMap. These included: Occupied areas, which were digitised with a polygon around areas featuring a house or small group of houses (villages); Coastal structures such as jetties and seawalls were also digitised with a polygon along the outer edges of the feature; Track marks and trampling paths were digitised with a polyline. In order to differentiate we assumed that visually upon the criteria that the track marks contained a thick wheel mark and trampling paths were visually thin and did not contain a wheel mark. A pipeline was also digitised for each year following 2008. This pipeline was identified by the location in the spit of the island due to the knowledge of a prior field visit.

Natural elements were also digitised within the imagery. Salt marsh/tidal flats were defined with a polygon upon the criteria of a water body inside the island and/or a pattern of an infiltrating wetland feature, and knowledge of a prior field visit. The beach was marked with a polygon identified by vast areas of sand on the edges of the island. Dune vegetation was also marked with polygons in areas of vegetation appearance outside the above digitised, according to visually vegetated areas,

3.6 IDENTIFICATION OF DUNE PERTURBATION CAUSES

Dune vegetation state maps were superimposed with digitised cartography in order to find the sources of dune perturbation. An observation for the type of recovery was made for each year along with an observation on the cause of disturbance according to the superimposed digitisations.

4 RESULTS

4.1 CLASSIFICATION ACCURACY

The image with the highest agreement accuracy was 2014, with all 3 classes having an agreement accuracy of 100. Class 2 had the lowest agreement accuracy for all years with 2008 having the lowest agreement accuracy of 40 (Table 4). This meant that 2008 (class 2) had the lowest probability of a correctly labelled pixel. 2014 had the lowest omission error of 0 for each of the three classes (Jackson et al. 2019). 2005 had the highest omission error of 38.5 in class 3 (2014).

TABLE 8: ASSESSMENTS OF AGREEMENT ACCURACY OF EACH CLASS IN EACH IMAGE

Year	Class	Agreement Accuracy	Omission Error	Commission Error	Overall Accuracy	Kappa Coefficient
2005	Class 1	80	20	0	73.3	0.56
	Class 2	83.3	16.6	37.5		
	Class 3	61.5	38.5	20		
2008	Class 1	88.9	0	11.1	70	0.51
	Class 2	40	60	71.4		
	Class 3	68.7	31.25	21.4		
2014	Class 1	100	0	0	100	1
	Class 2	100	0	0		
	Class 3	100	0	0		
2017	Class 1	90.9	0	23	86.7	0.79
	Class 2	76.9	23.07	0		
	Class 3	100	0	14.3		

The same image (2014) had the lowest commission error with 0 for all classes. The highest commission error was 2008, with a commission error of 71.4 for 2008 in class 2 (Table 4). This correlates with the error of commission and depicts that the lowest error equivalates to the most accurately classified class, which would be 2014. (Jackson et al. 2019). The image with the highest overall accuracy was 2014 with 100. 2005 displayed the lowest overall accuracy with 73.3 (Table 4). This meant that the 2014 image had the highest total number of correctly classified samples which were divided by the total number of reference samples (Cohen, 1960; Sen, 1968; Jackson et al. 2019). Furthermore, 2014 also had the highest Kappa coefficient indicating an excellent extent of agreement according to Fleiss et al. (2013) whilst 2008 produced the lowest Kappa score of 0.51 indicating a good extent of agreement (Fleiss et al. 2013).

4.2 EVOLUTION OF SAND COVER

There was an overall increasing trend in sand cover from 2005 to 2017, with a total island 459,100 m^2 increase. The biggest amount of sand coverage was between 1 – 20%. Percentage sand cover was observed to be between 1 – 20 % in the majority of the island in 2005 (Fig.6), approximately 1109100 m^2 of area on the island contained this amount of sand coverage (Fig.7). This image also featured some sand coverage between 20-40% in some sporadic areas located next to Farol village, which accounted for 239800 m^2 of the island. Sand percentage cover between 40 – 60% accounted for 117600 m^2 of Culatra island (Fig.8). From observation, Culatra island in 2005 had some definitive areas of percentage cover of sand between 40-60% located in some areas close to the beach and villages (Fig.6). There was also some percentage cover of sand between 40-60% coverage located in a faint linear fashion next to the villages. Percentage cover of sand between 80-100% (640,100 m^2, Fig.8) was observed to have been majorly located in the beach and spit areas in the East (Fig.6).

Percentage cover of sand was observed to have visually increased significantly in 2008 (Fig.6). There was a particular increase in sand percent cover between 40 -60%, which accounted for 613400 m^2 of the island (Fig.7 and Fig.8**).** This is in the west of the island next to Farol and Culatra villages. This sand cover percentage value was also observed in the East of the island, next to the spit (Fig.7). There was also an observed significant difference in sand percentage cover between

80 – 100% (Fig.7), accounting for 525000 m^2 coverage of the island (Fig.8). This was particularly seen in distinct areas such as a linear form of 80 – 100% sand cover in the west of the island next to Culatra and Hangares villages. There is another observed linear formation of sand between 80 – 100% coverage located in the east of the island just after Farol village following on through the beginning of the spit (Fig.6). The length of this area of coverage is around 2 km. The next observed common percentage coverage of sand is between 1- 20 % (Fig.7). This is mainly located in the east of the island, past the village of Farol, and covered around 498600 m^2 of the island in 2008 (Fig.8). There is also a distinct area of this value of coverage located in the west of the island, next to the village of Culatra (Fig.7). The majority of the sand percentage cover between 20 – 40% is located in the west of the island, accounting for 645800 m^2 of the island in 2008. (Fig.8).

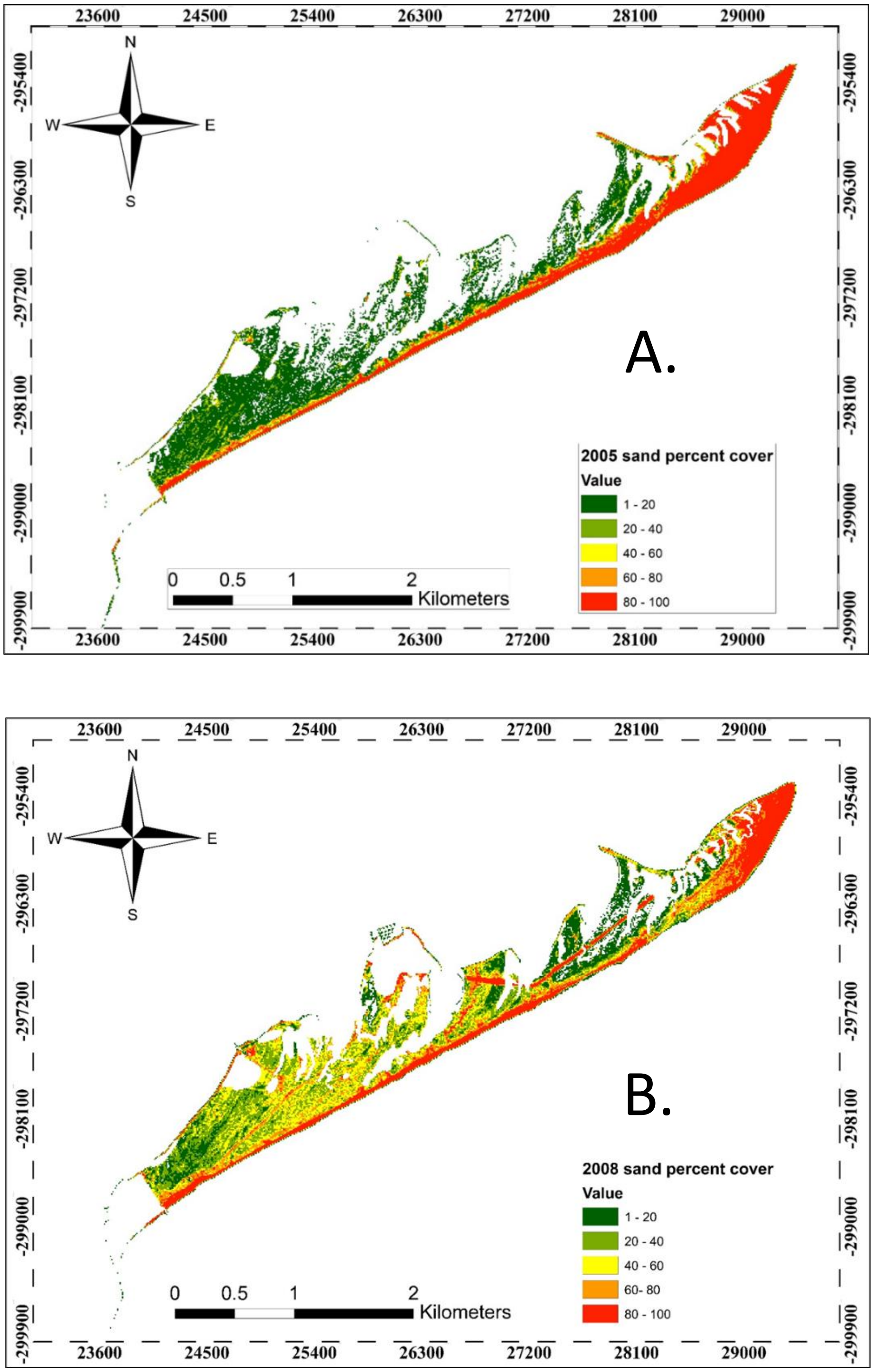

FIGURE 6 - EVOLUTION OF SAND COVER IN CULATRA ISLAND FOR (A) 2005 AND (B) 2008. (HUMAN OCCUPATION, SALTMARSHES, CHANNELS AND TIDAL FLATS HAVE BEEN REMOVED FROM THE MAP)

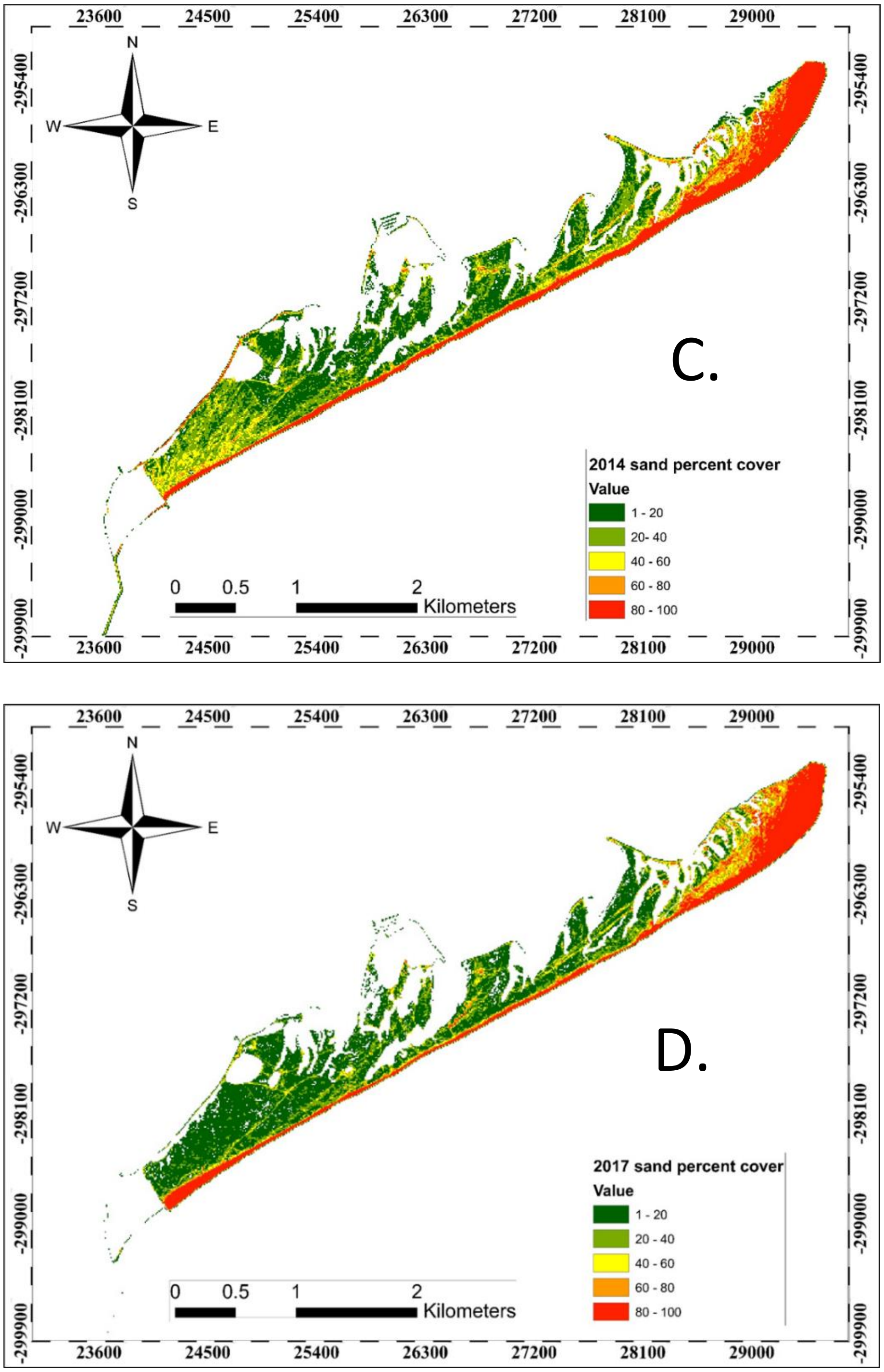

FIGURE 7 - EVOLUTION OF SAND COVER FOR CULATRA ISLAND IN (A) 2014 AND (B) 2017. (HUMAN OCCUPATION, SALTMARSHES, CHANNELS AND TIDAL FLATS AHAVE BEEN REMOVED FROM THE MAP).

The visual difference in sand percentage cover between 2008 and 2014 include the distinct increase in 80 -100% sand area coverage located on the island's spit toward the East along with the distinct decrease of the aforementioned linear formation of this coverage of sand (80-100%) located in the east and the west of the island (Fig.7). Sand coverage between 80 – 100% accounted for 441,400 m^2 of the island. There is also an observed distinct increase in sand coverage between 40 -60 % located in some areas close to Culatra village in the west and in the easterly direction close to the island spit formation. Moreover, an overall decrease of coverage with 337900 m2 of the island accounting for 40 – 60% of sand coverage (Fig.8). There are some distinct linear lines of sand coverage (40 – 60%) located coming from the villages and in particular one linear formed sand formation that is around 0.5km long coming from Hangares village.

Visually the first noticeable difference in sand percent coverage in 2017, is the coverage in the west of the island, where there seems to be a distinct increase in the 1 – 20 % sand percent cover (Fig.6), accounting for 486400 m2 of the island sand coverage (Fig.8). This area is broken up with some linear formed sand coverage areas of 40 – 60% coverage where there is not much change visually in area (Fig.6 and Fig.7). In the previously mentioned 2008 image (Fig.6) there is a linear fashioned percent cover of sand between 40 – 60 %, which has now decreased in sand percentage concentration of coverage from 2008 and 2014 (Fig.7). There is a visual increase in the percentage cover of sand area between 80 – 100 % located at the island spit in the east (Fig,7). However, there is a decrease in overall coverage at 481300 m2 coverage of the island of sand percentage in this category (Fig.8).

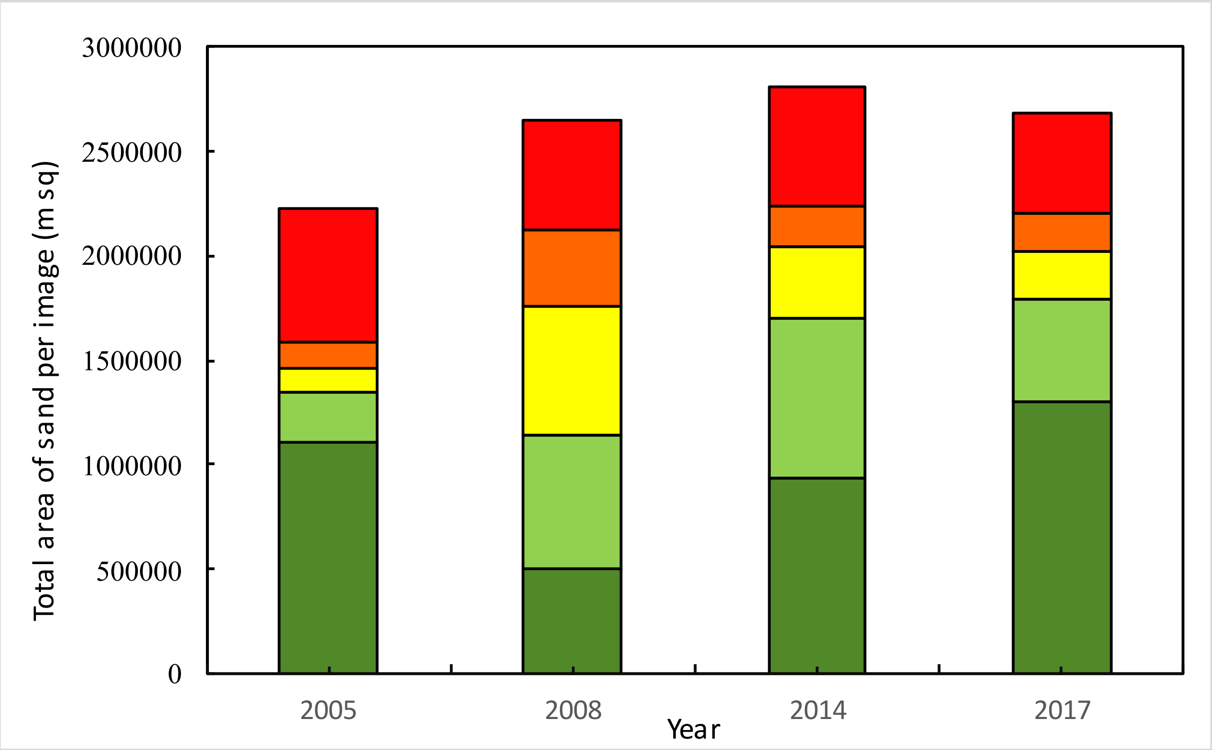

FIGURE 8 - TOTAL COVER AREA OF SAND COVERAGE PER IMAGE (M SQ) IN CULATRA ISLAND FOR EACH YEAR ANALYSED. COLOURS REPRESENT THE DIFFERENT CLASSES OF PERCENTAGE COVERAGE. WHERE; DARK GREEN = 1 – 20 %, LIGHT GREEN = 20 – 40 %, YELLOW =40 - 60 %S, ORANGE = 60 – 80%

4.3 EVOLUTION OF DUNE VEGETATION STATE

The general overall trend is that dune vegetation seems to have visually degraded, especially in areas close to villages and some distinct linear formations of perturbation.

Dune vegetation state is observed to be quite optimal in 2005 (Fig.9) with partial perturbation located in some areas close to the villages, and to the east of Culatra close to the island’s spit. They are rare and occur quite sporadically with little or no pattern. Most of the vegetation perturbation is classified along the beach areas and location of the island’s growing spit. (Fig.9).

In 2008 (Fig.9) dune vegetation has become perturbed in more concentrated areas such as linear formations close to the island’s spit in the east around 2 km in length and the increase in the island’s spit of perturbed vegetation seems to have visually increased (Fig.9) There is also a distinct linear formation close to Hangares village of partially perturbed vegetation. Vegetation that was partially perturbed can also be observed in some small areas from Hangares village to the beach. Partially perturbed areas are mostly observed close to the aforementioned perturbed areas. Furthermore, there was a 38.84% decrease in partially perturbed vegetation in the island all over from 2008 to 2014 (Fig.11). Apart from the previously mentioned dune vegetation states, there is an overall dominance of optimal vegetation (Fig.10). There was an increase from 53.31% in 2005 to 66.21% in 2008, with an increase in 26.6% (Fig.11) This is especially seen in areas close to the East at Farol village (Fig.8). Moreover, there was a visual decrease in perturbed dune areas (Fig.8) with a 49.6% decrease in percentage area of perturbation (Fig.11).

The first visually noticeable change since 2008 is the evolution of partial perturbance to full perturbance located in the island spit (east) in 2014 (Fig.11) which has also increased. Moreover, the observed state of vegetation seems to have reduced in some areas previously mentioned such as the two linear formations and in one area close to the Hangares village, with a 43.55% increase in perturbed area. Dune vegetation seems to have degraded to partially perturbed and perturbed in an area to the west of the island located close to where Culatra village is (Fig.10). Furthermore, perturbed dune vegetation increased by 43.55% (Fig.11). A decrease in optimal vegetation can be visually observed in 2014 (Fig.10) as there was a 5.68% decrease from 2008 to 2014 (Fig.11).

Dune degradation can be clearly observed in 2017 (Fig.10) in these degraded areas of vegetation are in some places new and located close to and connected to the villages and beach areas. There is some recovery observed in the previously mentioned 2 km linear formation of perturbation located next to the East part of the island. Apart from this, there is not much recovery in the island vegetation, in fact, there seems to be an increase in degraded vegetation (Fig.10), with a 52.56% increase in dune perturbed area (Fig.10). This is correlated with a decrease in optimal vegetation (Fig.11) with a 27.06% decrease.

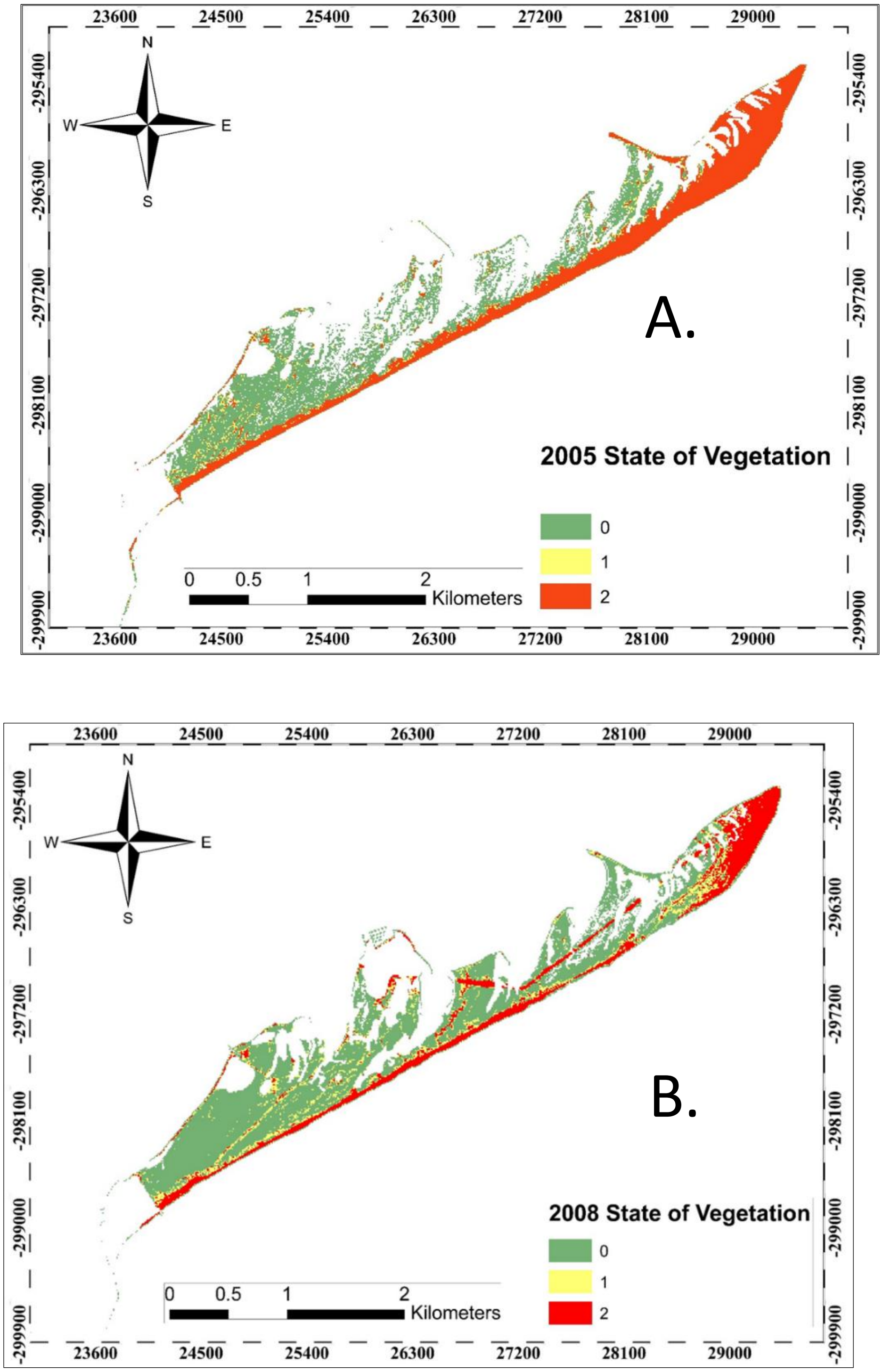

FIGURE 9 - STATE OF VEGETATION FOR CULATRA ISLAND FOR (A) 2005 AND (B) 2008. WHERE; 0 = OPTIMAL VEGETATION, 1=PARTIALLY PERTURBED AND 2= PERTURBATION. NOTE, THAT THE OCCUPATION, SALT MARSH, AND COASTAL STRUCTURES HAVE BEEN EXTRACTED FROM THE ANALYSIS.

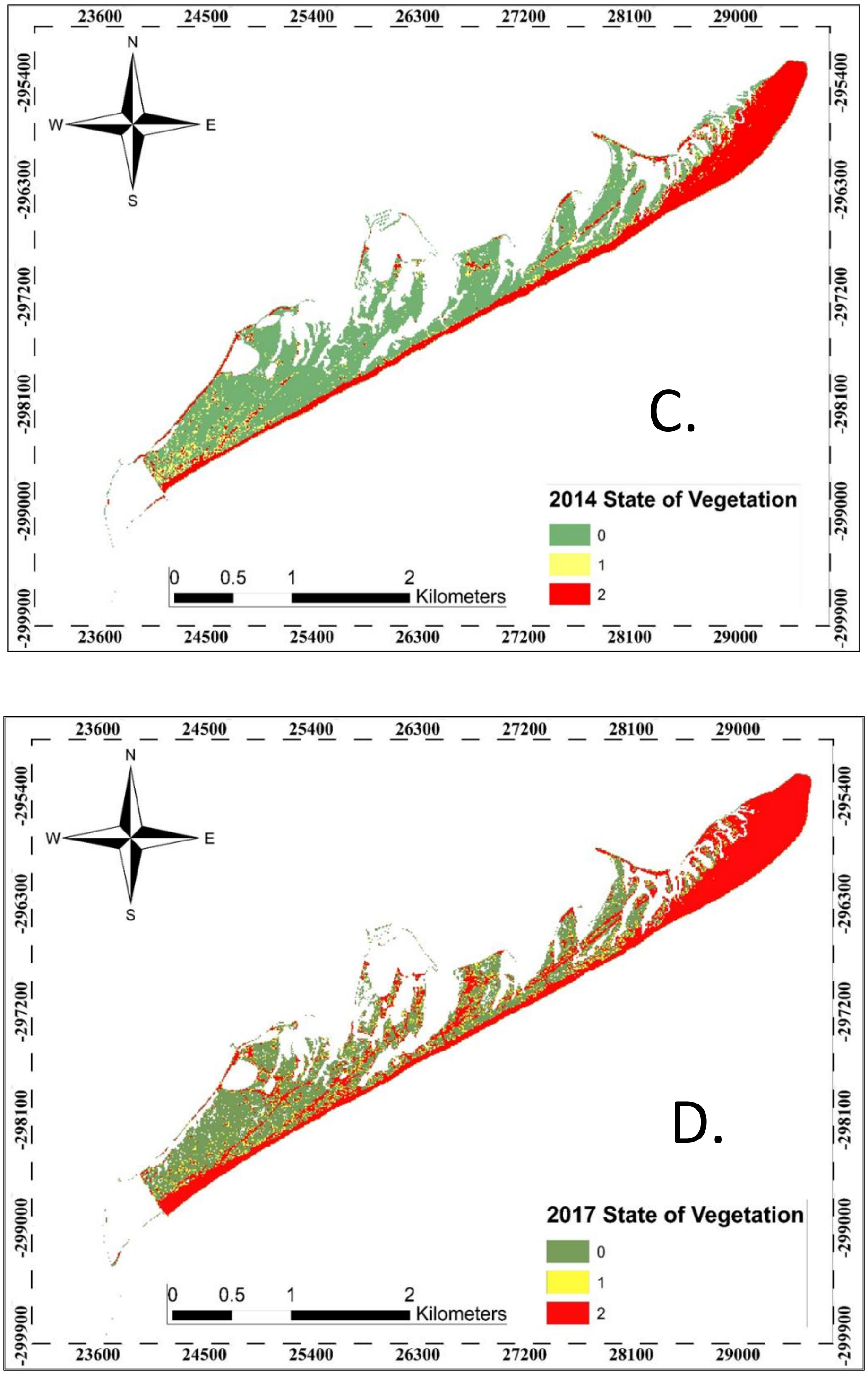

FIGURE 10 - STATE OF VEGETATION FOR CULATRA ISLAND FOR (C) 2014 AND (D) 2017. WHERE; 0 = OPTIMAL VEGETATION, 1=PARTIALLY PERTURBED AND 2= PERTURBATION. NOTE, THAT THE OCCUPATION, SALT MARSH, AND COASTAL STRUCTURES HAVE BEEN EXTRACTED FROM THE ANALYSIS.

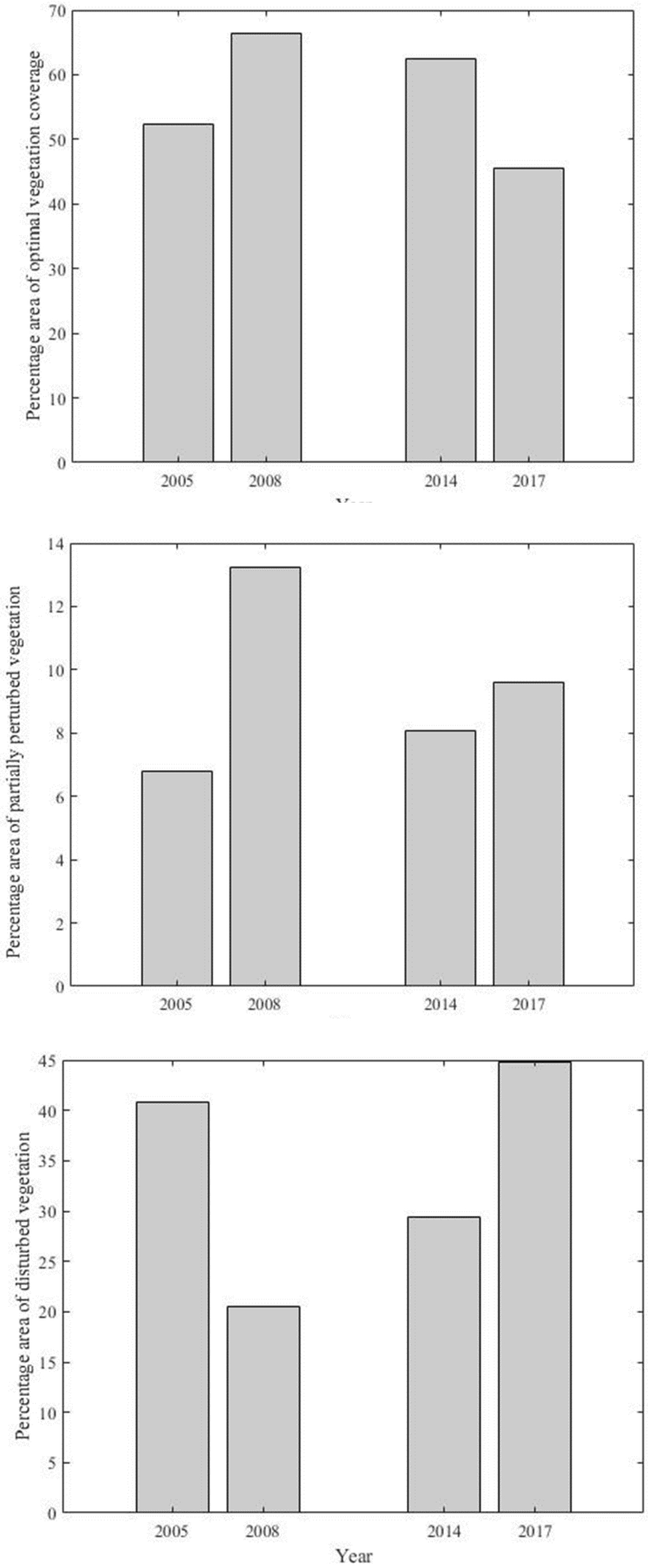

FIGURE 11 - PERCENTAGE COVER AREA OF DUNE VEGETATION STATES FOR EACH ANALYSED YEAR IN CULATRA ISLAND.

4.4 HUMAN OCCUPATION AND ARTIFICIAL STRUCTURES

Occupied areas are mostly located in the west and northwest of the island (Fig.12). These include the villages of Hangares, Farol and Culatra (Fig.12). Southeast of Farol there are some small, occupied areas (Fig.12). This includes a small, occupied area northeast of Farol village. Just below Culatra village there is some small, occupied areas. In 2008 and 2014 (Fig.13) there was no change in the occupancy of Culatra island. There is a small change in occupied areas in 2017 when a small area of occupancy appeared next to Farol village (Fig.13)

Trampling paths are mostly concentrated close to the occupied areas in particular the villages of Hangares, Farol and Culatra. There is an increase in trampling paths in 2008 (Fig.12). This is particularly seen at the west of the island where there is an increase in the appearance of trampling paths going across dune vegetation and to the beach. There is also an increase in the appearance of trampling paths coming from Farol and Culatra (Fig.12) and to the east past the village of Culatra. The appearance of trampling paths in 2014 seem to have remained the same from 2008 to 2014 and 2017 (Fig.13)

The appearance of track marks in 2005 (Fig.12) is light and not particularly connected in one area. There are large track marks which appear from Hangares village to outside Farol. There are another three main track marks concentrated to the east of the island past Culatra village. In 2008 (Fig.13), there is a large increase of track marks mainly concentrated around the three villages of Hangares, Farol and Culatra (in particular Culatra). To the east of the island there is a high concentration of track marks appearing close to the pipeline structures. There is also an appearance of track marks close to the beach, to the east of the island. In 2014 (Fig.13) the appearance of track marks is visibly similar to 2008 (Fig.12), with the disappearance of a minor track to the east.

Coastal structures appear the same throughout the four images apart from a new harbour which was built in 2007. A pipeline appears in the image of 2008 and remains consistent throughout. (Fig.12; Fig.13)

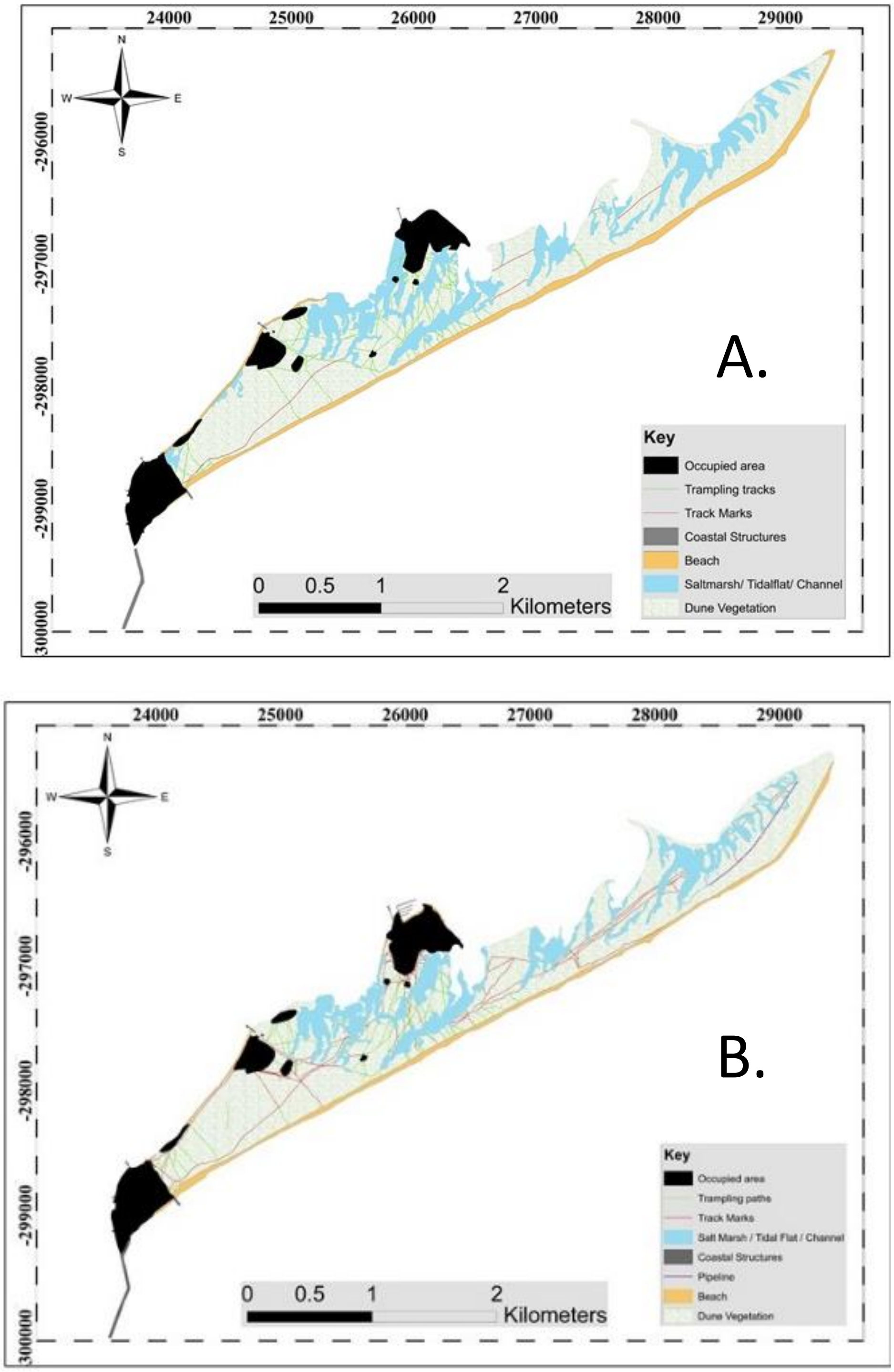

FIGURE 12 - EVOLUTION OF TRACK MARKS, TRAMPLING PATHS, OCCUPIED AREAS, SALT MARSH, COASTAL STRUCTURES, AND BEACH. (A) = 2005 AND (B) = 2008

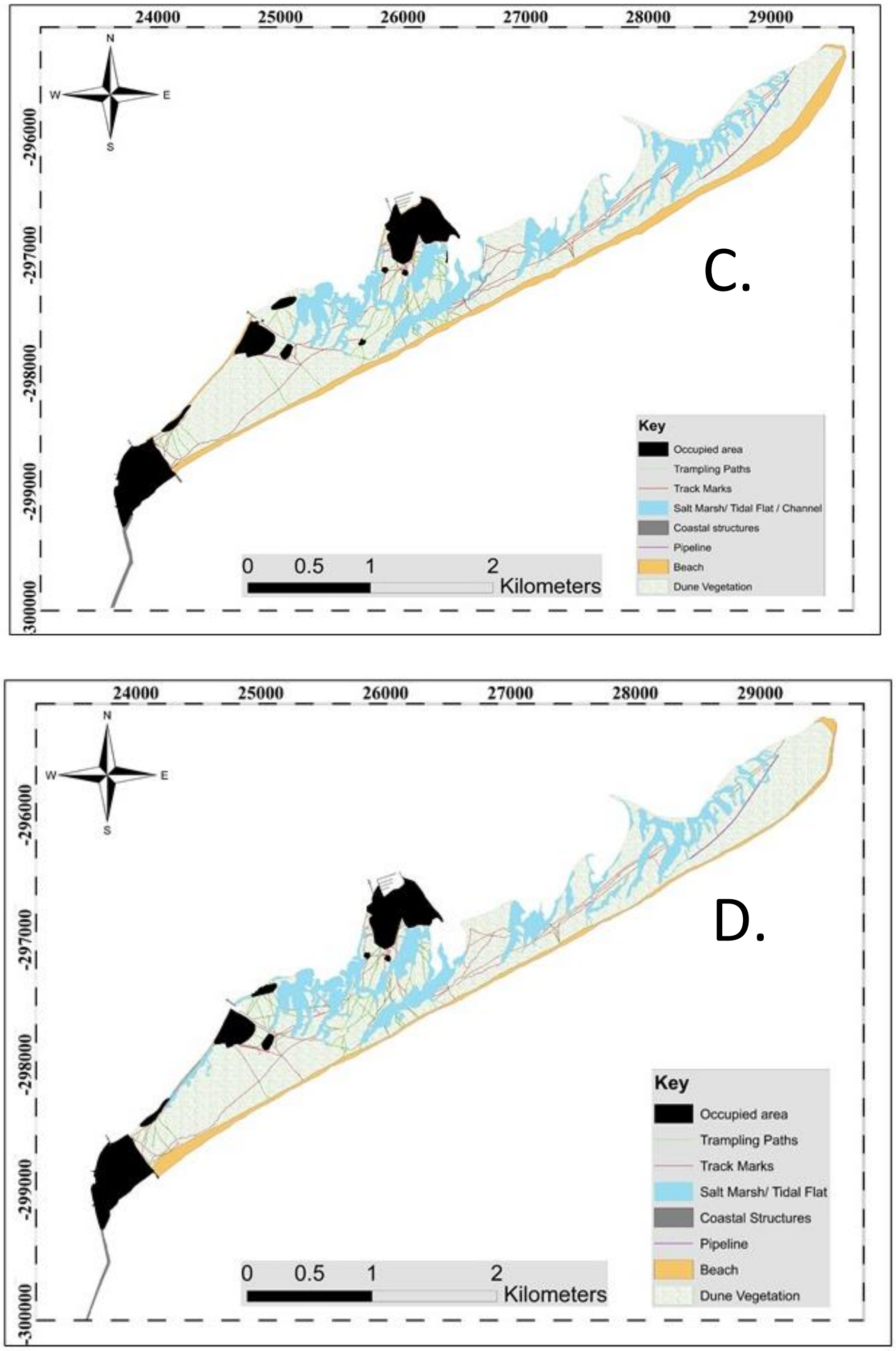

FIGURE 13 - EVOLUTION OF TRACK MARKS, TRAMPLING PATHS, OCCUPIED AREAS, SALT MARSH, COASTAL STRUCTURES, AND BEACH. (A) = 2014 AND (B) = 2017

5 DISCUSSION

5.1 INDEX PERFORMANCE AND METHODOLICAL CONSIDERATIONS

This vegetation index was relatively easy to apply to assess the evolution of vegetation states, especially if one is not completely competent with ArcGIS software or is only able to carry out basic analyst procedures. The concept is easy to apply to other coastal grey dune locations if one has good quality images with diverse temporal scales. This index is significantly relevant due to the increase in tourism, particularly on coastal dunes and its use for recreational activities and its environmental modifications (Westhoff, 1967; Gormley, 2010; Garcia- Romero, 2020).

The index revealed the need to use better quality images. For example, the orthomosaicked image that was created for the analysis of dune vegetative state for 2008 had an overall accuracy of 70 (Table 2). The overall accuracy represented the sum value of samples that were correctly classified divided by the total number of reference samples according to Jackson et al. (2019). This image had the lowest accuracy of the four that were analysed. The result of the 2008 image seems to have skewed the result of the percentage cover of sand (Fig.5). Since class 3 (bare soil or sand) was used to estimate optimal dune values (section 4.2). The final inaccuracy of the image of 2008 may have been due to variable illumination, cloud cover, wind speed and seasonality (Dandois et al. 2015). However, it seems more likely that variable illumination may have been the major cause for this due to visual overexposure.

Interpreting the human structures within the orthomosaicked date sets proved difficult in some areas. This was particularly in relation to distinguishing trampling and track marks featured in the datasets. This may have been due to an untrained eye with regards to ortho interpretation. In-situ methods such as identifying and distinguishing tracks from trampling may have been a useful to integrate into the methods. To improve the interpretation, the digitsations could be independently reviewed thoroughly by two different GIS users for consistency (Fernandez et al.2019). The changing and evolving nature of the island (both natural and human) led to the changes of certain digitised elements per year. This was the case for salt marsh and occupied areas, as these elements changed for each year due to the evolution of the island and the changing of the populations of inhabitants on the island. Furthermore, since these elements had to be extracted from the results, index results had to be converted into percentile in order to be directly compared. An improvement for further studies would be to extract these elements before the analysis.

Nevertheless, this methodology can depict the state of vegetation at a cost-effective rate, which can be quick and easy to apply for other dune vegetation systems or possibly can be tailored to different types of vegetation. Other studies adapted similar methodical approaches for coastal dune vegetation with the use of different types of imagery, classification, and indexes. For example, Laporte Fauret et. al. (2020) conducted a two-step classification approach which was based on the NDVI (normalised difference vegetation index and Random Forest classifier) of airborne hyperspectral imagery. These materials would have been too time consuming and costly for this study. Moreover, a 1 x 1 m pixel spectral index was used to differentiate pixels that had with or without vegetation covers, which was similar to this index used. Fernandez et al. (2010) developed a semi-quantitative approach to distinguish disturbance beginning with a dune mobility calculation (M), followed by an estimation of vegetation cover followed by an analysis of the disturbance and the digitisation of transport, calculating the density of visitors using the point density (spatial analyst). For this study, a dune mobility equation was not necessary as the purpose of the study was to analyse the state of vegetation only using remote imagery, and the process of digitising each type of transport to create a point density as no necessary as there is only one main vehicle on the island. Jackson et al. (2019) quantified changes in vegetation cover at 17 geographically dispersed sites using vegetation indexes derived from Landsat images over a 30-year period using an NDVI index followed by a classification analysis. This would have been too large of a temporal study as some images were already cut due to their lack of quality (2002 ortho and 2018 Google Earth imagery) this would have also been too time consuming. Other work such as Valentini et al. (2020) developed a discrete pixel-based analysis to derive basic geomorphologic parameters such as dune slope, crest and shoreline, developing a correlation model to interpret the complex interaction between landforms and cover. This may be a study that is able to be carried out with more technology and funds, however this current analysis provides a somewhat different take, where landforms and structures can be digitised. This can be said for the study of Giglio et al. (2019) where a low-cost unmanned aerial system for the classification of vegetation communities were applied with four algorithms to RGB ortho images, where both pixel and object-based classifications were applied. Although, the use of object-based classification is inherently more accurate, this would have taken more time and would defeat the simplicity of the methods.

Moreover, this method and index should be relatively easy for application if the above-described parameters are at bay, and can be an effective management methodology for in particular coastal barrier dune systems, but can be developed further to adapt to the evolving island and its changing occupation.

5.2 IDENTIFICATION OF DUNE PERTURBATION CAUSES

According to observations, there are some likely when the index was superimposed by the digitisations. Dune perturbation in 2008 was caused by a track located from Farol village close to the occupation of Culatra village. This causes for dune perturbation extends for up to 1 km and seems to have caused mostly partial perturbation (Fig.14). This is obvious from the depiction of the true colour image that a track mark has caused this degradation (Fig.14). There are also some areas of partial perturbation near the occupied areas, especially near the village of Hangares. There was a huge area of identified removal of dune and located track in 2008 **(**Fig.15). This was near to the east of the island spit. This excavation of the dune was caused by the installation of a pipeline in 2008 (Fig.15) This excavation has caused a huge disturbance of the dune which seems to have increased the value of perturbed area of vegetation for this image. The disturbance is also surrounded in some areas by some areas of partial perturbation upon closer inspection.

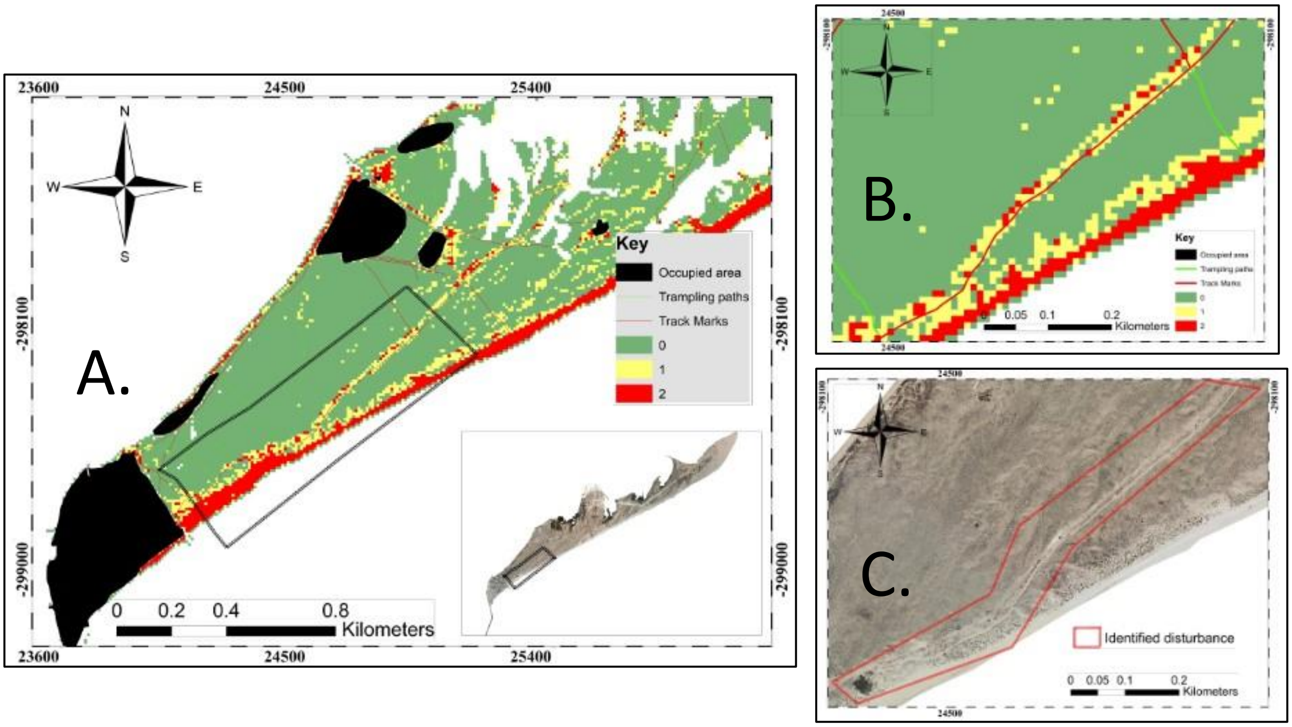

FIGURE 14 - OBSERVED CAUSES OF DUNE PERTURBATION IN 2008 (A) AN INSIGHT OF THE PERTURBED AREA AND CAUSE (B) AND THE IDENTIFIED DISTURBANCE IN TRUE COLOUR IMAGE (C). WHERE 0 = OPTIMAL DUNE. 1= PARTIAL PERTURBATION AND 2 = PERTURBATION.

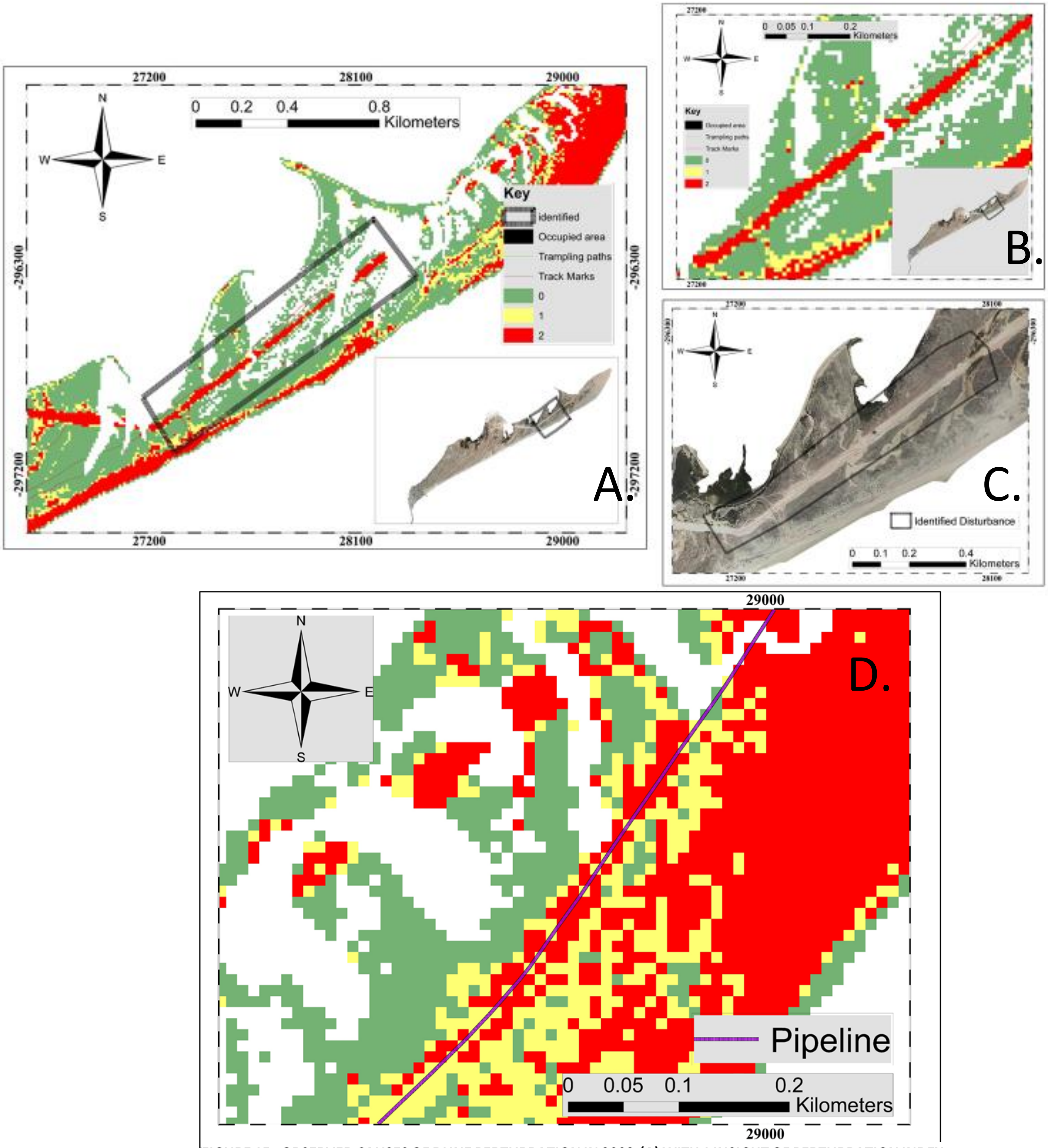

FIGURE 15 - OBSERVED CAUSES OF DUNE PERTURBATION IN 2008 (A) WITH 1 INSIGHT OF PERTURBATION INDEX (B), AN SIGHT OF DISTURBANCE ACCORDING TO TRUE COLOUR IMAGE (B) AND AN INSIGHT INTO A REASON FOR THE DISTURBANCE (D). (PIPELINE).

The disturbance from the previous year by track marks had perturbed even more in 2014 (Fig 15). This time with less partial perturbation and more perturbation. This could mean that the track is being used more for both track marks and trampling, as it is an easily distinguishable route for tourists/ residents when walking through the dunes from the beach to an occupied area. Or it could signify that the tractor on the island which collects the rubbish disposal is sticking to the track that was previously made to avoid further disturbance in the coastal dunes. However, (Fig. 16) shows some recovery of the aforementioned excavated dune.

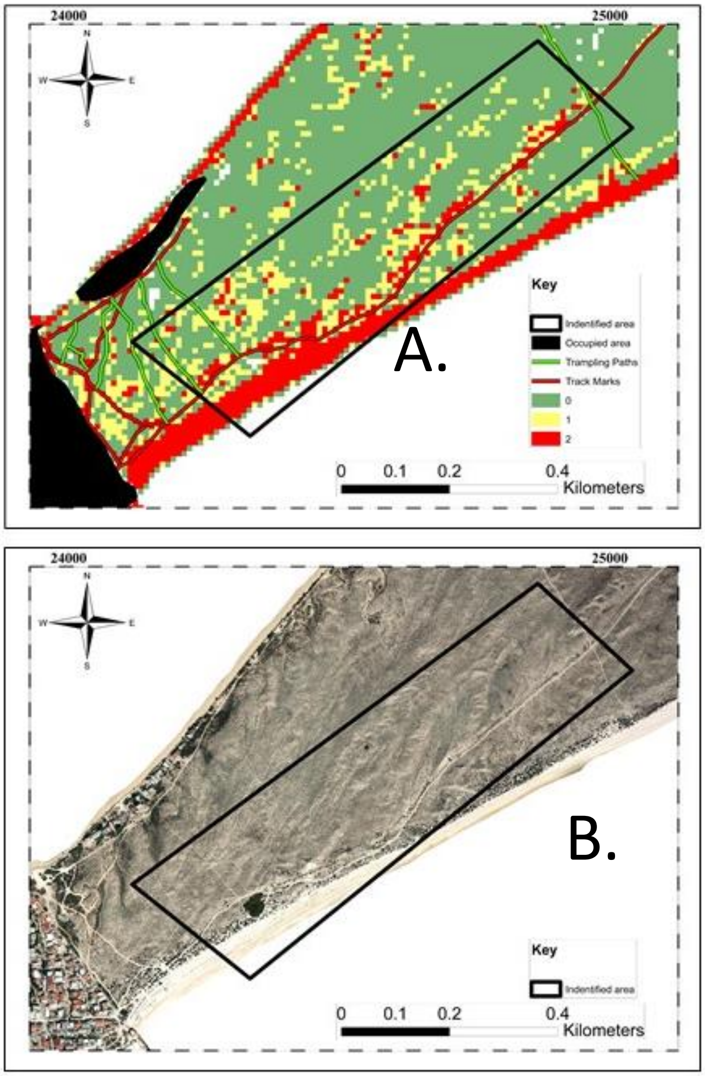

FIGURE 16 - OBSERVED CAUSES OF PERTURBATION RECOVERY FIR 2008 (A) DISPLAY OF INDEX MAP WITH SUPERIMPOSED CARTOGRAPHY AND (B) DISPLAY OF TRUE COLOUR IMAGE OF RECOVERY.

Since there was an overall increase in perturbation in 2017, some new key areas of perturbation were observed (Fig.17). Other key areas include new track marks and pathways leading to the beach that may have originated from track marks. There were some new pathways identified next to Hangares village but don’t seem to have caused as much disturbance as the track marks. It is also obvious that pedestrians will use pathways that are already provided by track marks (Fig.17). Despite this increase of perturbation in 2007, there appears to be a recovery of previously mentioned excavated dune in 2008. During 2017, there seems to be a slight regrowth and less distinctive characteristics of the excavated area (Fig.18).

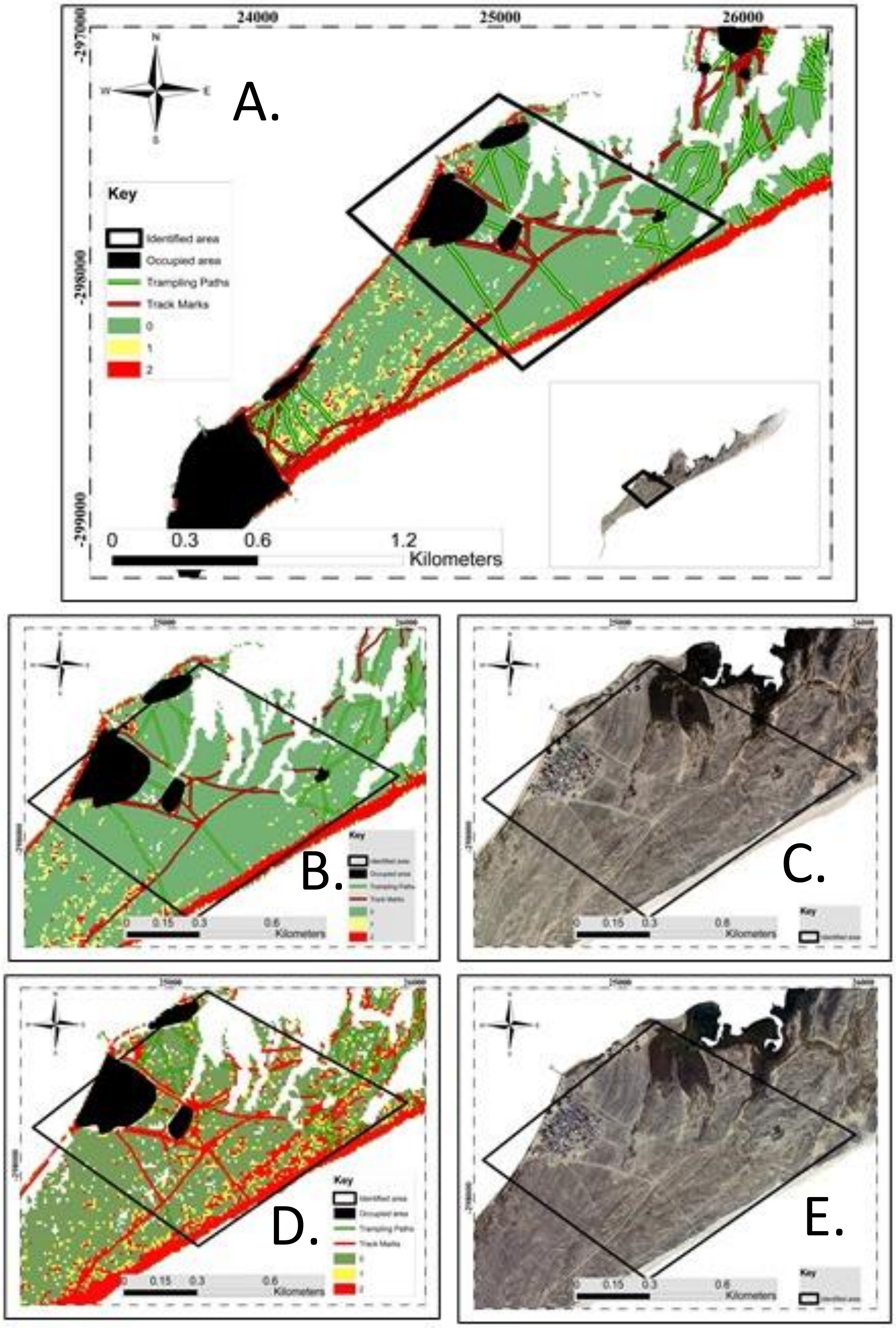

FIGURE 17 - INCREASE IN PERTURBATION CALCULATED OUTSIDE HANGARES VILLAGE. WITH A) = THE OVERALL AREA LOCATION, B = 2014 INDEX, C= 2014 TRUE COLOUR IMAGE, C= 2017 INDEX AND D) = 2017 TRUE COLOUR IMAGE. WHERE; 0= OPTIMAL VEGETATION, 1= PARTIALLY PERTURBED VEGETATION

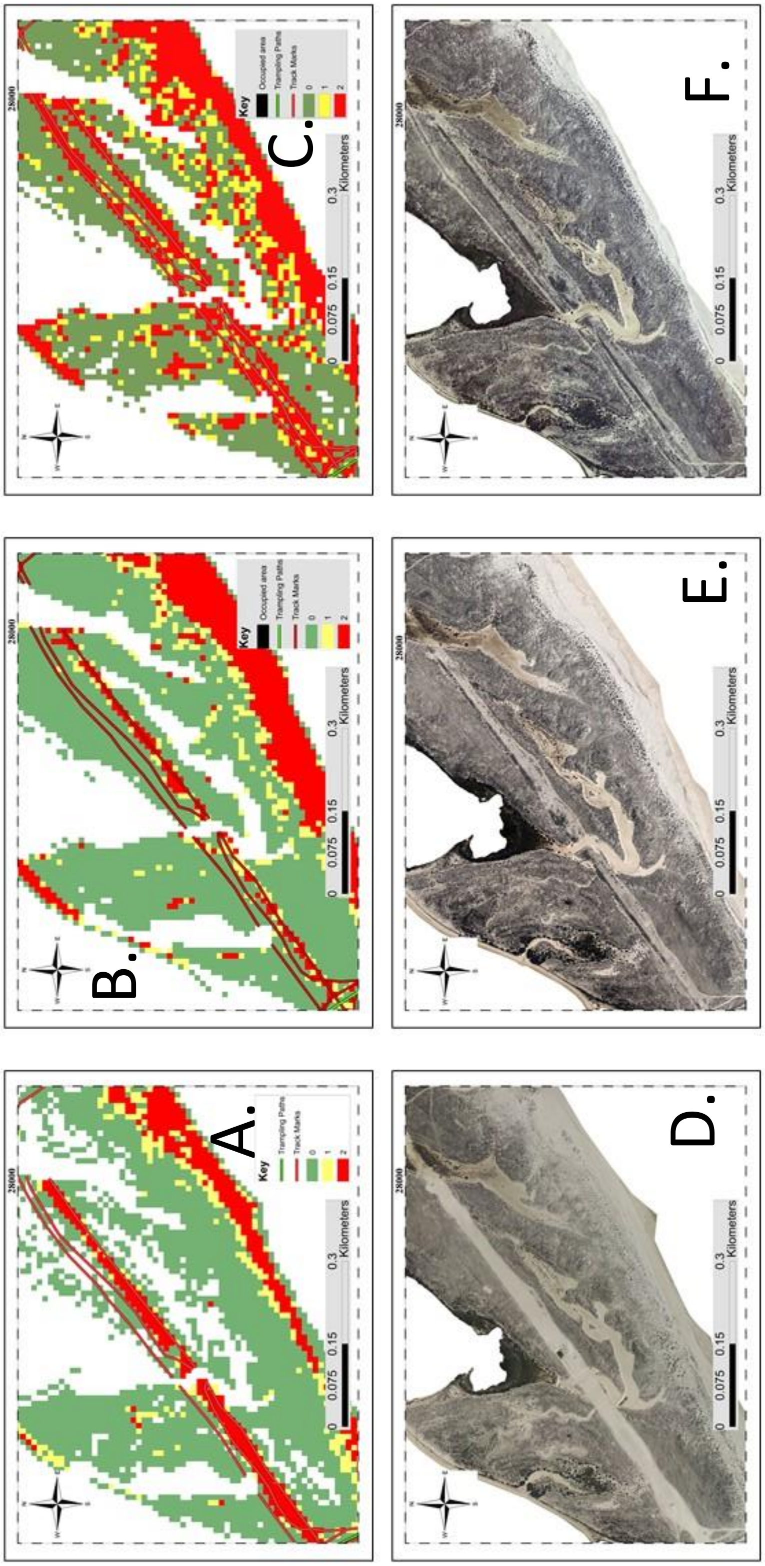

FIGURE 20 - RECOVERY OF EXCAVATED DUNE AREA IN EAST CULATAR ISLAND. WITH A) = 2008 INDEX, B) = 2014 INDEX, C)= 2017 INDEX, D)= 2008 TRUE COLOUR IMAGE, E) = 2014 TRUE COLOUR IMAGE AND F) = 2017 TRUE COLOUR IMAGE. WHERE; 0= OPTIMAL VEGETATION, 1 = PARTIALLY PERTURB

Dune vegetative state seems to have evolved to become increasingly perturbed according to the index. According to the index analysis, one of the main causes is the identifiable track marks and trampling that is located throughout the island, namely track marks.

Hylgaard and Liddle (1981) pioneered the study of the influence of trampling on outer dune heath and discovered that the relative cover was reduced with increasing number of passes, after 200 passes by pedestrians, the cover of vegetation was only 50%. It has been demonstrated that severity of impacts on habitats like coastal dune systems depend on the use of the area (Kindermann and Gormally 2010). Westhoff (1967) concluded that vehicle damage to coastal dunes is more detrimental than trampling due to the weight and type of motion. This can be seen in Culatra island where vehicle use seems to be the main culprit for the perturbation of dune vegetation. Rickard and Kerley (1994) concluded that pioneer communities appear to have the capacity to recover after the impact of track marks. This may ascribe to the fast recovery of the dune excavation close to the pipeline in the East of Culatra.

Although not related to the perturbation of the vegetation, the evolution of the island has played a role in the results due to the increase in the east of the island's growing spit. This is due to the increasing downdrift and shoal attachment due to the changing of the tidal prism in the Armona inlet (Komboadou et al.2019). Moreover, a not so obvious reason for an increase in perturbation may be due to the presence of gull colonies in the island, that are located in the east and tend to be near the recently installed pipeline in 2008. This was discovered through a field visit to the island prior to the analysis. The lifespan of plants may change due to the presence of gull colonies due to the excessive nutrient accumulation and the amount of physical disturbance that a gull may cause (Garcia et al. 2002; Serra et al. 2016). However, it was concluded that the Gulls in Culatra island did not arrive until after 2017.

Vegetation cover has increased globally between 1987 and 2017 due to changes in climate, according to Jackson et al. (2019). However, Jackson and Cooper (2011) found that a mixture of anthropogenic and natural processes had been linked as potential drivers for vegetation cover changes. In this study, the visual correlation between anthropogenic factors (track marks) and dune perturbation is high, with an overall 20.64% increase in sand percentage cover in Culatra island (Fig.7). Moreover, there was a calculated 9.59% increase in perturbed dune vegetation area coverage in Culatra island from 2005 to 2017 (Fig.10). Fernandez et al. (2019) reported that dune vegetation areas that were not under management conditions were subject to de-evolution and were a result of artificial and human led stressors. It is necessary to protect the dune vegetation habitats as both tourism and conservation can rely on the maintenance of natural areas (Kindermann and Gormally, 2010).

Since the results are somewhat skewed due to image quality and timing of steps in the methods, the results cannot be used for future management of the island dune vegetation. However, this method may be a baseline for other studies and/or managers to carry out as an easy cost-effective way to assess the state of the dune vegetation. However, this study identified the need to reduce track marks in the island and in particular a need for a proposal of a protected fenced and marked area to continue the restoration located in the east of the island where there was distinguished a large excavation of dune to build a pipeline in 2008. Considering the conservation status of coastal grey dunes, there is a need to conserve and implement some management strategies such as sign posted track marks or a possible change of track route that may cause less damage to the grey dunes.

6 CONCLUSIONS

Grey dunes are considered a priority habitat according to the EU habitats directive. Fixed coastal dunes or “grey dunes” contain herbaceous vegetation according to the CORINE biotype classification. Environmental modifications such as dune stabilization, erosion or remobilisation may be caused by human activities or natural changes (Garcia – Romero, 2020). Since the Ria Formosa is a protected natural reserve since 1987, it is also necessary to conserve these dunes which protect the lagoon system. A cost-efficient approach was used to develop a vegetation index, using orthophotos and Google Earth imagery to find any possible causes of perturbation (anthropogenic/ natural) from 2005 to 2017, using ArcMap.

Dune perturbation was calculated to have increased from 2005 to 2017. There was an overall 20.64% increase in sand percentage cover in Culatra island (Fig.7). Furthermore, there was a calculated 9.59% increase in perturbed dune vegetation area coverage in Culatra island from 2005 to 2017 (Fig.10). Track marks were seen to have contributed to the perturbation of vegetation, with a particular event in 2008 lead to a large disruption in dune vegetation. It was found that a large portion of track marks were used by the public for trampling.

The index revealed the need to use better quality images for a more full and accurate analysis. This was the case for 2008, which had an overall accuracy of 70, the lowest accuracy calculated for all four images. This was because of overexposure which may have been due to variable illumination, cloud cover, wind speed and seasonality (Dandois et al. 2015). Digitisation methods may have been more accurate if reviewed thoroughly by two different GIS users for consistency (Fernandez et al.2019).

Although the results are somewhat skewed by the aforementioned errors in the methods, it is still visually evident that track marks are causing a degradation of the dune vegetation on Culatra island. Therefore, it is necessary to conduct a further study with better quality and a variety of different types of data over a larger temporal scale, in order to calculate a more robust measurement. Moreover, it is necessary to begin to raise more awareness for the need to conserve these coastal dunes. Monitoring of the dune excavation to the east should be monitored to keep track of the rate of re-growth and restoration. Furthermore, methods to implement track control should be considered.

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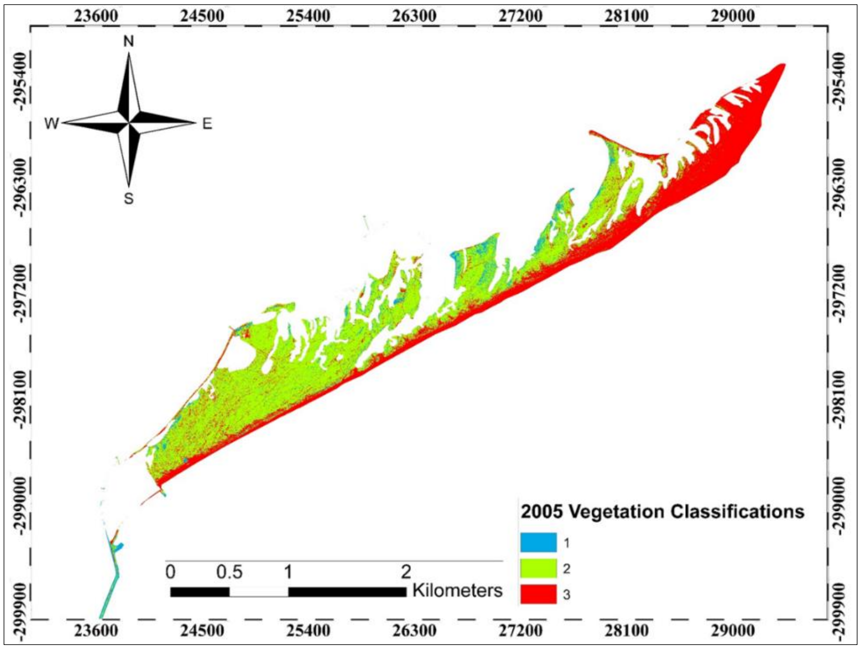
8 ANNEXES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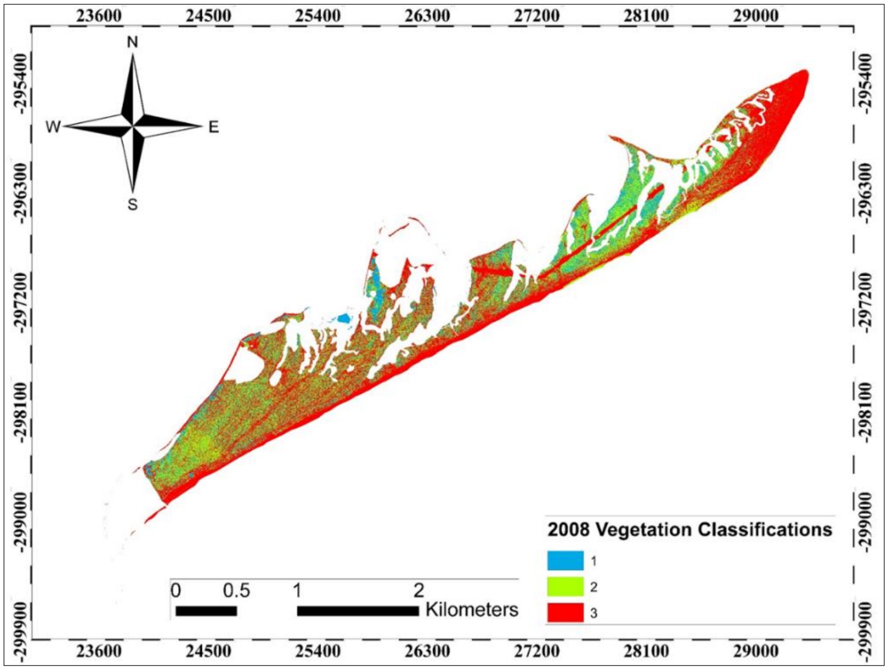
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26300
27200
28100
29000
-295400
-296300
-297200
-298100
-299000
-299900
N
W
E
S
2008 Vegetation Classifications
1
2
3
0
0.5
1
2
Kilometers

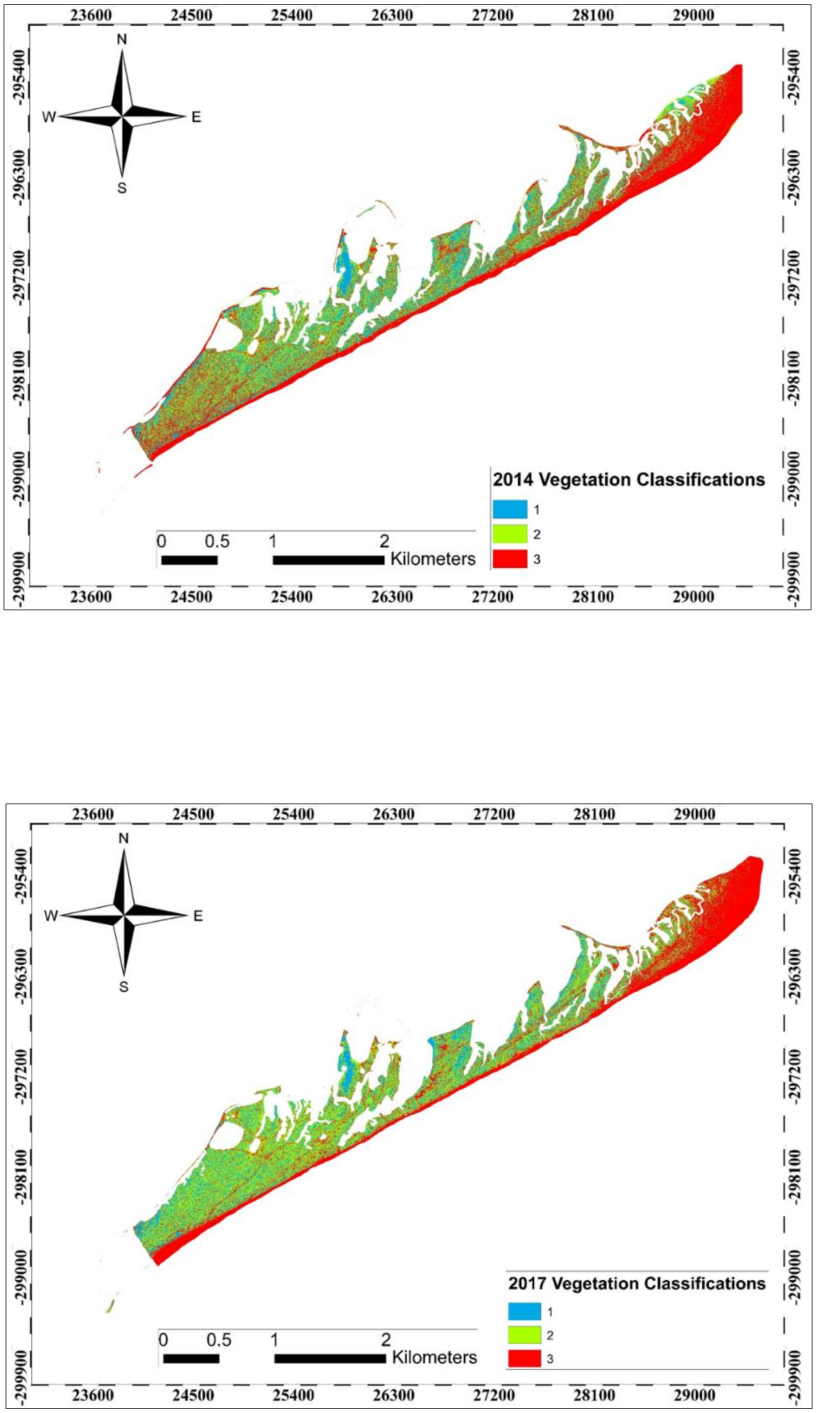

FIGURE 21: UNSUPERVISED CLASSIFICATION OF VEGETATION ON CULATRA ISLAND