Forest management and sustainable urban development in the Curonian Spit

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ABSTRACT

A major challenge in forest management is to balance the competing interests of different users. The conservation of biological diversity is an important goal when managing forests in an ecologically sustainable way but this overlooks aspects of sustainability in terms of urban development and other land use. This research examines physical and biological processes leading to changes in the spatial and temporal land cover on the Curonian Spit, in Lithuania, pre- and post-1990 when the political situation changed heralding new practices. Specifically, the levels of cover categorised as vegetation, sand, forest, urban and grassland, are determined using remote sensing images over the period 1989-2017. An assessment of the accuracy of the analysis, when compared with Google Earth, other images and *in situ* data, produces a high level of confidence in the results. The analysis indicates that the overall forest cover initially decreased until 2009 but since then it has increased by over 1% per year. No urban growth is observed. These, and other results are displayed graphically. The forestation of moving dunes, the human impact on the area and changes in the environment are all discussed. The results demonstrate how remote sensing and GIS methods can be used as an important tool for planners, dispensing with the need for costly field trips.

Keywords: forest management, LANDSAT, ArcGIS, sustainable urban development, sand.

1. Introduction

In our world today, where the climate is changing and the population growing, the ability to monitor the landscape has become an increasingly important way in which we can capture biodiversity as well as determining how humans employ the land and its resources. Land use and land cover (usually abbreviated to LULC) are the terms usually used when monitoring human modification of the Earth's terrestrial surface (Mishra *et al*., 2014; Petterson and William, 2005). Methods to detect, and analyse, how LULC are changing have the potential to form powerful tools to observe environmental and anthropogenic impacts and evaluate socio-economic developments. Studies of land use and the impact of policies on forest management, as well as urban growth, are relevant to many geographic areas but are specifically useful in coastal zones where the changes are more rapid, caused by both environmental changes and the pressure created by humans to occupy such land. Many countries have vulnerable coastal areas (e.g. the Maldives, see Karthikheyan, 2010) and changes in these areas might establish early warning signs for future changes likely to be experienced elsewhere. The Curonian Spit is a prime example where there is a delicate interplay between the environment and our use of the land, with both leading to permanent changes to the landscape.

Geographic information systems (GIS) and remote sensing are powerful and cost-effective tools for assessing the spatial and temporal dynamics of land cover, especially in fast changing environments. These are also very useful to illustrate the interactions between people and the environment in which they live (Rwanga, Ndambuki, 2017; Dewan, 2009) providing a visual narrative that can assist when it comes to decision-making.

The primary aim of this work is to assess the accuracy of remote sensing to reveal changes in the land cover over a period of years and overlay this with changes in land management policies. A secondary aim is to show how these methods can be used to assess the efficacy of management policies. Attention here is focused on the Lithuanian portion of the spit due to the high levels of protection for the site, with strictly managed forest and urban development policies, as well as the availability of data and information.

This work highlights a way forward both in the Curonian Spit and in other sensitive areas around the world where careful management is required. The procedure laid out here proves to be both an accurate way to detect changes in land cover but also a cost-effective tool which helps our understanding of the interaction between local geo-physical, bio-physical and socio-economic processes.

2. Study area

The Curonian Spit is a unique, thin strip of land emanating from Kaliningrad in the south and reaching towards the city of Klaipeda in the north between 55°33′14″N and 21°06′47″E (see Figure 1). The spit is 98 km long, with a width that varies between 400m and 4 km, forming a sandy barrier that separates the Curonian Lagoon from the Baltic Sea. The spit is divided into a northern portion (50 km) belonging to the Republic of Lithuania and the southern part (48 km), which is part of the Kaliningrad enclave region of the Russian Federation (Sergeev *et al.*, 2016).

[Figure 1 near here]

The spit is a geographically interesting area formed from sand that becomes moulded into dunes by the wind, but these dunes then move and additionally become invaded by tracts of maritime forests. This process has created the highest sand dunes in northern Europe with heights reaching more than 30m in many areas (Sergeev *et al.*, 2016; Dobrotin *et al.*, 2013; Gudelis, 1998), although it must be said that this is only about one third that of the dune du Pilat in France. All the biggest sand massifs (the term used by a pioneer of aeolian formations (Bagnold, 1951)) or star dunes, merge to form the Great Dune Ridge that stretches along the entire coast of the spit on the lagoon side (Dobrotin *et al.*, 2013). This portion of the dune system is still actively moving (unlike the Dune du Pilat). The area now has the status of a nature reserve in order to protect the dunes from damage, to prevent the loss of vegetation cover and halt excessive development.

Like other, similar geographic features, the topology and geography of the region of the Curonian Spit are sensitive to both local and global changes in external factors and yet, paradoxically the spit has been with us for thousands of years. A combination of a narrow shoal offshore, prevailing winds and sea states creates the conditions whereby sand is transported from the southwest and deposited in the northeast along the spit. However, these conditions are sensitive to changes. New structures further south may change the sand availability or climatic changes may affect how this sand is moved and deposited (Soomere *et al.*, 2015). Rather like the self-organised criticality of sand piles (see Bak, 1996), the spit remains an ever present feature, but one which could still be changed by modern developments.

Sandy beaches run over the entire length of the spit along the Baltic side of the Curonian Spit, coupled with protective dunes that separate the coast from the littoral plain beyond on the landward side (see the pictures in Figure 2a). On the lagoon side of the spit, a crest of higher dunes runs along the entire length of the coast (Dobrotin, 2013) with the highest dune, called the Vecekrugo dune, rising up to 67.2 meters.

[Figure 2 near here]

One aspect that is important in fixing the sand in place, is the level of vegetation. It is also recognised that further areas of forestland protect the duneland from wind and sea erosion. Therefore, encouraging the growth of vegetation can be seen as a good thing. However, the question of over-forestation also needs to be considered since this may prevent human use. Over recent years there have been various forest management policies and the aim here is to highlight changes in the land cover and use as a result of, or in spite of, these alternative policies.

The Curonian Spit has a long history of human influence and is perhaps one of the best examples of how nature and human interactions change the land shapes. The spit has historically been the home of a number of coastal settlements (Buynevich *et al.*, 2015; Morkūnaitė, 2011; Gudelis, 1998). For these towns, the movement of the dunes then becomes a natural hazard forcing humans to adapt to the environment although, luckily, today we are better equipped to predict sand movement using models of dune migration (Momiji *et al.*, 2002). There is historical evidence that during the XVI-XIX centuries, the aeolian activity on the Great Dune Ridge was much higher than it is today, due to the removal of trees or fires. As a result of deforestation, followed by sand movement, 14 villages have been buried beneath the sandy dunes along the coastline of the Curonian Spit (Česnulevičius *et al.*, 2017; Dobrotin *et al.*, 2013; Brukas *et al.*, 2013; Albrecht, 2008; Gudelis, 1998). These losses triggered the beginning of a period of forestation in XIX century. Trees form an effective tool that stabilise sand dunes and prevent movement (Dobrotin *et al.*, 2011). In the past, dune movement was also prevented (or at least slowed) with the positioning of wooden poles and the introduction of halophyte grass, to develop roots below the surface (Albrecht, 2008). The levels of forestation have thus changed over the years and various policies have influenced these changes although it is, of course, possible that forestation may have reached a peak due to natural processes without intervention, a process referred to as the “green brick up” (Brukas *et al.*, 2012).

The shoreline area of the spit, in particular, is constantly exposed to increasing levels of human activity which, in turn, then becomes a geological factor affecting many shore-formation processes (Jarmalavičius, 2005; Bitinas *et al.*, 2005). Once seen as an ideal holiday destination, the spit is now designated as a site of special interest and so human visitors, plus associated activities, are now tightly controlled.

Along the spit, the settlements of Smiltyne, Juodkrante, Pervalka, Preila and Nida form major tourist attractions as well as centres of recreation, all within the national park area. These resorts are noted for their sandy beaches, attractive dunes and pine forests. The resorts are also popular due to their fabled healing properties, and so every year they attract more and more visitors seeking a healthy lifestyle. The Lithuanian part of the Curonian Spit is administrated by the Municipality of Neringa and Klaipeda. The number of inhabitants in 2017 was listed as 3069 (Lithuanian Census data, 2017), however, almost one third of the registered inhabitants only use their homes on the spit as a weekend or holiday home and therefore the amount of full time inhabitants is fairly low in reality (Albrecht, 2008).

As an area of research, the spit is interesting because of its mild coastal climate and fascinating formations created by aeolian processes. The average wind speed is moderate of only 5-7 m/s, but an increasing number of storm events, when wind speeds have reached more than 28 m/s, have led to serious damage, not only to the Curonian Spit but also to other areas of the Lithuanian coastline and beyond (Jarmalavičius *et al.*, 2016; Soomere *et al.*, 2015).

Climate, meteorological and hydrological regimes in the SE Baltic Sea were, and still are, the most important physical-geographic factors that determine the landscape and the local environment on the Curonian Spit. During recent decades the climatic and hydrological conditions in the Curonian lagoon have changed significantly. Westerly winds have strengthened since the middle of the XX century with greater frequency of storms. According to the assessment of the warming trend, the mean air temperature has risen about 0.06^{o}C per year from 1991 onwards (Dailidiene *et al.*, 2012). Significant warming started in the 1980s corresponding to climate change processes occurring in many regions around the globe during this time (IPCC, 2013; BACC Author Group, 2008). Climate change affects the face of the earth's surface. Therefore, it is important to assess not only the human impact but also the potential impacts of climate change on the unique nature of this sandy spit's ecosystems.

Today, politics still play a role in developments on the spit, both nationally and internationally. In the Lithuanian portion, the current regulations mean that there are now restricted areas, allowing natural vegetation to develop in fragile environments. As the surface changes to form a layer of greenery these zones are ideal places to study how flora may be used to prevent desertification - a problem that is also relevant in several other areas around the world. Meanwhile, the forests that develop on the grasslands form a natural tool for the protection of the environment from other natural hazards (Gravenhorst *et al*., 2005; Brang *et al*., 2001; Gudelis, 1998).

3. Historical regional management

Historical information regarding the Curonian Spit can be gleaned from a number of sources both in terms of its geography, politics and land use (see Dobrotin *et al*., 2013; Brukas *et al*., 2012; Morkūnaitė, 2011, Albrecht, 2008).

During World War II the Curonian Spit was part of the Soviet Union. During this period, more than 500 ha of forest was lost or damaged due to the lack of a coherent management system and a lack of responsible personnel. At that time the forest cover occupied 54-55% of all the territory. In September 1960, the land was given the status of a nature reserve making it a restricted area. Detailed scientific investigations began with geomorphological studies and research on dune development. After receiving this restricted area status, the number of personnel managing the region grew to 100 and a number of documents were produced detailing how to regulate the forest. During the period 1970-1990, forest expansion was encouraged and the result was that the forest cover on the spit reached its peak to-date of 75%. In 1991, after Lithuania gained independence, the Curonian Spit was established as a national park. A new general plan for forest management was approved but, up to 2000, the forest area grew uncontrollably. After 1991, all the settlements were deemed to belong to the National Park territory. Furthermore, in 2000 this protected status was reinforced when the Curonian Spit was included in the UNESCO World Heritage list, one result of which is that urban development became severely limited and indeed the number houses that were demolished increased. However, to manage the zone the administration had its lowest numbers of employees at this time despite the fact that all the equipment and environmental facilities required renovation. In this decade, several fires occurred forcing the authorities to pay particular attention to environmental aspects.

Legal aspects were tightened further when, in 2004, Lithuania became a member of European Union, after which the authorities had to adapt to additional EU environmental regulations and projects such as Natura 2000 run by the EU. On the positive side, this last change did mean that EU structural funds could be used to develop new projects and modernise equipment.

4. Sustainable land cover and land use management

A major challenge in forest management is to balance the competing interests of different forest users and the need to manage the biological environment within the forests. The conservation of biological diversity has become one of the important goals of managing forests in an ecologically sustainable way. In order to achieve this, ecologists and forest resource managers need quantitative measures to judge the success or failure of particular management schemes and, in the case of the Curonian Spit, policies must be designed to sustain biological diversity in the face of increased visitor interest in the region. However, these biologically driven schemes must also accept the need for sustainable development that has also been accepted at the highest levels of the European Union and its neighbours (Kavaliauskas, 2009; Lindenmayer *et al.*, 2000).

Forest management and the planting of vegetation along the Curonian Spit, has been carried out since the XIX century primarily as a protective basis for the dunes but, in other parts of Lithuania, and elsewhere, forestation is encouraged due to economic reasons (Dikšaitė, 2016; Brukas *et al.*, 2012) to harvest wood or to reverse the overall decline in forest areas and aid carbon capture.

Efficient institutional structures and sensible management policies, as always, are key to changing hearts and minds when it comes to public acceptance of urban growth and natural resource management (Yin *et al.*, 2018). Coastal zones, due to their natural appeal, are among those areas that have been subject to intense human pressure. The resulting local changes, along with wider anthropogenic environmental effects, alter the coastal landscapes (Rivis *et al.*, 2016; Buynevich *et al.*, 2015).

The Curonian Spit environment, landscape, climate and biological diversity have all been previously observed from different points of view, with different findings, but there is generally a lack of research to synthesis this information (Česnulevičius *et al.*, 2017; Morkūnaitė, 2011; Bitinas *et al.*, 2005). This work demonstrates a way to measure and evaluate changes in forest and other land cover in the Lithuanian section of the Curonian Spit during the period 1989-2017 by combining remote sensing methods with additional scientific information.

The question of how big a role a policy has made, with regards to the protection of the dunes as well as further impacts on urban development on the spit, is a point of discussion (Brukas, 2012; Kavaliauskas, 2009). The spit has effectively been a human managed landscape for more than 200 years (Albrecht, 2008) and therefore it is an excellent test case to study the use of information in the policy-making process.

5. Materials and methods

Remote sensing methods, in conjunction with GIS, have been recently used to detect changes to other forest areas (Bochenek *et al.*, 2018; Humagain *et al.*, 2017; Lukeš *et al.*, 2016; Castillo *et al.*, 2015) and so becomes the method of choice here. While land covered by urban developments, and indeed forest areas planted as a resource, are clearly examples of land use, the latter requires more information to determine if humans have deliberately or unconscientiously modified an area. While this on-the-ground information is available for some places on the Curonian spit, the methods used here merely detect land cover and so this term is used from here.

5.1 Data collection

The analysis of land cover was undertaken using satellite images of the Lithuanian portion of the Curonian Spit (see Figure 1) acquired in May of 1989, 1994, 2000 and 2009 using Landsat 5 TM and Landsat 8 OLI for 2017 with a 30 m spatial resolution to determine the details of land cover. These dates are taken to correspond to changes in management policies on the Curonian Spit. The Landsat images were chosen among other available records due to the low cloud cover present at the time, which did not exceed 20%, and because they were taken at a time in the year when there was visible vegetation. In addition, geospatial, statistical and other information sources have been used here to support the analysis (see Table 1). Specifically, Landsat (TM) and Landsat (OLI) records were used to analyse the evolution of the land cover over the study area to investigate the impact of forest management practices that had been implemented at specific times.

[Table 1 near here]

5.2 Image processing and classification

The area of study within the Curonian Spit was spatially discretised using a square mesh producing a set of numbered cells. Each cell measured 1x1 km (so having an area of 100 hectares, where one hectare, or 1 ha, corresponds to 100 ares or 10,000 square metres).

In total, 170 cells were identified to cover the landmass of the spit, as shown in Figure 2b. Each cell was then analysed to determine the land cover based on the following six categories: water, vegetation, sand, forest, urban, or grassland.

Each Landsat image underwent intensive pre-processing, such as geo-referencing, mosaic and calibration, before any classification was made. The size of a Landsat scene was clipped according to the GDR10LT GIS layer of the Curonian Spit national park.

Each image was classified separately using the supervised classification maximum likelihood algorithm. The reference classes were defined beforehand by means of photo-interpretation, using the high-resolution natural colour imaging and maps of the study area. The six land cover categories identified for this research were calibrated at a set of training sites (Table 2, Figure 2a). A flow chart of the methodology of the analysis is illustrated in Figure 3. The land cover change analysis was performed between pairs of Landsat images during year 1989 - 2017. The images were processed using the ArcGIS 10.4.1 software.

[Figure 3 near here]

[Table 2 near here]

The detection of water (*W*) could potentially be used to assess changes to the land mass or coastal outline. However, since there are no inland water reservoirs on the Curonian Spit, cells that were recorded as being made up of the water (*W*) category were discarded here and left for some future study.

Grassland (*G*) cover can be distinguished separately from vegetation (*V*) or forest (*F*), due to significant difference observed in the colour of each type.

Accordingly, changes to the number of cells recorded for each of the land cover categories were then obtained and the total land cover area of each category was established in hectares.

As part of this research, as an additional tool to establish the urban cover, a series of orthophotographs taken in 1997, 2013 and 2017 of the study area was also digitised.

5.3 Accuracy assessment

An assessment of the accuracy of the Landsat images was available as Google Earth maps covering the research area is also available with images taken from 1989. The accuracy assessment of the land cover maps was performed considering 131 targets sites. For each target area, the ground truth was determined via a field trip and then compared with the corresponding satellite image. To perform this accuracy assessment additional geospatial data, including municipal boundaries and road networks were also established from the officially recognised Lithuanian geodatabase GDR10LT GIS layer for 2013 which has been prepared by the Lithuanian National Land Service (see Table 1).

For a quantitative assessment of the overall accuracy, a Kappa coefficient was established when comparing the two sets of data (the images from Landsat and those from Google Earth). The assessment of the classification showed an overall accuracy, derived from the stratified random sampling method, of higher than 91% with an overall Kappa statistic of no less that 0.89 (see Table 3). Considering the accuracy in each of the categories, the stratified random method provided very high accuracy of the assessment for the forest (*F*), water (*W*), vegetation (*V*) and sand (*S*) categories, each with an accuracy of 85-100%. However, difficulties did occur in determining the areas of urban (*U*) and grassland (*G*) due to the similarity of colour that the surfaces produce. The accuracy of the detection of urban (*U*) areas was only 40–50% before additional information was applied. The use of additional geospatial information was thus vital for a correct assessment. Information on urban (*U*) areas was then corrected and levels identified using a geo-referential database GDR10LT of roads, settlements, and buildings. The Orthophoto ORT10LT was used for the data in 2013, in combination with the geo-referential database GDR10LT, to detect changes due to new buildings in order to explore, in detail, any sites of urban development and to verify the existence of any new urban zones. After corrections, data on the urban cover category (*U*) then reached an accuracy of nearly 89%.

In parallel to the analysis by remote sensing, a field trip was carried out to collect localised photographs and check places of disagreement where there were doubts about the classification. The field trip was carried on 7th April 2018 with 25 places selected for assessment and photographs taken for confirmation.

The goal of the accuracy assessment was to measure the frequency of errors between the assessment of the images and what was actually in place on the ground. This prevents repeated mistakes leading to misinformation so that accurate overall statements can be created.

6. Results

6.1 Evidence of Land Cover Changes

Once the water element has been removed, by analysing the amount of each category visible in each of the cells, it was established that the regions of forest (*F*) were by far the dominant type of land cover. This is illustrated in Figure 4, which shows a time history of the percentage of cover in each category over the time frame being considered. Certain trends are clearly visible in this figure. The area of forest declined gradually between 1989 and 2009, falling to 58.31% of the total area of land in the Lithuanian part of the Curonian Spit, and then increased, almost returning to the amount found in 1989, covering 66.49%. Despite this more recent increase, a total decrease of 3.27% is observed for the forest cover over the research period, but recall that growth had previously been unchecked and management policies put in place to limit growth.

[Figure 4 near here]

Turning to the changes in vegetation (*V*) and grasslands (*G*), it can be seen in Figure 4 that these two categories are out of phase with each other, so that an increase in one, leads to a decrease in the other. This is most marked between 2009 and 2017. Aggregating the numbers, the grassland cover increased by 8.58% in the past 28 years, from 1989 to 2017. The data shows that vegetation cover decreased gradually until 2009 after which it increased by 5.22% in comparison with the level from 2000.

Also, looking at Figure 4 it can be noted that the land cover representing urban developments changed little over the entire period of the study with urban cover representing less than 3%.

The overall analysis for each land cover category is shown here in Figures 5 to 9 where the information is plotted both on a map and graphically, using a time history of the total area in each category.

Turning first to forest cover (*F*), diagrams to illustrate the changing amount of area classified as being covered by forestland can be seen in Figure 5a. In 1989 69.76% of the area on the spit was detected as being covered with forest. The other maps in Figure 5, diagrams 5b, 5c, 5d and 5e, give the changes in forest cover during the different sub-periods detected in 1994, 2000, 2004 and 2017 respectively. These diagrams show that from 1994 until 2017 the total increase of forest cover was 4.06%. The diagram at the bottom of the figure, Figure 5f, is a plot of the change in forest cover in hectares for two consecutive time frames plotted along the length of the Curonian Spit. The biggest loss of forest cover reaching -76.64 ha per measurement cell was recorded in the period from 2000-2009 near Smiltynė in the area most affected by the forest fire in May of 2006. This change can be seen in Figure 5f where the light blue line drops significantly towards the right had side of the plot corresponding to the affected area. After 8 years this fire affected area recovered with an observed increase of 8.65 ha per measurement cell of forest cover was observed.

[Figure 5 near here]

The same treatment was carried out for the other categories of land cover. These are displayed for vegetation cover (*V*) in Figure 6, grassland (*G*) in Figure 7, sand (*S*) in Figure 8 and urban cover (*U*) in Figure 9. Although viewing each of these individually highlights interesting findings, it is their collective assessment which is most important as the various categories interact with each other.

6.2 Forest as a protection from natural hazards

Forest cover today spreads over almost the entire Curonian Spit National park territory and now accounts for over 60% of the available area, as seen in Figure 4. This forest cover forms a natural protective base in order to stabilise sand dunes. Figure 5d illustrates a gradual expansion of the forest area, starting in 2009, mainly in the southern part of the Curonian Spit but more recently new growth has also been detected in the northern part (Figure 5d). In the area from Nida up to the Great Dune Ridge, there has been a significant growth leading up to 2017, as observed in Figure 5e and Figure 5f.

The results displayed here confirm that there is a natural progression of the conversion of the land cover from vegetation to grassland and then to forest. The link between grassland cover and forest cover can be seen by comparing Figure 6c, showing data for 2000, and Figure 5d, which corresponds to the same areas in 2009. An increase of grassland cover observed in the area of the Great Dune Ridge during the period 1994-2000 was followed by a decrease during 2000-2009 (Figure 6f), while during 2009-2017 an increase of forest cover is then observed (Figure 5e, Figure 5f). The same situation is observed in the northern part of Curonian Spit, where an increase of grassland cover observed during 1994-2000 (Figure 6c) was followed by a decrease during 2009-2017 (Figure 6d), while an increase of forest cover is observed during 2009-2017 (Figure 5e). A decrease of grassland cover could thus be explained by the gradual increase of forest cover over the same area. The process developed here indicates that, armed with new techniques of analysis, and also especially with more detailed information on vegetation and grassland cover, any increase in forestation could be predicted and therefore managed.

[Figure 6 near here]

Some might say that the land is there to be enjoyed, but heavy forestation prevents this to some extent and, therefore, especially in some parts of the Great Dune Ridge, forestation should be tightly managed in order to save or create landscapes that visitors find are attractive or interesting. The fast growth of grassland observed in this research (see Figure 6) over the whole of the territory within the Curonian Spit should act as a warning to the authorities that these areas rapidly will soon be transformed into forest, as shown in the results of 2017. While this forest protects the dunes from erosion it does change the landscape and importantly reduces urban development to nearly zero. Therefore, practices that encourage forestation do not always recognise sustainable considerations with regards to the built environment.

The last inventory of the forest zones within the Curonian Spit was carried out in 2009. This inventory was then used to formulate the forest management strategy for the period of 2013-2022 (Brukas *et al.*, 2012). The suggestion here is that these new methods can be used for almost real-time monitoring at reduced costs in comparison with manual inventories.

6.3 Urban development in area of national park

As opposed to the Russian part of the Curonian Spit, the entire portion of the Lithuanian part is now a national park with all settlements belonging to national park authority. This explains why there is no significant increase observed in the urban cover (*U*) over the research period. Results produced here show that the area of urban cover only changed marginally from 1.69% in 1994 to 2.9% in 2009 (Figures 7b and 7d). Even this change does not mean that further building took place since this increase is due to a quantity of new open roads and pathways being created between trees which are denoted here as urban cover. Figure 5d shows that there was a loss in the area of forest cover during 2000-2009 in all settlements except Juodkrantė (Figure 5f, Figure 7g). Over this period, in areas where forest had previously existed, there was an observed increased level of urban area. During the period 2009-2017 there was an increase in forest cover (Figure 5e) the result of which was a decrease in urban cover in the same settlements (Figure 7g). This inverse relationship obviously depends on the forest density and therefore more detail is required in order to take this density into account (Lukeš *et al.*, 2016) and hence special attention must be given to obtain information on urban cover to clarify the situation.

[Figure 7 near here]

From the digitised orthophotographs it was established that the total number of buildings in 2017 was 1023. During the period between 1997-2013 the number of new buildings increased by 8.6%. During the period between 2010-2017 an increase of 2.93% was observed in the urban area due to new buildings in Nida, Preila and Klaipeda (Figure 7f). It is worth noting that in the Great Dune Ridge territory there is no urban cover besides the paths or roads used to access the dunes (Figure 7g).

6.4 Sustainable and land cover management

These results, which monitor the change in land cover, show that the management of the Curonian Spit territory operates between sustainability extremes. Forest growth is so rapid that the overall forest territory could expand over 1% per year (Figure 4).

Changes in the vegetation, grassland and forest categories of cover have all been observed during the research period, all of which have a direct influence on area of sand cover. A change in the distribution of areas of vegetation in 1994 was apparent throughout the entire region of the Curonian Spit territory. This is linked to an increase in forest areas, which reduces the areas of vegetation cover (Figure 4; Figure 5; Figure 8).

[Figure 8 near here]

These results show that the Great Dune Ridge is one of the most active areas in terms of land cover changes during year the period 1989-2017 (Figure 6 and Figure 9). Leaving aside the most northern tip, grassland cover expanded from the northern to the southern part on the Great Dune Ridge (Figure 6). The decrease in sand cover in this part of the Curonian Spit was greatest in 2017 and some parts of the Great Dune Ridge (Figure 9) had a reduction in sand area of up to -16.93 ha per measurement cell in comparison with 2009. That is, around a 58% change in 9 years in this particular area (Figure 9). Investigations into changes in this territory are a good example of where the tracking of ongoing changes will prove particularly useful and any predictions of future further changes would form a particularly valuable resource.

[Figure 9 near here]

7. Discussion

Policies dating back to the beginning of the XIX century have been utilised to protect the dunes on the Curonian Spit from erosion and to prevent dune movement (Dikšaitė, 2016). Land use and land cover on the spit have altered over the years due to changes in forest management policy with the actual distribution of forests within the spit now on the increase as the trees adapt to the changing shape of the landscape (Figure 5). Forest management policies, and actions taken to protect the dunes during different periods, have caused forest growth (Figure 5). In 2013 a forest management project was started on the Curonian Spit National Park producing visible results, as can be seen by a comparison between the analysis for the amount of forest areas in 2009 compared with those in 2017, where an increase in forest area of 8.18% was observed. By 2017 the forest area had almost returned to the high level encountered in 1989, making up to close to 67% of the entire territory within the Curonian Spit. A decrease of forest cover was observed between the settlements and the border with Russia during 1994-2000. This observed decrease was, in all probability, due to a new custom clearance agency established after independence. Recently, the forest growth is particularly noticeable in the southern part of the spit. The increase in areas of forest can be said to have been the result of the management actions and the strict observance of schemes put in place during the 2013 project.

After fires occurred in the northern part of the Curonian Spit in May of 2006 and 2014, the forest management policy has been strictly adhered to. The practice of clearing dead wood and replacing old trees with new ones has become a feature of the management ethos. According to the Lithuanian State Institute for Forest Management (2013), land covered by forests on the Curonian Spit has increased by 9.1% over the last 50 years (a longer period than considered here). The biggest increases have been observed in the number of naturally, self-seeded trees (more than 50%, up to 1442 ha). The forest has started to change the landscape and is even seen to interfere with the activities of some local inhabitants who increasingly live amidst a dark forest. Residents constantly fear the dangers of forest fires, especially in the summer.

It is not enough to consider forest management independent of other factors. In particular, human interaction plays a big role due to the massive interest in the area, especially in the summer. The landscape of the Curonian spit has been known as an area for recreational activities since the second half of the XX century (Dikšaitė, 2016). In order to protect the dunes from recreational activities that depart from specific laid out routes, lots of additional paths and stairways have been established to protect the dune ridge.

Environmental restrictions, while good for the environment do however mean that there are serious limitations for the urban environment in terms of increased development with no urbanisation visible. By comparison, in the suburbs of Klaipeda city there has been an increase of over 50% in new buildings during the (almost) matching period between 1997-2013 (Galinienė and Verkulevičiūtė-Kriukienė, 2014). During 1997-2010 the Lithuanian Census data shows an increasing number of inhabitants in the Curonian spit but this increase is anomalous, created by the ferry that travels from Klaipeda on the mainland to Smiltyne on the Curonian Spit and the preference for people to be registered locally (Denyer, Galland, 2009). According to the census data, the number of inhabitants of Klaipeda is increasing, despite the fact that in rest of Lithuania the population is decreasing. In 2017 the total recorded number of people in the Neringa municipality on the spit was 3069, while in 1989 it was 2478 inhabitants. The number of tourists to the spit rapidly inflates this number and their foot traffic subsequently changes the shape of the dunes. The number of tourists, according to ferry data, could be up to 2 million people per year (EUCC, 2006; Žilinskas *et al.*, 2003). Recent research has shown that there is movement of the sand forming the dunes caused by this large number of tourists, especially the Great Dune Ridge and the Parnidžio dunes near Nida (Bautrėnas and Morkūnaitė, 2016).

The effect of tourists and visitors on the sand dunes can be distinguished from changes caused by vegetation cover. Vegetation cover is one of the most important indices to evaluate the conditions of the ecosystem and anthropogenic activities (Zheng et al., 2017). In order to prevent movement of dunes, during 1985-2002 in the most vulnerable coastal zones from Nida to Juodkrante (see Figure 1), reeds were planted in the shore area. The reeds were subsequently harvested and used as a building material for a specific type of housing historically seen in this part of the Curonian Spit (Ilginė, 2016). The increase of vegetation created by this shore-zone planting is significant and an expansion of this type of vegetation has been observed throughout the spit. The area of the shoreline on the Curonian lagoon side that is covered with reeds almost doubled from 13 km in 1996 to 22 km in 2016 (Ilginė, 2016). This finding has also been confirmed here in Figure 8, particularly in the territories of Nida, Preila and Pervalka from 1994 onwards.

In 2000 and 2009 significant growth of vegetation was observed in the territory between Pervalka and the Great Dune Ridge (Figure 8f). The recent rapid expansion of reeds is uncontrolled and has a negative impact on the existing habitats of different plants and even birds. Reed planting was seen as a natural tool to protect and entrench the Great Dunes Ridge in the eastern part of the spit but grass rapidly transforms into bushes and, in few years, into forest. To counteract this transition, goat grazing was proposed in 2017 after the Naglių Natural Reserve rapidly became overgrown with bushes and trees. This goat grazing was been seen as a natural means to reduce the spread of plant material and had already successfully worked in 2014 (Nikitenka, 2017). The planting of reeds does form an effective tool to stabilise dunes but their spread also needs to be carefully monitored and controlled.

Over the period of this study, besides areas in the northern part where a slight increase in sand cover was observed, the rapid growth in areas of vegetation, grassland and forestation all along the Curonian Spit lead to a rapid decrease in the area of sand cover. The increase in sand cover the north can be explained because the sand accumulation here is due to the natural processes of a spit formation and the protective impact of the Klaipėda port entrance channel (Bagdanavičiūtė *et al.*, 2012).

On the 4th December 1999, an extreme weather event, called "Anatolijus", struck the Lithuanian coast bringing with it a southwestern wind of up to 35 m/s and sea level rises of up to 165 cm. During this event, approximately 1.8 million m^3 of sand was lost. In contrast to this, a less extreme weather event also occurred on 9th January in 2005 (southwestern and western winds of up to 28 m/s and sea level rises up to 153 cm) when the spit this time was nourished with an estimated 0.14 million m^3 of sand (Jarmalavičius *et al.*, 2016; Dailidienė *et al.*, 2012). These two events clearly influenced the sand content of the spit occurring, as they did, within the research period and these changes are reflected in the levels of sand cover (*S*) in Figure 9d and Figure 9e. These significant changes of sand area can be specifically observed in the territory of the Great Dune Ridge.

The growth of grassland (*G*) on top of the Great Dune Ridge can be explained as a consequence of a successful forest and national park management strategy, the aim of which was to stop the movement of the dunes that form the ridge. The land in the territory of Great Dune Ridge that is covered with sand has decreased each year of this study (Figure 9). This change in sand cover can be explained with the corresponding expansion of the grassland (*G*) zones (Figure 6). The amount of open spaces in the middle of the forest, which are also classified as grassland, started to increase in 2009 (Figure 6d). Huge fires in 2016 and 2014 influenced this growth, affecting the northern part of the Curonian spit, not far from urban territories (Figure 5e, Figure 5g, Figure 7e, and Figure 7g).

During the fire in 2006 more than 235 ha of forest burned, while in 2014, more than 60 ha of forest was lost. This was the main reason for the introduction of the programme to cut old pine trees, which are highly flammable. Tracks or open spaces are commonly used to create fire-breaks to prevent any fire from spreading (Brukas *et al.*, 2012) but this practice had the additional benefit of also creating more open spaces. The only problem is that unchecked, these tracks rapidly overgrow with new vegetation and bushes and soon, once again, they become forest. Constant maintenance of these spaces is thus required. The increase of such spaces can be seen in the northern part of the Curonian Spit, between Smiltynė and Juodkrantė (Figure 7d, 7g,) corresponding to 2009, after the fire of 2006, but care must be taken that these are not marked as areas of vegetation or indeed urban cover due to the dark surface of the tracks since here the soil is dark. These tracks were also present in 1989, but during the subsequent years they became overgrown with vegetation (Figure 8b) and subsequently change to areas of forest (Figure 5c). In 2017, no significant tracks were observed in these territories (Figure 5e).

In the future, with forecasts of increasing air temperatures and an extended growing season for vegetation, new methods will need to be adapted in order to facilitate the sustainable management of sensitive and protected areas. The methodology utilised here will be the key process in the design of policies based on assessments of the change in vegetation levels and forest cover while also taking into account the impact of human activities and climate change.

8. Conclusions

Satellite remote sensing and GIS technologies have been used to extend manual assessment systems to classify land cover in a research area consisting of the Lithuanian section of the Curonian Spit in the southeastern Baltic Sea region. The research enabled changes in various forms of land cover, including changes to the built environment, to be assessed and tracked over time. The methodology used here highlights the way forward to create a cost-effective tool to manage forest areas and assess the processes that change the surface of parcels of land, either similar in nature to the Curonian Spit or potentially somewhat different.

This research shows that the tracking of data dealing with land cover has the potential to explain many ongoing processes, predict their development and hence influence decisions regarding further actions. Inventories that take place in Lithuania measure external boundaries of the forests but do not look inside the forest. This work demonstrates that LANDSAT images, which are repeated every 16 days and cover all of the Lithuanian territory, can be used as up-to-date method to detect changes in the land surface, knowledge of which can then influence development of the region.

9. References

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