



**HAL**  
open science

# Monitoring Land Cover Change in the Southeastern Baltic Sea Since the 1980s by Remote Sensing

Sébastien Gadal, Thomas Gloaguen

► **To cite this version:**

Sébastien Gadal, Thomas Gloaguen. Monitoring Land Cover Change in the Southeastern Baltic Sea Since the 1980s by Remote Sensing. Simona Niculescu. European Spatial Data for Coastal and Marine Remote Sensing. Proceedings of International Conference EUROMARE 2022-Saint Malo, France, Springer International Publishing, pp.59-79, 2022, 978-3-031-16212-1. 10.1007/978-3-031-16213-8\_4. halshs-03881795

**HAL Id: halshs-03881795**

<https://shs.hal.science/halshs-03881795v1>

Submitted on 14 Mar 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

# MONITORING LAND COVER CHANGE IN THE SOUTH-EASTERN BALTIC SEA SINCE THE 1980s BY REMOTE SENSING

S. Gadal <sup>1,3</sup> (sebastien.gadal@univ-amu.fr)

T. Gloaguen <sup>1,2</sup> (thomas.gloaguen@ktu.edu)

1 CNRS, ESPACE, UMR 7300, Aix-Marseille Université, Université Côte-d'Azur, Avignon Université, 13545, Aix-en-Provence, Cedex 04, France

2 Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Cultural and spatial environment research group, LT-51367 Kaunas, Lithuania

3 North-Eastern Federal University, Republic of Sakha, Yakutia, 670007, Yakutsk, Russian Federation

## Session 3, Land Use/Land Cover – Sea Use/Sea Cover and planning

**KEYWORDS:** Land Cover Change, Land Planning, Remote Sensing, Machine Learning, Data accuracy, South-eastern Baltic Coast

### ABSTRACT:

The political, economic, and social changes associated with the collapse of the Soviet Union at the end of the 1980s led to major land cover and land-use changes in the south-eastern Baltic Sea coastal regions. These changes (demilitarisation of the coasts, end of collective ownership, specialisation of economic activities, etc.) are characterised by a fast process of coastalisation with the growth of urban areas, coast suburbanisation, and the decrease of agricultural land. At the same time, we observe the implementation of protected natural areas at the regional level and through cross-border cooperation with international organisations (UNESCO, European Union, etc.). Both processes have an important impact on the management of the coastlines of Latvia, Lithuania, and Russia. The analysis of the coastal changes is based on the use of Landsat remote sensing data series from the 1980s to 2020 combined with EU geographic databases and the land use plans. The comparative analysis of the land cover changes in the Oblast of Kaliningrad, Lithuania and Latvian coastal zones allows us to understand the impacts of the three different planning policies since the end of the 1980s. The territorial dynamics are modelled using the GEOBIA package with object-oriented classification and machine-learning algorithms (Maximum Likelihood, Minimum Distance to Means, Parallelepiped Classifiers) applied to the Landsat 5 TM and Landsat 8 OLI satellite multispectral images. The produced land cover maps are compared with the Climate Change Initiative Land Cover of the European Space Agency from 1995 to 2015.

## INTRODUCTION

In recent years, the South-East Baltic (fig. 1) has been characterised by significant changes. The land cover maps made using remote sensing show the transformations of the coastal zones of Kaliningrad Oblast, Lithuania, and Latvia. Jūrmala (Latvia) is one of the emblematic examples of a significant illegal real estate investment due to the environmental impact of private Russian citizens destroying the dunes of the coastal zones during the 2010s. Several of the projects built villas directly on the dunes. The number of abandoned houses since the Latvian restoration of independence are the object of strong real estate speculation (Aubin, 2013), contributing as well to the gentrification of the coastal zone. Jūrmala is emblematic of this current development in the south-eastern Baltic Sea, i.e., a progressive littoralisation of their coastal region.

The dynamics of coastalisation modelled here are common with others observed around coastal lands of the world at the global scale with a high concentration of populations and economic activities (Afanasyeva, 2014; Pranzini, Williams, 2013). However, the particularity of the South-East Baltic region is related to the context of political, social, economic, and cultural changes due to the collapse of the Soviet Union (Gadal, 2010). The transition to a market economy led to “a chaotic territorial development” and has made “permanent penetration of intensification of urban process” (Spiriajevas, 2014).

Furthermore, the redistribution of the expropriated lands and properties after the Soviet Union induced conflicts between public and private interests. Moreover, due to the inexperience of the inhabitants with land use regulations, many cases of abuse occurred, especially from the newcomers. They did not respect the legislation, such as limiting access to the coastline, and took part in behaviours that national international laws try to limit as much as possible, such as reconstructions not adapted to the

specificities of the coastal landscape and natural processes, using natural resources, etc., (Spiriajevas, 2014). The spatial analysis modelling of the coastal changes of the South-East Baltic provides a global diagnostic of the environmental and territorial impacts. It is based on the quantification of land-use changes, using remote sensing Landsat 5 TM and Landsat 8 OLI archives series from 1987 to 2020 based on the GEOBIA approach. The cartographies of the land cover changes are merged with the land-use policies implemented for coastal environmental management in the context of the transition from the Soviet regime to a liberal system.

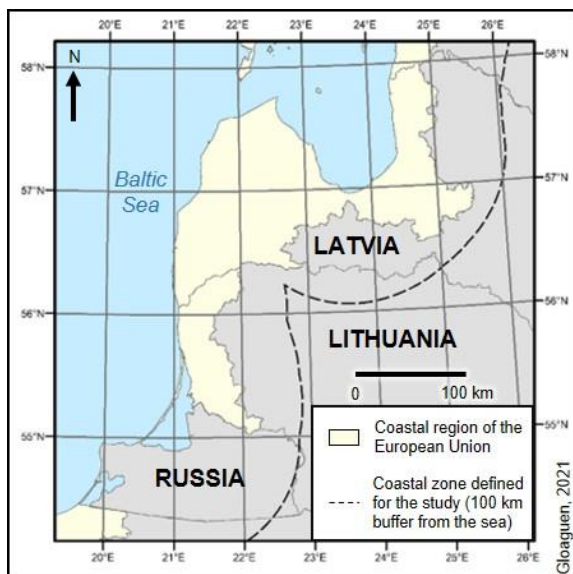
## 1. CONTEXT

The societal and political concerns about the Baltic coastline vulnerabilities went hand in hand with a growing awareness of the pressures stemming from increasing human activities, which themselves have undergone rapid political, social, and economic change in recent decades (Bitinas et al. 2005; Brunina et al. 2011).

### 1.1. The Soviet period: Military control and economic specialisation

The coastal territories of the south-eastern Baltic Sea of the Soviet Union were heavily controlled; as they were the border territories of the Soviet Union, these territories were militarised, and the restricted access limited the numbers of inhabitants on the shores (Pranzini, Williams, 2013; Spiriajevas, 2014).

At the same time, the Soviet economic system undertook the policy of economic planning specialisation with the development of activities related to fishing, tourism, shipbuilding, and the port



**Fig. 1 – Definition of the coastal zone studied**

industry giving the coastal zone a function of an interface (Fedorov et al. 2017).

The second investments in terms of economic development concerned agriculture, with the collectivisation of lands in the 1940s. In Latvia, the economic and territorial collectivisation of agriculture generated massive moves of the populations to the cities, for example (Nitavska, Zigmunde, 2013).

### 1.2. Liberalisation and gradual coastalisation of the Southeast Baltic countries

The collapse of the USSR in the early 1990s led to an increasing concentration of economic activities in the coastal regions. The Latvian and Lithuanian coastal zones contribute 5% and 12% of national GDP, respectively (Brunina et al. 2011; Fedorov et al. 2017; Veteikis et al. 2011).

The economic sectors became more specialised. Traditional activities such as small-scale fishing or local farm agriculture units were replaced by heavy industrial manufacturers, ports, and tourism. The opening of the local economy to the Baltic area and the European Union after the countries gained independence accelerated this process (Bitinas et al. 2005; Eaglet, 1999; Fedorov et al. 2017; Gulbinskas et al. 2009; Spiriajevas, 2014; Veteikis et al. 2011).

The “economic growth and increase of population are reflected in the landscape by an increase of construction and a decrease of natural territories” (Nitavska, Zigmunde, 2013).

Because of the capacities of Earth observation satellite images to measure the territorial changes, the modelling of land-use change by remote sensing helps to capture these rapid economic, demographic, and territorial transformations.

## 2. METHODOLOGY

### 2.1 Definition of the coastal zone study area

One of the main problems in coastal research is the delimitation of the coastline and its region of influence. A buffer zone of 100 km was used to delimitate the coastal area from the coastline (marine and lagoon) (fig. 1).

This method of determining the coastal area was developed by Fedorov et al. 2017 in their study analysing the impacts of the sea interface on the economic and urban development of Kaliningrad Oblast.

The estimated area of sea influence based on their model is 100km from the coastline. This area of sea influence is calculated spatially from the administrative units used by the European Union (level 3). Some areas are not administratively considered by the EU to be coastal zone territories even though their distance from the coast is only about 50 km.

### 2.2 Data acquisition

The spatial land change monitoring is based on the Landsat 5 TM and Landsat 8 OLI satellite multispectral image archives of the Earth Explorer platform (<http://earthexplorer.usgs.gov>).

Landsat is today the only archive offering free-access, remote sensing data that allows for modelling the land cover change transformations from the mid-1970s till today. It offers a spatial resolution of 30x30m since the launch of Landsat 4 in 1983. The South-East Baltic coastal zone landscape structures and areas are matched with a spatial resolution of 30m. The spatial resolution of 30x30m is considered efficient for monitoring all the geographic objects of the coastal zone that organise and structure the landscapes.

The analysis used the 7 bands covering the visible, near infrared and middle infrared (SWIR 1 and SWIR 2). Because of the spatial resolution of 80m, we did not select the Landsat 1-3 MSS images from the 1970s to 1983. The Landsat scenes cover the study area from the border of Poland with the Kaliningrad Oblast to the Latvian-Estonian border. To improve the level of land use objects detection and recognition the selected scenes covered the end of spring, summer, and the beginning of the autumn seasons from May to October. The intensity of light received on the land surface, seasonally, is at its highest during these months of the year. Snow and clouds covers are limited during this period, and the chlorophyll activity improved the capacities of detection among the geographic objects composing the land use classes.

A temporal interval of 10 years was determined to analyse the land cover change dynamics with a total of 24 scenes (table 1). Six Landsat scenes are required to cover the entire coastal region studied.

We used Landsat Level-1 (only for cloud mask, see section 2.3.1.) and Level-2 images satellite archives with a calibration level set to surface reflectance (top of canopy), eliminating artefacts related to the atmosphere (e.g., humidity, aerosols), to the intensity of light received on the Earth’s surface, and to the geometric offset from the observation area.

### 2.3 Method of analysis of land-use change

The land-use changes analysis is based on a GEOBIA approach that aims to study “geographical entities or phenomena through delineating and analysis *image-objects* rather than individual pixels” (Chen et al. 2018). This approach leads us to use a segment-based classification to identify the different modes of land use. This method facilitates the interpretation of land-use

**Table 1 – Landsat satellite images used in land cover processing.**

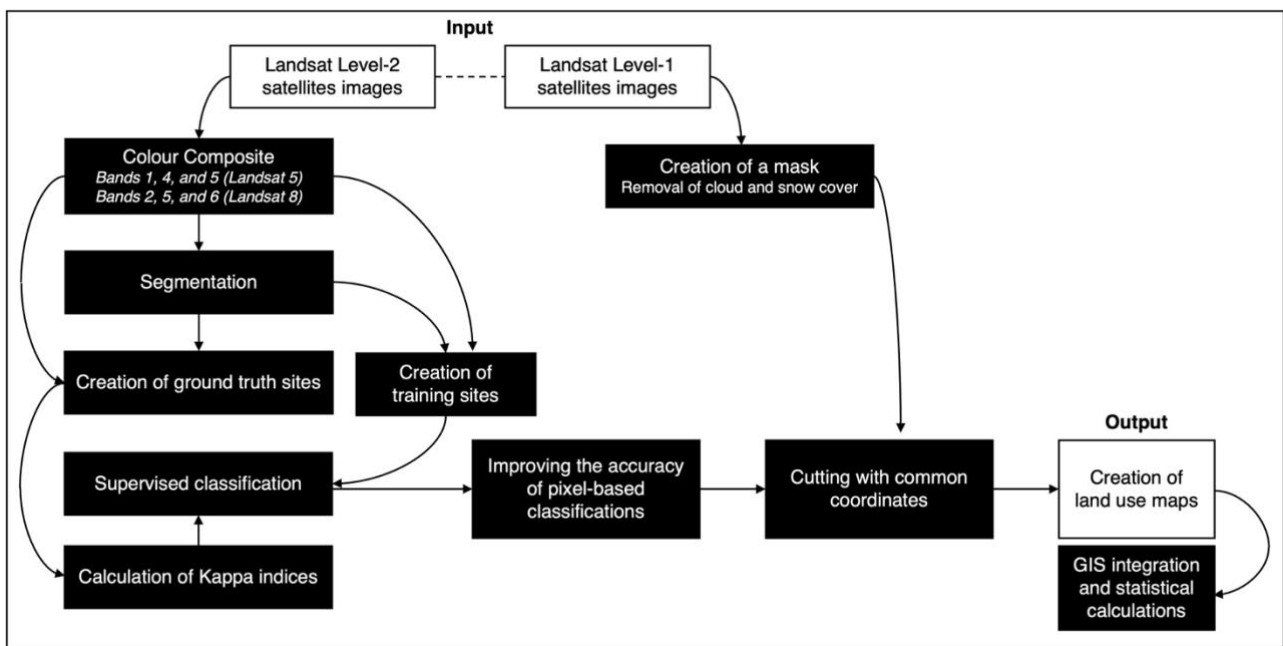
Date of acquisition		Processing date		Mission Landsat	WRS coordinates		Kappa index
Year	Month/Day	Year	Month/Day		Path	Row	
1987	10/12	2017	02/10	L5	187	020	0.91
						021	0.90
						022	0.94
	10/10				189	020	0.92
						021	0.92
						022	0.93
1997	08/20	2018	02/25	L5	187	020	0.96
						021	0.92
						022	0.93
	05/14				189	020	0.97
						021	0.97
						022	0.95
2009	08/21	2016	10/22	L5	187	020	0.94
						021	0.92
						022	0.94
	05/31				189	020	0.95
						021	0.96
						022	0.93
2020	05/31	2020	06/08	L8	187	020	0.91
						021	0.92
						022	0.93
	09/18				189	020	0.94
						021	0.93
						022	0.94

changes and allows for a more accurate representation of landscape features than a classification based on the original pixels. Figure 2 summarises the different steps of the method.

**2.3.1 Pre-processing**

The identification of potential cloud cover in satellite images archives is a necessary step to take advantage of the data they offer. For this purpose, we use the F-Mask algorithm from Landsat level-1 images to perform an automated raster containing land surfaces, water surfaces, clouds with the associated

shadows, and snow surfaces. These last three elements are extracted and merged into new rasters used as masks for classifications. This operation is applied to each scene with the same WRS coordinates, regardless of the year. This operation allows the calculation of statistics from the classifications based on the same area between the different years of the period analysed.



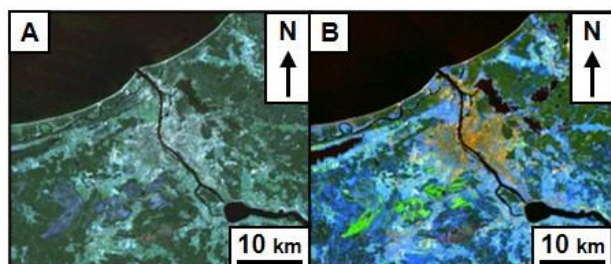
**Fig. 2 - Methodological scheme of the treatments applied in this study.**

### 2.3.2 Image segmentation

The image segmentation constitutes the first step of the production of land-use maps/land-use change by object-oriented classification. The segmentation is processed using a colour composite combining the near-infrared, mid-infrared 1 and blue bands (table 2, fig. 3). This allows the best identification of the geographical objects of the analysis i.e., water surfaces, forest surfaces, agricultural surfaces, urban surfaces and bare surfaces. These colour compositions are used in the segmentation to create oriented-object land uses composed of group pixels sharing a spectral similarity. The algorithm requires a tolerance threshold that defines the level of generalisation of the segmentation identifying the land uses. A low similarity tolerance produces homogenous segments, while a high similarity tolerance produces heterogeneous and generalised segmentation (fig. 4).

**Table 2 – Colour compositions used for land use classification.**

Landsat 8			
Canals	Band number	Spectral band	Wavelength
Red	5	Near-infrared	0.85-0.88 $\mu\text{m}$
Green	6	Mid-infrared 1	1.57-1.65 $\mu\text{m}$
Blue	2	Blue	0.45-0.51 $\mu\text{m}$
Landsat 5			
Canals	Band number	Spectral band	Wavelength
Red	4	Near infrared	0.77-0.90 $\mu\text{m}$
Green	5	Mid-infrared 1	1.55-1.75 $\mu\text{m}$
Blue	1	Blue	0.45-0.52 $\mu\text{m}$



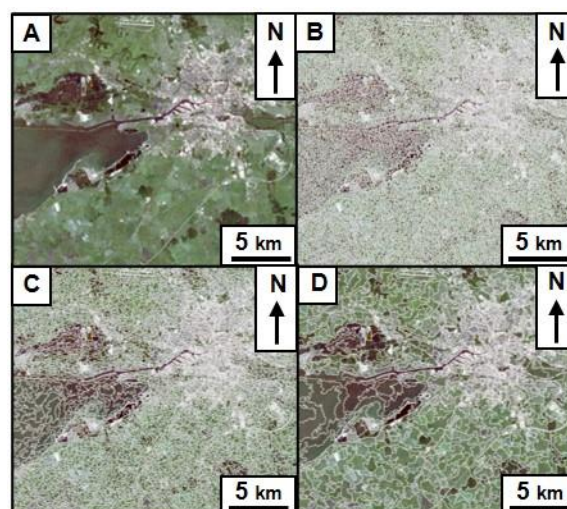
**Fig. 3. - Colour composition of a Landsat image for land cover studies.**

**Example with a Landsat 5 image with “natural colour” composition (A) and colour composition with bands 4, 5 and 1 (B). They allow the identification of urbanised surfaces (orange), water surfaces (black), agricultural surfaces (blue and green), forest surfaces (dark green) and bare surfaces (white).**

### 2.3.3 Oriented-object land use classification

From the colour compositions produce in the previous step, the geographic knowledge acquired during the field surveys are contributing to the creation of vector ROI training sites on the segmented images. About 30 ROI training sites were determined for each land-use class, the number of which should vary between 20 and 40 for accurate classification. Then, different supervised classifiers, including parallelepiped, minimum distance, maximum likelihood, Fisher LDA, and K-Nearest Neighbour (KNN), were tested and compared (fig. 5).

The accuracy of the different classifiers is evaluated by comparing the interpreted image and geographic ROI sites



**Fig. 4. - Examples of different tolerance values used for segmentation.**

**On a “natural colour” composition (A), segmentation was performed with a tolerance value of 20 (B), 50 (C) and 100 (D). The tolerance value chosen for the study is 20.**

described during the surveys. These geographic sites of accuracy control integrate both field knowledge and GIS databases. A comparative analysis of the classification methods is performed. The Kappa indices of each classifier show that the “Maximum Likelihood” is the most efficient of them with a value of 0.94 (table 3). A majority rule algorithm is applied in each segment to determine its class from the classification performed with “Maximum Likelihood” and to create a segment-based classification.

**Table 3 – Kappa indices the supervised classifications used**

	1	2	3	4	5
Average of Kappa indices	0.91	0.88	0.94	0.88	0.62
1 – Fisher LDA		4 – Minimum Distance			
2 – KNN		5 – Parallelepiped			
3 – Maximum Likelihood					

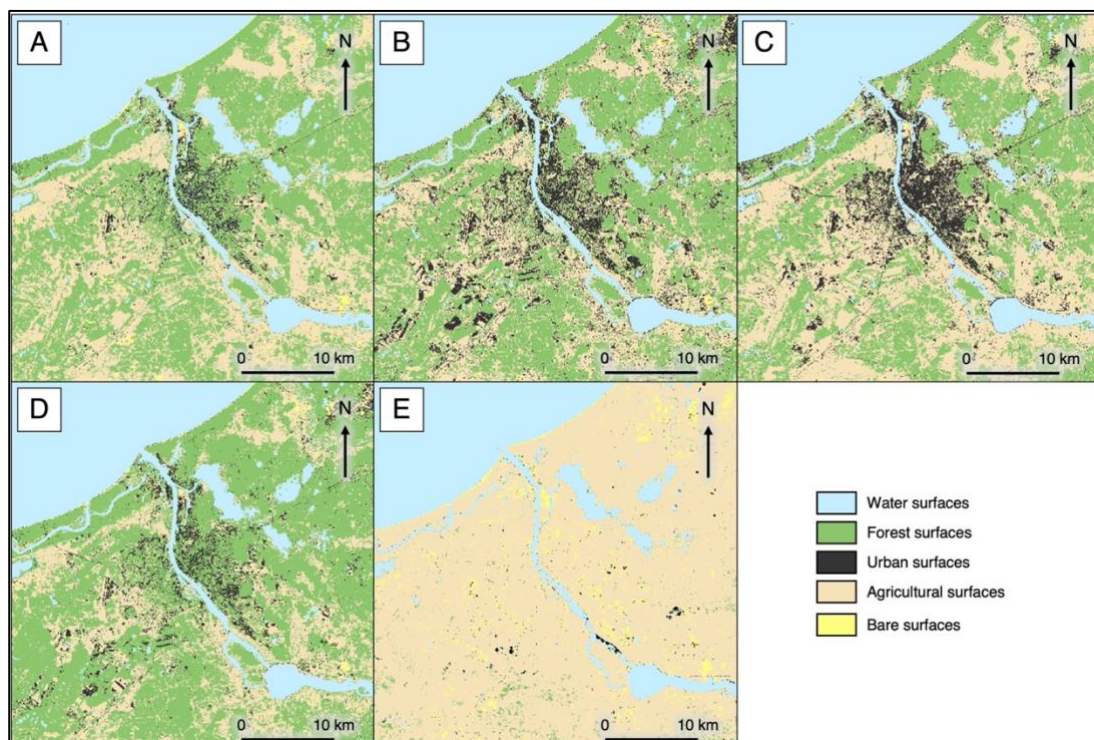
### 2.3.4 Post-processing

The common region of interest among the different scenes and dates covering the same study area is extracted based on the same WRS coordinates. The statistics obtained from the classifications are based on the same area and make it possible to compare land use between different years.

## 3. RESULTS

Based on the segment-based classifications, the statistics of the land use cover were produced for 1987, 1997, 2009, and 2020. The results obtained show a clear trend of the territorial transformations “footprinted” by the land use maps despite a variability of values obtained due to the spatial accuracy errors (see part 4. discussion). Maps are compared with maps from 1995 and 2015 from the Climate Change Initiative (CCI) Land Cover database of the European Space Agency (ESA) with a resolution of 300x300m. Compared to our land use classes focused on agricultural, forestry and urban areas, the CCI Land Cover





**Fig. 5 – Extracts of land use maps obtained using different supervised algorithms**

**Example of land use in the Riga region (Latvia) with (A) Fisher, (B) KNN, (C) Maximum Likelihood, (D) Minimum distance, (E) Parallelepiped classifications.**

databases also include other classes such as grassland, sparse vegetation, and wetlands.

### 3.1. Significant and distinctive trends towards coastal urbanisation

In Latvia, a clear dominance of urbanised areas can be observed in the zone closest to the shore (table 4). For example, in 2020, the urban areas represent 13% of the 0-25 km band compared to less than 5% for the 25-50 km, 50-75 km, and 75-100 km bands. In the same way, the CCI Land Cover databases show that in 2015, the rate of urban areas was 1.7% for the 0-25 km band compared to less than 0.5% for the other bands (table 4). The Latvian coast is “the most densely populated coastal area in the Baltics” with half of the country’s population concentrated there (Brunina et al. 2011; Pranzini, Williams, 2013). However, there are still relatively unoccupied areas with low building density, especially in the Gulf of Riga (Pranzini, Williams, 2013).

The results of classification indicate that one third of the coastal region is occupied by forests (table 4), although their area has decreased between 8 and 20% for the period 1987-2020. While the trend of decreasing forest area is confirmed by the CCI Land Cover databases (decrease between 6 and 10% for the period 1995-2015), the area of forests could be underestimated as it covers almost two-third of the coastal region. Indeed, according to CCI data, the proportion of forest area in each coastal strip varies between 57% and 70% in 1995 and between 51% and 66% in 2015 (table 4).

On the other hand, agricultural areas have increased slightly: the rates of changes are 3 to 9% between 1987 and 2020 compared with 10 to 13% for the CCI Land Cover databases for the period 1995-2015.

In Lithuania, urbanisation is the main geographic trend dynamic observed in the 0-25 km band and the 75-100 km band. Except

for the 1987 results, the urban areas vary between 7 and 15% from 1997 to 2020 in the 0-25 km and 75-100 km coastal bands compared to 2 and 6% in the 25-50 km and 50-75 km bands (table 5). The concentration of urban areas in the coastal region can be explained, in part, by the short length of the coastline – less than a hundred kilometres (Veteikis et al. 2011). However, the increase of urban areas between 1987 and 2020 took place outside the most coastal band (0-25 km). Surface covered have more than doubled for the 25-50 km, 50-75 km and 75-100 km bands, but it is difficult to have accurate statistics because of the large variability in values observed between these two years (table 5). Moreover, the same trend is visible with the CCI Land Cover databases for the period 1995-2015, which shows that the smallest increase is observed in the 0-25 km band (14% increase between 1995 and 2015 compared to 24-115% for other bands). In general, the coastal area has experienced less urban development than the rest of the country (48% growth for the coastal zone against 88% for the rest of the country between 1995 and 2015).

Forest cover has remained generally stable: the variation is between -1 and 2% for the bands between 0 and 75 km from 1987 to 2009 (2020 shows abnormally low data). The CCI Land Cover databases confirm this relative stability with evolution of 3 to 9% between 1995 and 2015.

For agricultural land, the classification results show a net decline of between 9 and 23% between 1987 and 2009 (the 2020 data is unusually high). The CCI Corine Land databases show the same trend but with much lower rates of change, 2-4% between 1995 and 2015. Both the classifications and the CCI Corine Land database show that the most significant decline is in the most coastal band.

**Table 4. - Share of land use classes by coastal zoning in Latvia with classification database (1987-2020) and CCI Land Cover databases (1995-2015)**

Segment-based classification results (1987-2020)					CCI Corine Land Cover Databases (1995-2015)							
Year	Coastal strip	Forest area	Urbanised areas	Agricultural land	Year	Forest area	Urbanised area	Agricultural land				
1987	0-25 km	37.14	11.69	33.78	1995	69.83	1.12	19.93				
	25-50 km	37.63	4.75	46.24								
	50-75 km	32.07	4.16	53.98								
	75-100 km	41.24	4.79	43.07								
1997	0-25 km	29.38	31.14	22.40								
	25-50 km	33.24	17.36	34.18								
	50-75 km	34.94	7.65	42.99								
	75-100 km	46.22	4.12	36.68								
2009	0-25 km	33.67	12.12	36.96								
	25-50 km	35.37	2.67	49.34								
	50-75 km	34.68	2.13	52.96								
	75-100 km	47.89	1.85	37.10								
2020	0-25 km	34.10	13.12	34.82					2015	65.63	1.74	22.61
	25-50 km	34.29	4.50	48.01								
	50-75 km	28.37	2.90	56.17								
	75-100 km	33.17	3.07	47.02								

**Table 5. - Share of land use classes by coastal zoning in Lithuania with classification database (1987-2020) and CCI Land Cover databases (1995-2015)**

Segment-based classification results (1987-2020)					CCI Corine Land Cover Databases (1995-2015)							
Year	Coastal strip	Forest area	Urbanised areas	Agricultural land	Year	Forest area	Urbanised area	Agricultural land				
1987	0-25 km	69.73	4.13	20.77	1995	28.46	2.11	59.30				
	25-50 km	75.30	1.04	21.36								
	50-75 km	77.04	0.58	19.57								
	75-100 km	19.04	3.04	74.17								
1997	0-25 km	62.21	15.33	17.29								
	25-50 km	69.12	6.72	19.77								
	50-75 km	70.52	6.84	17.91								
	75-100 km	19.14	11.47	62.43								
2009	0-25 km	71.14	10.07	15.95								
	25-50 km	74.90	3.59	19.24								
	50-75 km	78.04	2.01	17.23								
	75-100 km	22.18	9.32	64.58								
2020	0-25 km	75.56	7.12	14.68					2015	31.01	2.40	57.08
	25-50 km	30.25	6.14	57.04								
	50-75 km	31.66	5.80	53.76								
	75-100 km	19.48	10.33	66.10								

**Table 6. - Share of land use classes by coastal zoning in Kaliningrad Oblast with classification database (1987-2020) and CCI Land Cover databases (1995-2015)**

Segment-based classification results (1987-2020)					CCI Corine Land Cover Databases (1995-2015)				
Year	Coastal strip	Forest area	Urbanised areas	Agricultural land	Year	Forest area	Urbanised area	Agricultural land	
1987	0-25 km	22.80	7.11	58.28	1995	29.98	1.67	56.97	
	25-50 km	70.45	0.91	27.23					
	50-75 km	59.89	2.34	35.63					
	75-100 km	52.76	1.51	44.26					
1997	0-25 km	17.58	24.91	44.95		19.29	0.35	74.66	
	25-50 km	66.05	5.20	25.88					
	50-75 km	59.61	6.89	30.81					
	75-100 km	64.63	2.02	31.91					
2009	0-25 km	27.00	19.47	40.74		19.01	0.12	76.70	
	25-50 km	78.70	2.43	16.84					
	50-75 km	73.55	3.46	21.49					
	75-100 km	68.96	0.74	29.02					
2020	0-25 km	23.46	27.03	41.04		2015	36.95	3.32	48.56
	25-50 km	69.34	10.56	18.81					
	50-75 km	69.17	10.57	18.91					
	75-100 km	80.79	2.24	15.52					
						27.30	0.67	66.33	
						21.20	0.47	73.90	
						21.88	0.17	73.53	

In the Oblast of Kaliningrad, many urban areas are in the coastal strip. For example, the CCI Land Cover databases show that in 2015, the rate of urban areas was 3% for the 0-25km band compared to less than 0.6% for the other bands (table 6). The results of our classifications show the same trend, although the results fluctuate. In 2020, the urban area in the 0-25km band was more than double any other band (table 6). Indeed, more than 80% of the population of the Oblast lived in a coastal strip of about 50 km (Fedorov et al. 2017).

The most significant changes are realised in the strips near the coastline. Urban areas have almost doubled in the 25-50km band between 1997 and 2020. The CCI Land Cover databases show that this increase is highest in the 0-25km band between 1995 and 2015 (Table 6).

Agricultural lands have decreased between 4 and 15% from 1995 to 2015 according to the CCI Land Cover databases, while the decrease is measured between 30 and 65% over the period 1987-2020 according to our classification results.

Forests have increased in area by 23-42% between 1995 and 2015 according to the CCI Land Cover databases, while the variations range from -2 to 53% between 1987 and 2020 according to the classification results.

Clearly, the variability of the data produced from the oriented-object classifications (Table 6) prevents the proposal of robust conclusions. But the results show similar evolutions between the two datasets and are like those observed in Lithuania regarding forest and agricultural areas.

### 3.2. The evolution of land use, territorial development, and planning policies.

Results from land use classifications and CCI Corine Land Cover databases provide clear trends that highlight the importance of planning and development policies and their effectiveness.

The legislation during the Soviet Union, created in the early 1980s, aimed to control the “location of recreational places for the national economy objects and arrangement of such territories [...]”, thus allowing a balance between environmental protection and the development of economic activities (Nitavska, Zigmunde, 2013).

Since the restoration of independence, the legislative framework for environmental protection, especially in coastal areas, has evolved differently in the Baltic countries and the Oblast of Kaliningrad.

In Lithuania and Russia, we observed a stabilisation or increase of the forest cover, while in Latvia there has been a decrease in recent years (see section 3.1.). In the latter, this loss could be associated with “excessive exploitation of natural resources” caused by agricultural and forestry activities, despite considerable progress in environmental regulation, particularly since Latvia’s accession to the European Union (Kraus, Meyer, 1998; OECD, 2019). The natural protected coastal areas are also the main tool for environmental preservation, but the lack of management plans and insufficient funding limits the effectiveness; forestry contributes to more than 6% of Latvia’s GDP but only half of the country’s forests are certified for sustainable management, which is lower than the averages of other OECD countries with a high forest cover (OECD, 2019).

In Lithuania, natural processes such as reforestation of wetlands, mainly swamps, in part explain these results (Lekavičiūtė, Gadal, 2009). However, this growth of forest cover is mainly related to the forest “recovery” programmes: forestry companies engage in replanting when they clear land, which led to “forest management in Lithuania [...] rather intensive and sustainable during the last decades” (Lekavičiūtė, Gadal, 2009; Vaitkus, Vaitkuvienė, 2005; Veteikis et al. 2011). The forest growth has been at the expense of abandoned agricultural plots (Lekavičiūtė, Gadal, 2009).



This decline in agricultural land has been observed since the 1950s following policies of nationalisation and collectivisation of the land (Lekavičiūtė, Gadal, 2009). However, since the restoration of independence, the agricultural sector has lost a lot of its economic value: This has resulted in a decrease in the number of agriculture workers, and the abandonment of farms and land fields (Spiriajevas, 2014). In Lithuania and in the Kaliningrad Oblast, these dynamics are observed through remote sensing and the CCI Land Cover databases (Lekavičiūtė, Gadal, 2009; Veteikis et al. 2011).

The decrease in agriculture led to the development of second homes, which has resulted in the increase of urban areas in the coastal strip for the three countries (Spiriajevas, 2014). Most of the urban areas in Latvia and Russia are close to the coastline. Considering only the coastal zone, the classification data indicates that 48 and 63% of urban areas are concentrated in the 0-25km band in Russia and Latvia in 2020. In comparison, the CCI Land Cover databases show that this rate reaches 80 and 70% in 2015. This concentration is due to the presence of large cities like Riga, Jūrmala, Kaliningrad, and Baltiisk. While an increase in urban areas has been observed, spatial variations of this extension can be also observed.

The weak legislation due to “lack of definition of the main pressures on biodiversity” (OECD, 2019) could explain that urbanisation is spreading in the most coastal strip of Latvia and Russia, reflecting an “uncontrolled construction of buildings on the seashore, in connection with the development of tourism activities” (Kraus, Meyer, 1998).

Compared to the Oblast of Kaliningrad (Russia) where there is no independent legislation specific to coastal areas (the source of multiple conflicts of interest), the increase of urbanised areas in the most coastal strip in Latvia is less significant. It reflects the relative effectiveness of protected areas, present on half of the coastline, as a brake for urbanisation growth (Afanasyeva, 2014; Bass, 2015; Nitavska, Zigmunde, 2013).

However, the development of protective legislation has been eventful and has allowed “the illegal use of natural resources and quite often also degrading of natural territories”. Moreover, the entry into the European Union (2004) allowed the implementation of new planning legislation with the follow-up of European environmental directives (Brunina et al., 2011; Nitavska, Zigmunde, 2013).

In contrast, the increase of urbanised areas is mainly located outside the 0-25 km band in Lithuania (see section 3.1.) with a regular and continuous growth, showing a “well-developed legal basis for the spatial planning” in this country (Vaitkus, Vaitkuvienė, 2005; Veteikis et al. 2011). In general, the Lithuanian legislation is well developed in giving priority to the protection of natural coastal processes and landscapes (Gulbinskas et al. 2009; Spiriajevas, 2014; Žilinskas, 2008).

Several laws define the management and use of coastal zones of Lithuania. The Law of Coastal Strip (2002) is based on the principles of sustainable development: the development of economic activities while ensuring the protection of the environment and exploited natural resources (Žilinskas, 2008). The aim is to limit construction within a hundred-metre strip from the coastline and to regulate work on properties, their renovation and restoration; the coasts are state property whose anthropic activities must be regulated (Spiriajevas, 2014).

Another important law is the Law on Spatial Planning (1995). It aims to protect emblematic landscapes and biodiversity, as well as cultural and natural heritage by promoting “sustainable development” and “reasoned urbanisation” of the Lithuanian territory. This law defines the compatibility of the various urban

planning documents and the “requirements of the decision of territorial planning process” (Gaudėšius, 2015).

In the South-East Baltic countries, the implementation of specific legislation for coastal zones has been influenced by the development of international strategies and programmes such as: the Helsinki Convention (definition of environmental protection objectives), or the recommendation of the European Parliament and the European Council concerning the implementation of Integrated Coastal Zone Management, which implies an articulation of the different planning tools and documents between multiple actors and scale of intervention (Gulbinskas et al. 2009).

## 4. DISCUSSIONS

### 4.1. Limitations of coastal zone management policies

In Lithuania, the environmental protection laws are considered too restrictive for the economic activities in protected areas (Spiriajevas, 2014). Planning policies based on “integrated” management are difficult to apply when public and private interests are divergent, especially in unprotected areas of the coastline such as in Giruliai or Melnragė (Lithuania), where the interests of private landowners override existing national and local legislation (Spiriajevas, 2014).

These policies require significant financial, technical, and human resources to be fully effective, but these are currently still insufficient (Žilinskas, 2008).

For example, former military sites and collective farms were privatised in the early 1990s in Latvia with independence. In the absence of management strategies, there have been many cases of abuse. Insufficient funding did not allow the state to acquire these lands, which were degraded despite providing minimal environmental protection during the Soviet period (Brunina et al. 2011; Nitavska, Zigmunde, 2013). In Lithuania, expenditure to preserve coastal dunes amounts to almost 15000 euro per kilometre of coastline and justifies limited action on critical sections only (Spiriajevas, 2014).

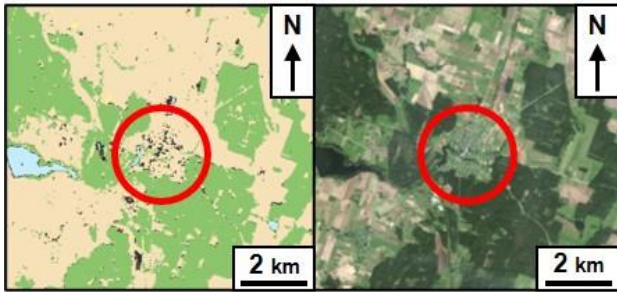
Similarly, in Russia, the lack of funding leads to an increasing number of human settlements that are now vulnerable to erosion, for example (Burnashov, 2011).

### 4.2. Limits of supervised classification by GEOBIA approach

The main analysis of the dynamics of the coastal changes was made using remote sensing and the CCI Land Cover databases.

Numerous spatial accuracy errors were identified due to the use of automated processing to carry out the land use classification. The spatial accuracy errors identified are at the origin of significant variations in the results of land use cartographies and statistics generated despite Kappa indices greater than 0.90. These data do not allow us to determine the fine impact of the end of the Soviet system on the evolution of land use, especially in the first years after independence.

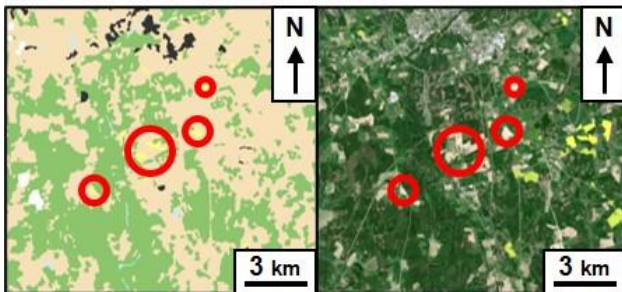
These errors of accuracy to the land field reality are linked to difficulties in identifying certain land use classes, particularly the smallest urban entities (villages) and suburban residential areas because of the Landsat 5 TM and Landsat 8 OLI spatial resolution of 30x30m (fig. 6).



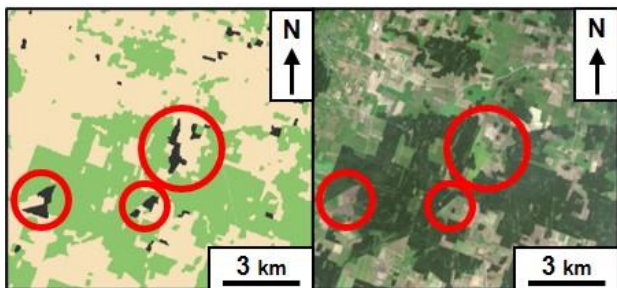
**Fig. 6. - Difficulties in identifying the village of Darbėnai (Lithuania).**

The spatial resolution of the Landsat 5 TM satellite images limits the level of detection of isolated habitats not covering an area of 900m<sup>2</sup>. The use of the panchromatic band with a resolution of 15m of Landsat 8 OLI images can improve the spatial accuracy level of the urban areas. However, to standardise the processing and the comparability of the land use produced among the dates, pansharpening (fusion of multispectral data of 30m with the panchromatic band of 15m spatial resolution), possible only with Landsat 8 OLI data, was not applied.

Despite the use of remote sensing data in the chlorophyll optimum (spring and summer) for the improvement of the spectral separability among geographic objects such as the urban areas and agricultural lands, spectral confusions persist. They are visible between bare soil and some agricultural plots (fig. 7), between some agricultural plots and urban areas (fig. 8) and between some forest and agricultural plots.

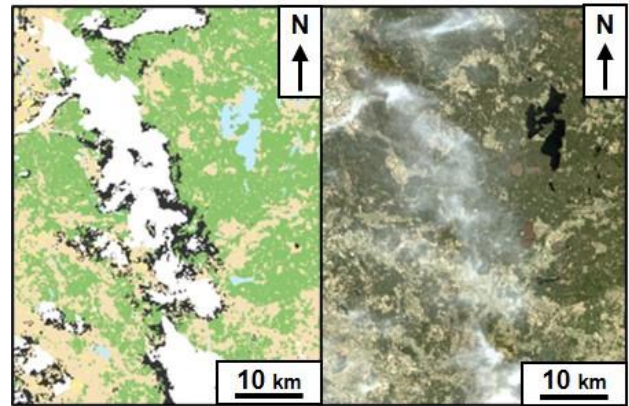


**Fig. 7. - Spectral confusions with agricultural plots considered as bare soil.**



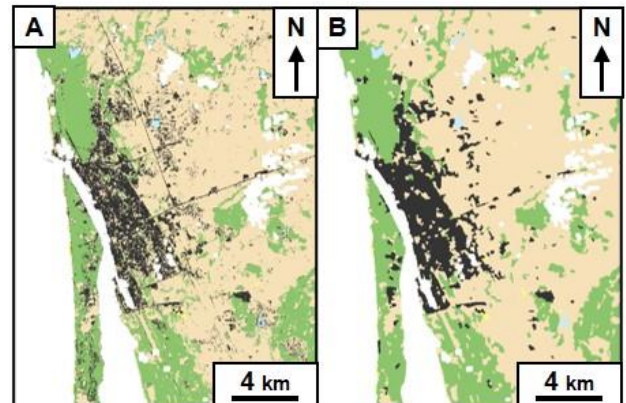
**Fig. 8. - Spectral confusions with agricultural plots considered as urbanised areas.**

The use of the F-Mask algorithm was not sufficient to eliminate the cloud cover from the satellite images. The clouds and their shadows are the cause of multiple spectral confusions with urbanised areas, which are overestimated on certain dates of satellite image acquisitions (fig. 9).



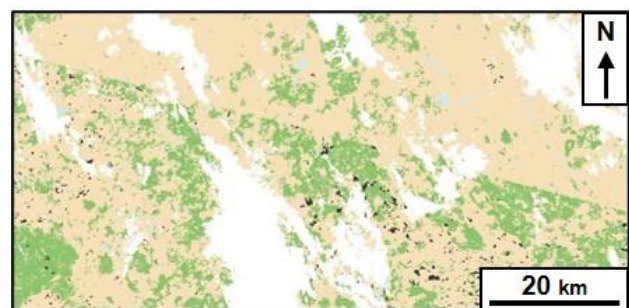
**Fig. 9. - Incomplete removal of cloud cover in supervised classification.**

The choice of segment-based classification with the use of a majority rule algorithm to smooth the results in segments causes a significant loss of information for certain land use classes such as urban areas for example especially in peri-urban areas (fig. 10).



**Fig. 10. - Segmentation effects on supervised classifications.**

Furthermore, despite the use of Landsat level-2 satellite images, the differences linked to the radiometry and the atmospheric properties of the satellite images did not allow for a homogeneous radiometric result (fig. 11), making it difficult to discriminate and detect each type of geographical object.



**Fig. 11. - Differences between atmospheric and radiometric properties of two separate Landsat scenes.**

## CONCLUSIONS

The study of the land cover changes between 1987 and 2020 in the coastal regions of the countries of the South-Eastern Baltic Sea has highlighted a generalised phenomenon of coastalisation, characterised by the progressive concentration of population and economic activities on the coastal zone, especially since the end of the Soviet Union.

We performed classifications based on the Maximum Likelihood classifier after comparing the performance of different supervised classification methods for the years 1987, 1997, 2009 and 2020 from Landsat 5 TM and Landsat 8 OLI satellite images archives. The use of the majority rule algorithm produces segment-based classifications for a more accurate representation of landscape features. The results were compared with the CCI Land Cover databases from 1995 and 2015.

They showed a stabilisation in agricultural areas in Latvia but a decline in Lithuania and in the Kaliningrad Oblast, which is associated with the privatisation of land and the decreasing economic interest in agriculture.

Economic activities related to tourism and the naval industry have benefited from the intensification of international trade caused by the transition to a liberal system. This movement has gone hand in hand with significant development of urbanised areas characterised by peri-urbanisation through the appropriation of second homes, workers' housing, or the development of illegal buildings.

The natural areas such as forest areas grew, and they are dependent on the implementation of management and protection policies to safeguard them. The protection policies and implementations may differ among each Baltic state and the Oblast of Kaliningrad (Russia) due to the legislative, technical and legal "vacuum" after the end of the Soviet Union. This "vacuum" has been resolved thanks to the accession to the European Union; but also, by the following of several international conventions and directives promoting sustainable development, reconciling environmental protection and economic activities: The Helsinki Convention, Recommendation of the European Parliament and of the Council on Integrated Coastal Zone Management, etc..

Finally, this study has highlighted the usual limits of automated remote sensing techniques which reveal problems in the recognition and detection of certain geographical objects, spectral confusions and errors related to the processing of images with different radiometric and atmospheric properties, etc. Segment-based classifications reflecting a GEOBIA approach show limits in terms of modelling the smallest urban entities (peri-urban housing, secondary houses, allotments, etc.). This method will undoubtedly demonstrate its relevance with the use of satellite images with a resolution of about ten metres, such as the Sentinel 2 MSI images.

## ACKNOWLEDGEMENT

This research is supported by the CNES AICMEE TOSCA program (Apport de l'Imagerie satellitaire Multi-Capteurs pour répondre aux Enjeux Environnementaux et sociétaux des socio-systèmes urbains).

## REFERENCES

Afanasyeva EP (2014) Characteristics of tourism development in the coastal areas of the Kaliningrad region. *Journal of Regional Studies* 18.

- Aubin L (2013) Le tourisme russe à Jūrmala : l'appropriation territoriale de la périphérie balnéaire de Riga. Regards sur l'Est. <http://regard-est.com/le-tourisme-russe-a-jurmala-lappropriation-territoriale-de-la-peripherie-balneaire-de-riga>. Accessed 15 Jun 2021
- Bass O (2015) Modern conception of coastal protection and problems of hydraulic engineering in Kaliningrad region. *Vestnik IKBFU* (1).
- Bitinas A, Žaromskis R, Gulbinskas S, Damustyė A, Žilinskas G, Jarmalavičius D (2005) The results of integrated investigations of the Lithuanian coast of the Baltic Sea: geology, geomorphology, dynamics, and human impact. *Geological Quarterly*, 49 (4), pp. 355-362.
- Brunina L, Rivza P, Konstantinova E (2011) Coastal Spatial Planning Problems in Latvia. *Journal of Coastal Research*, pp. 1224-1227.
- Burnashov E (2011) Current coastal dynamics in the Kaliningrad region, base on annual monitoring surveys. *Issues of modern science and practice*. Vernadsky University. IV Vernadsky (2), pp. 10-17.
- Chen G, Weng Q, Hay G, He Y (2018) Geographic object-based image analysis (GEOBIA): emerging trends and future opportunities. *GIScience & Remote Sensing*. pp. 159-182
- Eaglet V (1999) Environmental problems of the Baltic Sea and the Kaliningrad region.
- European Space Agency Climate Change Initiative, Land Cover project (2017) 300 m Annual Global Land Cover Time Series from 1992 to 2015. Retrieved from <https://www.esa-landcover-cci.org/?q=node/175>
- Fedorov G, Kuznetsova T, Razumovskii VM (2017) How the proximity of the sea affects the development of economy and the settlement in Kaliningrad Oblast. *Regional Research of Russia*, 7 (4), pp. 352-362.
- Gadal S (2010) Urban dynamics in Kaliningrad and Klaipėda coastal regions by remote sensing and GIS. *Bridges/Tiltai*, 0 (1).
- Gaudėšius R (2015) Influence of General Plans on Urbanization of Agrarian Territories on Lithuania's Seaside. *Environmental Research, Engineering and Management*. 71 (4), pp. 19-27.
- Gulbinskas S, Suzdalev S, Mileriene R (2009) Coastal management measures in Lithuania Baltic coast (South-eastern Baltic). *Coastal Engineering 2008: (In 5 Volumes)*, pp. 4042-4052.
- Kraus H, Meyer T (1998) Environmental Policy in Latvia. European Parliament.
- Lekavičiūtė J, Gadal S (2009) Forest Cover Changes during 1975-2005 in the Lithuanian Coastal Region. *Rural Development 2008*. 241.
- Nitavska N, Zigmunde D (2013) The impact of legislative rules and economic development on the coastal landscape in Latvia. *Civil Engineering*'13, 259.

- OECD (2019) OECD Environmental Performance Reviews: Latvia 2019 (short version). OECD Environmental Performance Reviews, OECD Publishing.
- Pranzini E, Williams A (2013) Coastal Erosion and Protection in Europe. Routledge.
- Spiriajevas E (2014) Hindrances and suggestion for sustainable development of Lithuanian Coastal Strip (Zone). Regional Formation and Development Studies. 6 (1), pp. 125-136.
- Vaitkus G, Vaitkuvienė D (2005) Land cover changes in the Lithuanian coastal zone during 1975-2000. Acta Zoologica Lituanica. 15 (2), pp. 183-187.
- Veteikis D, Šabanovas S, Jankauskaitė M (2011) Landscape structure changes on the coastal plain of Lithuania during 1998-2009. Baltica. 24 (2), pp. 107-116.
- Žilinskas G (2008) Distinguishing priority sectors for the Lithuanian Baltic Sea coastal management. Baltica. 21 (1-2), pp. 85-94.