LACOAST ATLAS: A CONSISTENT DATABASE TO SUPPORT SUSTAINABLE COASTAL ZONE MANAGEMENT

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Abstract – The European Union Demonstration Programme on Integrated Management in Coastal Zone (1999) addresses most problems of the coastal areas to the criticalities of policies, planning and procedural tools, deriving from an overall lack of awareness about the economic, social and strategic importance of coastal zones sustainable management. Moreover, in Europe it is difficult to assess unique coastline definitions. In some countries the coastline coincides with administrative limits of the country, in others is a physical limit dictated by sea level fluctuations. The paper illustrates the LaCoast Project (LAnd cover changes in COASTal zones), a harmonised and consistent geo-referenced database that constitute a base tool for integrated spatial analysis of policies. It is meant to support sustainable management of the coastal areas trough the collection of information about their state and the impact of anthropic activities on them. The aim of the project ad its tools is assisting the development of tailored European policies for coastal zone management to be used both at regional and national level. LaCoast objectives were quantifying the changes of land cover for the European coastal zones, providing information to develop environmentally related indicators for the European Environment Agency and foster the use of earth observation data for operational use of vast area management.

The LaCoast Atlas data was gathered thanks to the efforts of an international team that in addition to performing the selection of similar Spectral Bands composition images from Corine Land Cover databases, followed by a geometric correction of Landsat images also performed a quality control process checking the completeness, geometry and topology of data. The investigation also dealt with the changes happening to the coastline and coastal zone, building a matrix of changes to evaluate land cover class changes for the investigated areas. Quantitative and qualitative information about land cover changes and their nature is meant to provide useful indicators to assist European coastal zones management and to support decision-making. LaCoast Atlas offers an overview of both spatial distribution and extension of coastline changes, sided by statistical analysis that quantify coast changes and their nature.

Important indicators for coastal zone sustainable management can be extracted from the data collected in the atlas, to assess land use thanks to the integration of protection of nature information, socio-economic information and administrative data. Land cover changes analysis is fundamental and instrumental to forecast trends and tendencies of future land use.

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Introduction

The most important requirement for sustainable management of coasts and coastal areas is having information about the state of such areas, in addition to an archive of the consequences and effects of anthropic impact on them. Use of land and its cover change over time and space, influencing and being reciprocally influenced by human-environment interactions, climate change, socio-economic changes and even changes in biodiversity. Many types of land uses are pressing on coastal zone nowadays, therefore investigating land change processes and identifying root causes and motives leading to landscape transformation is particularly relevant. As shown by history, anthropic use and human processes have transformed and affected coastal areas during the development of humanity, up to the point that coasts have been instrumental for development of society. This is due to their importance in food production, biodiversity preservation and nature protection, in addition to their relationship with the job market throughout history, economic growth, groceries production and all sea-related activities such as fishmongering, mobility, commerce.

The dynamics of coastal areas were influenced by human presence and activities, mostly by the introduction of elements of disturbance such as infrastructure and urban development, excessive exploitation of resources. These dynamics compromised the evolution of coastal zones, resulting in many cases in the disruption of coastal habitats and their capacity to perform basic functions.

On the one hand, to understand the changes that coastal areas have undergone it is fundamental to assess land use and changes in land cover. On the other, understanding these processes are fundamental to predict scenario changes in the future and transformations of coastal zones. To achieve this is fundamental to have a standardized, harmonized and mostly geo-referenced database for land cover and use, providing an accurate representation of the happening phenomena and usable statistics to design such scenarios.

Aim of the LaCoast Project and Project Organization

The LaCoast Project (LAnd cover changes in COASTal zones) is a harmonised and consistent geo-referenced database that constitute a base tool for integrated spatial analysis of coastal areas development policies. It is meant to be used at local, national and European level to provide assistance in the development of European shared policies. The main aims of the project are:

- Quantify land cover changes that have affected the European coastal zones;
- Contributing to the European Commission demonstration Programme on Integrated Management of Coastal Zones (IMCZ), covering the coastal changes of the last decades;
- Support and integrate the reporting activities of the European Environment Agency (EEA), laying the base for deriving environmental indicators and trend indicators for land use change;
- Promote the use of observation and georeferenced data during scenario predictions for large areas.

The Agriculture and Regional Information System Unit (ARIS) and the Space Applications Institute of the European Joint Research Centre (SAI JRC) coordinated the project, involving National Teams for local surveys and data collection. Belgium, Denmark, France, Germany, Greece, Italy, Ireland, Netherlands, Portugal and Spain have taken part to the project with national and regional teams, in addition to national institutions and Universities supporting the project itself.

The presence of multiple teams from different backgrounds required for a standardized methodology and harmonized processes, information standards and definitions, in addition to accurate quality control at every step and sub-step of the database generation process. To overcome this challenge, the Joint Research Centre provided an initial training to all local teams with the purpose of integrating national results with the European database and its quality control.

Coastal Zones

Coastal zone definition varies according to the reference framework, be it a different nation or administration. From time to time, coastline and coastal zones are ruled by administrative and physical limits or in some cases are affected by fluctuations of sea level. Therefore, aiming to a shared and standard definition, the workgroup agreed on the definition provided in the GISCO database for coastal erosion. Since the LaCoast project focuses on the land portion of the coastal areas, its boundaries needed to be defined, hence determining the width of the landstrip to take into account for the database building. To achieve this, 1 km wide buffers were determined following the Corine Land Cover (CLC) Level 1 items, ranging from 0 to 20 km from the coastline. These study buffers have been confronted with the CLC database, calculating its coverage percentage. The evolution of surface percentage occupied by coastal areas in the study framework is depicted in the following Figure 1.

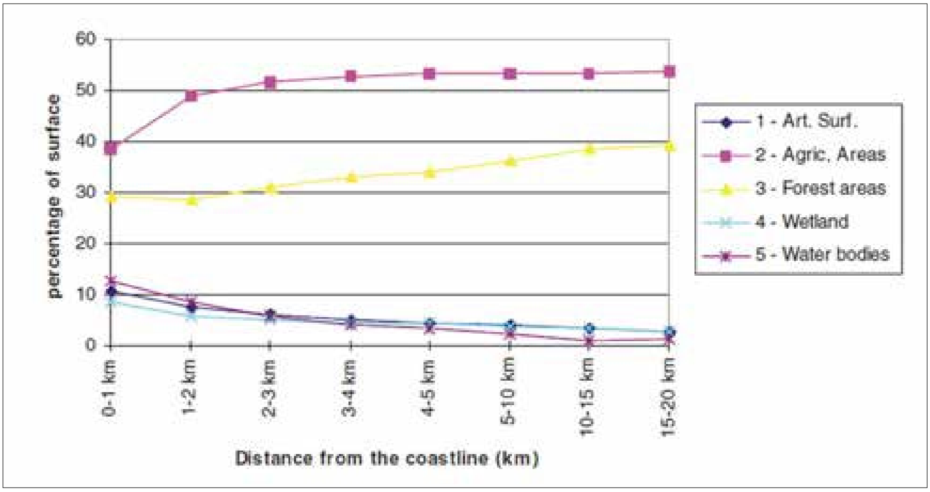

Figure 1 - Changes in land cover in relation to distance from the coastline [13].

Taking into account the outcome of this initial investigation, for the sake of building the LaCoast Atlas it was agreed to consider as coastal area a 10 km wide strip starting from the coastline. The choice is motivated by the relative consistency of land use classes percentages over this distance from the coastline. In addition to this, given the parametric costs calculated at the onset of the project, setting the sharp 10 km limit contributed in keeping the costs and information need under control, going in the direction of keeping in check the overall cost of the project.

Drawing useful elements from the above paragraph, the final definition of LaCoast Coastal Zone is “the land surface included in a 10 km wide strip from the coastline”.

Data Collection

Multiple data sources have been combined to constitute the LaCoast Atlas database. The three main sources were the Corine Land Cover (CLC) Database, Earth Observation Data acquired through satellite images and available MSS Landsat data. Additional details regarding how each data type has been selected and used is provided in the following paragraphs.

Corine Land Cover Database

The Co-ordinate of Information on the Environment (CORINE, CLC in short) programme started in 1985 thanks to the joint efforts of the European Council and the European commission. Its scope was the gathering and coordination of information regarding the state of the environment and natural resources to ensure its consistency and usability.

Building this data with a homogenous methodology resulted in comparable and consistent data about land cover. All data collected in the CLC Database is geo-referenced and collected in a three-level hierarchy. Land Cover and land use is categorized under forty-four different types, and represented with the minimum scale of 1:100.000 in 25 ha unit plots. The CLC Database was built deducting the land use from satellite images and compiled between 1985 and 1995.

On top of providing the Land Cover data as a reference, LaCoast Atlas uses a similar data output and representation methodology, consistent with the CLC data, to map the changes. In addition to the CLC Database, Earth Observation Data and Landsat spectral images have had an instrumental role in building the LaCoast Atlas. Images captured by satellites cover large areas, defining the spectrum and cover consistency of land zones and are particularly useful when dealing with wide areas such the ones object of study [3; 6; 8; 9]. Taking into account that the first pictures obtained throughout the Landsat Multi-Spectrum Scanner are from 1975, it was possible to investigate images for a 20 year span, analysing the progressive changes in land cover. Nevertheless, investigating a large time window not only allowed to cover the entirety of the study areas, but also to have multiple progressive images of certain zones. If on the one hand the Landsat MSS images provided important information for Coastal Zones Land Cover Changes determination, on the other hand difficulties have been encountered by the research team due to discrepancies and asymmetries in the image quality. It was estimated that about 20 % of the images provided by the Landsat MSS were compromised (e.g. by the presence of clouds of obstacles) and/or lacking in quality to properly assess land use.

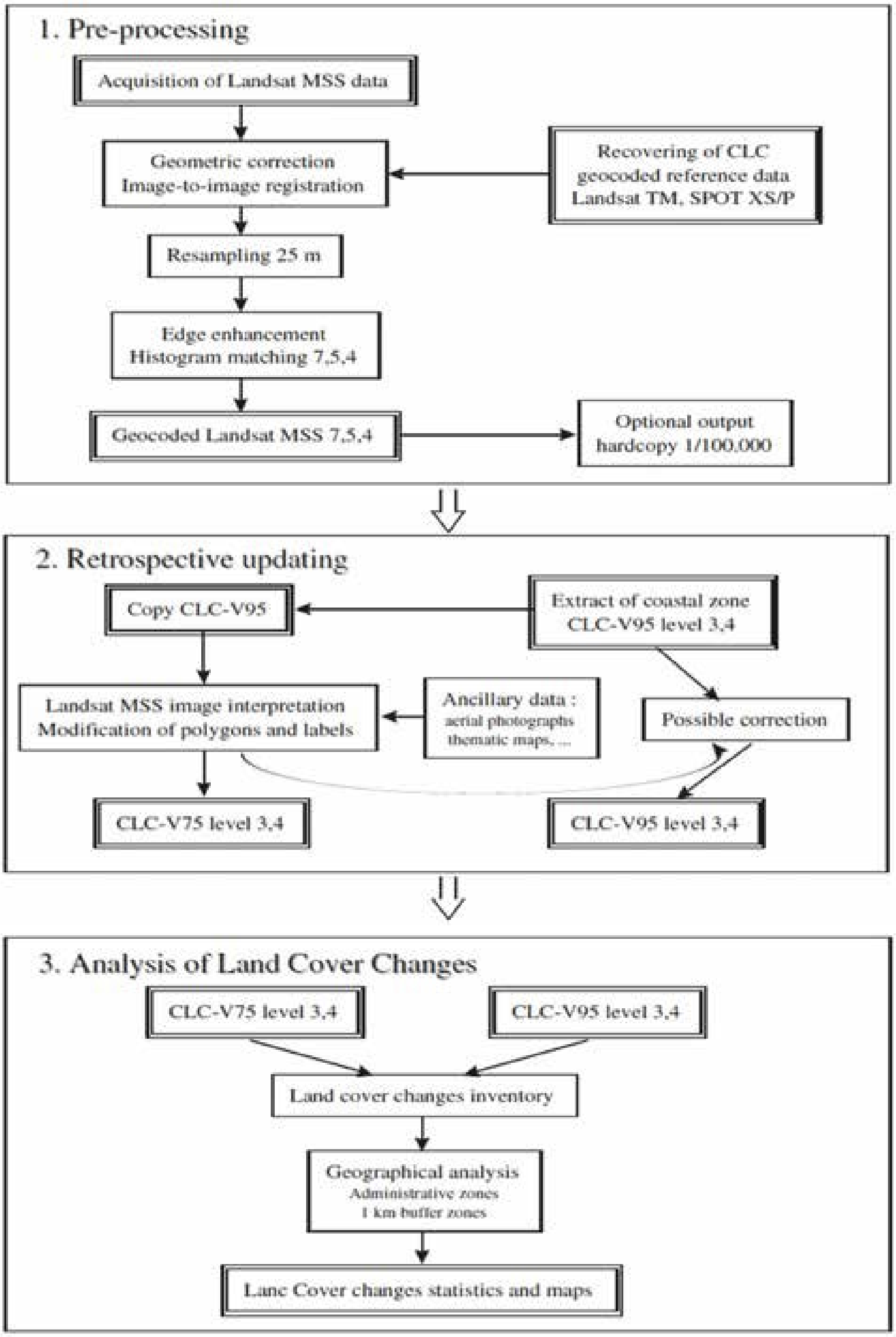

Figure 2 - Land Cover Changes analysis method [13].

Data Interpretation and Database building methodology

Given the large amount of images involved in the investigation and the difficulty in assessing whether changes appearing in the images were due to researchers' interpretation or actual change, the research group needed a shared and agreed definition for the subject of study: changes in land cover for coastal areas. This definition was particularly important considering the multiple sources of information. To use a shared definition of Coastal Zones changes, interpretations and transformation of the source data was needed to use them and compare:

- Selection of comparable composition of spectral bands: throughout the different origin databases, selected spectral bands were selected. Channel 7, 5, 4 for the Landsat MSS images and channels 1, 2, 3, 4, 5 for CLC Landsat and SPOT XS Images;
- Geometric correction of Landsat MSS Images: all images have been resampled to the same standard to obtain comparable images, using convolution transformations to make all images comparable with reference satellite data;
- Histogram Matching: the color composition histograms of all images were compared and aligned, using the MSS images as reference.

The identification of changes was performed with a direct comparison of the same grid unit images from different years, normalized in the previous steps. Every pixel of the images – equivalent to a twenty-five by twenty-five meters plot – was compared to assess land use, drawing useful elements to analyze its changes in time. As reported above, the outcomes of this interpretation and evaluation steps are categorized according to the CLC Database standards and validated in an iterative process by the various local research team, integrating were needed or data was misinterpreted. The final assembly of data and comparison of the outcome of every team was performed by the JRC, which also performed a quality and consistency control on the whole database. The pre-processing, updating and analysis of data is summarized in Figure 2.

Development of Database nomenclature standard

As mentioned above, the nomenclature standard of the LaCoast Atlas derives from the CLC Database, aiming to maximize the consistency of land cover category identification over time. The nomenclature standard is based on the following criteria:

- Scale of the map;
- Base map unit;
- Source data origin (i.e. satellite data)

In addition to all of the above, additional requirements have been integrated in the nomenclature, such as forbidding the use of the "unclassified" category and/or nomenclature terminology that may result ambiguous (also due to possible translation and language bias). Moreover, the nomenclature system has the additional requirement of being simple to read but exhaustive. The result of this nomenclature definition work is a three levels system, each composed of multiple items.

Level 1

This level of nomenclature defines the larger area at a global study level. It is composed of five items.

1. Artificial surfaces
2. Agricultural areas
3. Forest and semi-natural areas
4. Wetlands
5. Water bodies

Level 2

The second level, hierarchically subject to Level 1, is composed of 15 items and is used at the working scales of 1:1.000.000 and 1:500.000.

1. Urban fabric
2. Industrial, commercial and transport units
3. Mine, dump and construction sites
4. Artificial non-agricultural vegetated areas
5. Arable land
6. Permanent crops
7. Pastures
8. Heterogeneous agricultural areas
9. Forests
10. Shrub and/or herbaceous vegetation clusters
11. Open spaces with little or no vegetation
12. Inland wetlands
13. Coastal wetlands
14. Inland waters
15. Marine waters

Level 3

The third hierarchical level of the nomenclature system includes 44 items and is used at the smaller working scale of 1:100.000.

1. Continuous urban fabric
2. Discontinuous urban fabric
3. Industrial or commercial units
4. Road and rail networks and associated land
5. Port areas
6. Airport areas
7. Mineral extraction sites
8. Dump sites
9. Construction sites
10. Green urban areas
11. Sport and leisure facilities
12. Non-irrigated arable land
13. Permanently irrigated land
14. Rice fields
15. Vineyards
16. Fruit trees and berry plantations
17. Olive groves
18. Pastures
19. Annual crops associated with permanent
20. Crops
21. Complex cultivation patterns
22. Land principally occupied by agricul- ture with significant areas of natural
23. Broad-leaved forest
24. Coniferous forest
25. Mixed forest
26. Natural grassland
27. Moors and heathland
28. Sclerophyllous vegetation
29. transitional woodland shrub
30. Beaches, dunes and sand plains
31. Bare rock
32. Sparsely vegetated areas
33. Burnt areas
34. Glaciers and perpetual snow
35. Inland marshes
36. Peat bogs
37. Salt marshes
38. Salines
39. Intertidal flats
40. Water courses
41. Water bodies
42. Coastal lagoons
43. Estuaries
44. Sea and ocean

For the sake of readability and simplicity of use – also by non-technical members of the project organization - it was decided to have a non-relational hierarchical nomenclature system organization, with every level branching into the next one. Table 1 summarizes and explains the hierarchy of levels and items.

Table 1 - LaCoast Atlas Nomenclature structure [13; 14]

Level 1	Level 2	Level 3
1. Artificial surfaces	1.1. Urban fabric	1.1.1. Continuous urban fabric
	1.2. Industrial, commercial and transport units	1.1.2. Discontinuous urban fabric
	1.3. Mine, dump and construction sites	1.2.1. Industrial or commercial units
	1.4. Artificial non-agricultural vegetated areas	1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.4. Airport areas
		1.3.1. Mineral extraction sites
		1.3.2. Dump sites
		1.3.3. Construction sites
		1.4.1. Green urban areas
		1.4.2. Sport and leisure facilities
2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land
	2.2. Permanent crops	2.1.2. Permanently irrigated land
	2.3. Pastures	2.1.3. Rice fields
	2.4. Heterogeneous agricultural areas	2.2.1. Vineyards
		2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
		2.3.1. Pastures
		2.4.1. Annual crops associated with permanent crops
		2.4.2. Complex cultivation patterns
		2.4.3. Land principally occupied by agriculture with significant areas of natural
3. Forests and semi-natural areas	3.1. Forests	3.1.1. Broad-leaved forest
	3.2. Shrub and/or herbaceous vegetation associations	3.1.2. Coniferous forest
	3.3. Open spaces with little or no vegetation	3.1.3. Mixed forest
		3.2.1. Natural grassland
		3.2.2. Moors and heathland
		3.2.3. Sclerophyllous vegetation
		3.2.4. transitional woodland shrub
		3.3.1. Beaches, dunes and sand plains
		3.3.2. Bare rock
		3.3.3. Sparsely vegetated areas
		3.3.4. Burnt areas
		3.3.5. Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1.1. Inland marshes
	4.2. Coastal wetlands	4.1.2. Peat bogs
		4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats
5. Water bodies	5.1. Inland waters	5.1.1. Water courses
	5.2. Marine waters	5.1.2. Water bodies
		5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean

To deal with the complexity of land use during data survey – while at the global scale the aforementioned nomenclature was considered a standard – local teams working a smaller scale could use additional levels and items for their own data processing purposes.

The additional levels 4, 5 and 6 also had requirements:

- Every new sub-level and item had to be a sub of an already existing item;
- Every new item must be related to only one upper level item;
- Every new item has to identify an unambiguously discernible land use item and be understandable based on satellite images.

For example, many local teams decided to create additional items to distinguish between sport-aimed and leisure-aimed within “Green Urban Areas”.

Quality Assessment Process

Quality assessment of the source and output data was performed on two levels. First at local level by the single teams, then at a global, consistency level by the JRC. The scope of the quality assessment is checking the geometry, topology, completeness and consistency of provided data. The quality assessment process also included the definition of a matrix of land cover changes. This matrix was investigated thoroughly to verify the statements on land cover changes over time, excluding the less probable items.

Project challenges

During the development of the LaCoast Atlas, the research team encountered some challenges. These are mostly related to output data consistency and geometric accuracy at the base of image interpretation.

Harmony and consistency of product output

Difficulties were encountered in the definition and formulation of the atlas, given its pan-European and international coverage. Most of this difficulties and criticalities were caused by misinterpretation of source data and metadata of the satellite images. Minor issues were also caused by differences in the reference systems adopted for certain image analysis by the teams and by local data policies.

These generated a series of issues of image interpretation impacting some steps of the workflow, leading to sub-par outcome of certain analysis. After the iterative process of analysis, review and improvement of the output data, in some cases sub-optimal products have been accepted due to logistic, financial or time constraints. Additional rework of data would have impacted time and monetary resources more than including un-optimized data.

Accuracy of geometry data

The LaCoast Atlas is based on satellite images and projections that vary immensely in scale, ranging from entire continent projections to smaller scale detail images. At the larger scales, equal area projections are traditionally used: it is assumed that planet Earth is spherical, with non-appreciable discrepancies from the actual situation at the working scales of 1:1.000.000 and 1:500.00. Given the fact that LaCoast also operates with 1:100.000 cartography and images, the methodology used to determine large area maps becomes an issue. Due to this discrepancies, the team encountered difficulties in comparing statistical analysis done at different scales, as not all investigated areas had detailed material and images available.

Results

The LaCoast Atlas provides quantitative information regarding land cover changes over time and the nature of land cover on coastal zones. This information is at the base of management and decisional processes for territorial administration [1; 2; 4; 5; 11].

The information is presented in a database whose data is available through the means of queries. The query results provide at first glance an outline of the land cover changes in time. An example of query result is presented in Figure 3.

Area	Perimeter	Polygon-ID	CLC4-V75	CLC4-V95	country code	province code	Commune code	Distance
			2110	1330	4	41	412	2000

Figure 3 - Example of the LaCoast Atlas database structure [13].

In addition to database building, the team performed statistical analyses on the available data to understand in numerical terms the changes happened in coastal zones in the recent decades [6; 7]. These analyses were performed on the whole European coastal area including small islands. LaCoast Atlas offers an overview of both spatial distribution and extension of coastline changes, sided by statistical analysis that quantify coast changes and their nature.

Important indicators for coastal zone sustainable management can be extracted from the data collected in the atlas [12], to assess land use thanks to the integration of protection of nature information, socio-economic information and administrative data. Land cover changes analysis is fundamental and instrumental to forecast trends and tendencies of future land use. Statistical data represents the changes at levels 1, 2 and 3 of the LaCoast/CLC nomenclature database.

Changes in land cover are observed at all three levels of the standard LaCoast nomenclature structure, assessing both the changes happening in major (item) categories and in their sub-items. The changes are expressed both in absolute and relative units, with the latter represented by the ratio between the total land cover surface and the surface impacted by change. Observing the LaCoast Atlas data, most of the land cover change is observed at level 2. Change percentages at this level are generally three times higher in comparison to level 1.

Taking into account the outcomes of the study, Agricultural areas are by far the prevalent land use of the analyzed area. In addition to this, their changes are the biggest happening in the investigated period, with many of these territories changing between cultivation and arable land multiple times. In certain cases – such as the Netherlands territories – not only the land use changes, but due to the construction of new ridges and canals, new water bodies and greenfield land are determined by anthropic actions.

Artificial surfaces are the largest growing item in land use, observable mostly at regional and national scale rather than local. The average annual rate of land cover tends to be low, but when observed at the national level, coastal zones cover by urban fabric increases drastically.

Land change over time for coastal zones is summarized in Figure 4, that groups land cover classes and provides indicators to determine trends in land cover changes. The table matches the geometric units of the database, indicating their extension and the specific extension of every item in said units.

LaCoast Atlas data has also been associated with socio-economic data to further analyze the trends of changes in coastal zones, identifying how land use change and socio-economic conditions have effected land cover. The results of the study have been used also both at international and local level. For example, the European Environment Agency used the LaCoast database to build reports on the state of the European environment, while local authorities have used the database for coastal management purposes.

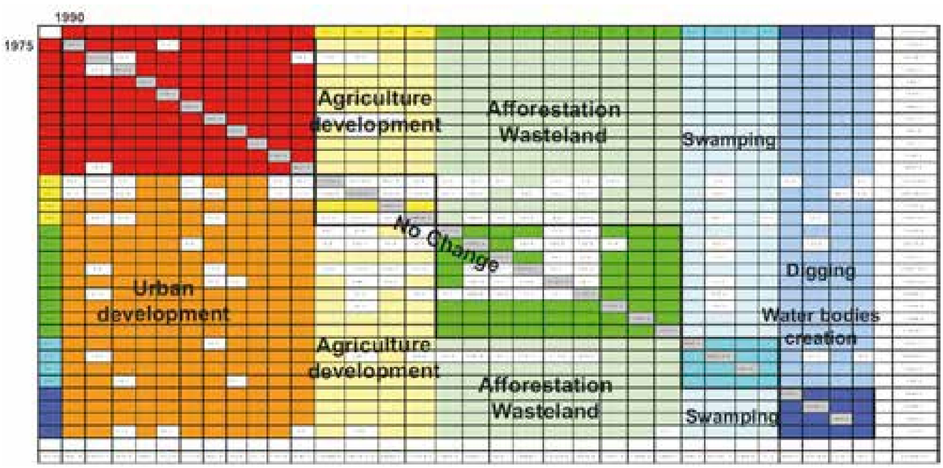

Figure 4 - Matrix of land cover and land use change for units 111-523 [12].

Conclusions

LaCoast Atlas represented an early step (1999) in assessing land use and land cover for coastal areas of Europe. It used for the first time remote sensing data for land cover/use information Combining land cover change data with socio-economic information, administrative data and other relevant indicators apply such kind of methodology is useful to forecast future trends and potential local changes of land use and land cover at low cost. Achieving this, LaCoast Atlas was an excellent example of consistent information source built on historical land use and harmonized with already existing databases. To detect time dynamics is an essential dimension for land cover and land use study: integrating time, LaCoast Atlas constituted a reference for reliable data bases not only for future trends forecasts, but also for the analysis of management policies and their impact on coastal land cover.

Future Perspectives

Looking at the technology evolution from 1999 to nowadays we can observe how digitalization in earth remote sensing observation is now much more advanced. The International Space Station (ISS) and a great number of satellites devoted to many uses are gathering immense quantities of different data by many type of sensors in each pass. Computers and software are more and more powerful and able to manage multilayered analysis for any kind of purpose.Still, the methodology put in place by the LaCoast Atlas can be a reference to design new projects [10] aimed at earth observation and time framed analysis. Reporting on this experience fosters the need to push interdisciplinary research and involve more the user communities to mine the potential use of the data from space observation. In the future, we should continue to look at the space technology to achieve innovation results on mankind activities.

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