TRACKING ENVIRONMENTAL IMPACTS AND HABITAT FRAGMENTATION ON COASTAL PROTECTED AREAS THROUGH OBJECT ORIENTED ANALYSIS. IDENTIFICATION AND CATEGORIZATION OF LINEAR DISTURBANCES IN CORRUBEDO NATURAL PARK (NW IBERIAN PENINSULA)

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ABSTRACT:

The increase of tourism in coastal protected areas is potentially one of the drivers of ecosystem fragmentation with the consequent important damages to their biodiversity values. One of the key management issues relates to the access regulations in protected areas to avoid the negative effects of trampling on natural and semi-natural habitats. These measures have to be carefully designed to achieve an effective protection of biodiversity and minimizing as possible the constraints to tourism development. Indeed, the accurate design and performance monitoring of such measures need effective methods of fragmentation evaluation. Besides, the retrieval of information about habitats past condition is necessary for understanding their present state and trends.
In this work, we aimed the development of a consistent method for the automatic recognition of linear environmental impacts -namely paths and tracks- on natural and semi-natural habitats using colour aerial photographs and also applicable to historic black and white images. The method is based in a multi-scale segmentation of the images. Brightness, shape and connectivity criteria were implemented at several scales of the analysis by means of a fuzzy knowledge base, allowing the recognition of linear elements corresponding to networks of trails. We used as study case a protected area in the NW coast of the Iberian Peninsula with a complex pattern of vegetation. The method applied allowed the general discrimination of linear artificial features, identified with environmental impacts and human-driven habitat fragmentation, against other linear elements with similar brightness and shape, but different thematic meaning regarding their conservation implications.

1. INTRODUCTION

Environmental planning in coastal protected areas needs taking into account the pressure on biodiversity due to the increase of leisure and tourism activities in these locations. In this regard, the tourism pressure may cause important damages to biodiversity values in ecosystems with high vulnerability and low resilience. The effects of trampling on habitats like coastal sand dunes may remove and destabilize the vegetation cover and cause its fragmentation, particularly in the case of creation of linear features like footpaths.

Although several definitions may be found in the literature, habitat fragmentation is often regarded as a process in which "a large expanse of habitat is transformed into a number of smallest patches of smaller total area, isolated from each other by a matrix of habitats unlike the original" (Wilcove *et al.* 1986). According to this definition, the fragmentation of a certain habitat involves both a loss of area and changes in its spatial arrangement or configuration. Assuming the existence of a relationship between the landscape pattern and processes taking place on it, an accurate characterization of the landscape structure contributes significantly to the understanding of ecological processes and eventually in the identification of threats on the long term maintenance of biodiversity (Turner, 1989).

Linear infrastructures are acknowledged to be one of the main causes of fragmentation of habitats and involving several kinds of environmental impacts (Geneletti, 2004). The reduction of overall amount of habitat and mean fragment size, the increase of edges, the decrease of core area and the isolation of habitat fragments are some of the principal effects on the landscape structure derived from fragmentation. Depending on the particular ecological requirements, not all the species show the same response to these effects. Nevertheless, is possible to state a general negative effect on the overall ecosystem biodiversity rising from habitat fragmentation (Fahrig, 2003).

Tourism pressure -and particularly non-regulated circulation of people and vehicles- is one of the main reasons of sand dune ecosystem fragmentation in coastal areas. Thus, the management of such areas needs frequently to establish a control of the public access to avoid irreversible damages to ecosystems derived from the unplanned rising and enlargement of footpaths and trails. These measures have to be carefully designed in order to constraint as few as possible the tourist development and to contribute efficiently to the protection of biodiversity. Hence, it is necessary to have accurate and updated spatial data about the state and response for its correct design and for the further monitoring of their performance. Besides, the retrieving of information about past condition of the habitats is also necessary for a better understanding of their present state and trends.

In the current work, we aimed the development of a consistent method for the automatic recognition and mapping of linear environmental impacts -namely trails and footpaths- on natural and semi-natural habitats in a protected area of the NW of Spain. As most of these paths arose in an unplanned way and even in some cases are temporary (according to changes in the tourism affluence) they are not included in the official topographic cartography and therefore have to be retrieved form other data sources, namely remote sensed imagery.

Remote sensing data and analysis techniques show advantages over traditional mapping techniques for cost effective generation of environmental data, such as the exhaustive and systematic covering of the territory, its periodical data acquisition or the possibility of automation of analyses. Nevertheless the availability of remote sensed data sources with enough resolution (temporal, spectral, spatial and so forth) to identify certain environmental features may be quite limited, particularly when historical data records are demanded. In this regard, collections of aerial photographs may be a valuable source of information, despite of their frequent shortcomings in quality, homogeneity and spectral information.

Hence, the basic dataset for the study was a mosaic of ortho-rectified aerial photographs with a spatial resolution that allows the identification of narrow linear features. In this particular case the target is the classification of footpaths result of seasonal tourist impact in a complex coastal sand dune system. Since in further work it is foreseen the analysis of historical aerial photographs, one of the premises of the research is to develop a methodology valid for both colour and black and white images. Therefore, the method has to be based in as few as possible spectral information and has to take profit of other kind of information as morphology and spatial context of image objects.

2. MATERIAL AND METHODS

2.1. Study area

The study area is located inside the Natural Park of "Complexo dunar de Corrubedo e lagoas de Carrexal e Vixán" located in the NW coast of the Iberian Peninsula (Figure 1). The environmental importance of the area was recognised -apart from the declaration of Natural Park- by its declaration as international importance wetland (Ramsar Wetland), Special Area of Conservation (SAC) forming part of the Natura 2000 network in the Atlantic region and Special Protection Area (SPA) for Birds.

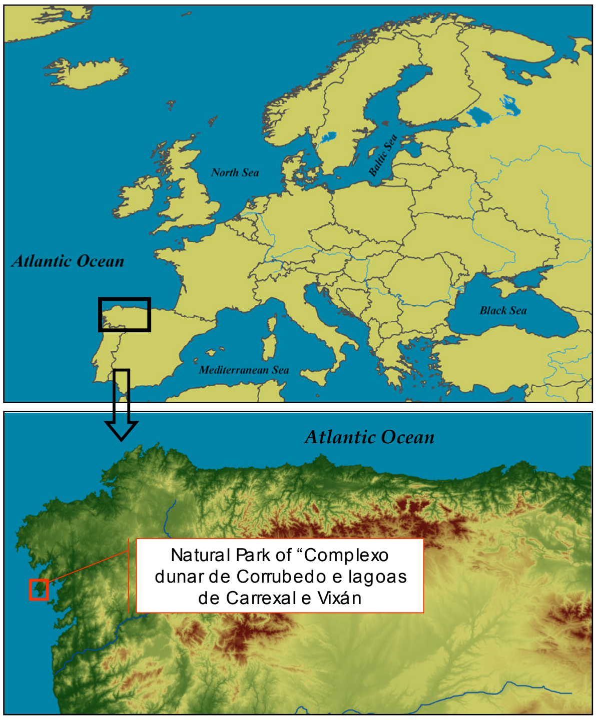

Figure 1. Location of the study area in the European context.

A rectangular area of around 65 ha within the limits of the Natural Park was used to set the limits of the study area. Its size results of a compromise between the computational costs of high resolution images and the need of exemplifying the problem of fragmentation in coastal sand dune ecosystems.

The study area comprises a complex pattern of ecosystems, including sand beaches, white dunes (i.e. no stable with bare and loose sand) and grey dunes (more stable, with higher amount of organic matter), near the shore. Agricultural fields, grasslands, meadows and hedgerows are mainly distributed further in the inland. Finally, rocky slopes and different kind of scrublands are distributed throughout the area. This complex mosaic of environments host a great variety of fauna and flora, in some case recognised as international importance species by biodiversity protection figures and official bodies (García-Bobadilla Prósper *et al*. 2003). In addition, the study area has an important presence of human-made features such as infrastructures (mainly narrow roads, tracks and footpaths) as well as some buildings.

2.2. Datasets

We used a subset of an 8-bit orthorectified real colour aerial photograph with a spatial resolution 0.20 m, meaning an image size of 3695 by 3536 pixels for the study area. The original photographs were recorded in 2002-2003 with an original scale of 1:18000 (FOGGA, 2003). We also took information about the current distribution of habitats and path network development by means of fieldwork and aerial photograph interpretation. Existing habitat maps for the area at a scale of 1:5000 were used as well as ancillary data in the classification process (Consellería de Medio Ambiente, 2005).

2.3. Classification methods

For the design of the method, we worked from the basic premise that the target elements (i.e. the network of paths and roads) accomplish several general conditions:

- To show a linear morphology
- To have high brightness values (i.e. to have a low vegetation coverage)
- To take part in a network with a certain degree of connectivity

These simple basic rules usually perform well when typical anthropogenic features like roads or paths are the targets of the classification. These infrastructures are supposed to be built according certain standards, so some characteristic features and scales for the recognition of these features are relatively easy to model (Lang and Blaschke, 2003). However, in the current work, this basic statement is likely to present exceptions. Indeed, some parts of the path network could be partially colonized by vegetation (i.e. might show relatively low brightness values). Besides, some natural and seminatural habitats might show the similar morphology as paths and roads and intermediate or high brightness values. In other cases some sections of the paths might not be connected with the general infrastructures network (particularly in the case of temporal unplanned footpaths). Consequently, although the targets of the classification are anthropogenic, they tend to show an important variation as they are the result of unplanned human activities. Hence, for its recognition we used a quite flexible system based on a fuzzy logic approach in order to take into account such variability.

We used the overall brightness of the image instead of individual information for the RGB channels of the colour photograph. This will ease the replication of the method for the identification of linear features in other datasets, such as historical black and white aerial photographs. In addition to this basic spectral information, we integrate information of shape (linear vs. non-linear morphology of objects) and context by mean of topological information (connectivity between certain classes).

Classificatory analyses were done following an object-oriented approach, since it shows advantages comparing to pixel-oriented approach when features such as shape, texture and topology of objects are to be used (Blaschke *et al*., 2001; Giakoumakis *et al.* 2002). The analyses were based on a multi-scale segmentation and subsequently a rule-based classification of the resulting image objects by means of a fuzzy knowledge base. The multi-scale approach allowed the recognition of complex features resulting from the integration of basic elements (i.e. objects) at different levels of analysis.

We used the software eCognition Professional^{TM} V4.0 both for the segmentation of the image and for the implementation of the knowledge base. In the segmentation process, the image is divided or segmented in a number of spatial clusters likely to represent objects belonging to the same class. The method is based on a bottom-up region growing technique that starts from the objects with the lowest spatial entity in the image (i.e. individual pixels) and iteratively builds spatial clusters that meet a criterion of minimum heterogeneity according to certain parameters of spatial scale and shape of the resulting segments (see Baatz *et al.*, 2004 for further details). We implemented the classification knowledge-base by means of decision rules based on spectral, morphological and topological information retrieved from the image objects combined at several scales via fuzzy logic operators at different levels of analysis.

A basic level (Level 2) of image objects was derived using values for the segmentation parameters that allowed the discrimination of elements likely to belong to the trail network (c.f. table 1). Several trials followed by a visual comparison of results against known target features on the aerial photograph were done until satisfactory image segmentation was achieved. The scale parameter was adjusted so as to allow the discrimination of segments of the paths against other land cover types (even if it meant a certain degree of over-segmentation). As the classification will not be based exclusively on spectral features, the shape parameter was set to a relatively high value. The same weight was assigned to the compactness and smoothness parameters.

Scale	Shape	Compactness
80	0.4	0.5

Table 1. Parameters for the basic level of the segmentation (Level 2).

A lower hierarchic level (Level 1) was derived for the purpose of line analysis. Each basic object was subdivided in sub-objects that maximize the border length to the outer environment. These sub-objects were used for the generation of shape information about the linear character of their respective super-object (see Baatz *et al*., 2004 for further details).

Level 2 objects were classified in several categories according its brightness and shape. Mean object value was used as brightness feature. Level 2 object asymmetry as well as sub-object width and width/length ratio was used for identifying the linear shape.

At this stage, linear elements with a low vegetation coverage and therefore likely to form part of trails were assigned to a class. Conversely there are linear elements corresponding with natural and seminatural vegetation with an inherent low vegetation coverage (e.g. long and narrow rocky slopes), that could be confused as part of the trail network in the former class. Other classes corresponded with elements linear and vegetated that form part of the trail network (e.g. temporal footpaths partially colonised). Besides elements that corresponded with hedgerows or narrow strips of natural or seminatural vegetation conceptually very different to the trail network were assigned to these classes.

To allow the semantic discrimination between these objects, an additional criterion of connectivity were introduced in the classification. The criterion had to be implemented for all the classes likely to take part of the trail network evaluating the existence of other neighbouring elements likely to form part of the same network. Besides, Level 1 objects with certain linkage to Level 2 elements likely to be trails, were assigned to two classes for its further integration in the Level 2 classification. These two classes were defined as:

- Possible trail (Level 1) when the objects were contained in any super-object belonging to any of the classes more likely to be trail at Level 2
- Near possible trail (Level 1) when the objects fell within certain distance of an element of the possible trail at Level 1

According to the classification, Level 2 objects with a certain vegetation coverage, linear shape and contacting linear non-vegetated elements were classified as “contacting non-vegetated and linear vegetation objects” (see figure 2). In the case of absence of this contact, were classified as “neighbouring possible trail” or “non-neighbouring possible trail”. The first class corresponds to linear objects with some vegetation coverage and close to linear unvegetated elements very likely to be trails. The second class corresponds with elements at a certain distance to linear unvegetated elements or to the previously defined class “contacting non-vegetated and linear vegetation objects class”. For the definition of this class, the Level 1 categories were used as intermediate step (see figure 2).

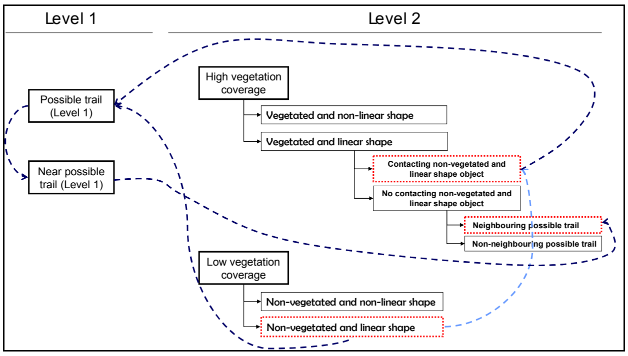

Figure 2. Hierarchical classification scheme at Level 1 and Level 2. The classes likely to form part of the trail network are marked with a red rectangle. Blue lines indicate relation-based features used for the definition of classes based on connectivity criteria.

At this point, a sort of circular reference arose, since the classification of one element in one of the classes likely to be part of a trail depends on the classification of the neighbouring and sub-objects as belonging to one of these classes. Accordingly, the classification of the neighbouring objects in one of these classes depend on the final assignation of the target segment. To allow the resolution of such problem, the option of class-related iterative classification of the eCognition software was applied.

A new higher hierarchical level (Level 3) was generated based on the Level 2 classification. In this case the main objective of this higher hierarchical level was to identify concatenations of Level 2 objects belonging to semantically affine classes and contiguous in the space (figure 3). The classes more likely to be part of the trail networks -underlined in red in figure 2- were grouped in a complex class at the Level 3 (see figure 4).

Based on this new hierarchical level, a new set of decision rules were developed. Rules were designed to recognize topological relationships between the elements assigned to classes with different probability of belonging to the trail networks and eventually, to discriminate which of the complex Level 3 objects were real trails

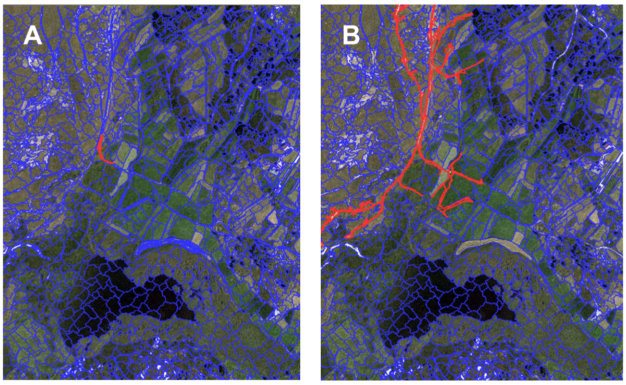

Figure 3. Level 3 classification based segmentation. In A, underlined in red, an example of level 2 object. In B this object assembled with other neighbouring objects belonging to different classes but conceptually alike as having a high probability of belonging to a connected trail network.

Apart form the spatial assemblage of the objects considered conceptually more likely to be part of the trail networks, a new abstract group –“not possible trail”- put together the classes more unlikely to be part of the trail networks at Level 3. This abstract group was created in order to facilitate the integration of the classes conceptually different to trails in the decision rules.

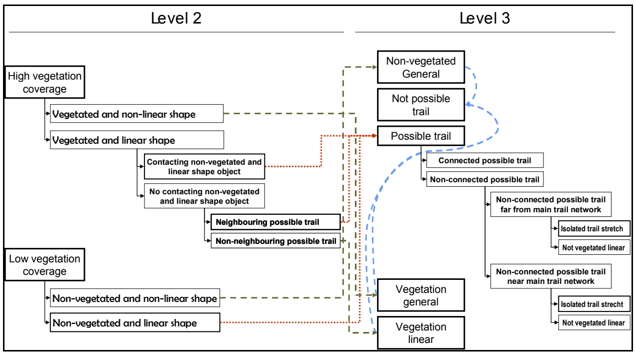

Figure 4. Hierarchical classification scheme at Level 2 and Level 3. Green arrows represent the direct correspondence between Level 2 and Level 3 classes. Red arrows indicate the spatial assemblage at Level 3 of classes more likely to be trails at Level 2. Blue arrows indicate the assemblage at Level 3 of the classes more unlikely to be trails.

At this stage, a subdivision of the composed class “possible trail” was done in order to refine the classification and filter some of the resulting subclasses as belonging to the trail network. Main criteria for this refinement were the connectivity and length of the Level 3 objects. Hence, long linear segments with a presumed connexion with the trail network outside the image limits or with a certain degree of vicinity with possible paths and showing more than a certain length were classified as trails. Conversely clearly isolated and short composed segments were classified as not vegetated linear elements (see figure 4).

3. RESULTS AND DISCUSSION

Figure 5 illustrates the results of the Level 2 classification results. The classification legend at this level comprises 6 classes result of the development of the classification scheme:

- Vegetated and non-linear shape objects
- Vegetated and linear shape objects contacting non-vegetated and linear shape object
- Vegetated and linear shape objects no contacting non-vegetated and linear shape object but neighbouring possible trail
- Vegetated and linear shape objects no contacting non-vegetated and linear shape object and non-neighbouring possible trail
- Non-vegetated and non-linear shape objects
- Non-vegetated and linear shape object

The most frequent assignation corresponds with different kind of terrestrial and aquatic vegetation without a linear character. Linear vegetation patches as hedgerows or strips of vegetation in the limits of plots of land, together with stretches of the trail network partially colonised by vegetation are in general correctly classified as vegetated linear elements. Besides it was possible to differentiate three subclasses of linear vegetation depending on their distance or connexion with other linear elements likely to configure the main network of trails in the area. Linear vegetation not neighbouring this network correspond in general with vegetation strips around hedgerows and fences that divide properties.

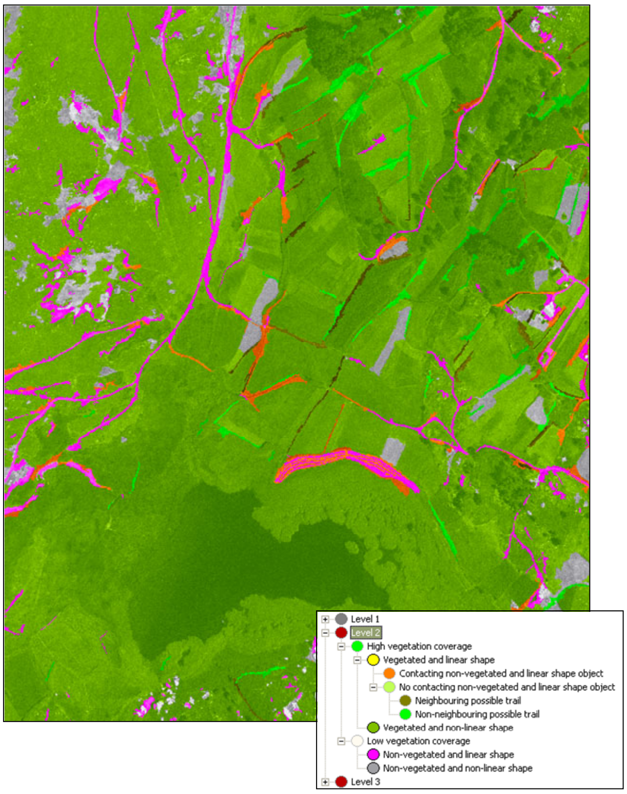

Figure 5. Results and classification scheme at the Level 2

The objects classified as unvegetated with linear shape, correspond clearly in most of the cases with stretches of trails. Nevertheless other kinds of vegetation types were recorded in this class. Particularly in the left-up sector of the image several objects corresponding with strips of pioneer vegetation on rocky slopes or bare sand were assigned to it. Thus the class linear unvegetated couldn't be directly matched with a thematic category corresponding only with trails, and some refinement of the classification was needed.

Non-vegetated objects with non-linear shape correspond mainly with rocky slopes, bare sand areas as well as tilled or recently harvested crop fields. Impervious surfaces as pavements or buildings were also assigned to this class.

In some particular cases, unexpected results were obtained that pointed out some potential problems of generalization of the knowledge-base classification. Figure 6 illustrates how the spatial sequence of linear strips of mowed reed and remains of vegetation in a plot of land was recognised as elements with a high probability of forming part of the trail network. Although the objects of this plot fulfilled the requirements for belonging to some of these classes, they conceptually corresponded to a single element of partially unvegetated land.

Figure 6. Example of confusion between a mowed reed plot and a concatenation of connected linear elements likely to form part of the trail network

In Level 3 classification a more specific discrimination of linear elements according their probability of belonging to the network of paths was achieved (cf. figure 7). The Level 3 classification legend allowed the discrimination of several classes different regarding its spectral response and degree of connectivity, but conceptually taking part of the network of trails:

- Connected possible trail
- Non-connected possible trail far from main trail network
- Non-connected possible trail near main trail network

In the two non-connected possible trail classes, additional rules allowed the discrimination of the objects more doubtfully assignable to trail classes.

The network of trails was in general correctly delineated, with the exception of some omission error of isolated stretches of trails and the above discussed plot of mowed reed.

The class vegetation linear corresponded mainly with hedgerows, vegetation strips around limits of properties or transitions between vegetation types. Nevertheless, some partially vegetated and clearly unconnected trails were assigned to this class. Some of the Level 2 objects classified as non-vegetated and linear, were identified as non-connected and therefore, not belonging to the trail networks.

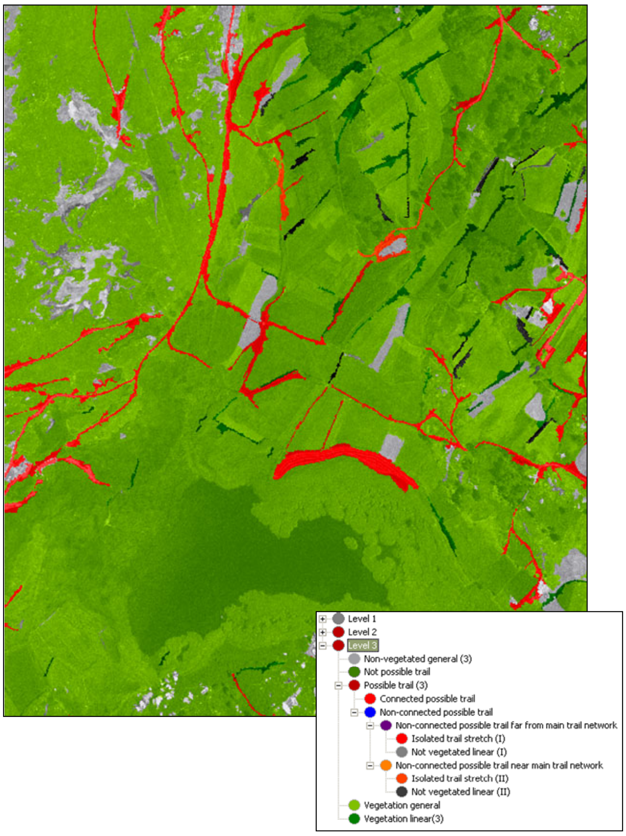

Figure 7. Results and classification scheme at the Level 3.

4. CONCLUSSIONS

The method allowed the general discrimination of the artificial features, identified with environmental impacts and human-driven habitat fragmentation, against other linear elements with similar brightness and shape, but different thematic signification regarding their biodiversity conservation implications. These anthropogenic features were classified despite of the fact that – as they arose in a unplanned way- showed an important variation in width, shape of the borders and in some cases were unconnected.

Several shortcomings were recorded when very complex patterns of interspersed natural and anthropogenic features with linear shape occur. In other cases, the intrinsic characteristics of particular cases, as happened with strips of mowed reed alternating with strips with some remains of vegetation, led to confusion between non-linear elements and complex linear elements.

Although the results for the particular area seem to be satisfying, new experiments in other areas are planned in order to point out potential shortcomings of the method. Besides an accuracy assessment analysis with field data would be needed for the analytical validation of the results.

EFERENCES

Baatz, M., Benz, U., Dehghani, S., Heynen, M., Höltje, A., Hofmann, P., Lingenfelder, I., Mimler, M., Sohlbach, M., Weber, M., and Willhauck, G., 2004. *ECognition Professional User Manual 4*. Definiens Imaging, München.

Blaschke, T., Conradi, M. & Lang, S., 2001. Multi-scale image analysis for ecological monitoring of heterogeneous, small structured landscapes. *Proceedings of SPIE*, Toulouse, pp. 35-44.

Consellería de Medio Ambiente, 2005. Plan de conservación de las Zonas de Especial Protección de los Valores Naturales de Galicia. IBADER. Universidade de Santiago de Compostela. Dirección Xeral de Conservación da Natureza. Xunta de Galicia. Lugo. (8 Tomos).

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics* 34, pp. 487-515.

FOGGA, 2003: SIXPAC. Xunta de Galicia. Consellería de Medio Rural. Available in internet, URL: http://www.xunta.es/visor/. Data last access: 22/06/2006

García-Bobadilla Prósper, F., Lago García, J. M., Juliani Aguado, C., Callejo Rey, A., Ramil Rego, P., Izco Sevillano, J., and (Coord.), 2003. *Humedales de Galicia*, DXCN. Consellería de Medio Ambiente. Xunta de Galicia. Santiago de Compostela.

Geneletti, D. (2004). Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. *International Journal of Applied Earth Observation and Geoinformation* 5, pp. 1-15.

Giakoumakis, N. M., Gitas, I. Z. and San-Miguel, J., 2002, Object-oriented classification modelling for fuel type mapping in the Mediterranean, using LANDSAT TM and IKONOS imagery- preliminary results. In Viegas, X.: Forest Fires Research & Wildland Fire Safety, Rotterdam, Millpress.

Lang, S., and Blaschke, T., 2003: Hierarchical Object Representation – Comparative Multiscale Mapping of Anthropogenic and Natural Features. *ISPRS Archives*, Vol. XXXIV, Part 3/W8, Munich, pp. 17-19.

Turner, M. G. (1989). Landscape Ecology: The Effect of Pattern on Process. *Annual Review of Ecology and Systematics* 20, pp. 171-197.

Wilcove, D. S., McLellan, C. H., and Dobson, A. T. (1986). *Habitat fragmentation in the temperate zone*. In M. E. Soulé: **Conservation Biology: Science of Scarcity and Diversity**. University of Michigan, Sunderland, MA, pp. 237-256.

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