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ORIGINAL ARTICLE

Effectiveness of Natura 2000 areas for environmental protection in 21 European countries

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Abstract
To assess the dynamics of changes in CORINE Land Cover classes in areas of the Natura 2000 ecological network, three landscape metrics were examined. Traditional pixel-based classification, with majority rules aggregation based on the example of the CORINE Land Cover dataset, was applied. To identify the possible differences in the considered metrics, according to the year as well as to the country, statistical analysis between the linear mixed model and the variance model with repeated measurements was performed. The results of both tests are very similar. In the 1990–2012 period, the share of CORINE Land Cover class "Artificial areas" in all tested areas increased by 21.1% (the highest growth ratios were recorded in Poland, Portugal, Slovenia and in Spain). On the other hand, such countries as Slovakia, Romania, Germany, Lithuania and Estonia are characterised by the loss of artificial areas. At the same time, the share of "Forest and semi-natural areas" as well as "Water bodies" increased slightly. Negative trends that took place in the periods 1990–2000 and 2000–2006 were effectively stopped in the subsequent period, 2006–2012. Overall, for all the analysed countries, a minimal loss in environmental and landscape diversity was observed. Our results may be used as a basis for drawing conclusions on the effectiveness of environmental and landscape management systems in various countries. They might also constitute the starting point for detailed analysis of the management process.

Keywords Natura 2000 · Landscape metrics · CORINE Land Cover classes · Statistical analysis

Introduction

The natural environment is constantly changing. The main driving force of these changes is humans who, through various kinds of activity, cause both positive and negative changes in the environment. This cause and effect relationship is reflected in a long history of changes in CORINE Land Cover (CLC). To strengthen the protection of biodiversity in all EU Member States, Natura 2000 (N2000), which is the world's largest network of protected areas, was created. Its aim is to maintain the natural and semi-natural habitat types listed in Annex I and the species listed in Annex II of the EU Habitats Directive within their natural range (EC 1992) and species listed within Annex I of the Birds Directive (EC 2009) and/or to restore them to Favourable Conservation Status. The N2000 network includes Special Areas of Conservation (SAC) and Special Protection Areas (SPA) designated, respectively, under the EU Habitats Directive and the EU Birds Directive. The natural values of N2000 sites provide numerous opportunities for many branches of the economy. Hence, CLC changes within N2000 areas may be natural processes, but the status of natural habitats and species protected under the network should not be affected negatively by any kind of human activity. However, we must take into account that changes in the whole area can be assessed in a positive way but in the case of specific species or habitats, they can still have negative effects. Despite the fact that each EU Member

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State is legally obliged to carry out the assessment of the state of the N2000 sites (both in and outside the network) and submit data about the species of community interest listed in Annex II of the EU Habitats and Annex I of the EU Birds Directive, the knowledge about long-term CLC changes in the entirety of the N2000 network still remains insufficient (Davis et al. 2014; Kleijn et al. 2014).

This leads to difficulties in assessing the dynamics of these changes in both the short-term and long-term aspect (Hatna and Bakker 2011) which also translates into the assessment of the impact of these changes on the environment as well as effective management of these areas (Peer et al. 2014; Kolahi et al. 2013; Trochet and Schmeller 2013; Lu et al. 2012; Abdulla et al. 2008; Johnson et al. 2008). Some works confirm that the newly established protection types, such as N2000 areas, are characterised by intensified pressure of development and landscape fragmentation (Kubacka 2018). There are many studies, reports and other documents about monitoring and assessing the status of N2000 sites (e.g. Fernandez et al. 2017; Kallimanis et al. 2015; Popescu et al. 2014). For instance, Kallimanis et al. (2015) analysed CLC changes between 2000 and 2006 inside N2000 sites and compared them with those observed outside the network. The share of "Forest and semi-natural areas" marginally increased inside the ecological framework, while it decreased outside it. Mairota et al. (2013) used the CLC dataset to conduct a quantitative analysis of the impact of human activities on landscape by assessing the spatial structure of habitat types in a Natura 2000 site in southern Italy. They confirmed that CLC changes in the extent of habitats as well as landscape and habitat structure are often caused by human pressure within protected areas and at their boundaries, with negative consequences for biodiversity and the distribution of species.

The most of the positive as well as negative CLC changes in the environment will only occur after several decades. In regard to the abovementioned, Meiner and Pedroli (2017) recommend monitoring of the CLC changes as very important in order to meet the targets of the EU 2020 Biodiversity Strategy. Therefore, our goal was to use broadly available data in form of the CLC database for as many EU Member States as possible to present the dynamics of changes in CLC classes in areas set within the framework of the N2000 ecological network. As far as other forms of nature protection such as national parks, nature reserves and other protected areas are concerned, grounds for their determination are individual to each Member State and therefore, they have not been included in our research area. However, we need to consider two very important aspects: the first is the fact that many sites are both SPAs and SACs and the second is that a large proportion of N2000 areas are also protected by other national or international designations (e.g. national parks, biosphere reserves). So, it is very difficult to attribute any measured change to a particular designation or other conservation programmes. Even when populations of species protected by N2000 are increasing, it is difficult to know if this is due to N2000 or other measures (EEA 2015).

Materials and methods

Study areas

The European countries for which the CLC database from 1990 to 2012 (see Appendix 1) is available were selected as the test area. In total there are 21 countries (Fig. 1) in the area where N2000 sites were designated. Other EU countries (i.e. Bulgaria, Cyprus, Finland, Luxembourg, Malta, Sweden and the UK) were excluded from the analysis due to the lack of CLC databases in all analysed periods (i.e. 1990, 2000, 2006 and 2012).

In the study areas, CLC classes in 2012, in N2000 areas (see Appendix 1), were dominated by "Forest and semi-natural areas" (app. 61%), "Agricultural areas" (app. 28%), "Water bodies" (app. 6%), "Wetlands" (app. 4%) and "Artificial areas" (app. 1%).

Methodology

To show the dynamics of the nature changes within the N2000 network (https://www.eea.europa.eu/data-and-maps/data/natura-8#tab-gis-data, accessed January, 2018), three metrics (see Appendix 1) at four points in time—1990, 2000, 2006 and 2012—were examined. The metrics used for the analysis are of a universal nature and are commonly used in landscape research (e.g. Lamine et al. 2017; Marco da Silva et al. 2015; Chefaoui 2014). Furthermore, they are easily interpretable, which is very important if the results are to be disseminated among a wide group of readers. The selection of landscape metrics was also dictated by the choice of data (the mapping scale of the CLC dataset is 1:100,000). Percentage of landscape (PLAND) corresponds to the proportion of the landscape occupied by a patch type. The most important landscape metric is the one that assesses the landscape class structure. The patch density (PD), which is more detailed, is used to evaluate the degree and dynamics of landscape class fragmentation, which is strongly reflected in the state of the habitats (e.g. Lai et al. 2017; MacLean and Congalton 2015; Bastian et al. 2006; Antrop 2004). The value of Simpson's diversity index (SIDI) represents the probability that any 2 pixels selected at random will be different patch types (McGarigal and Ene 2013).

The CLC database has a wide variety of applications, above all, supporting various community policies in the field of environmental protection (e.g. Krajewski 2019; Rodríguez-Rodríguez and Martínez-Vega 2018; Fernandez Calvache et al. 2016). The essence of the CLC programme is to provide

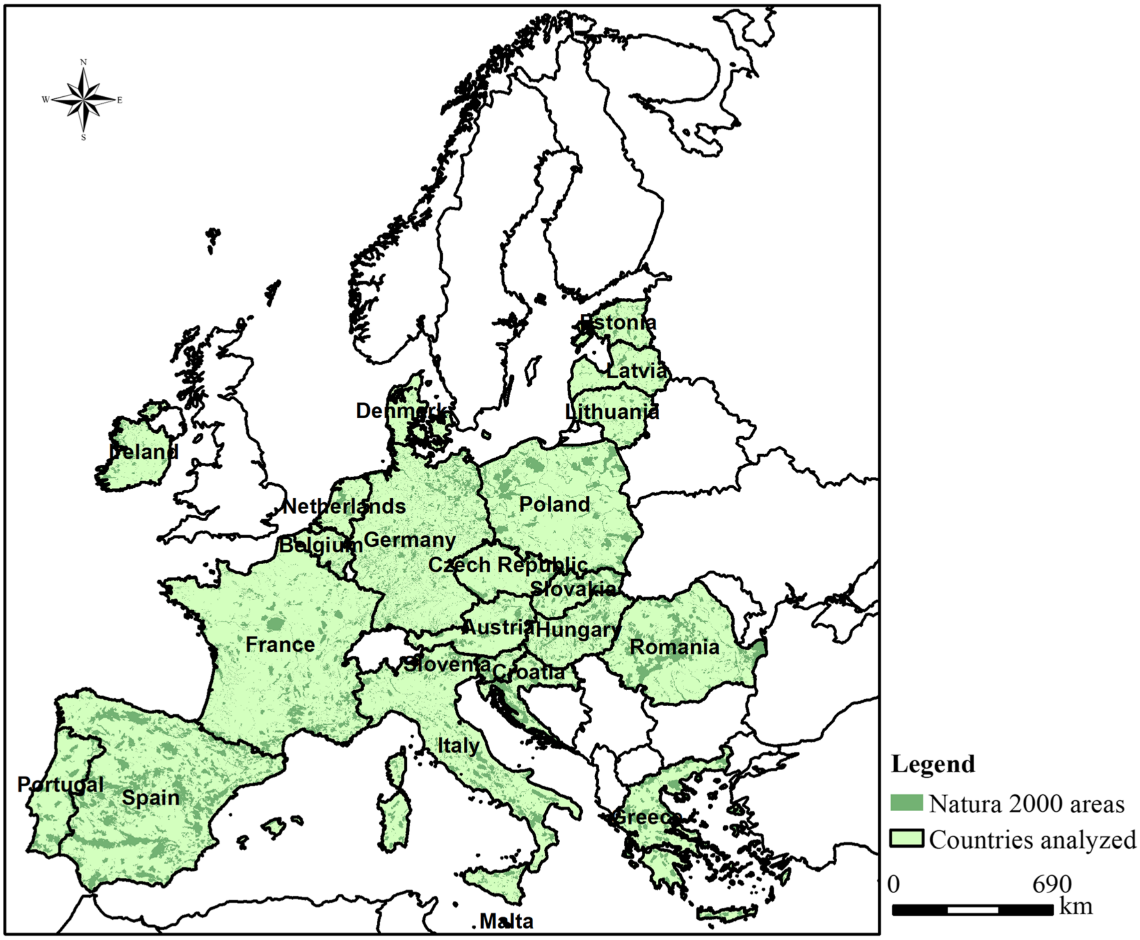

Fig. 1 Study area's Natura 2000 areas (reference year: 2017)

up-to-date information on CLC classes across Europe on a regular basis and to identify changes occurring between successive cycles. The classes of the first level of the CLC database were used to assess the changes (see Appendix 1). All activities related to the use of the aforementioned database were performed with the use of ArcMap 10.5.1 software. The metrics were calculated using the landscape structure analysis program FRAGSTATS (McGarigal et al. 2012). This software is recommended for use with raster datasets and is the most widely known and used fragmentation program (MacLean and Congalton 2015).

Then, we checked the statistical significance of the results of the experiment in different years and countries. To identify the possible differences in considered metrics according to the year as well as to the country, the statistical analysis in the linear mixed model was performed (West et al. 2014; Biecek 2013). The mixed model is a statistical model describing dependence between features, which contains fixed and random effects. A fixed factor is a categorical factor with only a few levels, which are representative of the whole population, and they all are present in the observed data. The fixed effects are treated as unknown constants, which are parameters of the model, and one may want to estimate them. On the other hand, a random factor is a categorical factor, which has a large number of levels, but only a random subsample of them is included in a design. Nevertheless, one may want to make general inference for all possible levels (not only for the observed levels). In the mixed model, the random effects are considered a realization of a random variable with some parameters. Then, these parameters are treated as parameters of the mixed model instead of levels of the random factor. In this way, the number of parameters of the model is reduced. Moreover, the mixed model can be applied to dependent data, which is not usually the case for standard (fixed) analysis of variance models. The mixed effect model was chosen for comparison due to the following reason: the observations for each country are dependent, as they are noted in four periods. Thus, it was impossible to use the usual two-way analysis of variance. To compare the effect of a period, we could use the analysis of variance with repeated measures (Vonesh and Chinchilli 1997). However, in this model, we were unable to check the statistical significance of the country effect. Moreover, the number of countries was quite large and it may have changed in repetitions of the experiment, so it seemed unreasonable to consider the effect of a country a fixed one. The mixed model provided the opportunity to include both factors in one model, where the effect of year was a fixed one (as we considered only four periods), while the effect of country was random.

To check the statistical significance of both factors (period and country), we performed a likelihood ratio test (LRT). In this test, we compared a model with the fixed or random effect vs. a model without it. We approximated the null distribution of the test statistic of the LRT by two methods. In the first one, a chi-squared distribution with degrees of freedom based on the difference between the number of parameters in the complete and reduced models was used (the LRT based on chi-squared distribution for short). The second method used the permutation approach based on 1000 random permutations (the permutation LRT for short). When the p value was smaller than or equal to the significance level α, then we rejected the null hypothesis and noted significant differences. On the other hand, if the p value was greater than the significance level α, then we could not reject the null hypothesis and did not note significant differences. In some samples, outlying observations were noticed. The presence of outliers was confirmed by the Grubbs test (Grubbs 1950). The outlying observations were removed before analysis. To confirm the results for statistical significance tests of the effect of analysed period, we also used the analysis of variance with repeated measurements mentioned above. Then, the subjects were the countries. The statistical analyses were performed with use of the R program (R version 3.4.3; R Core Team 2017).

Results

The results of both tests are very similar, as may be seen in the p values of the tests that are depicted in Table 1. In fact, they confirm the results of the LRT in mixed model and one can also observe that the p values of all three testing procedures applied are quite similar. The calculated values of landscape metrics demonstrate significant statistical differences (p value < 0.05) between the analysed countries in each CLC class in areas of the N2000 ecological network (Table 1).

The situation is similar to the comparison of the results of the calculated metrics in the four analysed periods. The analysis of the dynamics of the changes in particular CLC classes in the period of 1990–2012 reveals that the most significant changes were recorded in "Artificial areas" (see Appendix 1). The highest growth ratios were recorded in Poland, Portugal and Slovenia (+ 110.65%, 110.48% and 97.29% respectively) as well as in Spain (+ 81.78%). On the other hand, such countries as Slovakia, Romania, Germany, Lithuania and Estonia are characterised by the loss of artificial areas. The average for all analysed countries is a 21.12% increase in "Artificial areas" in the period of 1990–2012 (Fig. 2). Further information is provided by the analysis of dynamics in the 1990–2012 period, in which most analysed countries have witnessed a decline of "Agricultural areas" (except Ireland and Italy). The highest loss of such areas was recorded in the Netherlands (− 20.68%) and Croatia (− 12.84%), whereas the average for all the analysed countries amounted to − 4.31%. The recorded changes in "Forests and semi-natural areas", "Wetlands" and "Water bodies" in areas of the N2000 ecological network were as low as 1–2.5% (Fig. 2). However, some countries noted distinctive results, e.g.

Table 1 Statistical test in mixed model and repeated measurements design for all metrics by CLC classes in different years

Percentage of landscape (PLAND)	Likelihood ratio test (LRT) based on chi-squared distribution	Permutation LRT	ANOVA with repeated measurements
Artificial areas	0.0006*	0.0000*	0.0008*
Agricultural areas	0.0000*	0.0000*	0.0000*
Forest and semi-natural areas	0.0004*	0.0010*	0.0005*
Wetlands	0.0460	0.0520*	0.0545
Water bodies	0.3174	0.3540	0.3380
Patch density (PD)			
Artificial areas	0.0000*	0.0000*	0.0000*
Agricutural areas	0.2905	0.2970	0.3100
Forest and semi-natural areas	0.0289*	0.0340*	0.0346*
Wetlands	0.5925	0.6060	0.6100
Water bodies	0.4600	0.4740	0.4810
Simpson's diversity index (SIDI)			
	0.7610	0.7540	0.7730

*Significant statistical difference (p value < 0.05)

Source: Own works

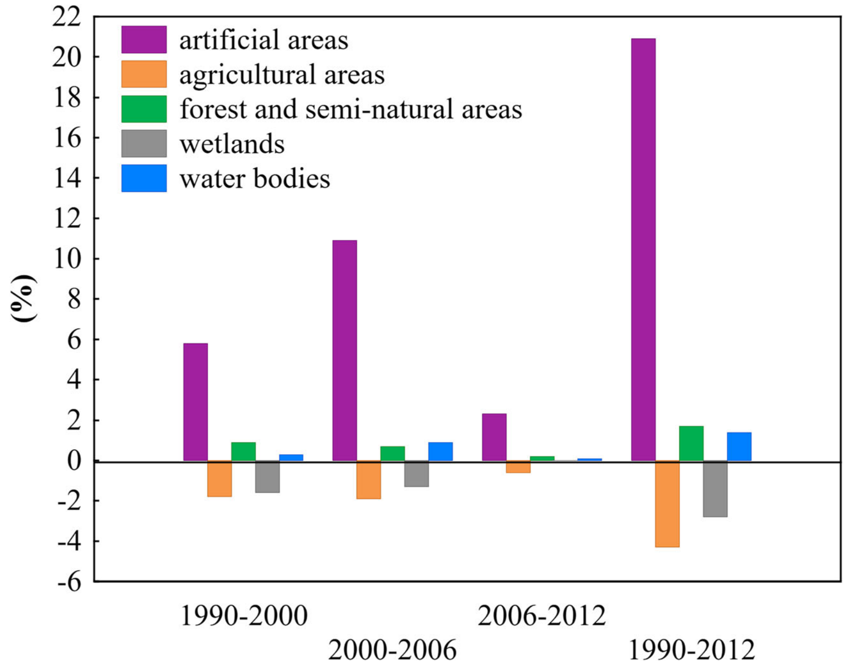

Fig. 2 Average percentage of landscape (PLAND) changes (%) in the study area's Natura 2000 areas by CORINE Land Cover classes for the three partial periods and overall

Ireland, where an increase by more than 32% in "Forest and semi-natural areas" was recorded as well as Slovakia, where a decrease by more than 28% in CLC class "Wetlands" was recorded. On the other hand, the areas occupied by "Water bodies" have increased by more than 40%. Some clearly visible trends are also noticeable in the average values for all analysed countries. For example, the greatest increase in CLC class "Artificial areas" was recorded from 2000 to 2006, i.e. within the period of designation of protected areas within the N2000 ecological network. It may be concluded that the process of separation of areas subject to the new form of protection led to an increase in their quality/value which, in turn, resulted in intensified activity towards the occurrence of new development and ancillary infrastructure (+ 11.85% "Artificial areas"). In total, during the period from 1990 to 2012, "Artificial areas" within N2000 areas increased by more than 22% (Fig. 2). This phenomenon should be assessed negatively from the point of view of preservation of valuable habitats and species. However, data from the period of 2006–2012 prove that the changes were effectively stopped (+ 3.11%). This observation was confirmed by the post hoc tests for ANOVA with repeated measures (Table 1).

The results for the PD metric also indicated significant statistical differences both between the analysed countries and the selected years (Table 1). In the analysed period, the average value of the PD metric for all testing areas in the Natura 2000 ecological network was 0.19 (No. of patches per 100 ha). Significantly higher values were recorded in the following countries: Belgium (0.58), Ireland (0.41), Denmark (0.34) and Germany (0.32). On the other hand, such countries as Greece, Portugal, Croatia, Spain and Italy had significantly lower values of the indicator (Fig. 3).

Full distribution of values for all the countries and analysed CLC classes is presented in Appendix 1. The analysis of changes in the indicator in all intervals reveals that the 2000–2006 period was marked by the highest dynamics of changes. The degree of landscape fragmentation was significantly negative for CLC class "Artificial areas" (+ 7.2%), while for "Water bodies" (− 4.4%) as well as "Wetlands" (− 4.1%), it was significantly positive. Moreover, in the 2006–2012 period, shortly after the approval of most N2000 areas, a significant increase in new patches of "Wetlands" and "Water bodies" was noted so the intensification of the landscape fragmentation process, which resulted from growing human pressure, could be observed (Fig. 4). On the other hand, the creation of new "Wetlands" may be the result of the restoration of natural habitats.

The results of the PD have been confirmed by Simpson's diversity index (SIDI) which is another popular diversity measure borrowed from community ecology. Differences in values of compared areas are statistically important in all the analysed countries (p value < 0.05), although no differences were noted in the tests carried out for the years considered (Table 1). The highest diversity of landscape (Fig. 5) was observed in Denmark (on average 0.71), Ireland (on average 0.68) and the Netherlands (on average 0.67), whereas the lowest ones were found in Slovenia (on average 0.35), Italy and Austria (on average 0.40). However, the analysis of landscape diversity growth dynamics in the 1990–2012 period (Fig. 6) showed that the highest growth was noted in Ireland (+ 4.32%), while such countries as Croatia (− 5.28%) and Slovakia (− 5.18%) were characterised by a loss of landscape diversity. The average for all the analysed countries also shows a minimal loss in environmental and landscape diversity (− 0.32%).

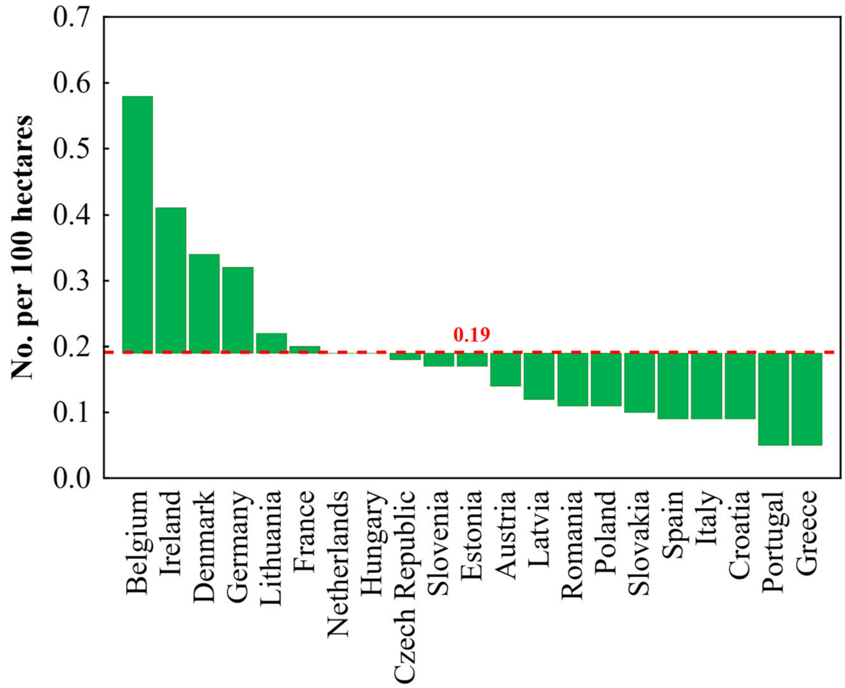

Fig. 3 Average patch density (PD) changes (%) in the study area's Natura 2000 areas by country for the overall period (1990–2012)

Discussion

Urban and infrastructure expansion continues to consume a lot of valuable environment and landscape (McDonald et al. 2008). This is confirmed by our results, which show that, in the 1990–2012 period, the share of CLC class–"Artificial areas" in all tested areas increased by 21.1%. This is a constant trend that has been observed in the entire EU landscape since 1990, although the increase in the 2006–2012 period was lower than in the 2000–2006 period (Kallimanis et al. 2015). This is also confirmed by our results in which the negative trends that had been witnessed in the 1990–2000 and 2000–2006 periods were effectively stopped in the subsequent period, i.e. 2006–2012. It should be remembered that the important factors are not only the changes, but also the structure and speed of changes that take place, which will be visible only in a decade or even in several decades.

At the same time, there was a slight increase in "Forest and semi-natural areas" as well as "Water bodies". On the other hand, space occupied by "Agricultural areas" (−

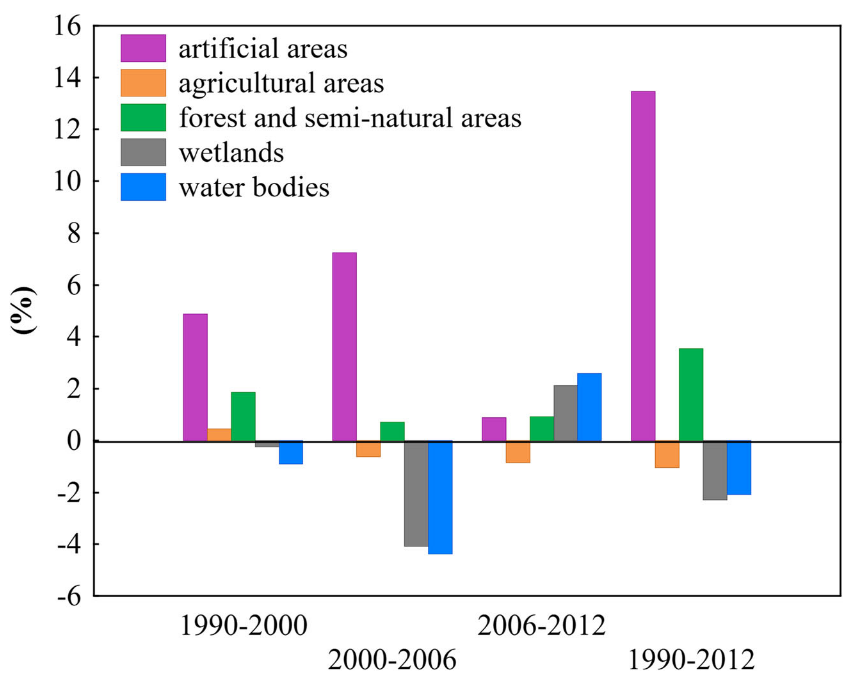

Fig. 4 Average patch density (PD) changes (%) in the study area's Natura 2000 areas by CORINE Land Cover classes for the three partial periods and overall

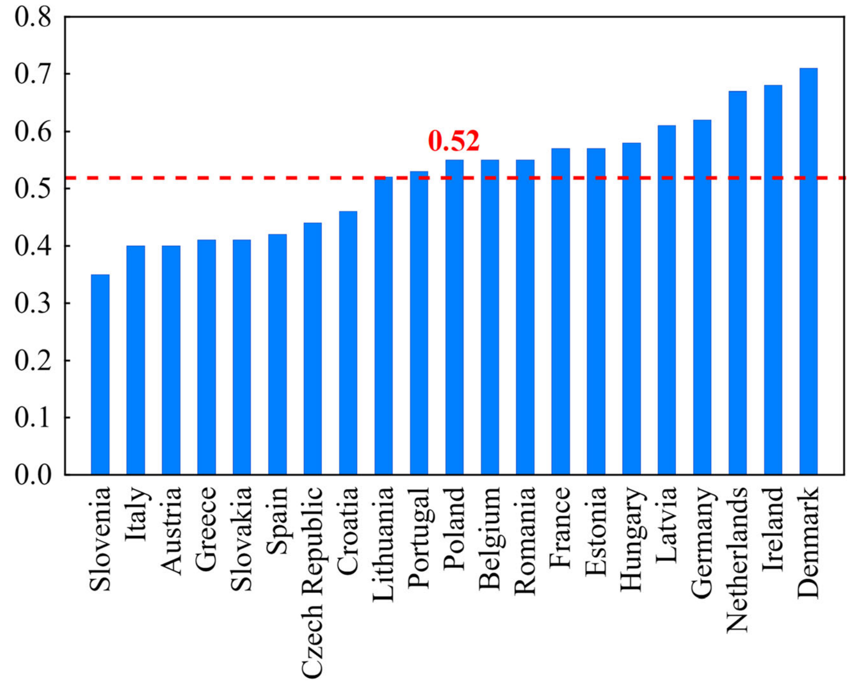

Fig. 5 Average Simpson's diversity index (SIDI) value for all testing areas for the overall period (1990–2012)

4.3%) and "Wetlands" (− 2.%) decreased. Widespread abandonment of agricultural land and increase in forest land have had a long history and affected many countries in the whole world (Ellis et al. 2013; Cramer et al. 2008). There is no doubt that the implementation of the Common Agricultural Policy (CAP) has been the main driving force of this situation over recent decades. There are many examples that demonstrate how CAP measures have led to landscape changes (Serra et al. 2008; MacDonald et al. 2000). On the other hand, the degree of abandonment inside N2000 areas is substantially lower than outside those areas (Levers et al. 2018). Abandonment and intensification of agricultural and forestry activities were cited by many studies as main driving forces of habitat loss and degradation within the N2000 network (e.g. Young et al. 2007; Santos et al. 2008; Iojă et al. 2010; Halada et al. 2011; Fischer et al. 2012; Beilin et al. 2014; Miklín and Čížek 2014; Plieninger et al. 2014; Touloumis and Pantis 2014). Often, post-agricultural and abandoned areas are afforested, which, in a very short time, causes destruction of many valuable habitats, especially farming-related biodiversity (Tomaz et al. 2013; Moreira and Russo 2007). The analyses of Kallimanis et al. (2015) and Maiorano et al. (2008) showed that forests and semi-natural areas increased marginally inside N2000 while they marginally decreased in areas outside the ecological framework.

Many of Natura 2000 areas and other protected areas are located in regions that contain large unfragmented patches of environment and landscape. The higher the value of the PD metric, the higher the degree of landscape fragmentation. According to the results from EEA Report (2015), high fragmentation values are often found in the vicinity of large urban centres and along major transportation corridors. This is also confirmed by our results which apply particularly to the CLC classes "Artificial areas" and "Forest and semi-natural areas". In the 2006–2012 period, the fragmentation process intensified for CLC classes "Wetland" and "Water bodies". This can be interpreted as a negative phenomenon as it means the disappearance of large water surfaces due, for example, to draining being conducted or an increasing process of global warming (Opdam and Wascher 2004).

The main role of the Natura 2000 network is to ensure long-term survival of Europe's most valuable and threatened species and habitats. Our results show a minimal loss in environmental and landscape diversity (− 0.32%) in the analysed period, i.e. 1990–2012. This confirmed a global trend which causes biodiversity loss in all kinds of CLC classes.

Conclusion

The available data sources, i.e. the CLC dataset, as well as the selected research methodology showed some measurable results on the dynamics of CLC changes in the N2000 ecological network in most EU Member States. Of course, we need to take into consideration that each country has a completely different history of environmental and landscape protection which constitutes the main

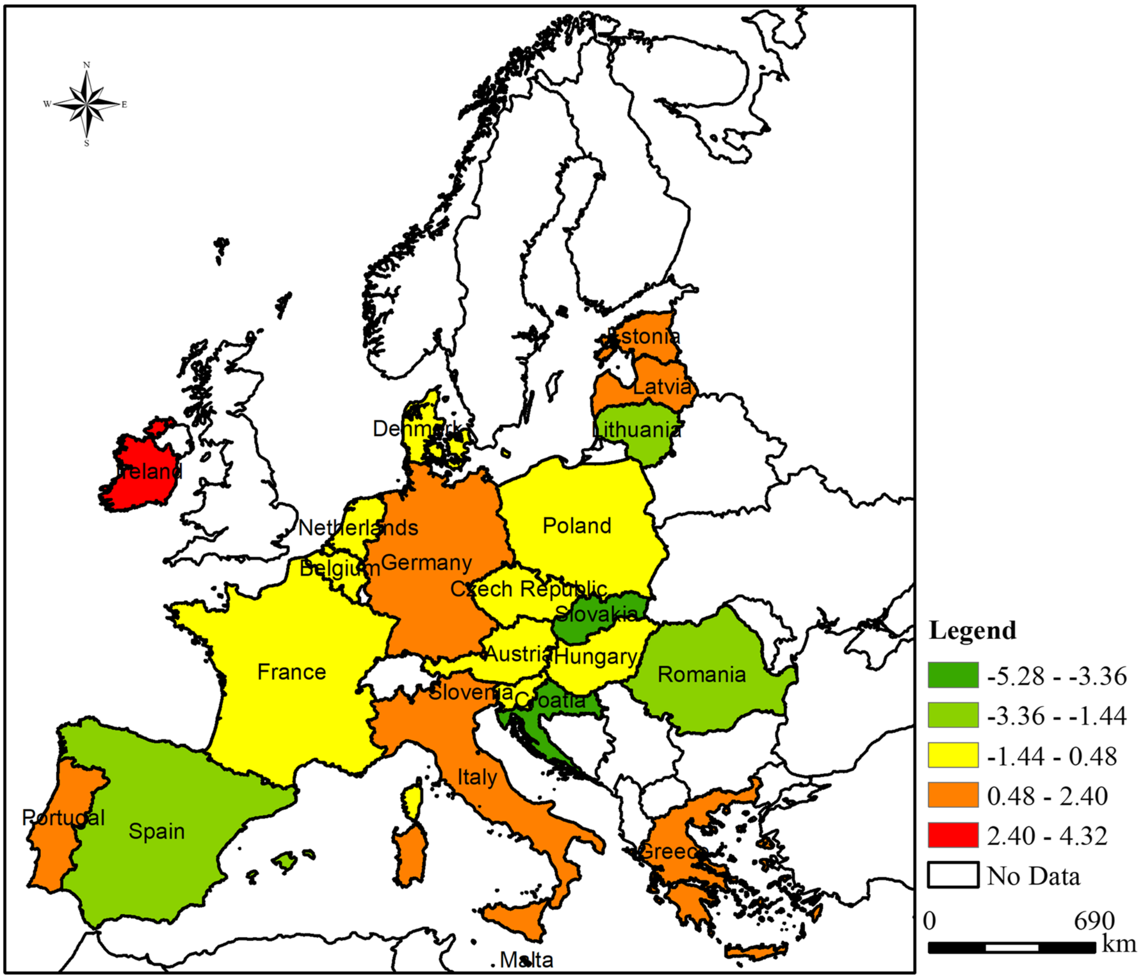

Fig. 6 Simpson's diversity index (SIDI) changes (%) in the study area's Natura 2000 areas by country for the overall period (1990–2012)

aspect of effectiveness of the protective actions taken up. Our results may be used as a basis for drawing conclusions on the effectiveness of environmental and landscape management systems in various Member States of the European Union. They may also constitute the starting point for a detailed analysis of the management process. On the other hand, due to a high level of dataset generalization, the obtained results cannot constitute a basis for determining the state of habitats and species.

The landscape metrics that were calculated and subjected to analysis allowed us to state that the abundance of environmental diversity may be at risk on the European scale and in particular countries and that the tools adopted for its development and conservation may be insufficient.

Any kind of land-monitoring analysis provides valuable information about landscape changes in spatial and temporal aspects. Quantitative landscape structure analysis is useful for monitoring protected areas. The literature review shows that data about the state and quality of the N2000 network are available, but they do not allow for general conclusions at the EU level. Therefore, this issue was raised in this article.

Our analysis shows explicitly which countries are characterised by higher dynamics of changes in areas subject to N2000 and which deal better with these changes. Therefore, further tests should be aimed at getting to know and comparing N2000 site protection systems used in various countries.

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