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Bird communities analysis and Marxan software for the management of a Mediterranean protected area

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Abstract – The bird community analysis, carried out by transect and point count methods, are quantitative analysis. Our aim in this paper is to analyse the results, based on each of these tools, using Marxan, a mapping software to obtain a zonation of a protect area in Mediterranean central Italy . The management algorithms of protected areas are widely used to identify potential networks of natural reserves that meet pre-established ecological limits, such as the presence of a specific percentage of habitats or a specific number of populations, at the same time minimizing costs. The Marxan software was made for different habitat where fragmentation of natural patches are significantly lower than in the study area, but it show interesting and useful result also in this situation. Marxan is particularly useful to solve the problem of the minimum set, in which the aim is to identify, at the lowest possible cost, the areas in which the biodiversity preconditions identified are present. In this work the Circeo National Park (Central Italy) was analysed, as an example of the Mediterranean area. We elaborated, through Marxan a series of maps of the priority areas for conservation that can be used as a starting point working with all the stakeholders involved in the management of the area itself. The main information suggests is to take particular attention to seasonal variations in the composition of the bird communities and, consequently, to the weight that the Park assumes at national and international level in the context of migratory movements and biodiversity conservation. In addition, special attention must be paid to the growing of intensive, rapidly expanding agricultural activities that are not enough controlled and are potentially highly damaging for the Park's biodiversity, both in terms of vegetation and fauna.

Key-words: natural area management, bird communities, zonation.

INTRODUCTION

Bird community studies contribute to improve of natural area management results according to the quality of the data, but also the analysis method used (Simberloff 1994, Bibby 1999, Benayas & Montaña 2003, Arponen *et al.* 2008). Ecological information on the bird species are used to define community structure, as well as general conclusions on biodiversity evaluation in the whole area (Simberloff 1994, Bibby 1999, Uezu *et al*. 2005, Piratelli *et al.*2008). In the same way the knowledge of bird community needs gives information on the quality level necessary to the area to improve the diversity (Haila & Hanski 1984, Simberloff 1994, Piratelli *et al.* 2008).

Local land management authorities are showing increasing interest in bird community studies, because, due to communities complexity and structure, birds are honest indicators of conservation level of a natural area (Bernstein *et al.* 1991, Bellamy *et al.*1996, Boulinier *et al.* 1998, Battisti 2003, Isotti *et al.* 2010).

Our goal in this work is to elaborate the results given by the indexes of community structure to obtain a zonation by Marxan software. In order to use this software in a Mediterranean areas we selected the National Park of Circeo (Central Italy) as the study area being a wide natural patch, included among a 'sea' of human-altered landscapes (Blasi, 1994, Acosta *et al.* 2000). The bird communities have been studied using an eight-year data collection series, more-than-one transect repetition per each habitat and point count method for breeding season (Isotti *et al.* 2014, 2015a, 2015b).

MATERIALS AND METHODS

Study area

The Circeo National Park is situated in southern area of Lazio Region, inside the Pontine Plain. In the past, much of the territory was covered by large swamps. The area has been the subject of several land reclamations projects throughout history from the Roman era and up to the 30s of the last Century, when the last one determined the current aspect of the territory (Isotti 2013). The Circeo National Park was founded in 1934 and covers an area of 8,917 hectares (Blasi 1994, Acosta *et al.* 2000). The territory of the Park can be divided into 5 macro-areas (Blasi 2005): the coastal dune cordon; coastal lakes (Fogliano, Monaci, Caprolace and Paola), declared "Wetlands of International Interest" under the Ramsar Convention ; the ancient dune, which hosts the State Forest, a vestige of the ancient Selva of Terracina; the Circeo Promontory; the Island of Zannone (which is not part of the study area of this work), located about 25 kilometres from the Promontory. The climate of the area is characterized by mild and rainy winters and dry summers (Blasi 2005).

DATA COLLECTION

Two methods were applied in the study area from 1997 to 2008 (Blondel 1969, Blondel & Frochot 1981, Bibby *et al.* 2000): the transect method (TRM) and the point count method (PCM) with index of abundance (IPA). TRM was carried out on a monthly basis. Records were collected by identifying species both through direct sightings and through acoustic identification. PCM was carried out during the breeding season (from April to the end of June) in different monitoring stations. Each station is assumed to be independent from the others because they were spaced at least 1,0 Km apart.

Seven main vegetation types were classified and investigated for this study: Maquis and Mediterranean forest (M), Pine forest (P), Oak forest (Q), Grassland (A), Agricultural areas (C), Wetland (L), Coastal dunes vegetation (D). The mentioned vegetation types are represented by the following phytosociological associations (Blasi 2005): Maquis and Mediterranean forest (M) (Viburno/Quercetum ilicis in maquis, Viburno/Quercetum ilicis in wood); Pine forest (P) (Pine forest, ancient reforestation); Oak forest (Q) (Echinopo/Quercetum. Viburno/Quercetum ilicis ericetum, Viburno/Quercetum ilicis suberetosum); Grassland (A) (Dry prairie vegetation); Agricultural areas (C) (Crop vegetation); Wetland (L) (Wet prairie vegetation. Pool vegetation, Wet wood. Rubo/Ulmion); Coastal dunes vegetation (D) (Garigue. Coastal dune vegetation) (Blasi 2005).

A maximum of 3 transects were drawn within each of the main vegetation (habitat) types: The 3-Km transects were covered during the first week of each month, totalling about 288 Km/year. The collected data were representative of the various habitat typologies of the Park as well as of the different periods of the year. Bird species were listed indicating for each species the total number of individuals, the habitat type in which they were sighted and their status in the study area (M = Migrator; B = Breeding; W = Wintering; S = Stantial).

Management aims

The user selects in advance which conservation features must be present in the areas that the software is going to select (Cowling *et al.* 2004, Stewart *et al.* 2008, Watts *et al.* 2009). It is possible to choose both information on species and/or habitats (Agardy 1997, Dayton *et al.* 2000, Airamé *et al.* 2003, Smith *et al.* 2009).

The data collected in the field were organized in order to obtain information on the bird community, using the following parameters: S: Richness (number of species); diversity index ($H = - \Sigma Pi * \ln Pi$; Shannon & Weaver 1983).

The data on richness and diversity have been organized by dividing each year into 5 seasonal periods: Winter (15 December - 15 March), Spring (15 March - 15 May), Breeding period (15 May - 30 June), Summer (1 July - 31 August), Autumn (1 September - 15 December).

Then some biological indicators were selected because of their peculiarity and/or their ecological and behavioural needs. Knowledge of the distribution of biological indicators of a natural area provides very valuable information regarding the ecological conditions of the area and its level of conservation (Frank & Battisti 2005, Bani *et al.* 2006, Lorenzetti & Battisti 2006). In this study were chosen the following biological indicators: the Red-backed Shrike *Lanius collurio*, as an indicator of the environmental quality of open areas; the Nuthatch *Sitta europaea* and the Green Woodpecker *Picus viridis*, species sensitive to environmental fragmentation (Matthysen 1998, Matthysen *et al.* 1995).

Furthermore, the breeding species were considered both as an indicator of the high quality of the natural environments and as a guarantee for the long-term perpetuation of the species themselves (Lovaty 1980, Lande *et al.* 2003). Only when an environment has a good level of conservation can sustain a high abundance of birds, both in terms of abundance and species diversity. This is particularly true during the most delicate period of their biology, when the birds have the major ecological needs of their entire cycle (availability and heterogeneity of food, availability of space, low anthropic pressure, etc.) (Isotti 2013).

After the selection of the biological characteristics on which base the management of a nature reserve, is necessary to set the conservation objectives. In this work was chosen the 50% target for all the biological characteristics examined.

Marxan software analysis

In this work Marxan has been used to contribute to a zoning of the Circeo National Park that guarantees the achievement of specific conservation objectives as an example of the use of this software in the Mediterranean habitat.

The software was executed for each scenario (Fig 1) in order to generate a series of "very good" solutions. In a management context, in fact, it may be useful not to have a single solution to a problem, but a variety of possible solutions that can meet the particular conservation objectives decided by the user (Possingham *et al.* 2000, Schneider *et al.* 2011). To do this the program uses a mathematical optimization algorithm called "simulated annealing" (Kirkpatrick *et al.* 1983, Cook & Auster 2006).

In its simplest form, Marxan's aim function is a combination of the total cost of the reserve system and a penalty for each of the ecological goals that are not met. Marxan also allows to consider the fragmentation measure of the reserve system, to ensure that the selected areas are not excessively fragmented. A fragmented reserve system will not only lead to a fragmentation of ecological communities, it will also be harder and more expensive to manage. The objective function of Marxan is the following:

$$\sum_{PUs} Cost + BLM \sum_{PUs} Boundary + \sum_{Con\ Value} \begin{matrix} SPF*Penalty+ \\ Cost\ Threshold\ Panalty \end{matrix}$$

in which the first term is the total cost of the solution, (PU = Planning Unit). The second term represents the Total Length of the Reserve Boundary x BLM (Border Length Modifier). The third term represents the penalty linked to not having adequately included all the characteristics of conservation within the reserve (SPF = Species Penalty Factor) (Ardron *et al.* 2002). In this work was set for each of the biological characteristics the same SPF value, in order to give all of them same relevance in the site selection process. Finally, the fourth term represents the penalty associated with having exceeded a preset cost threshold. The second and fourth term of the objective function are optional, not necessary for the algorithm's execution (Game & Grantham 2008). In this study, the border length modifier was used for some scenarios, while no cost threshold was set.

The software performs simulations that start by generating a set of planning units taken randomly from the general dataset. This process is repeated in each execution of the model for a number of times equal to the set value of the iterations (10 million in this work), in order to find an optimal solution. Through the simulated annealing algorithm, Marxan is able to reject suboptimal sets, greatly increasing the probability of final convergence on the most efficient set of PU (Andelman *et al.* 1999, Chan *et al.* 2006, Game & Grantham 2008).

The resulting maps provide a necessary index for each PU. The necessary index represents the number of times each individual unit has been chosen within 100 individual solutions. Higher is the necessary index, the more likely that specific planning unit is needed as part of the protected area to achieve conservation objectives (Ardron *et al.* 2002, Chan *et al.* 2006).

Then Marxan produces two different results: the first shows the "best" solution, i.e. the solution with the lowest cost; the second calculates the number of times each PU has been chosen among all the solutions (Smith *et al.* 2009).

Conservation Costs

Marxan selects the planning units in order to achieve conservation objectives, but it also considers another factor: the software assigns a planning cost to each PU (Ball & Possingham 2000, Ardron *et al.* 2002, Smith *et al.* 2009).

Developing data on PU costs is complex, as this involves deciding which of these values should be measured. Some studies used data on human activities to develop a "natural" index, preferentially selecting planning units that are less likely to be valuable for human economic activities (Polasky *et al.* 2001, Eastwood *et al.* 2007, Mills *et al.* 2007, Smith *et al.* 2009).

In this work, to define the economic costs of an area, we used the land use categories and the relative average agricultural values defined by the Province of Latina (year 2005), by the Territory Agency, incorporated in 2012 in the Revenue Agency.

RESULTS

The bird community totalled 149 species, out of which 70 were breeding species. The number of species did not differ significantly by habitat type (χ^2= 29.71, df= 6, P<0.00001).

Through the use of Marxan this study developed several scenarios (Table 1), each one based on specific diversity characteristics. In each scenario, the program was executed either without using the Border Length Modifier (BLM), or by setting a high BLM value (250), in order to reduce the level of fragmentation of the results. Comparing the two results for each scenario it is evident how this parameter has a strong influence on the results. Changes in BLM affect the spatial configuration of the selected areas in the various scenarios, as can be seen in Figure 1. Using

Table 1. Number of Planning Units (PU) and Border Length (BL) of the best solutions obtained by Marxan for each scenario when the value of the Border Length Modifier (BLM) changes.

Scenario	BLM	PU	BL
1	0	138	106000
1	250	138	56000
2	0	140	112000
2	250	142	70000
3	0	90	84000
3	250	95	61500
4	0	139	108000
4	250	138	53000
5	0	53	47000
5	250	51	36000
6	0	52	46000
6	250	53	32000
7	0	136	80500
7	250	135	30500
8	0	186	133500
8	250	185	66500

a high BLM value the total number of planning units selected in the solution remains roughly the same while the total perimeter of the solution decreases clearly for all scenarios.

The results of the software include: a) the solutions for each execution; b) the best solution among all executions; c) the summed solutions of all executions (or irreplaceable analysis). The summed solutions describe the number of times each PU has been selected within the total number of solutions (Airamé *et al.* 2003). Marxan has generated 100 efficient solutions for each scenario, each of which meets all the pre-set conservation objectives. Among these, the best solutions found by Marxan for the various scenarios taken into consideration were represented on a map and displayed from Fig. 1 to Fig. 8.

Fig. 1 (diversity and richness during the autumn) shows how the most important areas are the coastal lakes and the area of the State Forest. Fig. 2 (diversity and richness during the winter) highlights the lakes and agricultural areas adjacent to the lakes. In Fig. 3 (diversity and richness during the spring) highlights the coastal lakes along with some areas of the state forest and an area of connection between Paola Lake and the State Forest itself. In Fig. 4 (greater richness and diversity during the breeding season) the areas that have the highest priority for their conservation value are the lakes and the State Forest. Fig. 5 (diodiversity and richness in summer) shows only coastal lakes. The same result was obtained by Marxan by setting the analysis on the annual values of diversity and richness (Fig. 6). Fig. 7 shows the two solutions identified by Marxan for the biological indicators and the areas with the greatest presence of breeding species. We can see that the areas selected in the solution are mainly the State Forest and part of the Circeo Promontory, together with the area just north of the promontory and adjacent to the southern limit of Lake of Paola. Finally, Fig. 8 shows the two best Marxan solutions calculated for a set of values (species richness and diversity + biological indicators + breeding species). The areas of greatest value are the State Forest, the coastal lakes and the Circeo promontory, together with the area immediately north of it.

In addition to generate the "best" solution Marxan also calculates the number of times each PU has been chosen among all the solutions for each scenario. The results of these selection frequencies obtained by the software are shown in figures 9-16 with a more intense color and are those which have a higher degree of indispensability. Other planning units are also frequently selected (> 90%).

DISCUSSION

Wildlife studies are an important tool to support the analysis of environmental quality in landl management activities. The maps represent a visualization of the results of scientific research work and have great importance in sharing scientific results with all stakeholder involved. Marxan software was used by setting conservation objectives in all scenarios at a level equal to 50% of the distribution for each feature taken into examined. Setting goals is at the basis of a systematic conservation planning and the extension of each protected area will be strongly influenced by this. The best solutions calculated by Marxan were displayed on the maps (from Figs. 1 to Fig. 8), that show the most important areas of the Park, based on different biological characteristics. We decided to take into consideration seasonal variations of the species richness and diversity values, allowing in this way to include the assessment of biological phases in the list of variables involved in the designation of territorial planning. The maps show that during the autumn the most important areas are the coastal lakes. Which in this period of the year have the highest value of richness, and the State Forest, which has the highest diversity value. This indicates the importance exerted by the Circeo Park, and in particular by the lakes areas, as a stopping point for many bird species along the migratory routes.

In winter, in addition to the lakes also the agricultural areas, included in the zone between the State Forest and coastal lakes, take on a great importance from the biological point of view. A part of this area falls outside the boundaries of the Park, while it is included different management categories (Santolini *et al.* 2003). Must be emphasized that winter is the only season when diversity in agricultural areas is greater than in the natural areas of the Park. The cause of this phenomenon is probably due to the trophic use, by some aquatic species, of the agricultural areas adjacent to the lakes. This result is particularly interesting because those areas have been chosen by the software despite the planning units inside these zones have a higher cost compared to the natural areas. During the spring the areas of greatest conservation value are the lakes (higher richness values) and part of the State Forest, in association with a zone that connects the Lake of Paola to the State Forest itself (higher diversity values). Therefore, also during the spring, as for the autumn, the wetlands of the Park represent an important rest area for migratory birds, which need suitable areas for rest and food integration.

The maps concerning the breeding season indicate the lakes and the State Forest as the areas of greatest biological value. In the summer, only the lakes are found among the best solutions calculated by Marxan because they present the highest values of both diversity and richness at that time of year. The same result was obtained in the scenario based on the annual values of these two indexes, demonstrating the overall weight that the coastal lakes assume for the conservation of the entire area.

The mapping of the results concerning the potential distribution of some biological indicators makes it possible to emphasize at least two important management strategies. At the species level, the presence of Red-backed Shrike, selected for its ecological needs, has highlighted some small areas, to which would be appropriate guarantee a particular level of conservation, minimizing the anthropic disturbance. Instead in these areas there is a progressive expansion of agricultural activities at the expense of the forest areas of cork oaks, often with disadvantage of monumental trees (isolated within the cultivated fields) that have a significant role for some bird species that prefer forest habitat (Frank & Battisti 2005, Bani *et al.* 2006). Nuthatch and Green Woodpecker have allowed to highlight the area most subject to the phenomenon of habitat fragmentation, i.e. the areas that have a size minor than necessary to meet the ecological needs of these species. In these areas it would be advisable to set up environmental quality assessment interventions, to determine the causes that produced the fragmentation and, eventually, provide an environmental restoration.

In the scenario based on the potential distribution areas of the threatened species, the coastal lakes are once again the most valuable areas, in fact is in these important wetlands that these species can be found. In the cases, as in this work, in which the study area is analysed taking into account many variables, the creation of many single-issue cards risks to produce less comparable results. Therefore, when it is intended to contribute to the management of a complex area such like the Circeo Park, it may be useful to condense the results in a single summary map. This in order to provide the managing staff with an exhaustive and easy to ready tool. However, a summary map presents the limit of a result in which the not all the variances of the diverse biological characteristics taken into consideration are included.

For example, it is not highlighted whether an area has an important conservation value only during some periods of the year. The summary map shows how both the State Forest, the lakes, and part of the promontory with associated agricultural area just north of it should be considered as priority areas for the conservation of the biological characteristics mentioned above.

Each habitat has a particular role in the different biological phases of a bird species, assuming a specific ecological importance (Bennett 1999, Fahrig 2003, Lorenzetti & Battisti 2006). The availability of a mosaic of different habitats within their home range may represent an advantage for many species of birds (Wilcove *et al.* 1986, Villard 1998), increasing their richness and making the bird community more complex (Bogliani 1995, Lomolino 2000, Battisti *et al.* 2003, Lindenmayer & Fisher 2006).

Marxan allows also to consider the level of the fragmentation of the results, so that so that the areas selected in its solutions are not excessively fragmented. By setting a high BLM value the best solution contains almost the same number of units compared to the best solution calculated without setting any BLM value. On the other hand, solutions with a high BLM value have a much smaller border length than those without this parameter. In the extreme case, the scenario based on the areas of biological indicators and breeding species shows that the length of the border modifier is a very important parameter for selecting grouped planning unit sets. An extremely important result because there are many ecological and economic reasons to prefer areas with low ratios between border and area (McDonnell *et al.* 2002). Finally, it is useful to know how often a planning unit is included in the set of solutions generated by the software (Necessary index for planning units from Fig. 9 to Fig. 16). However, even if some units are chosen less frequently, this does not necessarily mean that they have a low conservation value. Some planning units may be chosen less often if they are similar to other areas. Planning units that are not selected often can offer some planning flexibility (Chan *et al.* 2006).

In conclusion, this software is a support tool designed to help rather than to replace decision-making process (Possingham *et al.* 2000, McDonnell *et al.* 2002, Schneider *et al.* 2011). As regards the Circeo Park, the main information suggests is to take particular attention to seasonal variations in the composition of the bird communities and, consequently, to the weight that the Park assumes at national and international level in the context of migratory movements and biodiversity conservation. In addition, special attention must be paid to the growing of intensive, rapidly expanding agricultural activities that are not enough controlled and are potentially highly damaging for the Park's biodiversity, both in terms of vegetation and fauna. This applies in particular the areas that separate the State forest from the coastal lakes and the Park sector bordering the southern end Lake of Paola and the northern part of the Circeo Promontory.

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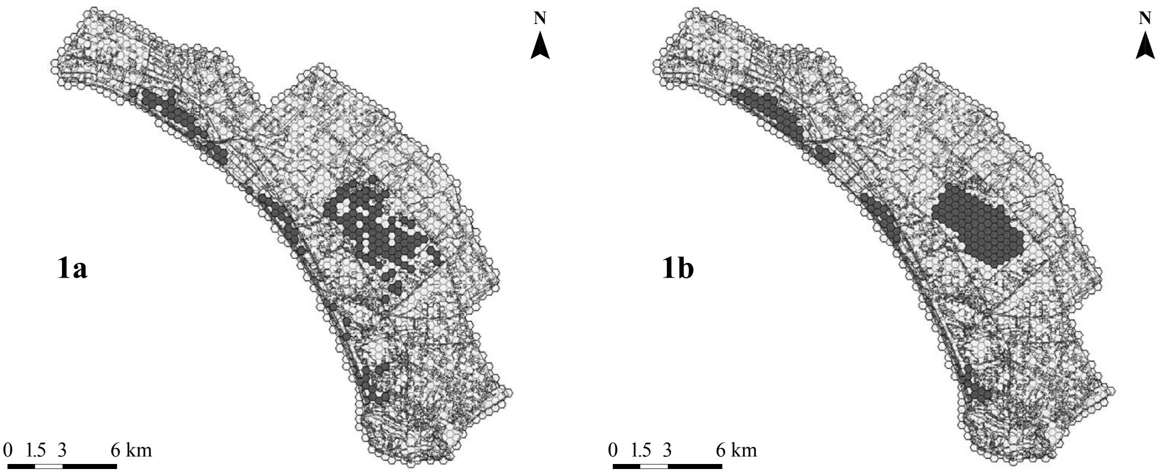

Figure 1. Scenario 1, Map of diversity and richness of species during Autumn (Fig. 1a BLM=0; Fig. 1b BLM=250).

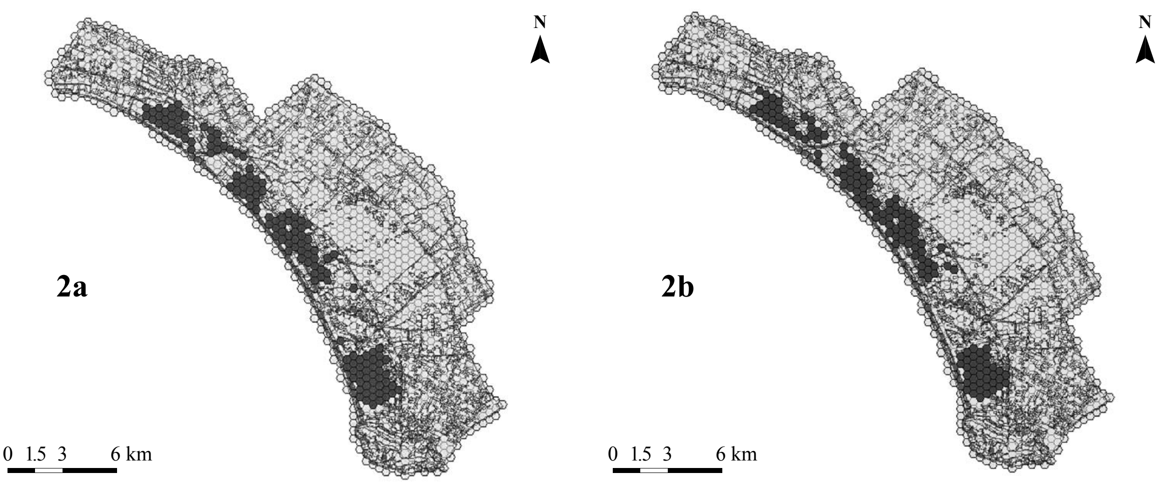

Figure 2. Scenario 2, Map of diversity and richness of species during Winter (Fig. 2a BLM=0; Fig. 2b BLM=250).

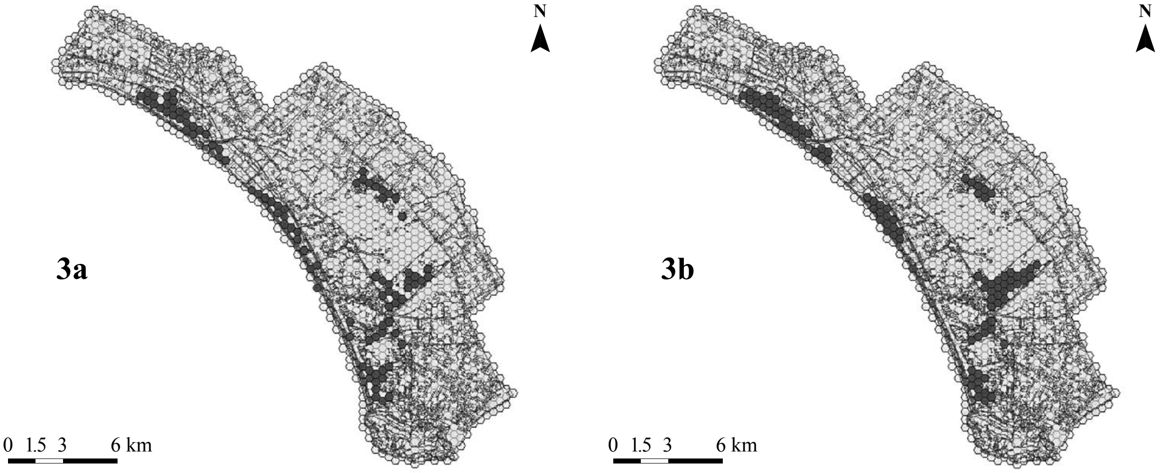

Figure 3. Scenario 3, Map of diversity and richness of species during Spring (Fig. 3a BLM=0; Fig. 3b BLM=250).

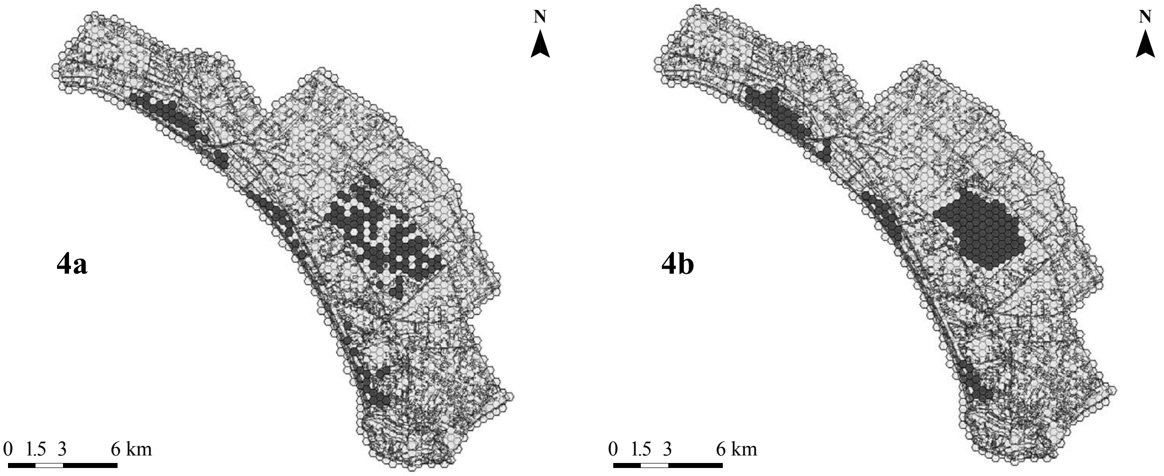

Figure 4. Scenario 4, Map of diversity and richness of species during Breeding season (Fig. 4a BLM=0; Fig. 4b BLM=250).

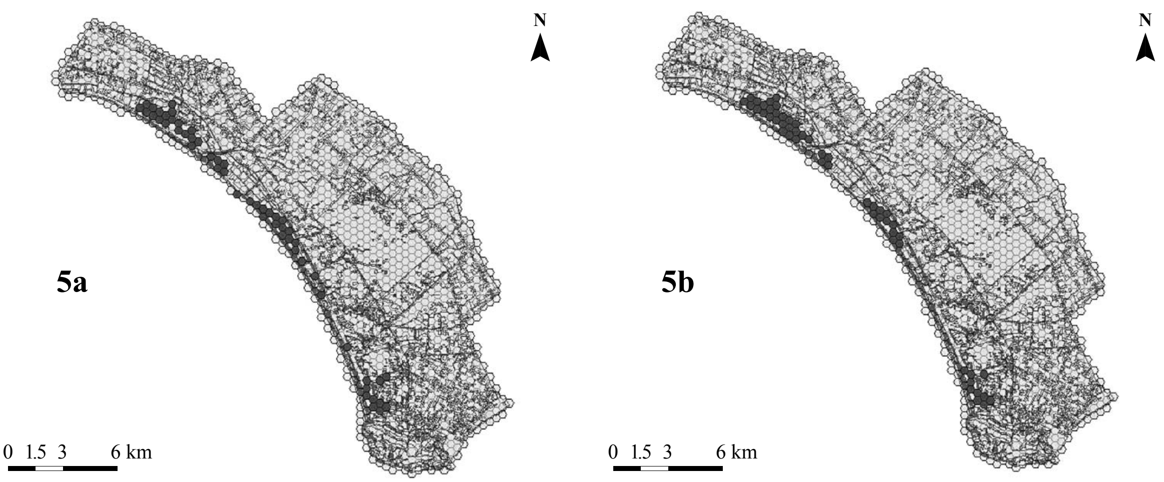

Figure 5. Scenario 5, Map of diversity and richness of species during Summer (Fig. 5a BLM=0; Fig. 5b BLM=250).

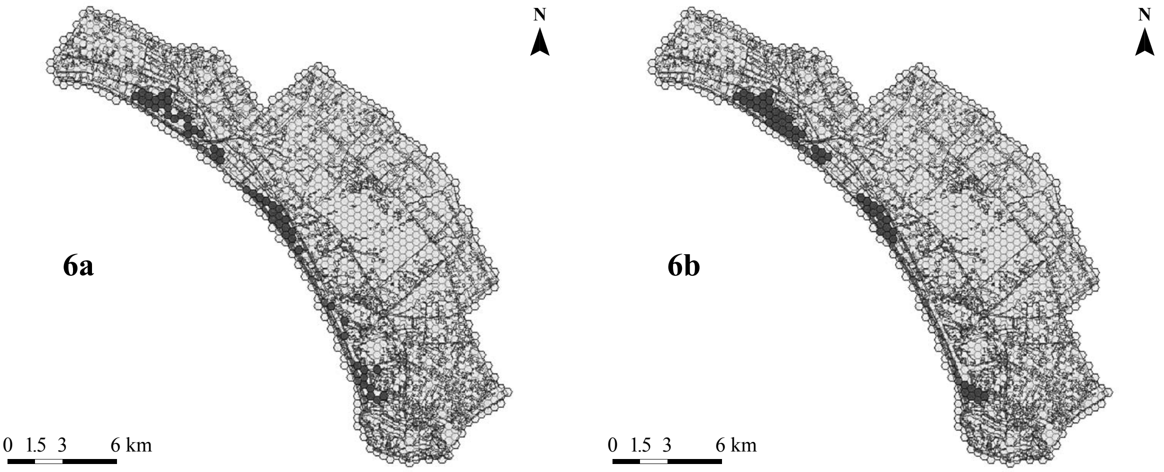

Figure 6. Scenario 6, Map of Annual diversity and richness of species (Fig. 6a BLM=0; Fig. 6b BLM=250).

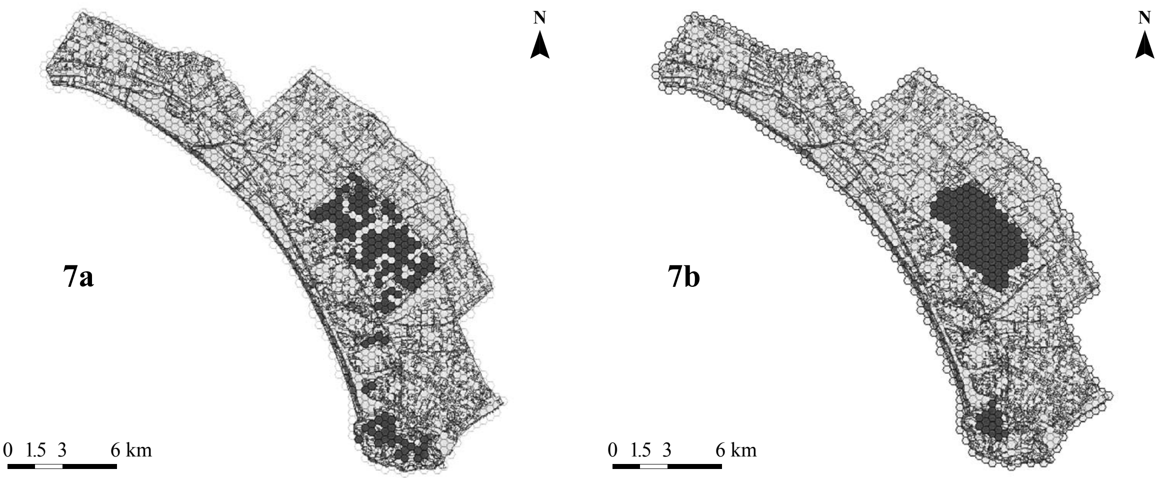

Figure 7. Scenario 7, Map of Biological Indicator and Breeding species (Fig. 7a BLM=0; Fig. 7b BLM=250).

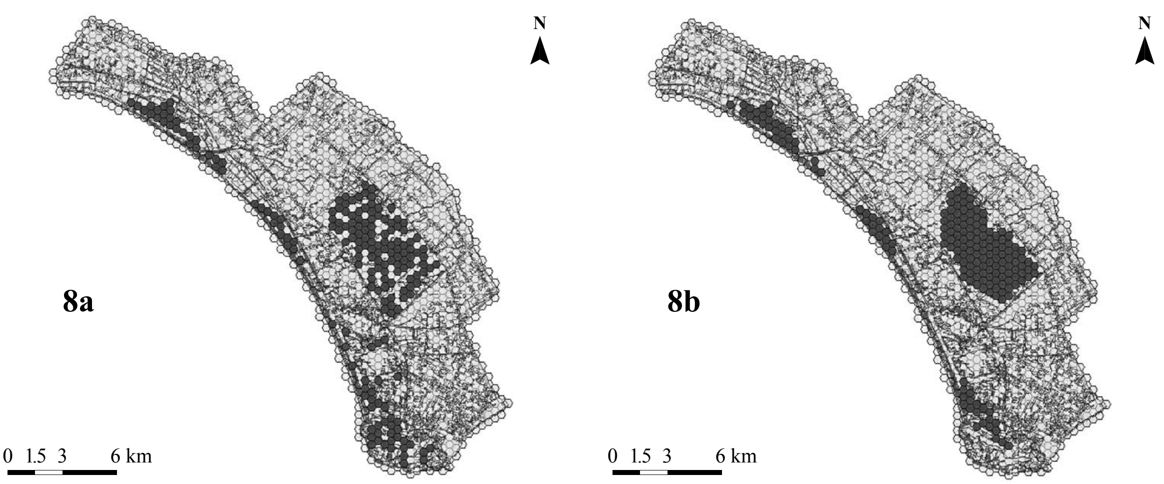

Figure 8. Scenario 8, Summary map of diversity, Richness, Biological Indicators and Breeding species (Fig. 8a BLM=0; Fig. 8b BLM=250).

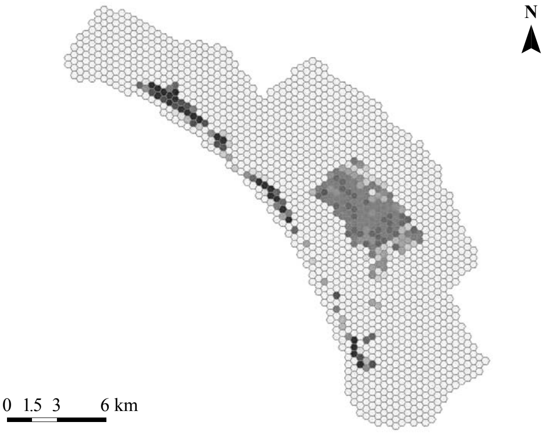

Figure 9. Frequencies of selection of planning units among all the solutions for Scenario 1.

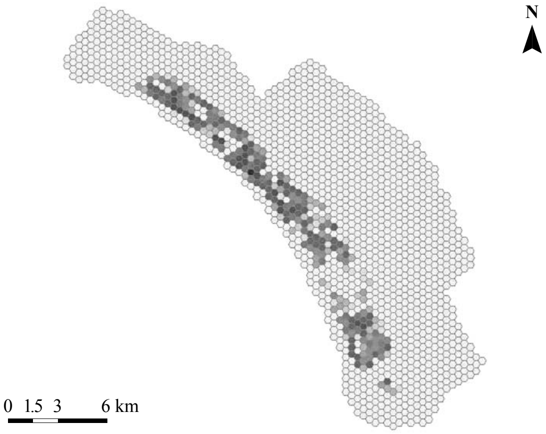

Figure 10. Frequencies of selection of planning units among all the solutions for Scenario 2.

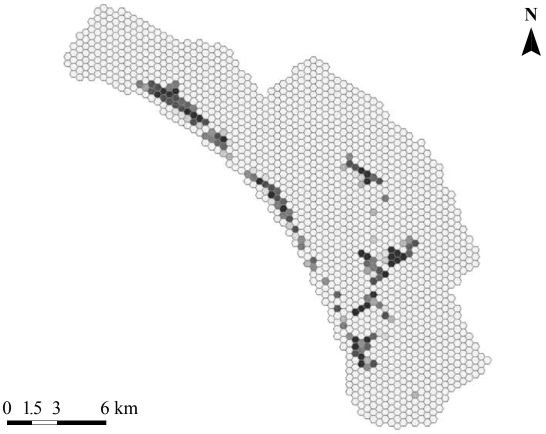

Figure 11. Frequencies of selection of planning units among all the solutions for Scenario 3.

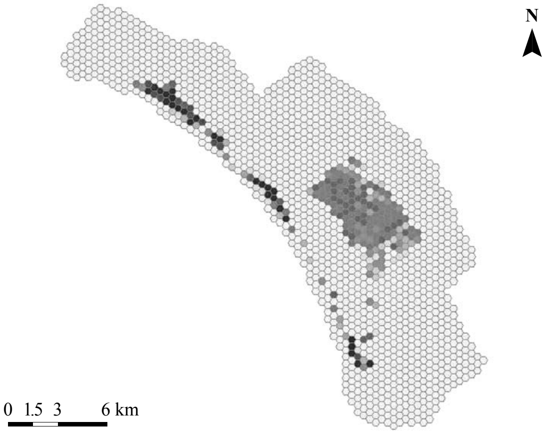

Figure 12. Frequencies of selection of planning units among all the solutions for Scenario 4.

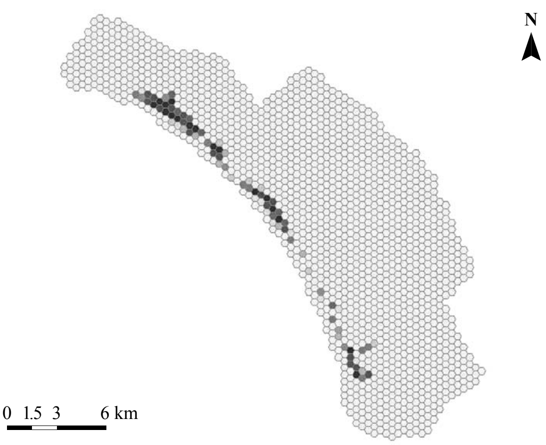

Figure 13. Frequencies of selection of planning units among all the solutions for Scenario 5.

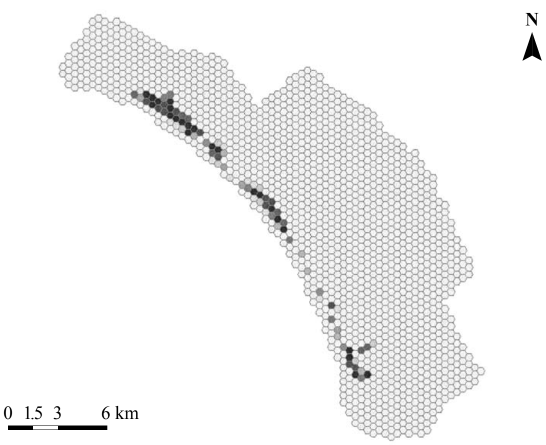

Figure 14. Frequencies of selection of planning units among all the solutions for Scenario 6.

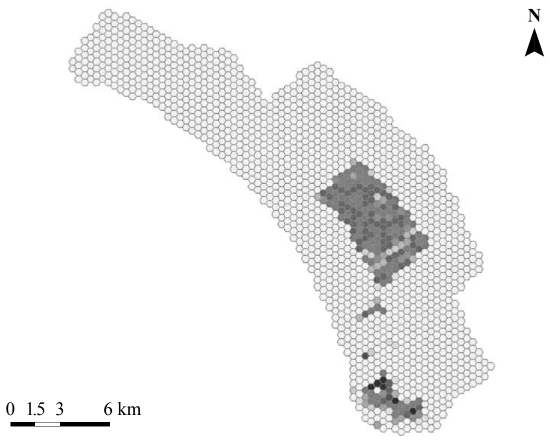

Figure 15. Frequencies of selection of planning units among all the solutions for Scenario 7.

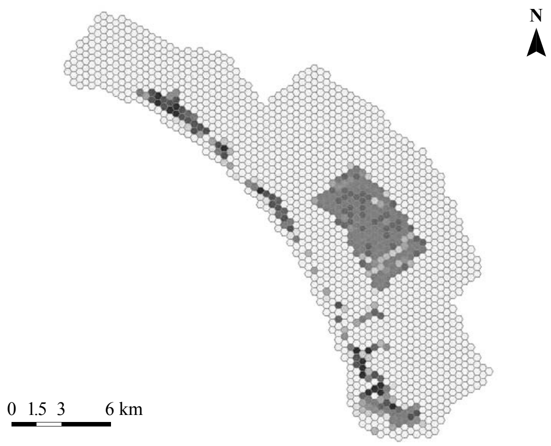

Figure 16. Frequencies of selection of planning units among all the solutions for Scenario 8.

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