Student thesis series INES nr 397

Conservation assessments of

Văcărești urban wetland in Bucharest (Romania):

Land cover and climate changes from 2000 to 2015

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2016

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Luana Andreea Simion (2016) Conservation assessments of Văcărești urban wetland in Bucharest (Romania): Land cover and climate changes from 2000 to 2015

Master degree thesis, 30 credits in Physical Geography and Ecosystem Analysis

Department of Physical Geography and Ecosystem Science, Lund University

Level: Master of Science (MSc)

Course duration: *January* 2016 until *June* 2016

Disclaimer

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Abstract

Văcărești urban wetland, a recently instituted nature park, is situated in Bucharest (Romania). It has been established over the last 27 years within an abandoned retention polder, built during the communist era. Although the area has been disregarded since the construction of the polder ceased, the importance of the Văcărești ecosystem was recently acknowledged by various international associations, due to its great biological diversity and presence of protected species. The aim of this research is to analyse how land cover has changed over the last decade, and to assess if climate change has influenced the habitats of species and therefore biodiversity. The present study focuses on the Văcărești wetland during the time interval 2000-2015. Satellite images have been used to estimate the percentage cover of six Land Cover Types (LCTs): bare soil, water bodies, water species, reed beds, open land and woody species. Climate variables, i.e. temperature and precipitation, have been collated from the European Climate Assessment and Dataset and used to document the main trends in temperature and precipitation of the study area since 2000. These climate data have also been used as explanatory variables to run Redundancy Analyses (RDA) to assess the LCT variation explained by each of those explanatory variables. Further, lists of plants, birds, insects and other animals have been synthetized based on the Substantiation Note that pursues the implementation of Văcărești Nature Park’s protection regime in order to link each LCT to the diversity of species. Note that the lists of species are available for the present only. The analysis indicated that temperature and precipitation specifically influence the water-related land cover types, which include water bodies, water species and reed beds. The reed LCT recorded a major increase throughout the studied period. Given that the presence of species depends on their specific physiological requirements, and therefore the availability of their respective habitats, I found that hydrophilic plants recorded an increase throughout the studied period. As local temperature and precipitation displayed an increasing trend between 2000 and 2015, it is assumed that the species that depend on the hydrophilic plants would also increase in the future. The results of this study could provide complementary support for the implementation of wetland conservation strategies. These strategies have the purpose of protecting the resources of the ecosystem and potentially enhance the species diversity of Văcărești wetland.

Keywords: Urban Wetland, Climate Change, Land Cover Types, Biodiversity, Protection and Preservation

Acknowledgement

I would like to express my sincere gratitude to my supervisors, Harry Lankreijer and Laurent Marquer, who always took the time to help me carry out this study. I would also like to thank my Erasmus coordinators, Ecaterina Ștefan and Paul Miller, who were constantly open and supportive.

Furthermore, special thanks are offered to Cristian Vasile, my home university supervisor (University of Agronomic Sciences and Veterinary Medicine, Bucharest), Ioana Tudora, who guided me in choosing the subject of the present study, Cristian Lascu, founding member of the Văcărești Nature Park Association, and Mirela Dragoș and Marius-Victor Bîrsan who provided me with useful information for this study.

I am very grateful to my family for the continuous support and care, and Tudor Buhalău for being beside me during all this time.

Lund, June 2016

Contents

1. Introduction

1.1 Context

Văcărești urban wetland has been developing throughout the last 27 years within an abandoned retention polder, where natural features (e.g. permanent ponds and marshes) have gradually recovered due to the lack of anthropic intervention. The wetland has recently been declared a nature park (i.e. 11 May 2016) as a result of a four-year project that aimed at the institution of the protected natural area regime, initiated by a group of environmental protection specialists (i.e. the Văcărești Nature Park Association). According to the national legislation of Romania and the International Union for Conservation of Nature (IUCN), a nature park is defined as "a protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic values and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values" (IUCN, 2016; Romanian Government, 2007). The origin of the initiated project was an article published in the May 2012 issue of the National Geographic magazine named "Delta between the blocks", in which the Văcărești urban wetland was presented for the first time to the public (Lascu, 2012). As a result of this article, various international associations such as the World Wildlife Fund, Wildfowl and Wetland Trust UK, and the Ramsar Convention (Convention on Wetlands) have given their support to the project. Tobias Salathé, the Ramsar Senior Adviser for Europe stated during a visit to the site in 2012 that "Văcărești will undoubtedly be one of the most innovative and pioneering urban wetland projects in the world" (Parc Natural Văcărești, 2016). The high environmental value of the landscape comprises both biotic and abiotic elements, being validated by an official notice published by the Romanian Academy in 2013 (Bărbulescu, 2015). This essential procedure required in order to declare the site a protected area was followed by a large range of scientific research conducted by specialists in geology, biodiversity, flora, entomofauna (insects), herpetofauna (reptiles and amphibians), ornithology (birds) and chiropteran fauna (bats) (Stoican et al., 2013). In September 2015, the project (see above) that aimed at declaring the site as a natural protected area was subjected to public debate and soon after, exhibitions as well as educational sessions (e.g. didactic field trips) started to take place, and people began to be conscious of the wetland's importance (Bărbulescu, 2015). Therefore, as specified on the official web page of the wetland, tens of thousands of people from Bucharest have signed support lists for the initiation of the nature park (Parc Natural Văcărești, 2016). After strenuous efforts and bureaucratic difficulties, Văcărești Nature Park was established by government decision, in May 2016. At the moment, Văcărești wetland is the first urban nature park and wetland centre in Romania, as well as the largest park in Bucharest. The approximately 183 hectares (Stoican et al., 2013) of the wetland contribute to the development of the urban green area in Bucharest with about one square meter per inhabitant, the site being the last meaningful available green area within the city (Bărbulescu, 2015).

Climate change and global warming in particular are assumed to have a great impact upon the current biological diversity of wetland ecosystems, which resulted from the equilibrium between the distinct constituent species and abiotic factors (e.g. temperature, humidity, hydration conditions and soil structure) throughout time (Ministerul Mediului și Schimbărilor Climatice, 2013). Therefore, conserving biodiversity is an essential consideration when climate change adaptation strategies are formulated.

In the context of climate change, Cristian Lascu, founding member of the Văcărești Nature Park Association, has expressed through personal communication the critical need to fulfil the information gaps respecting the future development of the wetland, specifically analysing the evolution of the site with regard to climate change and assessing the risk of valuable species disappearance. Therefore, this research would reduce the lack of knowledge on the biodiversity of Văcărești wetland and provide support for selecting future conservation strategies.

1.2 Research question and research objectives

The research question of the present study is: *To what extent is Văcărești urban wetland going to be affected by ongoing climate change in terms of land cover change and its related biodiversity?* Answering this question would be of high interest for the conservation of Văcărești Nature Park in the present day changing climate.

The specific objectives to answer the research question are to:

- Assess the trend in climate change;
- Estimate the spatial and temporal land cover changes;
- Explore the correlation between climate and land cover changes;
- Evaluate the present biodiversity;
- Discuss the likely impacts of climate change on land cover and biodiversity for nature conservation.

2. Background

2.1 Literature review

2.1.1 Wetland ecosystems

Although wetlands are said not to have any particular ecological definitions, being generally described as the “interface between water and land”, they are mainly determined by three particular characteristics: the presence of water, specific wetland soils (different from upland soils) and the occurrence of vegetation that is suitable for waterlogged conditions (Scholz, 2015). Although fluctuation between surface and groundwater levels varies considerably depending on the season, the hydrological conditions of a wetland define the species diversity and abundance (Scholz, 2015). Generally, the species richness within wetland ecosystems is considered to be of great abundance in relation to the surface area of the wetland and furthermore, rare or endemic species are often included in these habitats (Gopal, 2009). Besides the relatively continuous supply of water, the reasons why wetlands have a greater biologic diversity in comparison with other ecosystems include the prospect of tempering the surrounding microclimate, unfavourable conditions for competing or invasive species, and the difficulty involved for people to access the area (Maltby, 2009). The benefits of wetlands have been acknowledged all around the world (Scholz, 2015) and the human perception on these ecosystems has evolved from their being inhospitable and dangerous to life (an idea promoted by literature and cinematic media) to a wide recognised asset to society (Maltby, 2009). Urban wetlands occur all throughout the world (Figure 1), and their major benefits include the support of biological diversity and habitat provision to wildlife, the regulation of the surrounding thermal environment (depending on shape, location (Sun et al., 2012), the proportion and distribution of water bodies and vegetation (Wang and Zhu, 2011)) and the decrease of flood risk within the city. Other advantages of wetlands include water decontamination by means of pollution absorption, keeping a balance between ground and surface water, as well as offering cultural and recreational services (Lavoie et al., 2016). The importance of these fragile ecosystems is highlighted by the fact that they are exclusively protected by an international convention (i.e. the Ramsar Convention, which supports the conservation of wetlands and sensible use of their resources (Ramsar, 2016)) (Ibarra et al., 2013).

However, the evolution of the urban tissue that encloses wetlands often leads to fragmentation of these ecosystems and, eventually, to a loss in biodiversity (Lavoie et al., 2016). Therefore, conservation policies that encourage sustainable practices should be implemented in order to support the valuable ecosystem services provided by urban wetlands.

Figure 1. Examples of wetlands in urban settings: Hong Kong Wetland Park (to the left) and Bellandur Wetland from India (to the right) (greeningthejungle.squarespace.com, 2016; The Hindu, 2016).

2.1.2 An example of an urban wetland: London Wetland Centre

London Wetland Centre is a relevant example of how an urban wetland could become a successful project by means of conserving the biodiversity within an urban area (Harden, 2011), as well as encouraging cultural and recreational activities for the society. The site is located in the southwest of London, being encircled by a bend of the River Thames. The area, formerly known as Barn Elms Reservoirs, measures about 42 hectares (Figure 2). The reservoirs were constructed in the late nineteenth century in order to provide drinking water for the increasing population of London. Their initial purpose had eventually been abandoned, as the reservoirs did not follow the European Union regulations. However, due to the significant wildfowl populations developed within, the site was recognised as being of special scientific interest (i.e. representative areas for the natural heritage in the United Kingdom (Scottish Natural Heritage, 2016)), hence legislation stipulating that it should be maintained as a water body (Harden, 2011). Due to Sir Peter Scott who identified its potential in the 1980s, the wetland has become part of the Wildfowl and Wetlands Trust, a wetland conservation charity. In order for the site to be converted into a bio-diverse habitat (Figure 2), a small part of it has been sold to a property developer to acquire the necessary financial support. This decision has drawn the attention of private donors who have further contributed to the development of the site (Harden, 2011).

Figure 2. Aerial view upon Barn Elms Reservoirs, before the wetland was built (to the left) and London Wetland Centre in 2010 (to the right) (BBC, 2016; London Top 100, 2016).

Since the construction of the site between 1995 and 2000, the centre has been continuously promoting sustainability (e.g. the constituent Rain Garden aims at managing rainwater runoff), as well as providing societal and educational value. Children are taught about conservation and sustainability by means of thematic adventure playgrounds, interactive exhibits and social events (Harden, 2011). One key example is the design of the observatory at the Visitor Centre, resembling an airport terminal (Figure 3), to refer to it as London's "airport for birds". The bird migration routes, as well as seasonal times of bird arrivals and departures, are shown on educative panels (Whigham et al., 1993).

Figure 3. London Wetland Centre. The Visitor Centre is designed as an "airport for birds", where bird migration routes as well as seasonal times of bird arrivals and departures are presented (JTP, 2016; Whigham et al., 1993).

The London Wetland Centre is characterised by rich flora and fauna. More than 300,000 aquatic plants, hundreds of rare native bulbs and 25,000 trees have been planted after the landscaping and engineering work had ceased, in 1997 (The Galloping Gardener, 2016). In order to create an ecological refuge for different species, diverse habitats such as water meadows, reed beds and grazing marshes were integrated within the wetland (BBC, 2016). As of 2010, 222 bird species have been recorded, along with numerous reptile and amphibian species, as well as 446 plant taxa (BBC, 2016). Some of the species present today, such as the lapwing and the bittern, have been found within the wetland after not being able to breed in London for a very long time (Harden, 2011). In addition to the species that have naturally colonised the wetland, the Centre has initiated some reintroduction programmes, which turned out to be thriving, such as the prosperous establishment of the slow worm lizard, the tower mustard plant and especially the water vole, which had declined by 90% in England since the middle of the twentieth century (Harden, 2011). Judicious management should be continued so as to provide suitable conditions for new species to colonise the wetland that is, at the moment, internationally recognised as a symbol of urban conservation and an excellent study case for attaining sustainability for developing comparable sites around the world (Harden, 2011).

2.1.3 The Theory of Island Biogeography

The example above shows the importance of wetlands located in urban areas for nature conservation. However, these locations within cities could lead to isolated populations of fauna and flora that would be threatened. The Theory of Island Biogeography affirms that the number of species that occur in isolated habitats depends on the equilibrium between species immigration and extinction (MacArthur and Wilson, 1967; Figure 4). Further, the more isolated and smaller a habitat is, the less rich in species that area will be (Harrison and Bruna, 1999). The Theory of Island Biogeography emphasises the need of connectivity between fragmented habitats to maintain species diversity (Harrison and Bruna, 1999; Losos and Ricklefs, 2010). A couple of examples of environmental policies that support the need for connectivity are Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC). The main objective of these policies is to assist the European member states in decreasing the loss of biodiversity that results from habitat fragmentation and climate change through the implementation of connectivity measures (Kettunen et al., 2007).

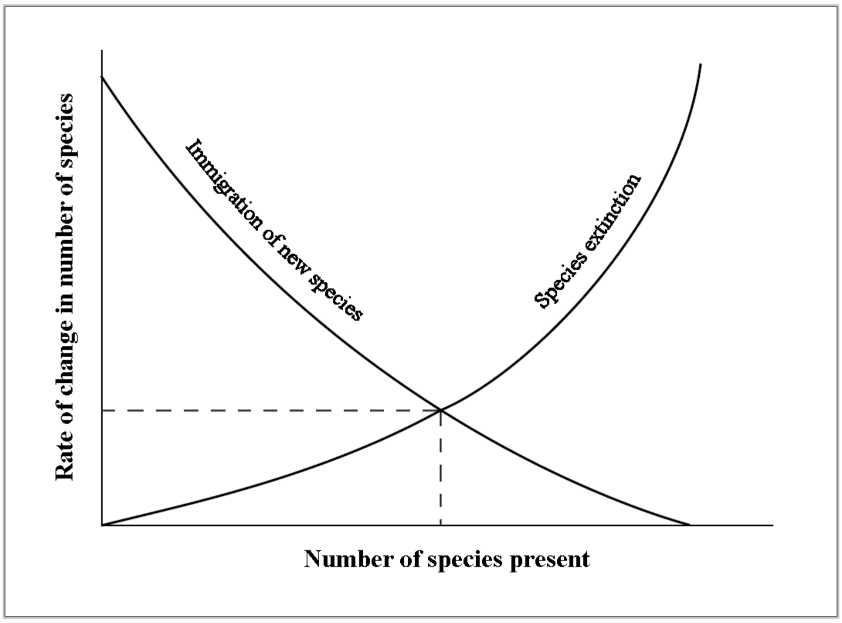

Figure 4. Equilibrium model of the species within an island (adapted from MacArthur and Wilson, 1967).

2.2 Study area

2.2.1 Location

Văcărești wetland, located in the southeast of Bucharest, is limited on the north by the Dâmbovița River (Figure 5). The geographical coordinates of the center of the wetland are 44°23’58’’N and 26°07’54’’E.

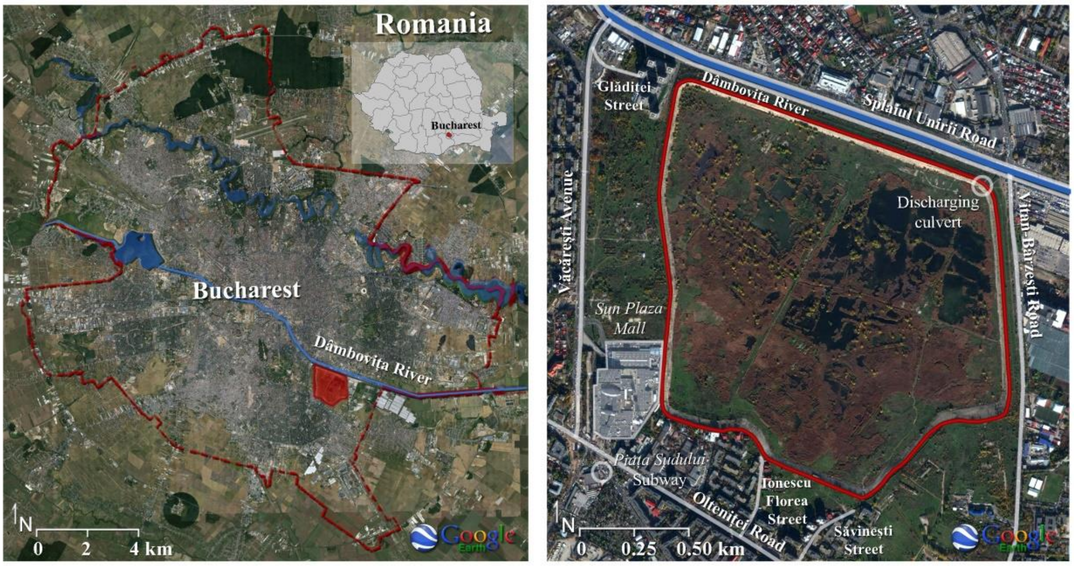

Figure 5. Bucharest map displaying the location of Văcărești wetland, represented by the red area (to the left) and the limits of the studied site illustrated by the red line (to the right).

The limits of the study area represent the outer contour of the former Văcărești Lake infrastructure, the whole area being surrounded by a concrete embankment (see next section about the history of Văcărești wetland):

- the northern border (towards Splaiul Unirii Road) streches from the intersection of Splaiul Unirii Road and Glădiței Street towards the discharging culvert situated in the northeastern corner of the site, lining the peripheral drain of the external embankment;

- the eastern border (towards Vitan-Bârzești Road) follows the path of the drain along the main road but southward from the culvert;

- the southern border (towards Oltenitei Road) follows the edge of the former lake, heading first to the west, afterwards to the southwest up to Săvinești Street and then towards northwest for 415 meters up to Ionescu Florea Street; further, the limit follows a sinuous trajectory towards the interior of the site until Lunca Bârzești Street, continuing towards west up the to Sun Plaza Mall;

- the western border (facing Văcărești Avenue) follows the former lake edge and then continues along the peripheral drain towards north on a almost straight trajectory.

The site, which has 183 hectares, is mainly a public property under the authority of the National Water Administration (i.e. Administrația Națională Apele Române), but there are some private landlords who also own about 2.5 hectares of the area. Furthermore, there are 131 applications for land claims (Stoican et al., 2013; see section 2.2.2 History).

2.2.2 History

Văcărești wetland lies on a former vast, open-spaced field known as the "Valley of Weeping" which was situated at the periphery of Bucharest at the beginning of the twentieth century. At that time, the area was characterised by marshy land and it was used as the main dumping site of Bucharest. (Stoican et al., 2013).

In 1921, King Ferdinand I provided allotments within this particular area for people to grow vegetable gardens. It has been continuously cultivated until 1988, although the land became national property in 1948 due to the communist era. The existent spring-fed water bodies were also used for fishing in those times (Figure 6).

However, the communist leaders decided to build an artificial lake on that specific area, and all the vegetable gardens were consequently destroyed. New waterlogged depressions occurred, resulting from the digging process executed in order to construct the encircling embankment. The work was completed in 1989, but as the basin was filled, water penetrated through the dam and underground, thus affecting the greenhouses situated on the northeastern side of the lake. Thereafter, the project ceased. In the period after 1990, the former landowners of the area applied to have the property returned to them, but did not succeed. Although the former lake was supposed to become a cultural-sport complex in 2003, the lake was abandoned (Stoican et al., 2013).

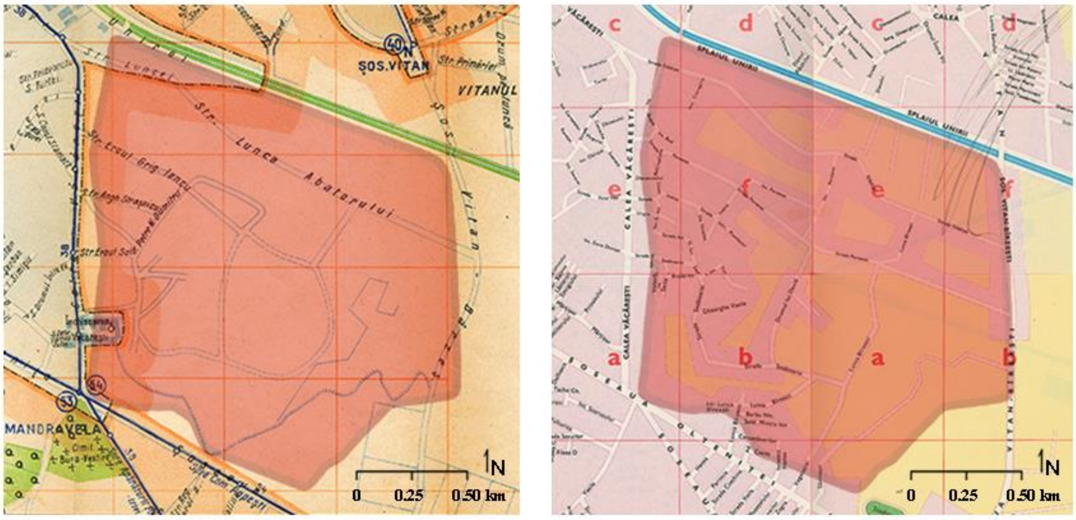

Figure 6. Present location of Văcărești wetland (highlighted in red) overlaid on maps from 1938 (to the left) and 1969 (to the right) (adapted from IdeiUrbane, 2016).

Although the area has been illegitimately used for the last 27 years as a dumping site and shelter for the homeless, nature revived surprisingly well. Different varieties of reptiles, insects, toads and mammals have found refuge within diverse habitats. Note that Văcărești wetland is nowadays situated at about 4 km from the city centre. The most thriving species found in Văcărești wetland are the water birds, which have encountered suitable conditions to nest and breed (see section 3.2.6 Biodiversity). Văcărești wetland is today the largest green area in Bucharest and despite being affected by considerable amounts of waste, the site recently became the first urban protected area in Romania (Stoican et al., 2013).

2.2.3 Geology

The study area corresponds to the predominantly calcareous Moesic platform with a Hercynian basement. The upper alluvial sediments, from Carpathian origin, are formed of various gravel, sand and clay mixtures and are overlaid with a sequence of different loess layers (Stoican et al., 2013) (Figure 8). Furthermore, the chernozem is the basic predominant soil type, rich in humus (i.e. fertile soil). This type of soil is situated at the top of the loess layers, being formed just beneath the herbaceous vegetation. However, it is important to note that the ground in the area has been heavily altered during the construction of the reservoir, and only few fragments of the area have remained unaffected (e.g. swamps and water bodies that existed on the site before the construction of the reservoir) (Stoican et al., 2013).

2.2.4 Hydrology

The Dâmbovița River is situated at the northern boundary of the studied site, flowing from northwest towards southeast of Bucharest. The natural meandring course of the Dâmbovița River was originally located at the southern limit of the study area (Manea et al., 2016), and had been modified in 1879-1880 (Stematiu and Teodorescu, 2012; Figure 7). Note that the swamp and wetland areas decreased over the nineteenth century due to the spread of human activities such as construction of buildings and houses as well as the development of greenhouses (see section 3.2.1 History and Figure 7).

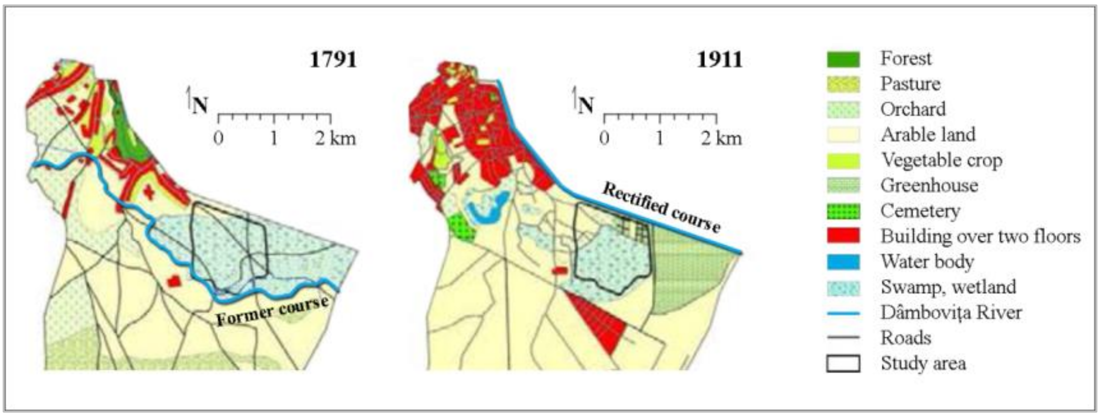

Figure 7. Former and rectified courses of Dâmbovița River (adapted from Manea et al., 2016). This figure also shows the decrease of swamp and wetland areas due to the increasing human activities such as construction of buildings and development of greenhouses.

The initial natural ponds and swamps, as well as the ones resulting from the construction of the reservoir, are spring-fed (Stoican et al., 2013); about 20 underground springs supply the water bodies in the study area (Adevarul, 2016). More particularly, the Văcărești area is characterised by porous and permeable quaternary groundwater aquifers (Stoican et al., 2013; Figure 8):

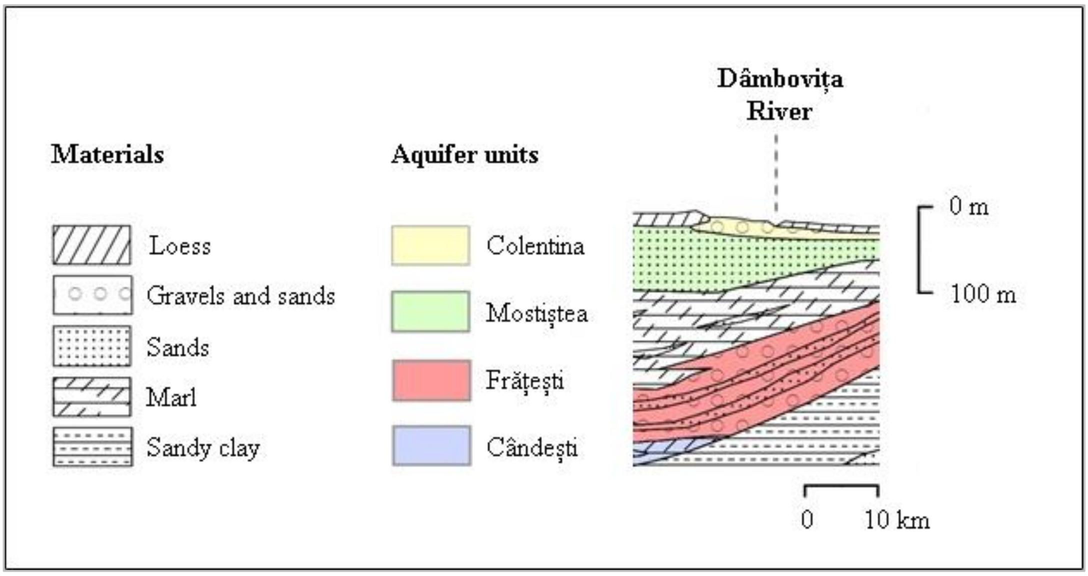

Figure 8. Stratigraphical sequence of Bucharest, showing the groundwater aquifers (adapted from Gogu, 2014).

- the Colentina aquifer (30-35 m depth) has a piezometric level of 1-10 m depth. The water of this aquifer has an ascending character (Consiliul General al Municipiului Bucuresti, 2013; Ministerul Mediului si Gospodăririi Apelor România, 2006) and is drained by a culvert situated under the Dâmbovița River. This aquifer has been declared at risk due to its high content of contaminants (Stoican et al., 2013);
- the Mostiștea aquifer (30-35 to 90-95 m deep) has a piezometric level of 2-13 m. The water of this aquifer has an ascending character (Ministerul Mediului si Gospodăririi Apelor România, 2006) and is also at risk (Stoican et al., 2013);
- the Frățești-Cândești aquifers (200 and 300 m depth) have piezometric levels of 45-75 m. The water of these aquifers also has an ascending character (Ministerul Mediului si Gospodăririi Apelor România, 2006). These aquifers are characterised by water of good quality (Consiliul General al Municipiului Bucuresti, 2013).

It is important to keep in mind that the piezometric lines have probably changed over time, as has been described by Gogu in 2014 (Gogu, 2014). In the study of Gogu, the Frățești-Cândești deep groundwater had a radial flow towards the city centre during the 1980s, after which the the groundwater was recorded to follow a southwest-northeast flowing direction, in 2011 (Figure 9). It has also been stated that the aquifer level was lower during the 1980s than in 2011 (Figure 9), mainly due to the development of urban areas and the end of industrial activity in the centre of Bucharest. More particularly, the urban groundwater was abandoned due to its poor quality and water pumping ceased, resulting in the rise of groundwater level and modification of the water flow towards the edges of Bucharest (Gogu, 2014; Figure 9).

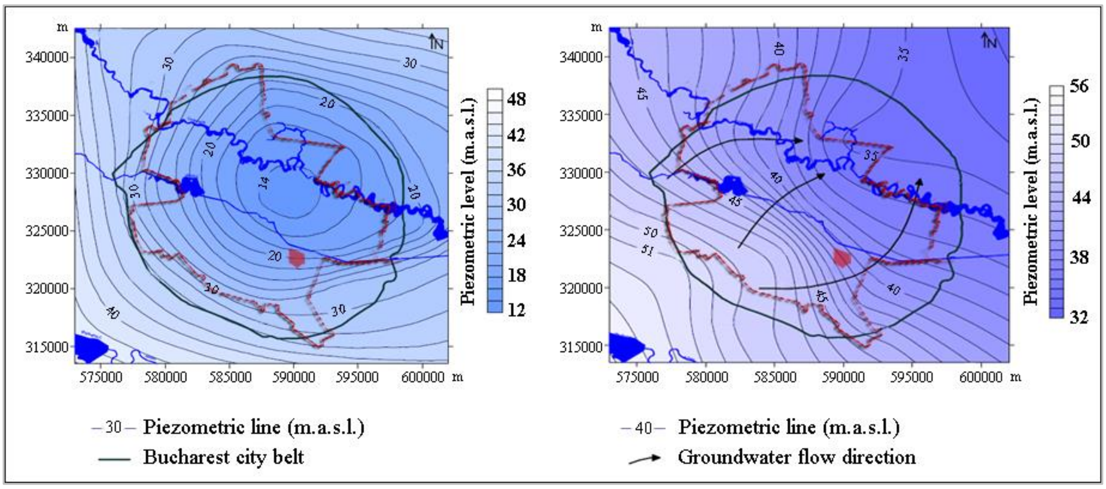

Figure 9. Frățrști-Cândești aquifer level oscillation in Bucharest since the 1980s (radial flow; to the left) to 2011 (northeast flowing direction; to the right); Văcărești wetland is highlighted in red (adapted from Gogu, 2014).

2.2.5 Climatology

Bucharest is described by a temperate continental climate, with hot summers and cold winters. The western air-mass influence is conducive to warm and extensive autumns, early springs, as well as mild winter days. Bucharest is subjected to low humidity due to the steppe climate (Stoican et al., 2013). The mean annual temperature is 10-11°C, the highest values were recorded in 1963 at 13.1°C, and the lowest in 1875 indicating 8.3°C. Observations reveal that high and low mean annual temperatures in Bucharest alternate frequently, due to recent increases in extreme climate phenomena (Ministerul Mediului si Dezvoltarii Durabile, 2008). The coldest month of the year is January, with a mean temperature of -2.9°C and July is the warmest month with a mean temperature of 22.8°C (Stoican et al., 2013).

2.2.6 Biodiversity

2.2.6.1 Flora

Văcărești wetland is a part of a former marshy area that was characterised by wetland vegetation. The present plant communities have been recently established (i.e. from 1988, see section 3.2.2 History). No studies on past vegetation and biodiversity have been done in the study area. The only information available is that the species *Menyanthes trifoliata* (Figure 10) is repeatedly mentioned in historical works dating back to 1880 (Stoican et al., 2013). Several plant species inventories of the current flora have been done, which result in the identification of 101 vascular plant taxa (Table 1) (Stoican et al., 2013).

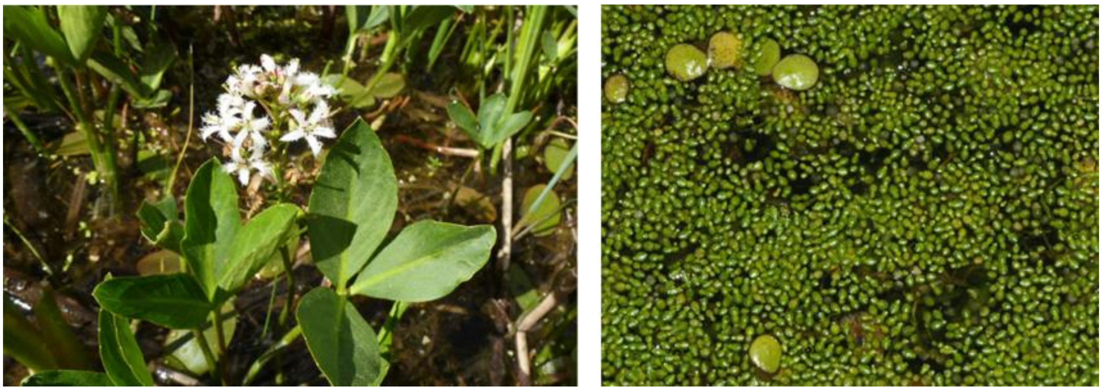

Figure 10. Few examples of plant species at Văcărești wetland: bogbean (*Menyanthes trifoliata*; to the left) and rootless duckweed (*Wolffia arrhiza*; to the right) (Swbiodiversity, 2016; GBIF, 2016).

The major tree species are willow (e.g. *Salix fragilis* and *Salix cinerea*), poplar (*Populus* sp.), Russian olive (*Elaeagnus angustifolia*), tree of Heaven (*Ailanthus altissima*), ash (e.g. *Fraxinus pennsylvanica*), elm (e.g. *Ulmus pumilla*), honey locust (*Gleditsia triacanthos*), fruit trees (e.g. *Prunus cerasifera* and *Morus alba)* and walnut (*Juglans regia*). The most common shrub species are wild rose (*Rosa canina*), hawthorn (*Crataegus monogyna*), elder (*Sambucus nigra*) and wild berries (*Rubus* sp.). Herbaceous plants are dominated by *Asteraceae* and *Poaceae* families (Stoican et al., 2013).

Table 1. Plant species

Family	Species
Poaceae	*Echinochloa crus-galli*
	Bromus sterilis
	Elymus repens s.l.
	Sorghum halepense
	Dichanthium intermedium
	Cynodon dactylon
	Phragmites australis
	Lolium perenne
	Setaria viridis
Typhaceae	*Typha angustifolia*
	Typha latifolia
Cyperaceae	*Scirpus lacustris*
Juncaceae	*Juncus effusus*
Caryophyllaceae	*Stellaria media*
Amaranthaceae	*Amaranthus retroflexus*
	Atriplex tatarica
	Chenopodium album
	Chenopodium strictum
	Caryophyllale Portulacaceae
	Portulaca oleracea ssp. oleracea
Portulaceae	*Bassia scoparia*
Polygonaceae	*Polygonum aviculare*
	Polygonum amphibium
	Polygonum lapathifolia
	Polygonum hydropiper
	Rumex patientia
Geraniaceae	*Erodium cicutarium*
Solanaceae	*Solanum nigrum*
	Solanum dulcamara
	Lycopersicon esculentum
Convolvulaceae	*Convolvulus arvensis*
	Calystegia sepium
Lamiaceae	*Ballota nigra ssp. nigra*
	Lamium amplexicaule
	Lycopus europaeus
	Mentha longifolia
Orobanchaceae	*Odontites serotina*
Plantaginaceae	*Plantago major s.l.*
	Plantago lanceolata

Family	Species
Vitaceae	*Parthenocissus inserta*
Brassicaceae	*Berteroa incana*
	Cardaria draba ssp. draba
Asteraceae	*Carduus acanthoides*
	Xanthium italicum
	Artemisia austriaca
	Centaurea micranthos
	Centaurea iberica
	Centaurea nigrescens
	Cichorium intybus
	Cirsium vulgare
	Arctium minus
	Arctium lappa
	Pulicaria dysenterica
	Cirsium arvense
	Artemisia absinthium
	Artemisia annua
	Sonchus arvensis
	Taraxacum officinale
	Achillea sp.
	Ambrosia artemisiifolia
	Conyza canadensis
	Helianthus tuberosus
	Picris hieracioides
	Erigeron annuus s.l.
	Lactuca serriola
	Crepis foetida ssp. rhoeadifolia
Malvaceae	*Malva sylvestris*
	Althaea officinalis
Apiaceae	*Daucus carota ssp. carota*
	Berula erecta
Fabaceae	*Galega officinalis*
	Trifolium pratense
	Trifolium repens s.l.
	Ononis hircina
	Meliloltus alba
Rubiaceae	*Galium humifusum*
Adoxaceae	*Sambucus ebulus*
Dipsacaceae	*Dipsacus fullonum*
Urticaceae	*Urtica dioica*
Onagraceae	*Epilobium hirsutum*

Family	Species	Family	Species
Alismataceae	*Alisma plantago-aquatica*	*Verbenaceae*	*Verbena officinalis*
Araceae	*Lemna trisulca*	*Lythraceae*	*Lythrum salicaria*
	Lemna minor	*Fabaceae*	*Gleditsia triacanthos*
	Wolffia arrhiza	*Salicaceae*	*Salix fragilis*
Butomaceae	*Butomus umbellatus*		*Salix cinerea*
Azollaceae	*Azolla filiculoides*		*Populus sp.*
Myrsinaceae	*Lysimachia nummularia*	*Elaeagnaceae*	*Elaeagnus angustifolia*
Haloragaceae	*Myriophyllum spicatum*	*Simaroubaceae*	*Ailanthus altissima*
Caprifoliaceae	*Cephalaria transsilvanica*	*Sapindaceae*	*Acer negundo*
Rosaceae	*Rosa canina*	*Oleaceae*	*Fraxinus pennsylvanica*
	Crataegus monogyna	*Ulmaceae*	*Ulmus pumilla*
	Rubus sp.	*Moraceae*	*Morus alba*
	Prunus cerasifera		*Morus nigra*
Adoxaceae	*Sambucus nigra*	*Juglandaceae*	*Juglans regia*

2.2.6.2 Fauna

Various species of mammals, birds, reptiles, amphibians, fishes and insects are present in the study area. Mammals are the weakly represented fauna species and include rodents (e.g. *Microtus arvalis*, *Sorex minutus* and *Ondatra zibethica*), carnivores (e.g. *Mustela nivalis*, *Vulpes vulpes* and *Lutra lutra*; note that *Lutra lutra* (Figure 11) is a protected species) and bats. Birds are the most prevalent species, the wetland providing exceptional conditions for feeding and nesting. 92 species have been identified between the years 2007 and 2012; all of these (listed in Table 2) have a national conservation status.

Table 2. Birds species

Family	Species	Family	Species
Podicipedidae	*Tachybaptus ruficollis*	*Anatidae*	*Aythya ferina*
	Podiceps cristatus		*Aythya nyroca*
	Podiceps nigricollis		*Netta rufina*
Phalacrocoracidae	*Phalacrocorax carbo*	*Accipitridae*	*Buteo buteo*
	Phalacrocorax pygmeus		*Accipiter nisus*
Ardeidae	*Egretta garzetta*		*Accipiter brevipes*
	Ardea cinerea		*Circus aeruginosus*
	Nycticorax nycticorax		*Circus cyaaneus*
	Ardeola ralloides		*Circus macrourus*
	Ixobrychus minutus	*Falconidae*	*Falco subbuteo*
Anatidae	*Cygnus olor*		*Falco tinnunculus*
	Anas platyrhynchos		*Pernis apivorus*

Family	Species	Family	Species
Anatidae	*Anas creca*	*Rallidae*	*Crex crex*
	Anas clypeata		*Fulica atra*
	Anas querquedula		*Gallinula chloropus*
Charadriidae	*Vanellus vanellus*	*Turdidae*	*Turdus merula*
Sciolopacidae	*Gallinago gallinago*		*Turdus pilaris*
Laridae	*Larus michahellis*	*Paridae*	*Cyanistes (Parus) caeruleus*
	Larus ridibundus		*Parus major*
	Larus canus		*Panurus biarmicus*
Apodidae	*Apus apus*		*Remiz pendulinus*
Hirundinidae	*Hirundo rustica*	*Passeridae*	*Passer domesticus*
	Hirundo daurica		*Passer montanus*
	Delichon urbicum	*Fringillidae*	*Fringilla coelebs*
	Riparia riparia		*Linaria (Carduelius) cannabina*
Picidae	*Dendrocopos syriacus*		*Carduelis carduelis*
	Jynx torquilla		*Carduelis chloris*
Motacillidae	*Anthus trivialis*		*Spinus (Carduelis) spinus*
	Anthus campestris		*Coccothraustes coccothraustes*
	Anthus spinoletta		*Emberiza schoeniclus*
	Motacilla flava		*Emberiza citrinella*
	Motacilla alba		*Miliaria calandra*
Tryglodytae	*Troglodytes troglodytes*		*Serinus serinus*
Sturnidae	*Sturnus vulgaris*	*Alaudidae*	*Alauda arvensis*
Corvidae	*Pica pica*		*Galerida cristata*
	Garrulus glandarius	*Liniidae*	*Lanius collurio*
	Corvus monedula		*Lanius minor*
	Corvus frugilegus	*Muscicapidae*	*Saxicola rubetra*
	Corvus corone cornix	*Prunellidae*	*Prunella modularis*

Family	Species	Family	Species
Sylvidae	*Sylvia communis*	*Phasianidae*	*Perdix perdix*
	Sylvia curruca		*Coturnix coturnix*
	Phylloscopus collybita		*Phasanius colchicus*
	Acrocephalus schoenobaenus	*Upupidae*	*Upupa epops*
	Acrocephalus arundinaceus	*Sternidae*	*Chlidonias hybrida*
Turdidae	*Turdus philomelos*	*Columbidae*	*Columba livia*
	Phoenicurus ochruros		*Streptopelia decaocto*
	Erithacus rubecula	*Cuculidae*	*Cuculus canorus*

Reptile species include turtles (e.g. *Emys orbicularis*), lizards (e.g. *Lacerta viridis* and *Lacerta agilis*) and snakes (e.g. *Natrix natrix*). The amphibians are represented by the following species, of which some are considered vulnerable: *Triturus cristatus* (Figure 11), *Lissotriton vulgaris*, *Bombina bombina* and *Pelophylax ridibundus.*

Figure 11. A few examples of fauna protected species from the study area: the common otter (*Lutra lutra*; to the left) and the great crested newt (*Triturus cristatus*; to the right) (Parc Natural Văcărești, 2016; Field Herping, 2016).

Concerning the fishes, there are no published studies conducted in the area. However, several observations show that the main species are: carp (e.g. *Carassus gibelio*), perch (e.g. *Perca fluviatilis*), roach (e.g. *Rutilus rutilus*), rudd (e.g. *Scardinius erythrophthalmus*), stone moroko (*Pseudorasbora parva*), bleak (e.g. *Alburnus alburnus*) and pike (e.g. *Esox lucius*). The insects are characterised by rich diversity and diverse microhabitats (e.g. marshy areas, open and dry habitats). It is important to underline the presence of *Mantis religiosa*, which indicates an ecosystem with a good conservation status (Stoican et al., 2013). Some rare insect species were also indentified at the Văcărești wetland (e.g. *Tetramesa cereipes*, *Bruchophagus astragali*, *Systole tuonela* and *Tetramesa variae*). The identified insect species are indicated in Table 3.

Table 3. Insect species

Family	Species	Family	Species
Calopterygidae	*Calopteryx splendens*	*Gryllidae*	*Gryllus campestris*
Lestidae	*Lestes virens*		*Melanogryllus desertus*
	Sympecma fusca		*Modicogryllus truncatus*
Coenagrionidae	*Coenagrion pulchellum*		*Pteronemobius heydenii*
	Enallagma cyathigerum		*Oecanthus pellucens*
	Erythromma viridulum	*Gryllotalpidae*	*Gryllotalpa gryllotalpa*
	Ischnura pumilio	*Tetrigidae*	*Tetrix subulata*
	Ischnura elegans	*Acrididae*	*Pezotettix giornae*
Platycnemididae	*Platycnemis pennipes*		*Calliptamus italicus*
Aeshnidae	*Aeshna affinis*		*Acrida ungarica*
	Anax imperator		*Oedipoda caerulescens*
Libellulidae	*Crocothemis erythraea*		*Aiolopus thalassinus*
	Libellula depressa		*Stethophyma grossum*
	Orthetrum albistylum		*Omocestus rufipes*
	Orthetrum brunneum		*Chorthippus brunneus*
	Sympetrum fonscolombii		*Chorthippus oschei*
	Sympetrum meridionale		*Chorthippus loratus*
	Sympetrum pedemontanum		*Chorthippus dichrous*
	Sympetrum sanguineum		*Chorthippus parallelus*
Phaneropteridae	*Phaneroptera nana*		*Euchorthippus declivus*
Tettigoniidae	*Conocephalus fuscus*		*Mantis religiosa*
	Ruspolia nitidula	*Corixidae*	*Hesperocorixa linnaei*
	Tettigonia viridissima		*Sigara nigrolineata*
	Tettigonia caudata		*Sigara lateralis*
	Metrioptera roeselii	*Nepidae*	*Nepa cinerea*
	Platycleis albopunctata grisea		*Ranatra linearis*
	Platycleis veyseli	*Naucoridae*	*Naucoris cimicoides*
	Ephippiger ephippiger	*Notonectidae*	*Notonecta glauca*

Family	Species	Family	Species
Pleidae	*Plea leachi*	*Hydrophilidae*	*Limnoxenus niger*
Gerridae	*Aquarius paludum*		*Anacaena limbata*
	Gerris argentatus		*Laccobius biguttatus*
	Gerris lacustris		*Helochares lividus*
Mesoveliidae	*Mesovelia furcata*		*Forst Helochares obscurus*
Veliidae	*Microvelia reticulata*		*Enochrus melanocephalus*
Haliplidae	*Haliplus obliquus*		*Enochrus coarctatus*
	Haliplus wehnckei		*Enochrus testaceus*
	Peltodytes caesus	*Limnebiidae*	*Limnebius sp.*
Dytiscidae	*Hydroporus sp.*	*Torymidae*	*Eridontomerus laticornis*
	Guignotus pusillus		*Idiomacromerus mayri*
	Hygrotus inaequalis		*Idiomacromerus pannonicus*
	Scarodytes halensis		*Idiomacromerus perplexus*
	Graptodytes bilineatus		*Idiomacromerus terebrator*
	Noterus clavicornis		*Microdontomerus annulatus*
	Noterus crassicornis		*Torymoides kiesenwetteri*
	Laccophilus minutus		*Torymus cupratus Boheman*
	Laccophilus variegatus	*Eurytomidae*	*Bruchophagus astragali*
	Colymbetes striatus		*Bruchophagus platypterus*
	Ilibius ater		*Eurytoma palustris*
	Ilibius sp.		*Eurytoma tibialis*
	Rhantus pulverosus		*Sycophila mellea*
	Hydaticus transversalis		*Systole tuonela*
	Cybister lateralimarginalis		*Tetramesa cereipes*
	Graphoderus sp.		*Tetramesa gracilipennis*
Hydrophilidae	*Coelostoma orbiculare*		*Tetramesa linearis*
	Megasternum boletophagum		*Tetramesa variae*

3. Materials and Methods

3.1 Data sources

3.1.1 Climate data

Climate data over the time interval 2000-2015 was collated from the European Climate Assessment and Dataset (ECAD) (ECAD, 2016), that collects climate data from stations all around the world. The data has a daily resolution and was freely downloaded from the official site. The “blended” option was selected, which means that the missing data from a particular meteorological station is filled in with data from nearby stations or nearby synoptical stations, the latter being based on global forecasts (Klein Tank, 2013; Software Ecmwf, 2016).

The two meteorological variables used for the entire 2000-2015 time interval are air temperature and precipitation. These variables were recorded at two meteorological stations, Bucharest-Băneasa and Bucharest-Filaret (i.e. the stations that contributed with climatic data to the ECAD database), that are nearby the study area. The Bucharest-Băneasa meteorological station is situated in the northern part of Bucharest, at about 12 kilometers from the study area. From this station, the daily mean temperature had been registered. The Bucharest-Filaret meteorological station is located westwards from the study area at about 3 kilometers. Daily precipitation records are available from this station (Figure 12). Bucharest-Băneasa and Bucharest-Filaret meteorological stations are situated at an altitude of 91 meters and 83 meters respectively, and there is no meaningful intervening topography that would cause any significant differences between the climatic data recorded at the two stations. Although it is likely that the climatic conditions recorded at Văcărești wetland are slightly different from the surroundings, due to the dense vegetation that developped within the concrete walls, climatic data from both above-mentioned stations were used for this research, as no meteorological recordings from the wetland particularly have been made yet.

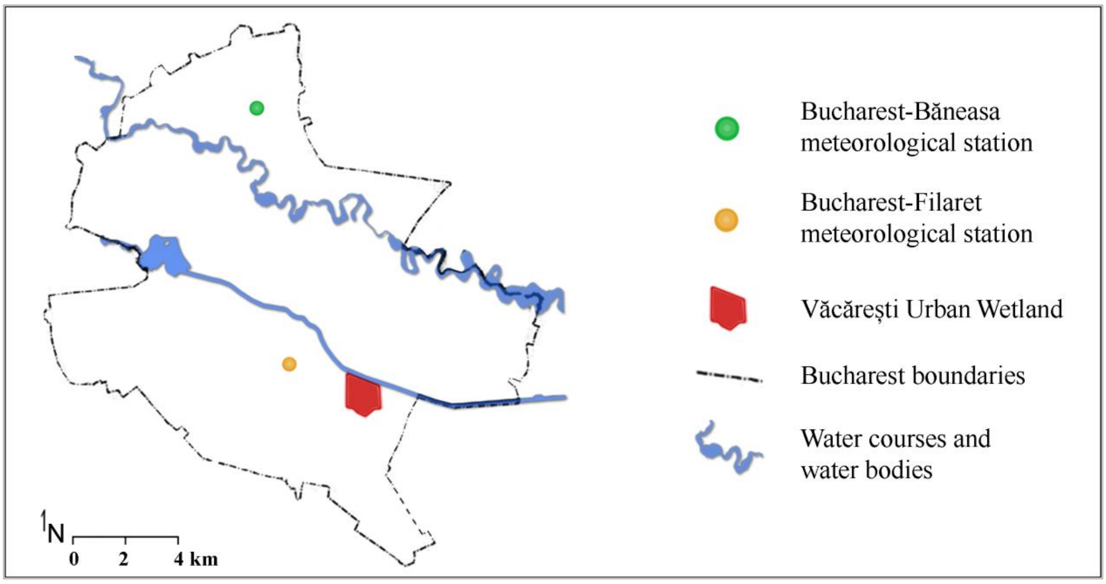

Figure 12. Map displaying the study area and the two meteorological stations location

3.1.2 Satellite images

Several historical and topographic maps dating back to between 1871 and 1989 are available, and these show the constant changes of land use over the study area (e.g. swamp, vegetable gardens (Figure 13) and the construction of the retention polder). The Văcărești wetland started to develop freely from 1989, without impact from human activities. Therefore, those historical and topographic maps were not included in the the present study. Aerial photographs were not available between 1989 and 2000. From 2000 to 2015, high resolution Google Earth satellite images were used to estimate the spatial and temporal land cover changes for the present study. The Google Earth images were chosen over Landsat 8 satellite images as the latter have a lower resolution (i.e. 30 meters spatial resolution for bands 1 to 7 and 9, and 15 meters spatial resolution for band 8- panchromatic; Landsat USGS, 2016). Landsat 8 satellite images would not have been sufficiently detailed to estimate the areas of different Land Cover Types (LCT) of the small-scale study area (i.e. approximately 183 hectares; Figure 13). In comparison, Google Earth images have a better spatial resolution, ranging between 0.32 meters (e.g. an image from September 2015) and 0,68 meters (e.g. an image recorded in July 2007). The resolution of these images has been identified by using the DigitalGlobe Image Finder website (Globe, 2016). The Google Earth images are collected by different spacecraft such as:

WorldView-3, WorldView-2, GeoEye-1 and QuickBird. Therefore, Google Earth images from a time span of 16 years (from 2000 to 2015) were collected; they display distinct months throughout the analysed period. Although several images were available for some of the months (i.e. the number of available images increased from one in 2000 to forty in 2015), only one image per month was selected (i.e. the image where the LCTs could be estimated more accurately). As a result, a total of 35 images were selected for the present study (Table 4).

Figure 13. Set of satellite images of the Văcărești wetland. Corona satellite image from 1966 (to the left), Landsat 8 satellite image from 2016 (band 8- panchromatic, in the centre) and Google Earth satellite image from 2015 (to the right) (Fostul București, 2016; Landsat USGS, 2016). This figure shows the difference in land uses between 1966 (before 1989, when the Văcărești wetland started to develop freely, without voluntary human activities) and 2015. It is important to note that the Landsat 8 satellite images do not have sufficiently detailed spatial resolution to estimate the areas of different Land Cover Types (LCTs) of the small-scale study area (i.e. approximately 183 hectares).

Table 4. Google Earth satellite images available for the time interval 2000-2015. The images that are available for each month and year are represented in grey.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Jan																	1
Feb																	2
Mar																	4
Apr																	2
May																	2
Jun																	4
Jul																	3
Aug																	3
Sep																	7
Oct																	5
Nov																	1
Dec																	1
Total	1	0	2	0	1	1	0	4	1	2	1	1	4	3	3	11	35

3.1.3 Data on biodiversity

The collection of data regarding the species presence at Văcărești wetland was based on the report named "Substantiation Note that pursues the implementation of Văcărești Nature Park's protection regime" (Stoican et al., 2013). This report was provided by the Văcărești Nature Park Association (i.e. the association that introduced the project for the institution of the protected natural area regime) and it has been made by local specialists in geology, biodiversity, flora, entomofauna (insects), herpetofauna (reptiles and amphibians), ornithology (birds) and chiropteran fauna (bats). This scientific study was validated by official notice by the Romanian Academy in 2013 (Bărbulescu, 2015) and highlighted the high environmental value of the landscape that is comprised of both biotic and abiotic elements. Other data regarding the biodiversity of the study area has been collected from various publications and websites (e.g. a published scientific article named "Văcăreşti Valley from 'Frozen in the Project' to the Largest Urban Natural Park in Romania" (Alianţa pentru Conservarea Biodiversităţii, 2016)).

3.2 Methodology

3.2.1 Temperature and precipitation

The daily temperature and precipitation information collected from the ECAD dataset (see section 4.1.1 Climate data) have been transformed for each month in order to be at the same temporal scale as the satellite images. Daily temperatures have been averaged for each month; the results are expressed in degrees Celsius (°C). Daily precipitations are summed up for each month. The results are expressed in mm/month.

3.2.2 Land Cover Types (LCTs)

LCTs have been defined using the 35 satellite images that covered the 2000-2015 time interval. Several adjustments have been done to increase the quality of the images, using Adobe Photoshop CS6 (Version 13.0, 2012, Adobe Systems, San Jose, United States). An example that explains the selection of this program over other image software choices is provided in Appendix A. First, the satellite images have been edited to focus on the study area only (Figure 14). Then, the visual quality of images has been enhanced by adjusting the image tone and exposure (Figure 14), as well as correcting the cloud cover which overlaid the study area and light reflection of the water bodies (Figure 14), to avoid any confusion between water bodies and other LCTs (e.g. bare soil which has similar colour with the water reflectance).

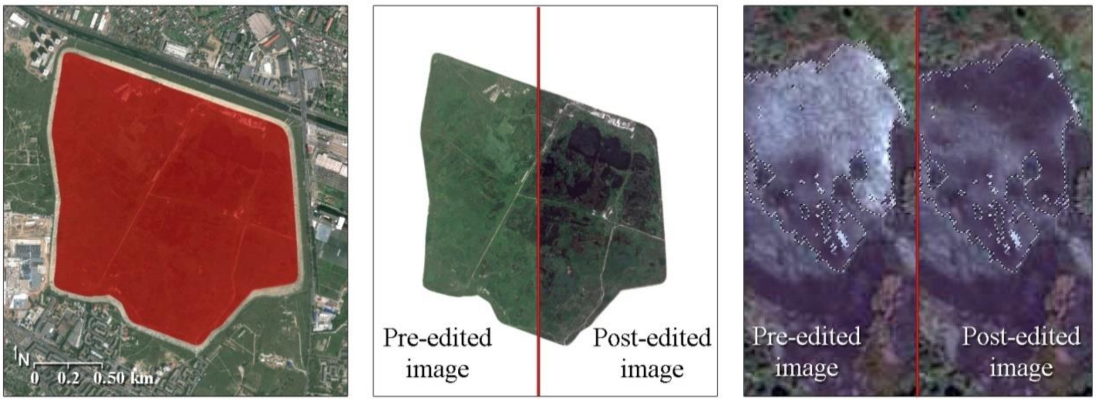

Figure 14. A red mask has been used to isolate the study area on the original satellite images (to the left). This figure also shows the adjustments of image tone (in the centre), and light reflection of the water bodies (to the right).

After the adjustment processes, the images were interpreted in order to identify the major features of the different LCTs visible in the satellite images, and correlate them with European habitat classifications. The LCT classification has been determined following the habitat usage in the Habitats of Romania book (Doniță et al., 2005) and the Palaearctic Habitats classification system that categorises the flora within the wetland. The resulting six LCTs are:

- bare soil LCT, that corresponds to vegetation-free dirt pathways, rocks, rubble, former lake concrete plates and burnt areas (Figure 15);

Figure 15. Illustrations of the bare soil LCT from the study area (Ioniță, 2013; Ioniță, 2013; Mexi, 2012).

- water bodies LCT, that corresponds to permanent ponds and swamps (Figure 16). This LCT is characterized by high light reflectance;

Figure 16. Illustrations of the water bodies LCT from the study area (Ioniță, 2013).

- water species LCT (Duckweed covers; e.g. *Lemna minor*, *Lemna trisulca*, *Wolffia arrhiza*, *Myriophyllum spicatum*, and *Alisma plantago-aquatica* (Figure 17)), refers to a LCT for which plant species appear in a bright green colour in the warm season. These water species grow in water with high nutrient levels, and are important as a food resource for fishes and birds;

Figure 17. Illustrations of the water species LCT (Bărbulescu, 2015; Ioniță, 2013; Bărbulescu, 2015). Duckweed cover (e.g. *Lemna minor, Lemna trisulca, Wolffia arrhiza, Myriophyllum spicatum,* and *Alisma plantago-aquatica*).

- reed LCT (Reedmace beds; e.g. *Typha angustifolia*, *Typha latifolia*, *Juncus effusus*, *Butomus umbellatus*, *Scirpus lacustris*, and *Polygonum hydropiper* (Figure 18)), corresponds to reed plants, which generally occur in shallow water, and are dependent on eutrophic water. Reed plants absorb pollutants (Halestrap, 2006) and are considered aggressive colonizing plants (Aulio, 2014);

Figure 18. Illustrations of the reed LCT (Ioniță, 2013; Bărbulescu, 2015; Ioniță, 2013) that includes *Typha angustifolia, Typha latifolia, Juncus effusus, Butomus umbellatus, Scirpus lacustris,* and *Polygonum hydropiper.*

- open land LCT, mostly corresponding to ruderal communities (e.g. *Polygonum aviculare*, *Lolium perenne*, *Sclerochloa dura*, *Plantago major*, *Agropyron repens*, *Arctium lappa*, *Artemisia annua* and *Ballota nigra* subsp. *Nigra* (Figure 19)). This LCT occupies an important area within the wetland. It is mainly distributed towards the edges of the study area. It generally appears as open meadows consisting in grasses and ruderal species, that in most of the cases characterize disturbed areas;

Figure 19. Illustrations of the open land LCT (Ioniță, 2013; Bărbulescu, 2015; Bărbulescu, 2015). It mostly corresponds to ruderal communities (e.g. *Polygonum aviculare*, *Lolium perenne*, *Sclerochloa dura*, *Plantago major*, *Agropyron repens*, *Arctium lappa*, *Artemisia annua* and *Ballota nigra* subsp. *Nigra*).

- woody species LCT, mainly consisting of water dependent tree and shrub species such as *Salix fragilis*, *Salix cinerea*, *Elaeagnus angustifolia*, *Ailanthus altissima*, *Prunus cerasifera* and *Crataegus monogyna* (Figure 20).

Figure 20. Illustrations of the woody species LCT (Mexi, 2012; Ioniță, 2013; Ioniță, 2013). It mainly includes *Salix fragilis, Salix cinerea, Elaeagnus angustifolia, Ailanthus altissima, Prunus cerasifera* and *Crataegus monogyna.*

3.2.3 Image processing

The image processing provides for the identification of the different LCTs on satellite images using the sofware ENvironment for Visualizing Images (ENVI, Version 5.3, 2015, Exelis Visual Information Solutions, Boulder, United States). The satellite images were imported into the ENVI software package, and training polygons were collected for all land cover classes on a vector file. Note that the woody species LCT was not included in this analysis because the idenfication of trees and shrubs by the sofware was not good enough, due to the similarity of pixel colours between LCTs of woody species, open land and reed. In that specific case, the woody species LCT has been mapped in a different way (see the further explanation in the next paragraph). For the other LCTs, multiple polygons have been created to capture the full spectral variability of the distinct classes. The vector file was converted into five different zones corresponding to each LCT (Figure 20). The original satellite images have been divided into the five LCTs using the Maximum Likelihood Classification tool. For this purpose, a probability threshold was defined, which describes the probability that the unclassified pixels would be distributed within a LCT. The threshold used for this analysis was 20%, to have a good compromise between the large amount of pixels included in each LCT and the few pixels remaining unclassified. Next, the Sieve Classes tool has been used to select isolated pixels and assign them a no data value when they were not close enough to any similar pixels. An isolated pixel has been classified as belonging to a particular LCT if the majority of its 8 closest neighbours have been attributed to that same LCT.

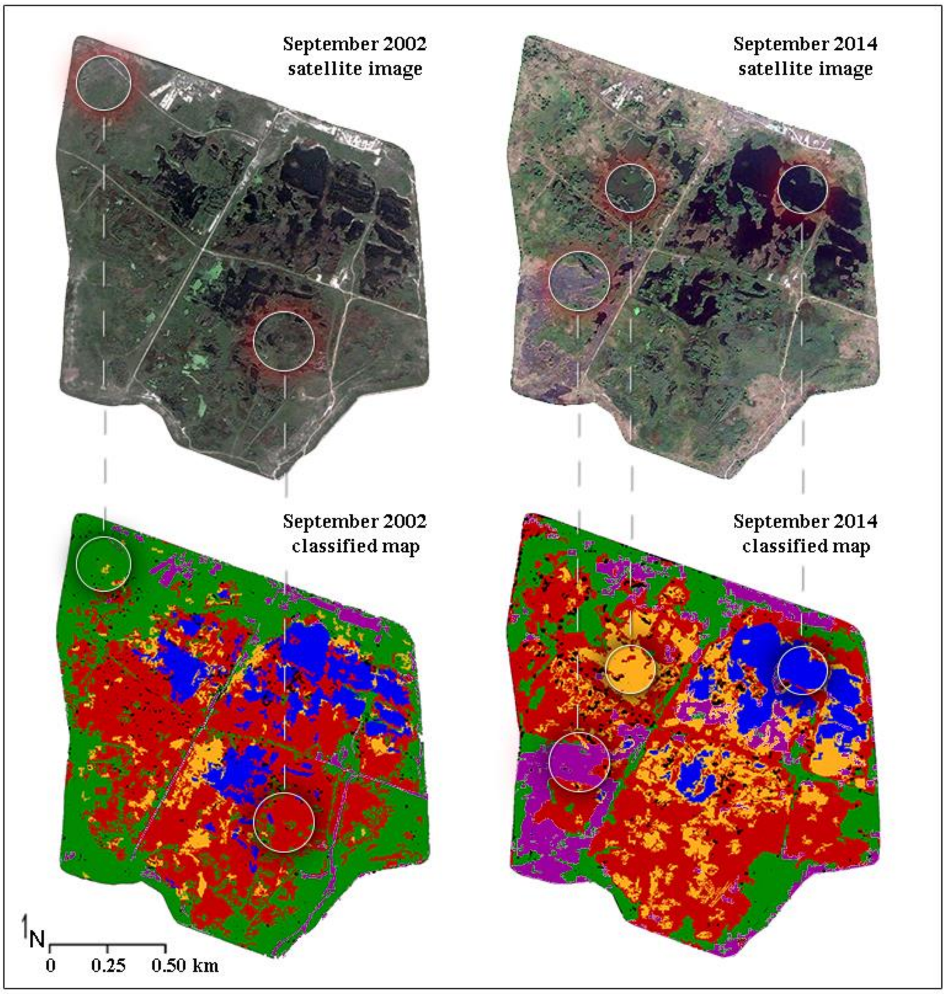

Figure 21. LCT classification using five different zones corresponding to each LCT (except for woody species LCT, see text for more explanations). The original satellite images have then been divided into the five LCTs using the Maximum Likelyhood Classification (i.e. classified maps). In white: bare soil; in blue: water bodies; in orange: water species; in red: reed; in green: open land; in black: woody species.

The image processing approach has been different for the woody species LCT. An image from November 2015, where most of the trees and shrubs were bright yellow (Figure 22), has been used to create a mask which was used to adjust the woody species LCT for all the satellite images. More particularly, the satellite images have been grouped in three categories, corresponding to different time intervals: 2000-2004, 2005-2009 and 2010-2015. The initial woody species LCT mask, based on the November 2015 satellite image, is defined as the mask used for the time interval 2010-2015. For the time interval 2005-2009, the mask based on the November 2015 satellite image has been overlaid on the July 2009 satellite image, and then adjusted to the actual tree cover by removing the tree top cover surplus from the initial image. For the time interval 2000-2004, the mask based on the July 2009 satellite image has been adjusted using the October 2000 satellite image, by applying the same method as described above. The percentage cover of the woody species LCT for each of the three masks (i.e. 1.84% for all satellite images between 2000 and 2004, 2.37% for all satellite images between 2005 and 2009, and 2.64% for all satellite images between 2010 and 2015 (Figure 22)) has been used in the estimation of the percentage cover of LCTs.

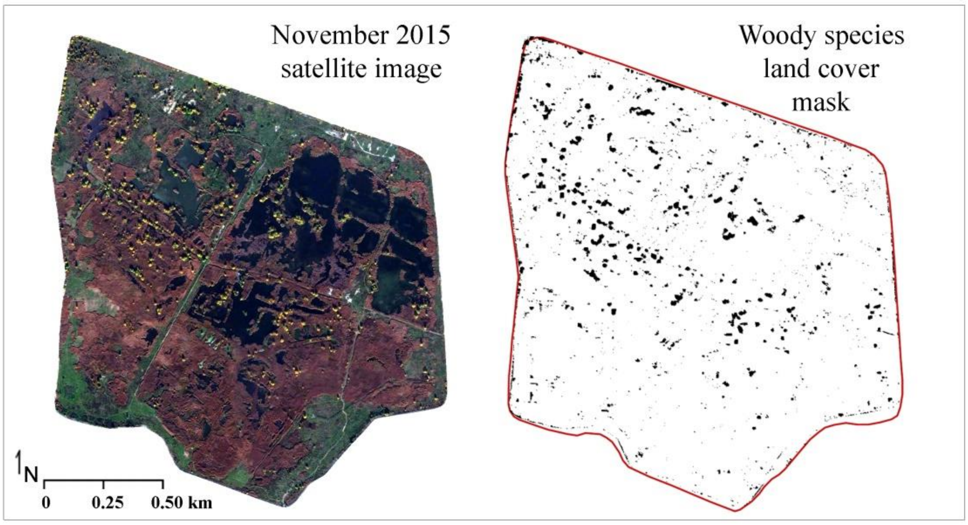

Figure 22. Image satellite from 2015 that have been used to create the woody species LCT mask. Note that most of the trees and shrubs appearas bright yellow (to the left) and dark in the mask (to the right).

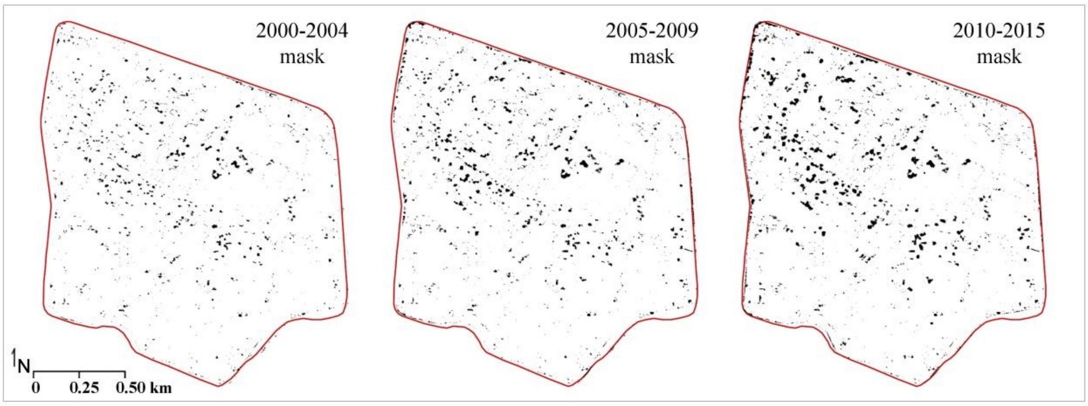

Figure 23. Woody species LCT masks used for each of the three time intervals: 2000-2004, 2005-2009 and 2010-2015 (see text for more explanantions).

The percentage cover associated with each LCT was assessed by using the ENVI software, after the image processing has been completed. The percentage cover was then recalculated for each satellite image using the woody species percentage values, based on the masks for each of the three time intervals (see paragraph above). Knowing the area of Văcărești wetland in hectares, the percentage cover was also calculated in hectares for each class.

3.2.4 Spatial and temporal land cover changes

The spatial and temporal LCT changes over time have been assessed from two points of view. The first aims at detecting changes during the entire time interval, 2000-2015, at the monthly scale. The data that are the most available correspond to September and October, and then the next most abundant data are for March and June months (see the number of satellite images per month in Table 4). Seven maps are available for September for different years, this providing an unique opportunity to follow LCT changes through the years, for the same month. The second point of view intends to describe the year-round LCT changes. For this purpose, only the year 2015 can be used, because satellite images for almost all months of the year are available (i.e. except for December).

3.2.5 Present flora and fauna diversity

Information regarding the flora and fauna species composition of Văcărești wetland has been acquired from the Substantiation Note that pursues the implementation of Văcărești Nature Park's protection regime (Stoican et al., 2013). Based on these data, the number of flora and fauna species, as well as the total number of species per LCT, have been estimated and expressed as relative percentages for all LCTs. More particularly, the species were divided into four major groups: plants, insects, birds and animals (i.e. mammals, reptiles, amphibians and fishes) based on their habitat characteristics, information that was available from various internet sources (e.g. IUCN official site). Each species has been assigned to one or more LCTs based on their particular habitat description. All details are available in Appendix B.

3.2.6 Statistical analysis

A statistical analysis has been used to assess the potential relationships between the LCT changes over time and climate data. A redundancy analysis (RDA) has been performed to explore the percentages of the LCT variation explained by temperature and precipitation. Temperature and precipitation (see 4.2.1 Temperature and precipitation) are used in the analysis as independent explanatory variables. The redundancy analyses have been performed using Canoco 5 for Windows (Šmilauer and Lepš, 2014). A Monte Carlo test, with 999 unrestricted permutations, was applied to assess the statistical significance (p-value) of the results.

Three separate redundancy analyses have been performed:

1) using all months for all the years over the time interval 2000-2015 to get the maximum variation in LCTs;

2) using all the months of year 2015 to get year-round variation;

3) using all September months for all the years (September is the month with the most data) to get the most variation explained by temperature and precipitation.

4. Results

4.1 Climate change

4.1.1 Temperature

The results for temperature indicate an increasing trend through time (Figure 24). Few anomalies within the general patterns (i.e. regular oscillation with high temperatures in summer and low temperatures in winter) are observed. Those anomalies are recorded in January 2003, January and November 2007, and November 2010. The highest mean temperatures during the 2000-2015 interval were recorded in July 2007 (26.19°C) and July 2012 (26.41°C), while the lowest mean temperature was reported in February 2012 (-5.90°C).

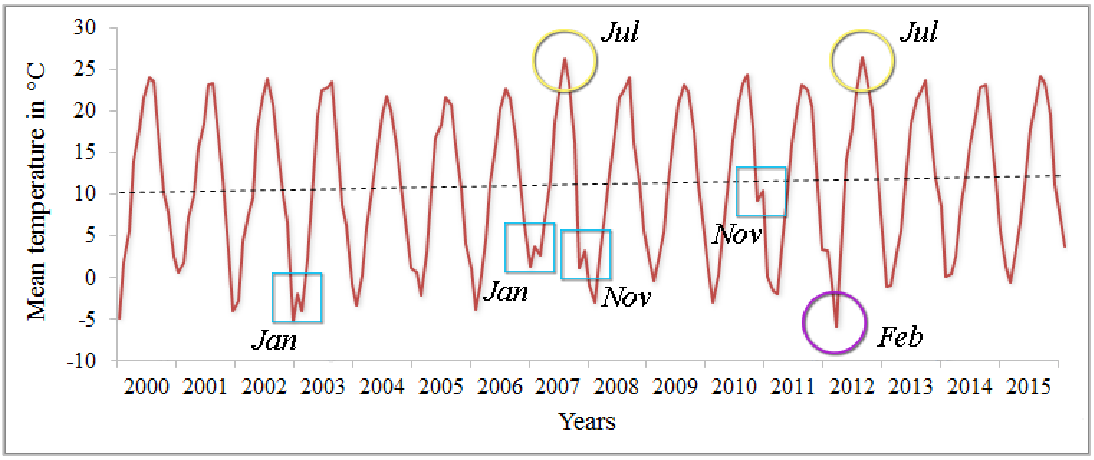

Figure 24. Change in mean temperature throught time, from 2000 to 2015, at monthly temporal scale. Note that the dashed line indicates the increasing trend of temperature. The anomalies (i.e. high temperatures in cold months) are shown by the blue squares and the highest and lowest mean temperatures are marked with yellow and purple circles, respectively.

4.1.2 Precipitation

Precipitation is also characterized by a general increasing trend from 2000 to 2015 (Figure 25). Note that from 2007, less seasonality is observed in the increasing trend than was observed in the previous period. Within a year, the highest precipitation values are recorded in May, June, and September, while the lowest precipitation values are generally registered in February, November and December.

The months that are characterized by the highest precipitation between 2000-2015 are September 2005 (269.60 mm) and May 2012 (234.20 mm). The lowest precipitation values between 2000-2015 are recorded in October 2000 (1.20 mm), August 2003 (1.20 mm) and December 2013 (0.70 mm).

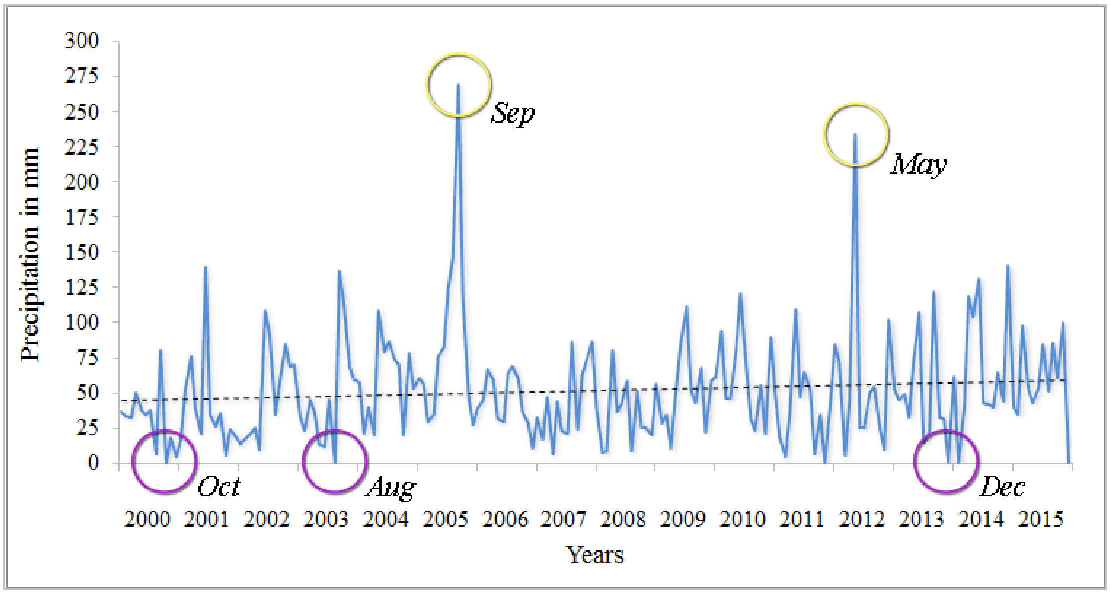

Figure 25. Change in mean precipitation throught time, from 2000 to 2015, at monthly temporal scale. Note that the dashed line indicates the increasing trend of precipitation. The highest and lowest mean temperatures are marked with yellow and purple circles, respectively.

4.2 Land cover changes

4.2.1 Spatial and temporal changes in LCTs

The results in Figure 26 indicate the spatial changes in LCTs through the 2000-2015 interval. Accordingly, the bare soil LCT registers a low extent, with the exception of few months (e.g. March and September). Water bodies record a continuous presence in the northeastern part of the study area. The slight decrease of the water bodies LCT is associated with the increase of reed and water species. Water species LCTs are situated around the water bodies. Reed is also situated near water bodies, and it has an opposite trend to the open land, which generally covers the extent towards the edges of the study area. Where woody species cover is concerned, the results show a continuous increase towards 2015.

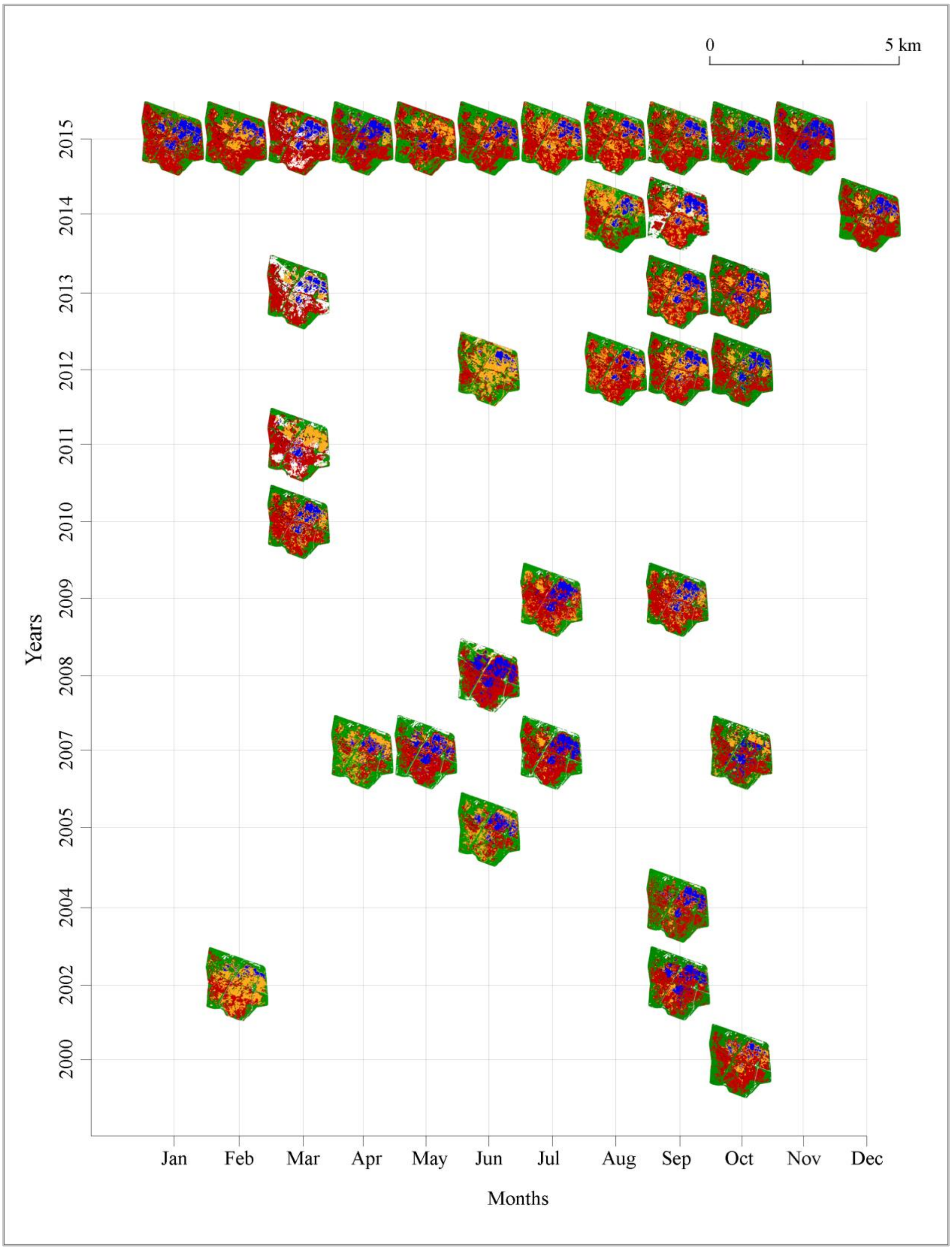

Figure 26. Spatial and temporal changes in LCTs throught time at monthly scale at Văcărești wetland. In white: bare soil; in blue: water bodies; in orange: water species; in red: reed; in green: open land. This figure is presented as a rough guide for the changes that occurred throughout the 2000-2015 period. The detailed maps for September months and the months available for year 2015 (i.e. the maps used for the main analyses of the research) are available in Appendices C and D.

4.2.2 Temporal changes in LCTs in relative percentage

The surfaces of each LCT have been calculated in hectares based on the maps of Figure 26. The surfaces have been expressed in relative percentages, shown in the pie graphs of Figure 27. The results show that the bare soil LCT generally registers low extents, for example in December 2015 (0.06%), with the exception of March 2011 (13.64%) and 2013 (14.96%), and September 2014 (10.38%). Water bodies are the most extensive during the cold season (i.e. October- April). However, during the warm season of the 2007-2009 interval, water bodies also covered a large extent (e.g. June 2008, 17.27%). The water bodies LCT is inversely correlated with the water species LCT (e.g. in July, water bodies generally record low cover percentage, while the water species are the most extensive). Likewise, the increase of water bodies towards the end of the year results in decreasing water species LCT. Water species record a larger extent during the warm season (e.g. June 2005, 18.63%), as well as in February 2015 (15.52%) and March 2010 (15.47%) and 2011 (16.07%). Reed is the major LCT throughout the studied period (a peak is recorded in March 2015 (57.7%)) with few exceptions (e.g. April 2007 (22.86%) and June 2012 (20.97%)). The opposite trend of reed to the open land is indicated by the low extent of the open land LCT in March (12.29%). The open land cover has decreased towards present, with a minimum recorded in March 2015 (12.29%). The area percentage of the woody species LCT has remained unchanged throughout the year, as a result of overlaying the tree cover mask on all the analysed monthly maps.

The interpretation of the results of this research is supported by the accuracy assessment of the LCT classification process. As a ground-based collection of verification data was not possible, due to the fact that the site has not been accessible during the research, Google Earth imagery was used as an alternative for an independent assessment of the classification accuracy. As a result, the overall accuracy values ranged 78-85% (see section 5.1 Evolution of Văcărești wetland from 2000 to 2015 under the impact of climate change).

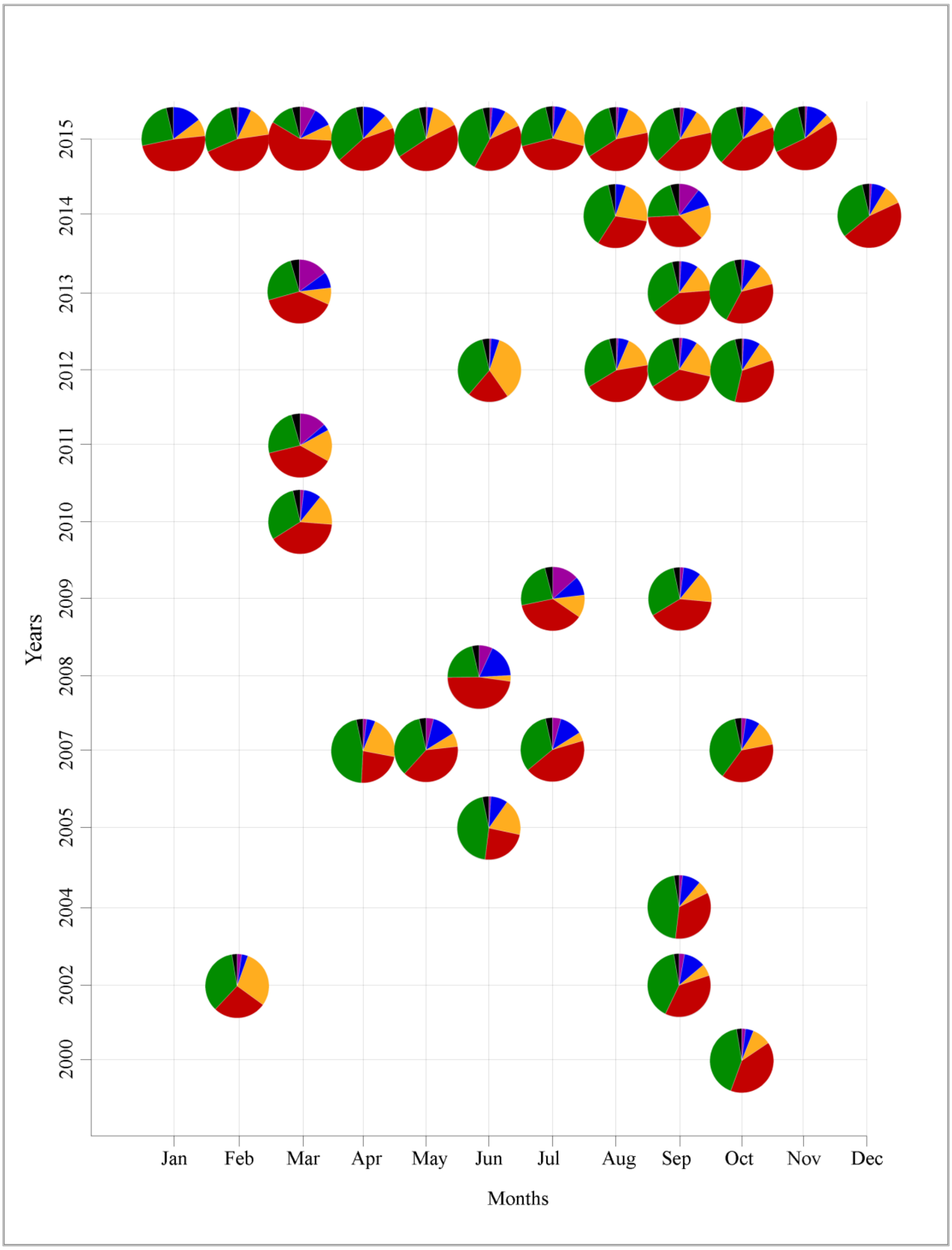

Figure 27. Temporal changes in LCTs in relative percentages through time at the monthly scale at Văcărești wetland. In purple: bare soil; in blue: water bodies; in orange: water species; in red: reed; in green: open land; in black: woody species.

4.3 Climate versus land cover changes

4.3.1 A year-round: 2015

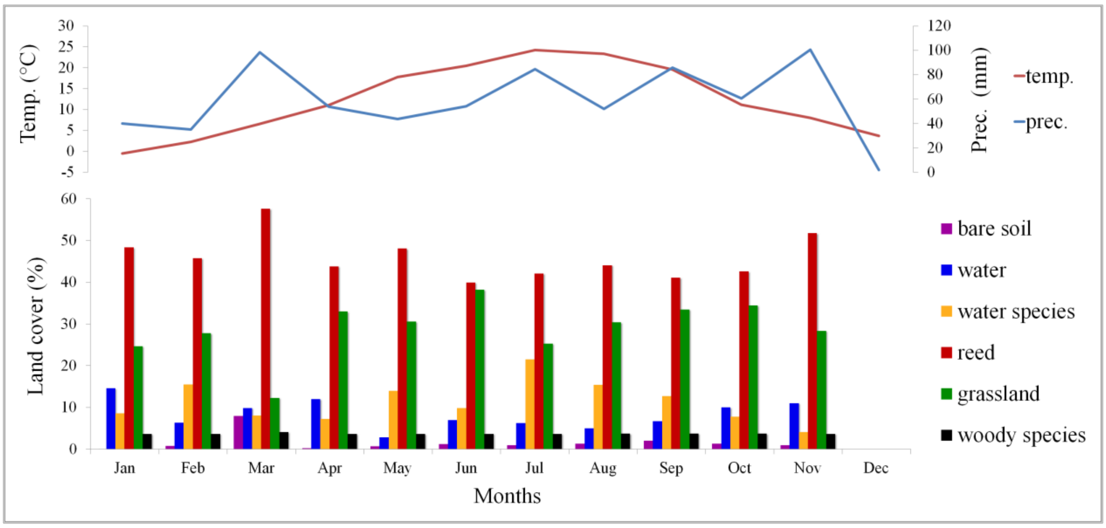

Figure 28. Monthly changes in LCTs within the year 2015 (at the bottom) and monthly changes in temperature and precipitation (at the top).

The results (Figure 28) show decreases in water bodies and reed LCTs during the warmer months (i.e. May to September) and lowest precipitation. Grassland and water species LCTs are increasing during these warmer months and lowest precipitation. Bare soil and woody species LCTs remain unchanged at those times.

The results of the RDA analysis (Figure 29) show that the colder months respond to the woody species, bare soil, reed and water bodies LCTs (i.e. the colder months are located in the right part of the RDA plot, close to the LCT vectors for woody species, bare soil, reed and water bodies). The warmer months appear to respond more to open land and water species LCTs (i.e. the warmer months are located to the left part of the RDA plot, close to the LCT vectors water species and open land). Note that July and September are a bit isolated from the other warm months. Warmer months are more linked to temperature (left panel of the RDA plot), while colder months are more linked to precipitation (right panel of the RDA plot).

The results (Table 5) of the LCT variation explained by temperature show that this parameter seems to have a significant effect on the LCT variation with

25.8% of the variation explained, at p-values of less than 0.05. Precipitation does not seem to have a significant effect on the LCT variation.

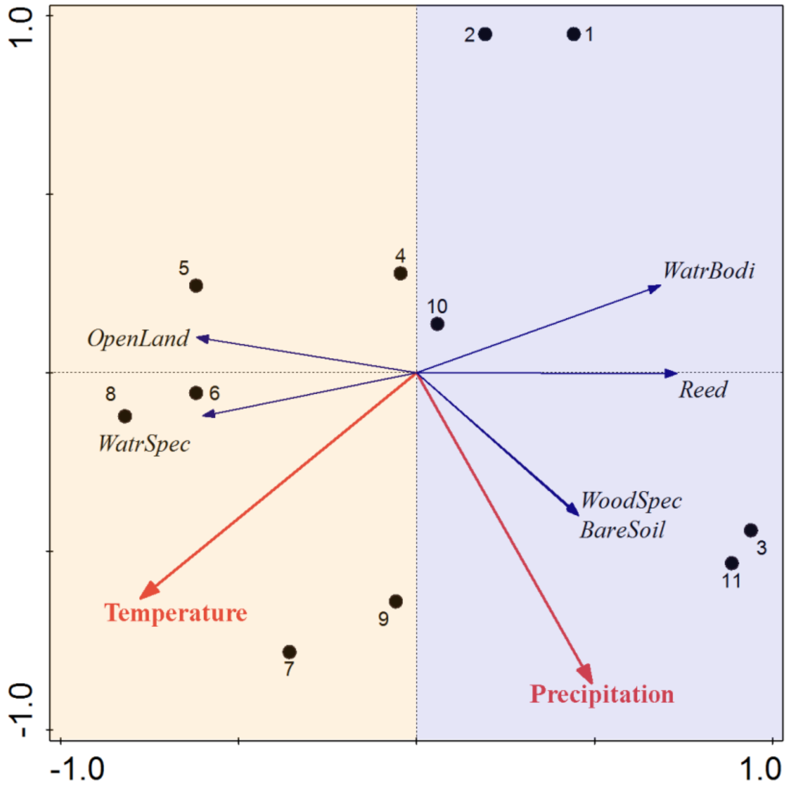

Figure 29. Results of the RDA analysis using all the months of year 2015, in order to get the year-round variation. Dots represent each month (1- January, 2- February, 3- March, 4- April, 5- May, 6- June, 7- July, 8- August, 9- September, 10- October, 11- November), blue vectors are the LCTs and red vectors the two explanatory variables: temperature and precipitation. In orange: warm season (May- September); in blue: cold season (October- April).

Table 5. LCT variation explained by temperature and precipitation based on the RDA analysis using all the months of year 2015 to get year-round variation. The results of the Monte Carlo test to assess the statistical significance (p-value) are also shown. NS: Not Significant, ***p<0.05.

Parameter	**LCT variation explained (%)**	**p-values**
Temperature	25.8	***
Precipitation	11.6	NS

4.3.2 Through years: September months for all years

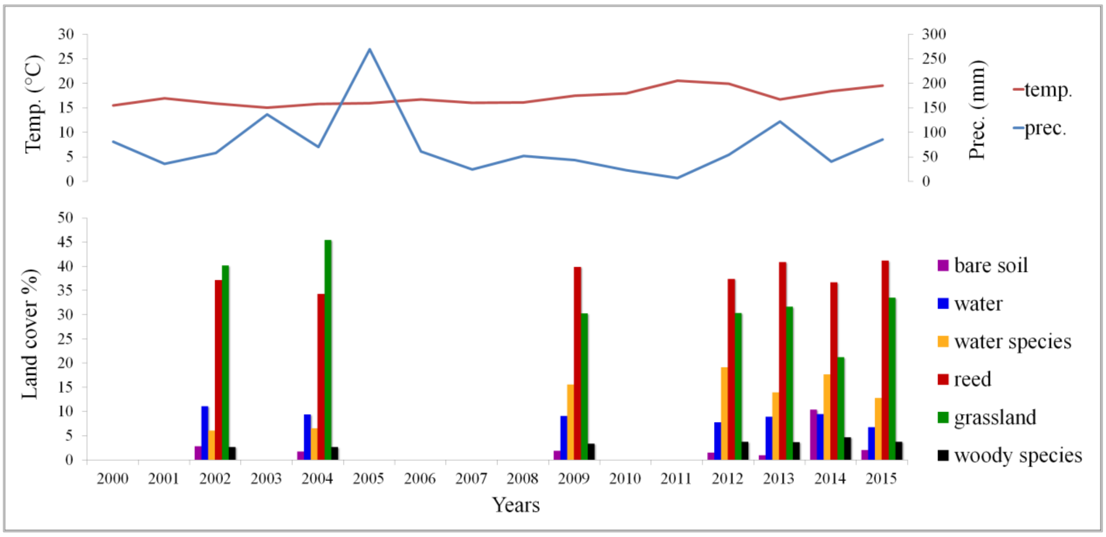

Figure 30. Yearly changes in LCTs for September (at the bottom), and in temperature and precipitation (at the top).

The results (Figure 30) reveal increases in the water species LCT in 2004 and 2014. In contrast, reed recorded decreases in the same years. Reed and water species LCTs have a general increasing trend. The open land LCT shows an increase in 2004 during higher precipitation. The bare soil LCT shows a significant increase in 2014 that does not seem to be related to any of the parameters.

The results of the RDA analysis (Figure 31) show that the abundance of reed, woody species and water species LCTs responds to increases in temperature, particularly in 2012 and 2015. The LCT changes in 2013 seem to correspond to changes in precipitation. Open land and water bodies LCTs seem to have been influenced by factors other than temperature and precipitation in 2002 and 2004. The same assumption is made for the bare soil LCT with respect to the years 2009 and 2014.

The results (Table 6) of the LCT variation explained by temperature and precipitation, based on the classified maps, show that neither temperature nor precipitation has any significant effect on the LCT variation for September months.

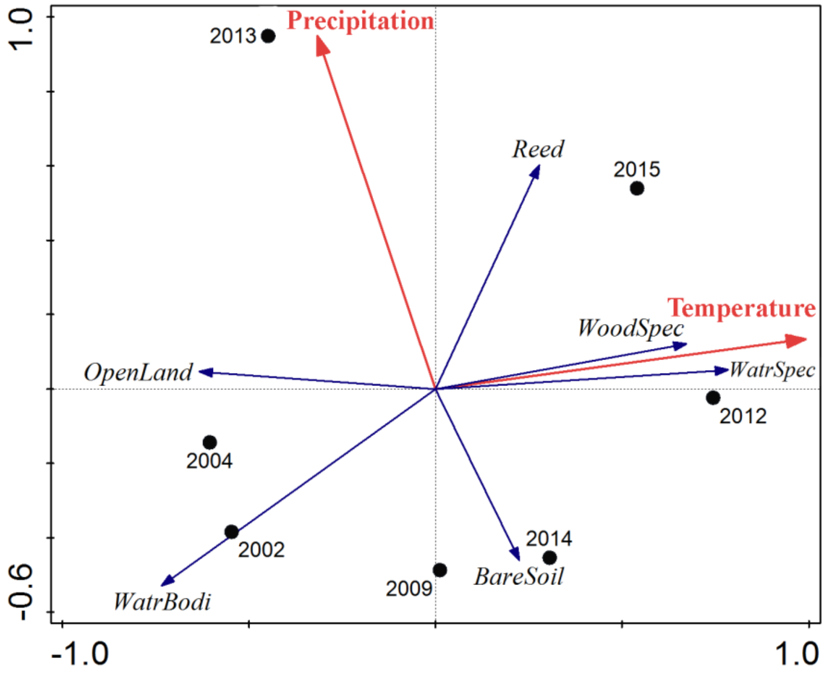

Figure 31. Results of the RDA analysis using all September months for all the years (September is the month with the most data), in order to get the most variation explained by temperature and precipitation through years. Dots represent each year, blue vectors are the LCTs and red vectors the two explanatory variables: temperature and precipitation.

Table 6. LCT variation explained by temperature and precipitation based on the RDA analysis using all September months for all the years (September is the month with the most data) to get the most variation explained by temperature and precipitation. The results of the Monte Carlo test to assess the statistical significance (p-value) are also shown. NS: Not Significant, ***p<0.05.

Parameter	**LCT variation explained (%)**	**p-values**
Temperature	39.4	NS
Precipitation	8.5	NS

4.3.3 Through years: all months for all the years

The results of the RDA analysis (Figure 32) indicated that both temperature and precipitation are in the bottom panels of the RDA plot. This shows that temperature and precipitation have more influence during the warm period. Water bodies and woody species appear to be influenced by precipitation, while for the other LCTs, the analysis does not reveal any significant correlations.

The results (Table 7) of the LCT variation explained by temperature show that this parameter does not have any significant effect on the LCT variation. However, precipitation has a significant effect on the LCT variation with 7.5 of the variation explained and p-values less than 0.05.

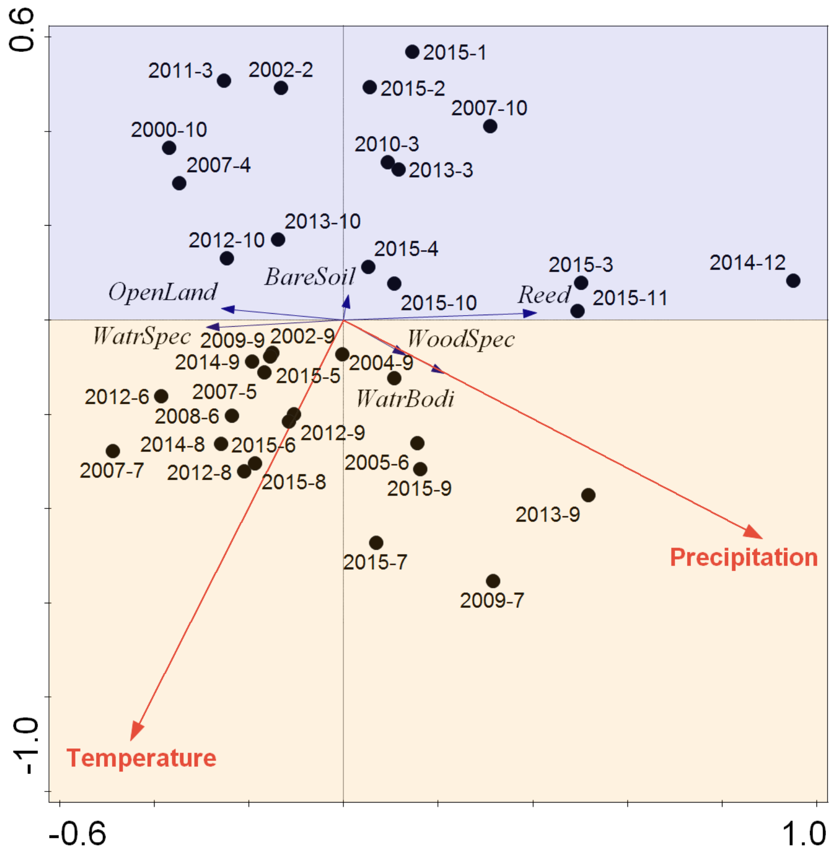

Figure 32. Results of the RDA analysis using all months for all the years over the time interval 2000-2015, to get the maximum variation in LCTs through years. Dots represent each year, blue vectors are the LCTs and red vectors the two explanatory variables: temperature and precipitation. In orange: warm season (May- September); in blue: cold season (October- April).

Table 7. LCT variation explained by temperature and precipitation based on the RDA analysis using all months for all the years over the time interval 2000-2015 to get the maximum variation in LCTs. The results of the Monte Carlo test to assess the statistical significance (p-value) are also shown. NS: Not Significant, ***p<0.05.

Parameter	LCT variation explained (%)	p-values
Temperature	2.0	NS
Precipitation	7.5	***

4.4 Present flora and fauna diversity and LCTs

As stated in section 3.1.3 Data on biodiversity, the diversity of species at the Văcărești urban wetland is based almost entirely on the species presence information extracted from the Substantiation Note that pursues the implementation of Văcărești Nature Park’s protection regime (Stoican et al., 2013). The results in Figure 33 indicate that the abundance of bird species is closely related to the presence of open land (33%) and woody species (22%) LCTs, and to a lesser extent to water species (16%) and water bodies (14%) LCTs (Figure 34). Insect species correspond mainly to water species (35%) and open land (29%) LCTs, and to a lesser extend to water bodies (19%). Plant species are essentially related to open land (51%) and water species (34%) LCTs. Animal species (i.e. mammals, reptiles, amphibians and fishes) are mainly associated with open land (38%), water species (24%) and water bodies (32%) LCTs.

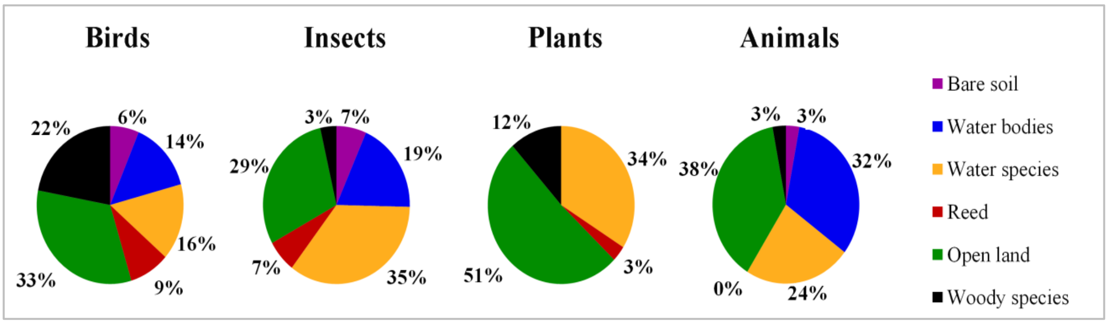

Figure 33. Number of species in each LCT expressed as relative percentage, for distinct groups of species: birds (left), insects (middle-left), plants (middle-right) and animals (right).

Considering all species, the results show that open land (37%) and water species (27%) are the major LCTs that support biodiversity, being followed to a lesser extent by water bodies (13%) and woody species (12%).

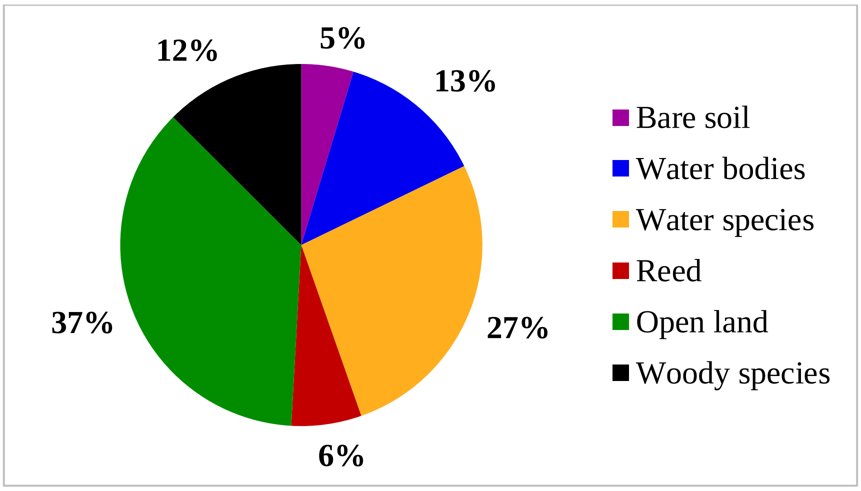

Figure 34. Total number of species in each LCT expressed as relative percentage, i.e. all groups of species together: birds + insects + plants + animals.

5. Discussion

5.1 Evolution of Văcărești wetland from 2000 to 2015 under the impact of climate change

As presented in the Introduction, urban wetlands provide numerous benefits to society. In the context of a rapidly developing urban setting, these wetlands could provide valuable ecosystem services, if properly managed. An example of such an ecosystem is the London Wetland Centre, which is considered a symbol of wetland urban conservation and a model for similar areas all around the world. It is important to mention that the conservation strategy of the London Wetland Centre is not only based on preserving the biodiversity, but also enhancing the habitat conditions found within it. The species diversity that characterises the area was the main feature that determined the conservation of the wetland. Similarly, Văcărești wetland presents a large variety of species, which attained the attention of environmentalists.

Văcărești wetland has undergone major land use changes throughout its evolution, from open-spaced marshy land to vegetable gardens, retention polder and eventually, an abandoned land. At present, the area is a diverse ecosystem that includes a rich diversity of flora and fauna. Detailed information on the development of the area in terms of biodiversity is not available. Though, as the wetland has just recently been declared a nature park, more and more attention is now being paid to the potential of this highly diverse habitat. The present study assesses the spatial and temporal changes that have occurred during the past 16 years with the purpose of evaluating the present biodiversity under the influence of climate change. The study concluded that the spatial and temporal changes in LCTs have continuously changed throughout the 2000-2015 interval. The results show that both temperature and precipitation have had an increasing trend towards 2015. With respect to the variation of monthly values, temperature registered a steady increase, while precipitation indicated an intensifying fluctuation within seasons (i.e. less seasonality was observed from 2007 onwards, as mentioned in section 4.1.2 Precipitation). These trends indicate a potential rising temperature and precipitation regime in the future in the studied area. Water bodies had a constant presence, but recorded slight increases towards the present. The water bodies LCT was found to be strongly correlated with hydrophilic vegetation (i.e. water species and reed classes). Therefore, the slight decrease in water bodies might be due to the increasing hydrophilic vegetation during the warm season. Generally, water species and reed LCTs had an increasing trend between 2000 and 2015, as opposed to water bodies and open land. This could be explained as a result of the increasing air temperature. Open land recorded minimum values when dry vegetation fires occurred (e.g. September 2014), often caused by high temperature values (PRO TV, 2016). Abrupt decreases in open land have been often associated with less humid conditions. Both monthly and yearly succession analyses indicate that woody species responded more to their slow and constant developing rate, and bare soil to hazardous incidents such as dry vegetation fires.

Land cover changes have indicated rather high levels of variation where spatial distribution is concerned. Apart from the actual land cover modifications that have occurred between 2000 and 2015, these changes are also potentially due to inaccuracy in the LCTs classification process, that might be caused by the varying resolution of the different satellite images (as stated in section 3.1.2. Satellite images). For example, reed cover has been often mistaken for open land, this issue being explained by the fact that these two categories have been difficult to differentiate during the classification process. However, the fluctuation in their surface areas might not have had a significant influence upon the remaining land covers, as a result of the equilibrium between the two classes (i.e. most of the time, while one of the classes was identified as having a greater extent, the other occupied a smaller area). Therefore, using the relative percentage to express the LCT surfaces was considered more appropriate in order to decrease the uncertainties due to misclassifications. Another example of classification inaccuracy concerns the woody species LCT, as the tree tops have initially been repeatedly confused with open land and reed LCTs during the classification process. Therefore, the woody species mask was created. Apart from these issues, the major limitations of the study are considered to be a result of the lack of more frequently recorded satellite imagery. Thus, a precise evaluation of the land cover dynamics was not possible, as images for certain time intervals were simply not available. Another limiting factor of the present study was the fact that the area of study has not been physically accessible during the research. Although ground truth points could not be collected, an accuracy assessment with regard to the classifying procedure was carried out by comparing a set of randomly selected points on Google Earth imagery with the classified maps. Confusion matrices, overall, producer and user accuracies along with kappa coefficients were calculated. The overall accuracy ranged from 78% to 85% for June 2005 and April 2015 classified maps, respectively, which is comparable to the results of similar studies. Kappa values varied with the overall accuracy, from 0.679 (June 2005) to 0.764 (April 2015). High accuracies of 85% and 83% were obtained for April 2015 and November 2015 classified maps, respectively, where the distinct LCTs could be better identified on the satellite images during the classification process (Figure 35).

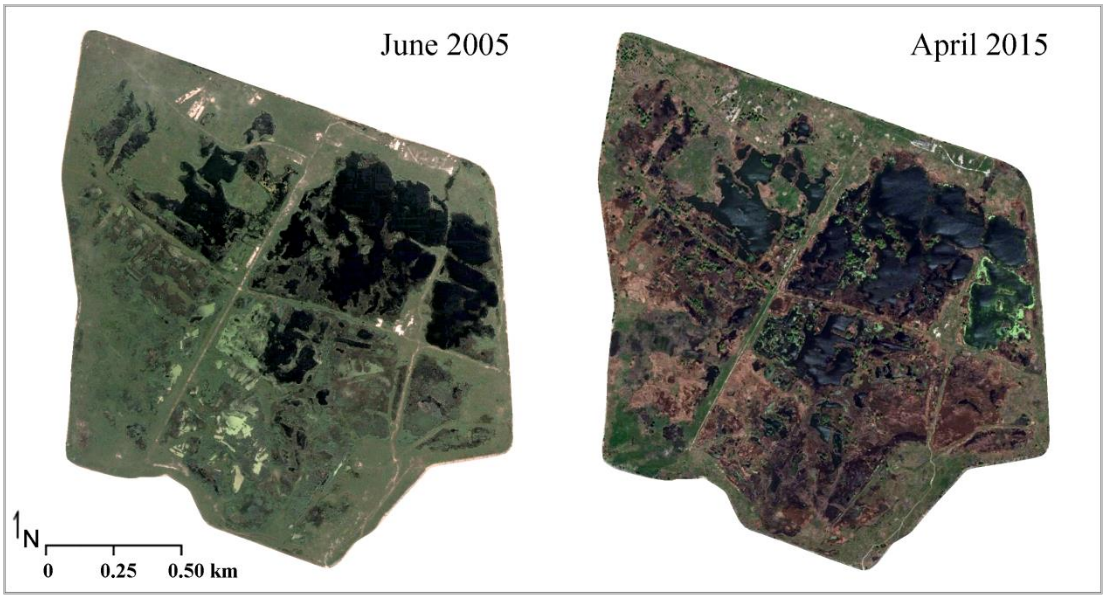

Figure 35. Comparison between the satellite images from June 2005 and April 2015. The distinct LCTs could be better identified in the satellite image at the right and therefore, the overall accuracy for the correspondent classified map was higher.

5.2 The evolution of Văcărești wetland and the risk for biodiversity

It is reasonable to assess that the present biodiversity is specifically influenced by its dependence on the physiological requirements of each species. By analysing these requirements, with regard to the spatial and temporal land cover changes as well as climate variables, the evolution of biodiversity during the 2000-

2015 time span has been estimated. Based on the species presence data extracted from the Substantiation Note that pursues the implementation of Văcărești Nature Park's protection regime (Stoican et al., 2013), it is evaluated that the biodiversity recorded fluctuations throughout the 2000-2015 period due to the spatial and temporal progression of LCTs. As a practical example, the increase in water species and reed LCTs is associated with the ongoing rise in temperature, which may further result in the occurrence of more hydrophilic vegetation. Generally, water species and reed covers had an increasing trend, as opposed to water bodies and open land. This could be explained as the result of the increasing temperature. Consequently, the water bodies become increasingly eutrophised and generate a growth in water species cover. Furthermore, as the edges of the water bodies become shallower, reed beds advance into the actual wetland and occupy a greater extent, a situation that is also exacerbated by the specific invasive character of these species. This could have a negative impact upon the species diversity within the wetland, as most the species that are found at Văcărești do not require habitats similar to that of reed LCT.

5.2.1 Groundwater level changes

Groundwater-dependent ecosystems, such as wetlands, are highly influenced by climatic variables (e.g. changes in precipitation, evapotranspiration, snow accumulation or snow melt) both directly and indirectly (Kløve et al., 2014), indifferent to the geographical and climatic context (Goderniaux et al., 2015). As the regional groundwater flow decreases, the superficial water from the wetlands is progressively directed towards the groundwater as to create a balance, which ultimately results in a lower surface water level (Kløve et al., 2011). An example of how groundwater could affect the areas within the urban infrastructure is Circului Lake in Bucharest. Despite being artificially built, Circului Lake is naturally recharged by the Colentina surface aquifer. It was assumed that the water level variation had been related to the urban aquifer system, and as a consequence, a model based on the most important elements of the urban hydrological cycle was created (Gogu et al., 2015). The study concluded that the water variation resulted from reduced rainfall deriving from climate change and execution of dewatering works that were necessary in order to lower the piezometric level of the aquifer, as to be able to build constructions with deep foundations that would not be negatively impacted by groundwater (Gogu et al., 2015). This example highlights that human activities could affect the stability of urban surrounded land. Therefore, it is important to consider all the aspects related to the groundwater system that could potentially have an influence upon the water bodies of Văcărești wetland. By overlooking these issues, it is possible that the entire ecosystem would ultimately be affected.

5.3 Wetland conservation requirements

Climate change and global warming in particular are assumed to have a great impact upon the current biological diversity of wetland ecosystems, which results from the equilibrium between the distinct constituent species and abiotic factors (e.g. temperature, humidity, hydration conditions and soil structure) throughout time (Ministerul Mediului și Schimbărilor Climatice, 2013). Therefore, conserving biodiversity is essential when climate change adaptation strategies are concerned. Future climate scenarios predict the extinction of endangered species, many of which can only be found in certain ecological niches that are, most of the time, extremely vulnerable. In order to preserve the biological diversity, reducing the additional pressures upon these sites as well as creating ecological corridors as to stimulate wildlife migration, as proposed by the Theory of Island Biogeography (Harrison and Bruna, 1999; Losos and Ricklefs, 2010), would conduct to civilisation benefiting more from the ecological services provided by these ecosystems (Ministerul Mediului și Schimbărilor Climatice, 2013). For suitable management plans and conservation strategies to be developed, it is essential that rigorous and high quality information on the biologic diversity of the site be available (Scheldeman and Zonneveld, 2010). As an example, a Wetland Planning Team was constituted in Florida in order to conduct projects, having the aim of making a wetland inventory, creating a model to prioritise the conservation process, as well as determining a description and classification database (Lavoie et al., 2016). If not properly managed, the wetland could be exposed to various threats, either human induced or even natural. For instance, natural changes such as sedimentation or peat growth may lead to hydrological changes, disappearance of certain species and consequently, the loss of the wetland ecosystem. One example from the United Kingdom, a particular small lake named Malham Tarn, demonstrates the possibility of aquatic ecosystems transforming over a period of time into dense woodland. This happens as the upper soil layer is gradually separated from the nutrient-rich groundwater, the vegetation becomes more dependent on precipitation and finally, trees start to develop, their roots contributing further to the desiccation process (Maltby, 2009). Present conservation measures for Văcărești wetland, which are proposed by the Substantiation Note that pursues the implementation of Văcărești Nature Park's protection regime (Stoican et al., 2013), are based on the Government Emergency Ordinance No. 57/2007 with ulterior modifications and additions, regarding the protected natural areas regime, conservation of natural habitats and wild flora and fauna. The proposal includes a detailed evaluation of the geology, pedology and hydrology of the area, as well as a more complete study on the specific flora and fauna along with sensible strategies for habitat enrichment. Other measures that are to be taken include the prevention of fires caused by dry vegetation, logging, fishing and poaching interdiction (Stoican et al., 2013).

The results regarding biodiversity changes throughout 2000-2015 that ensued from the present research supplement the current data that describe the condition of Văcărești wetland. This information could contribute to the development of future conservation strategies, which aim at the prevention of harmful occurrences that could threaten the integrity of the ecosystem.

6. Conclusions

The research question of the present study aimed at estimating the extent to which Văcărești wetland would be affected by the ongoing climate change in terms of land cover and its related biodiversity. Therefore, specific objectives were set and eventually fulfilled.

The results indicated that temperature and precipitation recorded an increasing trend since 2000 onwards. Temperature indicated a steady growth, but with several anomalous periods, especially during the 2003-2012 interval, while precipitation confirmed the less evident separation between seasons due to fluctuating rainfall within seasons and more evident peak values. The temporal and spatial changes in Văcărești wetland indicate a continuous variation in both seasonal changes within a year and the annual succession of land covers. Although not all land covers indicate a specific relation with the meteorological parameters, the most evident correlation between land cover and climate change regards water species. These are spatially dependent on the water bodies and record larger surface areas during the warm season. In contrast, bare soil and woody species (i.e. the least extensive land covers of the wetland) have been defined as depending more on the occurrence of hazardous incidents and progressive evolution of vegetation, respectively. However, it is concluded that there is an active interconnection between all the land covers and climate parameters changes throughout the 2000-2015 interval. As biodiversity depends on the physiological requirements of each species, and therefore the availability of respective habitats, it is concluded that the species that are dependent on hydrophilic vegetation have increased and are likely presumed to develop even further, while open land-dependent species would have an opposite behaviour.

Since the trends of local climate tend to correlate with the unfavourable future climate scenarios, the negative effects of climate change upon the biodiversity within Văcărești wetland could be limited if judicious conservation strategies are implemented. Suitable management policies would eventually lead to the preservation and potentially enhancement of the species diversity of Văcărești urban wetland.

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Appendices

Appendix A. Selection of software for image processing

The computer program used for the satellite imagery editing process was Adobe Photoshop CS6. This software was chosen over ENVI (which has been later used for the classification process), as the latter could not provide the appropriate tools in order to operate certain corrections, such as removing the cloud cover or water reflectance. Nevertheless, a comparison between the accuracy of similar image enhancement tools from each of these two programs was made. The observations rely on the satellite image from April 2015 (Figure 36), which displays definite land cover classes.

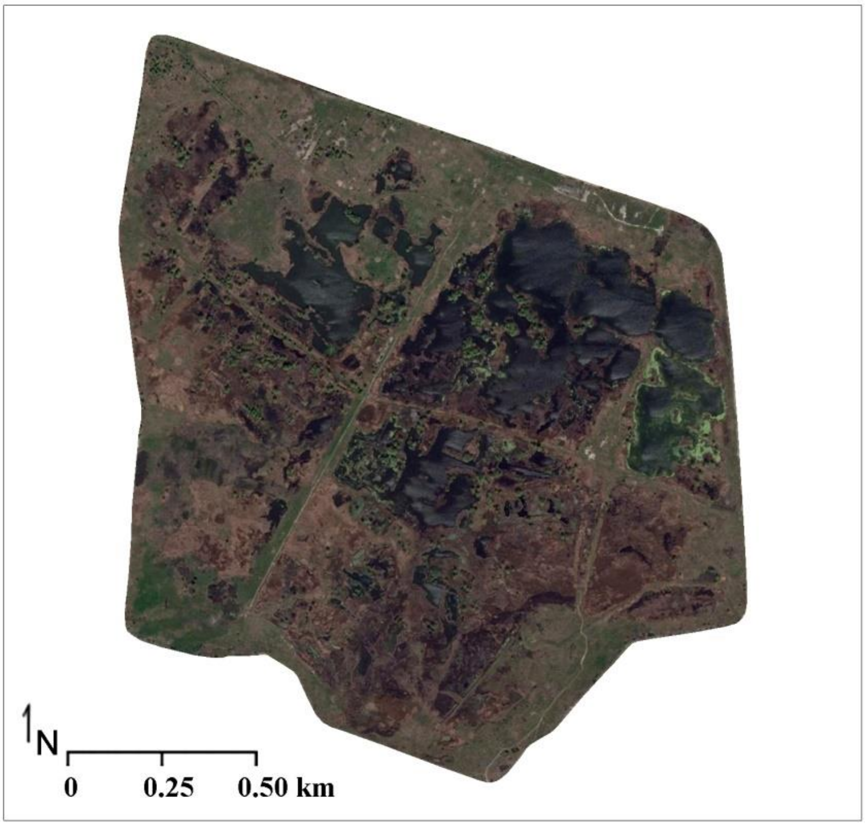

Figure 36. Satellite image from April 2015, displaying deffinite land cover classes.

The results demonstrated that the two software products are rather similar in which enhancing the clarity of images is concerned, as a mean of 0.4% land cover variation with regard to the individual class surfaces (i.e. 0.7 hectares) was recorded. The most evident difference between the classifications based on the Adobe

Photoshop CS6 and ENVI image processing procedure was related to the bare soil occurrence. This difference is exemplified in Figure 37.

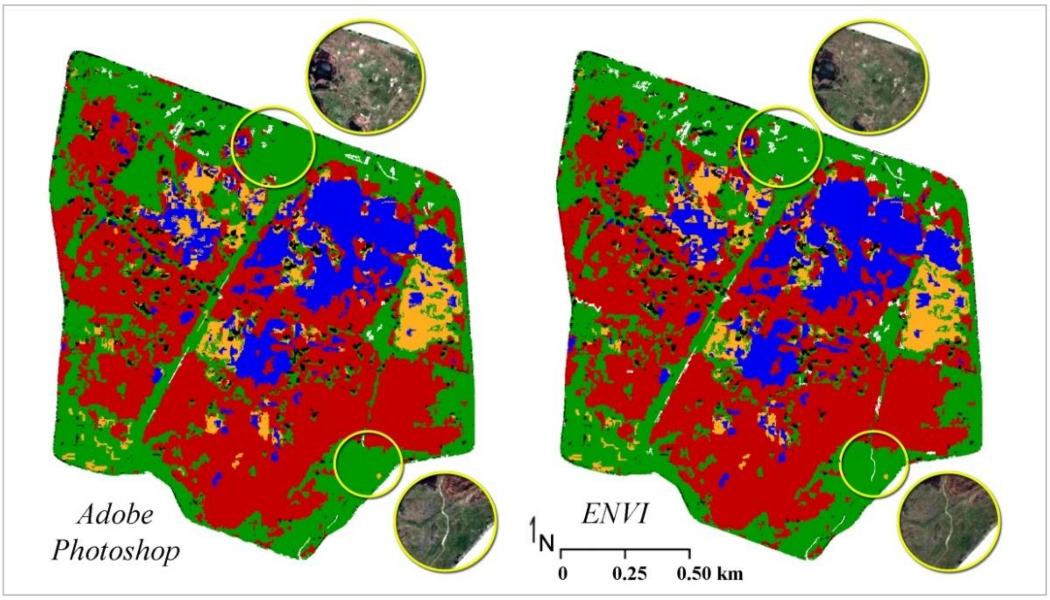

Figure 37. Comparison between Photoshop and ENVI edited images using the April 2015 satellite image as a background, case in which bare soil was better classified using ENVI. In white: bare soil; in blue: water bodies; in orange: water species; in red: reed; in green: open land; in black: woody species.

Accordingly, respecting ENVI, some small-scale areas (e.g. dirt pathways) were better classified. However, the fact that ENVI software cannot provide correction solutions to cloud cover and water reflectance, which most of the time cover extensive areas, led to the selection of Adobe Photoshop CS6 as the fundamental editing software for the present study. As corrections using Adobe Photoshop CS6 have been manually made throughout the editing process in correlation with proofing data (e.g. photographs of the site), major misclassifications were avoided.

Appendix B. Centralisation of species with relation to land cover types

Table 8. (B= bare soil, W= water bodies, WaS= water species, R= reed, O= open land, Wos= woody species).

BIRDS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Podicipedidae	*Tachybaptus ruficollis*		X	X			
Podicipedidae	*Podiceps cristatus*		X	X			
Podicipedidae	*Podiceps nigricollis*		X	X	X		
Phalacrocoracidae	*Phalacrocorax carbo*	X	X		X		X
Phalacrocoracidae	*Phalacrocorax pygmeus*		X	X	X		X
Ardeidae	*Egretta garzetta*		X	X			
Ardeidae	*Ardea cinerea*		X	X	X		X
Ardeidae	*Nycticorax nycticorax*		X	X		X	X
Ardeidae	*Ardeola ralloides*		X	X	X	X	X
Ardeidae	*Ixobrychus minutus*			X	X	X	X
Anatidae	*Cygnus olor*	X	X	X		X	
Anatidae	*Anas platyrhynchos*			X	X	X	
Anatidae	*Anas creca*		X	X	X		
Anatidae	*Anas clypeata*		X	X	X	X	X
Anatidae	*Anas querquedula*			X		X	
Anatidae	*Aythya ferina*		X	X	X		
Anatidae	*Aythya nyroca*		X	X	X		
Anatidae	*Netta rufina*		X	X	X		
Accipitridae	*Buteo buteo*					X	X
Accipitridae	*Accipiter nisus*					X	X
Accipitridae	*Accipiter brevipes*					X	X
Accipitridae	*Circus aeruginosus*			X			
Accipitridae	*Circus cyaaneus*			X		X	
Accipitridae	*Circus macrourus*		X	X		X	
Falconidae	*Falco subbuteo*					X	X
Falconidae	*Falco tinnunculus*					X	X
Falconidae	*Pernis apivorus*						X
Rallidae	*Crex crex*			X	X	X	X
Rallidae	*Fulica atra*	X	X	X			X
Rallidae	*Gallinula chloropus*	X	X	X		X	
Charadriidae	*Vanellus vanellus*	X		X			
Sciolopacidae	*Gallinago gallinago*			X		X	
Laridae	*Larus michahellis*		X		X	X	
Laridae	*Larus ridibundus*	X	X	X		X	
Laridae	*Larus canus*	X	X	X		X	
Apodidae	*Apus apus*					X	X
Hirundinidae	*Hirundo rustica*			X	X	X	
Hirundinidae	*Hirundo daurica*					X	
Hirundinidae	*Delichon urbicum*		X			X	X
Hirundinidae	*Riparia riparia*		X			X	X
Picidae	*Dendrocopos syriacus*						X
Picidae	*Jynx torquilla*					X	X
Motacillidae	*Anthus trivialis*					X	

BIRDS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Motacillidae	*Anthus campestris*	X				X	X
Motacillidae	*Anthus spinoletta*			X		X	
Motacillidae	*Motacilla flava*	X	X	X		X	
Motacillidae	*Motacilla alba*		X		X	X	
Tryglodytae	*Troglodytes troglodytes*		X			X	X
Sturnidae	*Sturnus vulgaris*	X		X		X	
Corvidae	*Pica pica*					X	X
Corvidae	*Garrulus glandarius*					X	X
Corvidae	*Corvus monedula*					X	X
Corvidae	*Corvus frugilegus*					X	
Corvidae	*Corvus corone cornix*	X				X	
Sylvidae	*Sylvia communis*					X	X
Sylvidae	*Sylvia curruca*				X	X	X
Sylvidae	*Phylloscopus collybita*		X			X	X
Sylvidae	*Acrocephalus schoenobaenus*		X	X	X	X	
Sylvidae	*Acrocephalus arundinaceus*		X		X	X	
Turdidae	*Turdus philomelos*					X	X
Turdidae	*Phoenicurus ochruros*	X				X	
Turdidae	*Erithacus rubecula*					X	X
Turdidae	*Turdus merula*			X		X	X
Turdidae	*Turdus pilaris*					X	X
Paridae	*Cyanistes (Parus) caeruleus*					X	X
Paridae	*Parus major*					X	X
Paridae	*Panurus biarmicus*		X	X	X		
Paridae	*Remiz pendulinus*					X	X
Passeridae	*Passer domesticus*					X	X
Passeridae	*Passer montanus*	X	X			X	X
Fringillidae	*Fringilla coelebs*					X	X
Fringillidae	*Linaria (Carduelius) cannabina*					X	X
Fringillidae	*Carduelis carduelis*					X	X
Fringillidae	*Carduelis chloris*					X	X
Fringillidae	*Spinus (Carduelis) spinus*		X			X	X
Fringillidae	*Coccothraustes coccothraustes*					X	X
Fringillidae	*Emberiza schoeniclus*				X	X	
Fringillidae	*Emberiza citrinella*					X	X
Fringillidae	*Miliaria calandra*					X	
Fringillidae	*Serinus serinus*					X	X
Alaudidae	*Alauda arvensis*			X		X	
Alaudidae	*Galerida cristata*	X				X	
Liniidae	*Lanius collurio*					X	
Liniidae	*Lanius minor*					X	X
Muscicapidae	*Saxicola rubetra*					X	X

INSECTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Prunellidae	*Prunella modularis*					X	X
Phasianidae	*Perdix perdix*					X	
Phasianidae	*Coturnix coturnix*					X	
Phasianidae	*Phasanius colchicus*		X			X	X
Upupidae	*Upupa epops*	X				X	X
Sternidae	*Chlidonias hybrida*		X	X		X	
Columbidae	*Columba livia*					X	
Columbidae	*Streptopelia decaocto*					X	X
Cuculidae	*Cuculus canorus*			X		X	X
Calopterygidae	*Calopteryx splendens*		X	X			
Lestidae	*Lestes virens*		X	X			
Lestidae	*Sympecma fusca*			X	X		
Coenagrionidae	*Coenagrion pulchellum*			X	X		
Coenagrionidae	*Enallagma cyathigerum*		X				
Coenagrionidae	*Erythromma viridulum*		X	X			
Coenagrionidae	*Ischnura pumilio*		X	X			
Coenagrionidae	*Ischnura elegans*		X	X			
Platycnemididae	*Platycnemis pennipes*	X	X			X	
Aeshnidae	*Aeshna affinis*		X		X	X	
Aeshnidae	*Anax imperator*		X	X	X		
Libellulidae	*Crocothemis erythraea*		X	X		X	
Libellulidae	*Libellula depressa*		X				
Libellulidae	*Orthetrum albistylum*		X				
Libellulidae	*Orthetrum brunneum*		X				
Libellulidae	*Sympetrum fonscolombii*		X				
Libellulidae	*Sympetrum meridionale*			X		X	
Libellulidae	*Sympetrum pedemontanum*		X	X			
Libellulidae	*Sympetrum sanguineum*			X	X		
Phaneropteridae	*Phaneroptera nana*					X	X
Tettigoniidae	*Conocephalus fuscus*			X	X	X	
Tettigoniidae	*Ruspolia nitidula*			X		X	
Tettigoniidae	*Tettigonia viridissima*					X	
Tettigoniidae	*Tettigonia caudata*					X	X
Tettigoniidae	*Metrioptera roeselii*			X		X	
Tettigoniidae	*Platycleis albopunctata grisea*	X				X	
Tettigoniidae	*Platycleis (Tessellana) veyseli*	X				X	X
Tettigoniidae	*Ephippiger ephippiger*					X	X
Gryllidae	*Gryllus campestris*	X				X	
Gryllidae	*Melanogryllus desertus*					X	
Gryllidae	*Modicogryllus truncatus*	X		X		X	
Gryllidae	*Pteronemobius heydenii*			X		X	

INSECTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Gryllidae	*Oecanthus pellucens*					X	X
Gryllotalpidae	*Gryllotalpa gryllotalpa*			X		X	
Tetrigidae	*Tetrix subulata*	X		X		X	
Acrididae	*Pezotettix giornae*	X				X	X
Acrididae	*Calliptamus italicus*	X				X	
Acrididae	*Acrida ungarica*					X	
Acrididae	*Oedipoda caerulescens*	X				X	
Acrididae	*Aiolopus thalassinus*	X		X		X	
Acrididae	*Stethophyma grossum*			X			
Acrididae	*Omocestus rufipes*	X				X	
Acrididae	*Chorthippus brunneus*	X				X	
Acrididae	*Chorthippus oschei*					X	
Acrididae	*Chorthippus loratus*					X	
Acrididae	*Chorthippus dichrous*	X				X	
Acrididae	*Chorthippus parallelus*			X		X	
Acrididae	*Euchorthippus declivus*					X	
Acrididae	*Mantis religiosa*					X	X
Corixidae	*Hesperocorixa linnaei*			X			
Corixidae	*Sigara nigrolineata*		X	X			
Corixidae	*Sigara lateralis*		X	X			
Nepidae	*Nepa cinerea*		X	X	X		
Nepidae	*Ranatra linearis*			X			
Naucoridae	*Naucoris cimicoides*		X	X			
Notonectidae	*Notonecta glauca*		X				
Pleidae	*Plea leachi*		X	X			
Gerridae	*Aquarius paludum*		X				
Gerridae	*Gerris argentatus*			X			
Gerridae	*Gerris lacustris*		X				
Mesoveliidae	*Mesovelia furcata*		X				
Veliidae	*Microvelia reticulata*			X	X		
Haliplidae	*Haliplus obliquus*					X	
Haliplidae	*Haliplus wehnckei*		X	X			
Haliplidae	*Peltodytes caesus*			X			
Dytiscidae	*Hydroporus sp.*		X	X			
Dytiscidae	*Guignotus pusillus*		X		X		
Dytiscidae	*Hygrotus inaequalis*		X	X			
Dytiscidae	*Scarodytes halensis*		X				
Dytiscidae	*Graptodytes bilineatus*			X		X	
Dytiscidae	*Noterus clavicornis*			X	X		
Dytiscidae	*Noterus crassicornis*			X			
Dytiscidae	*Laccophilus minutus*		X				
Dytiscidae	*Laccophilus variegatus*			X	X	X	
Dytiscidae	*Colymbetes striatus*		X	X			
Dytiscidae	*Ilibius ater*		X	X			
Dytiscidae	*Ilibius sp.*		X	X			
Dytiscidae	*Rhantus pulverosus*		X	X		X	
Dytiscidae	*Hydaticus transversalis*			X	X	X	

INSECTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Dytiscidae	*Cybister lateralimarginalis*			X			
Dytiscidae	*Graphoderus sp.*		X	X			
Hydrophilidae	*Coelostoma orbiculare*			X			
Hydrophilidae	*Megasternum boletophagum*			X		X	
Hydrophilidae	*Limnoxenus niger*			X	X	X	
Hydrophilidae	*Anacaena limbata*			X		X	
Hydrophilidae	*Laccobius biguttatus*			X			
Hydrophilidae	*Helochares lividus*		X	X			
Hydrophilidae	*Forst Helochares obscurus*		X	X			
Hydrophilidae	*Enochrus melanocephalus*			X			
Hydrophilidae	*Enochrus coarctatus*			X			
Hydrophilidae	*Enochrus testaceus*			X			
Limnebiidae	*Limnebius sp.*			X		X	
Torymidae	*Eridontomerus laticornis*					X	
Torymidae	*Idiomacromerus mayri*			X		X	
Torymidae	*Idiomacromerus pannonicus*			X		X	
Torymidae	*Idiomacromerus perplexus*			X		X	
Torymidae	*Idiomacromerus terebrator*			X		X	
Torymidae	*Microdontomerus annulatus*			X		X	
Torymidae	*Torymoides kiesenwetteri*			X		X	
Torymidae	*Torymus cupratus Boheman*			X		X	
Eurytomidae	*Bruchophagus astragali*			X		X	
Eurytomidae	*Bruchophagus platypterus*			X		X	
Eurytomidae	*Eurytoma palustris*			X			
Eurytomidae	*Eurytoma tibialis*			X		X	
Eurytomidae	*Sycophila mellea*					X	
Eurytomidae	*Systole tuonela*			X			
Eurytomidae	*Tetramesa cereipes*					X	
Eurytomidae	*Tetramesa gracilipennis*					X	
Eurytomidae	*Tetramesa linearis*					X	
Eurytomidae	*Tetramesa variae*					X	
PLANTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Poaceae	*Echinochloa crus-galli*			X		X	
Poaceae	*Bromus sterilis*					X	

PLANTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Poaceae	*Elymus repens s.l.*			X		X	
Poaceae	*Sorghum halepense*			X		X	
Poaceae	*Dichanthium intermedium*					X	
Poaceae	*Cynodon dactylon*			X		X	
Poaceae	*Phragmites australis*			X	X	X	
Poaceae	*Lolium perenne*			X		X	
Poaceae	*Setaria viridis*					X	
Typhaceae	*Typha angustifolia*				X		
Typhaceae	*Typha latifolia*				X		
Cyperaceae	*Scirpus lacustris*				X		
Juncaceae	*Juncus effusus*				X	X	
Caryophyllaceae	*Stellaria media*			X		X	
Amaranthaceae	*Amaranthus retroflexus*			X		X	
Amaranthaceae	*Atriplex tatarica*					X	
Amaranthaceae	*Chenopodium album*			X		X	
Amaranthaceae	*Chenopodium strictum*					X	
Amaranthaceae	*Caryophyllale Portulacaceae*					X	
Amaranthaceae	*Portulaca oleracea subsp. oleracea*			X		X	
Portulaceae	*Bassia scoparia*					X	
Polygonaceae	*Polygonum aviculare*			X		X	
Polygonaceae	*Polygonum amphibium*			X			
Polygonaceae	*Polygonum lapathifolia*			X		X	
Polygonaceae	*Polygonum hydropiper*			X		X	
Polygonaceae	*Rumex patientia*					X	
Geraniaceae	*Erodium cicutarium*					X	
Solanaceae	*Solanum nigrum*					X	
Solanaceae	*Solanum dulcamara*			X		X	
Solanaceae	*Lycopersicon esculentum*					X	
Convolvulaceae	*Convolvulus arvensis*					X	
Convolvulaceae	*Calystegia sepium*			X		X	
Lamiaceae	*Ballota nigra subsp. nigra*					X	
Lamiaceae	*Lamium amplexicaule*					X	
Lamiaceae	*Lycopus europaeus*					X	
Lamiaceae	*Mentha longifolia*			X		X	
Orobanchaceae	*Odontites serotina*			X		X	
Plantaginaceae	*Plantago major s.l.*			X		X	
Plantaginaceae	*Plantago lanceolata*			X		X	
Verbenaceae	*Verbena officinalis*			X		X	
Vitaceae	*Parthenocissus inserta*			X		X	
Brassicaceae	*Berteroa incana*					X	
Brassicaceae	*Cardaria draba subsp. draba*			X		X	
Asteraceae	*Carduus acanthoides*					X	

PLANTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Asteraceae	*Xanthium italicum*					X	
Asteraceae	*Artemisia austriaca*					X	
Asteraceae	*Centaurea micranthos*			X		X	
Asteraceae	*Centaurea iberica*			X		X	
Asteraceae	*Centaurea nigrescens*					X	
Asteraceae	*Cichorium intybus*			X		X	
Asteraceae	*Cirsium vulgare*			X		X	
Asteraceae	*Arctium minus*			X		X	
Asteraceae	*Arctium lappa*					X	
Asteraceae	*Pulicaria dysenterica*					X	
Asteraceae	*Cirsium arvense*			X		X	
Asteraceae	*Artemisia absinthium*					X	
Asteraceae	*Artemisia annua*			X		X	
Asteraceae	*Sonchus arvensis*			X		X	
Asteraceae	*Taraxacum officinale*			X		X	
Asteraceae	*Achillea sp.*			X		X	
Asteraceae	*Ambrosia artemisiifolia*			X		X	
Asteraceae	*Conyza canadensis*					X	
Asteraceae	*Helianthus tuberosus*			X		X	
Asteraceae	*Picris hieracioides*					X	
Asteraceae	*Erigeron annuus s.l.*			X		X	
Asteraceae	*Lactuca serriola*			X		X	
Asteraceae	*Crepis foetida subsp. rhoeadifolia*					X	
Malvaceae	*Malva sylvestris*					X	
Malvaceae	*Althaea officinalis*			X		X	
Apiaceae	*Daucus carota ssp. carota*					X	
Apiaceae	*Berula erecta*			X			
Fabaceae	*Galega officinalis*					X	
Fabaceae	*Trifolium pratense*			X		X	
Fabaceae	*Trifolium repens s.l.*			X		X	
Fabaceae	*Ononis hircina*					X	X
Fabaceae	*Meliloltus alba*					X	
Rubiaceae	*Galium humifusum*					X	
Adoxaceae	*Sambucus ebulus*					X	
Dipsacaceae	*Dipsacus fullonum*			X		X	
Urticaceae	*Urtica dioica*			X		X	
Onagraceae	*Epilobium hirsutum*			X		X	
Lythraceae	*Lythrum salicaria*			X		X	
Alismataceae	*Alisma plantago-aquatica*			X		X	
Araceae	*Lemna trisulca*			X			
Araceae	*Lemna minor*			X			
Araceae	*Wolffia arrhiza*			X			
Butomaceae	*Butomus umbellatus*			X			
Azollaceae	*Azolla filiculoides*			X			

PLANTS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Myrsinaceae	*Lysimachia nummularia*			X		X	
Haloragaceae	*Myriophyllum spicatum*			X			
Caprifoliaceae	*Cephalaria transsilvanica*					X	
Rosaceae	*Rosa canina*						X
Rosaceae	*Crataegus monogyna*						X
Adoxaceae	*Sambucus nigra*						X
Rosaceae	*Rubus sp.*						X
Fabaceae	*Gleditsia triacanthos*						X
Salicaceae	*Salix fragilis*						X
Salicaceae	*Salix cinerea*						X
Salicaceae	*Populus sp.*						X
Elaeagnaceae	*Elaeagnus angustifolia*						X
Simaroubaceae	*Ailanthus altissima*						X
Sapindaceae	*Acer negundo*						X
Oleaceae	*Fraxinus pennsylvanica*						X
Ulmaceae	*Ulmus pumilla*						X
Rosaceae	*Prunus cerasifera*						X
Moraceae	*Morus alba*						X
Moraceae	*Morus nigra*						X
Juglandaceae	*Juglans regia*						X
ANIMALS							
Family	**Species**	**B**	**W**	**WaS**	**R**	**O**	**WoS**
Cricetidae	*Microtus arvalis*					X	
Soricidae	*Sorex minutus*	X		X		X	X
Cricetidae	*Ondatra zibethica*		X	X			
Mustelidae	*Mustela nivalis*					X	
Mustelidae	*Mustela putorius*			X		X	
Canidae	*Vulpes vulpes*					X	
Salamandridae	*Triturus cristatus*					X	
Salamandridae	*Lissotriton vulgaris*			X		X	
Bombinatoridae	*Bombina bombina*			X		X	
Ranidae	*Pelophylax ridibundus*		X	X		X	
Emydidae	*Emys orbicularis*		X	X		X	
Lacertidae	*Lacerta viridis*					X	
Lacertidae	*Lacerta agilis*					X	
Colubridae	*Natrix natrix*		X	X		X	
Cyprinidae	*Carassus gibelio*		X				
Percidae	*Perca fluviatilis*		X				
Cyprinidae	*Rutilus rutilus*		X				
Cyprinidae	*Scardinius erythrophthalmus*		X				
Cyprinidae	*Pseudorasbora parva*		X				
Cyprinidae	*Alburnus alburnus*		X				
Esocidae	*Esox lucius*		X				

Appendix C. Classified maps for September months

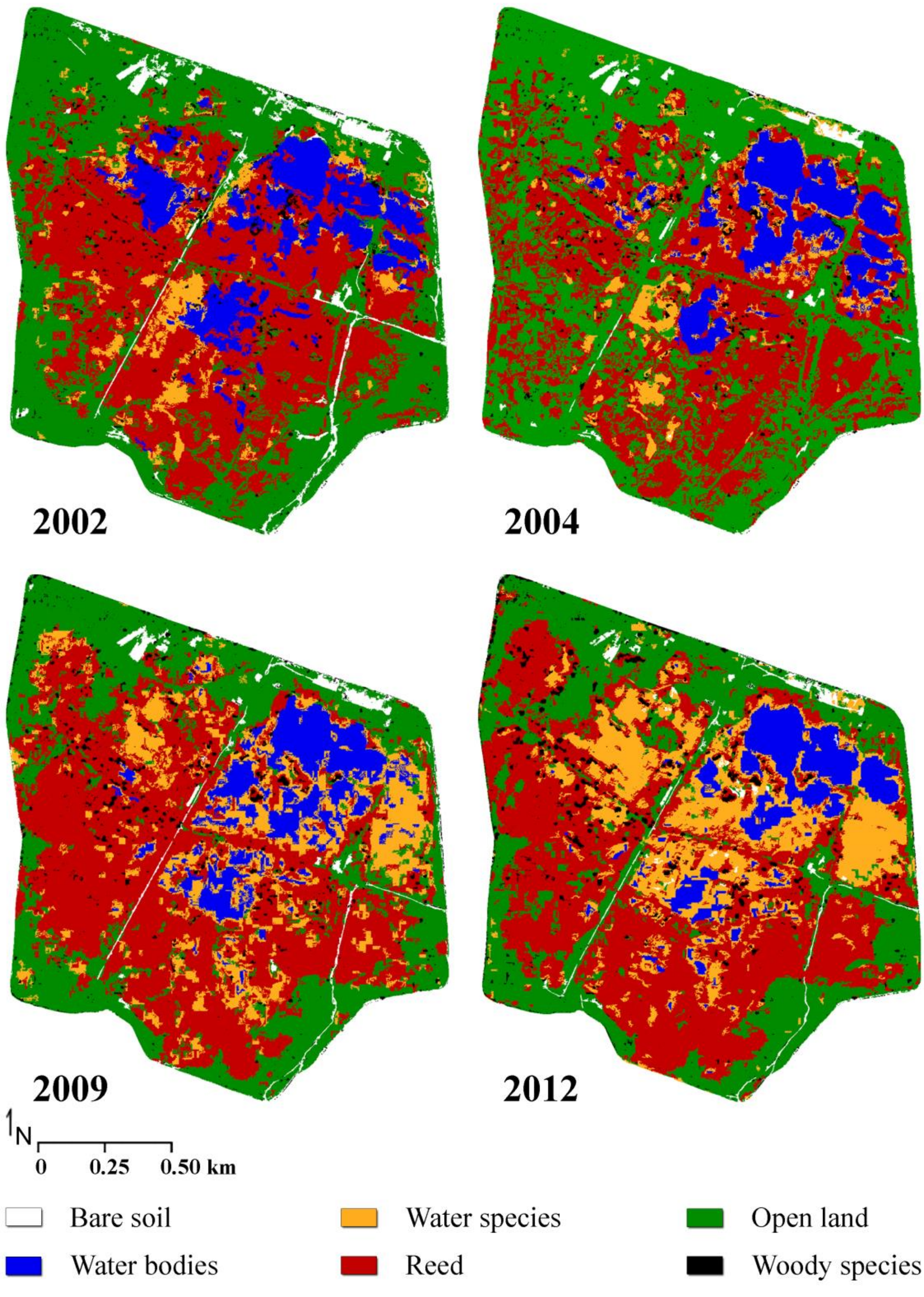

Figure 38. Classified maps for September months (2002, 2004, 2009 and 2012).

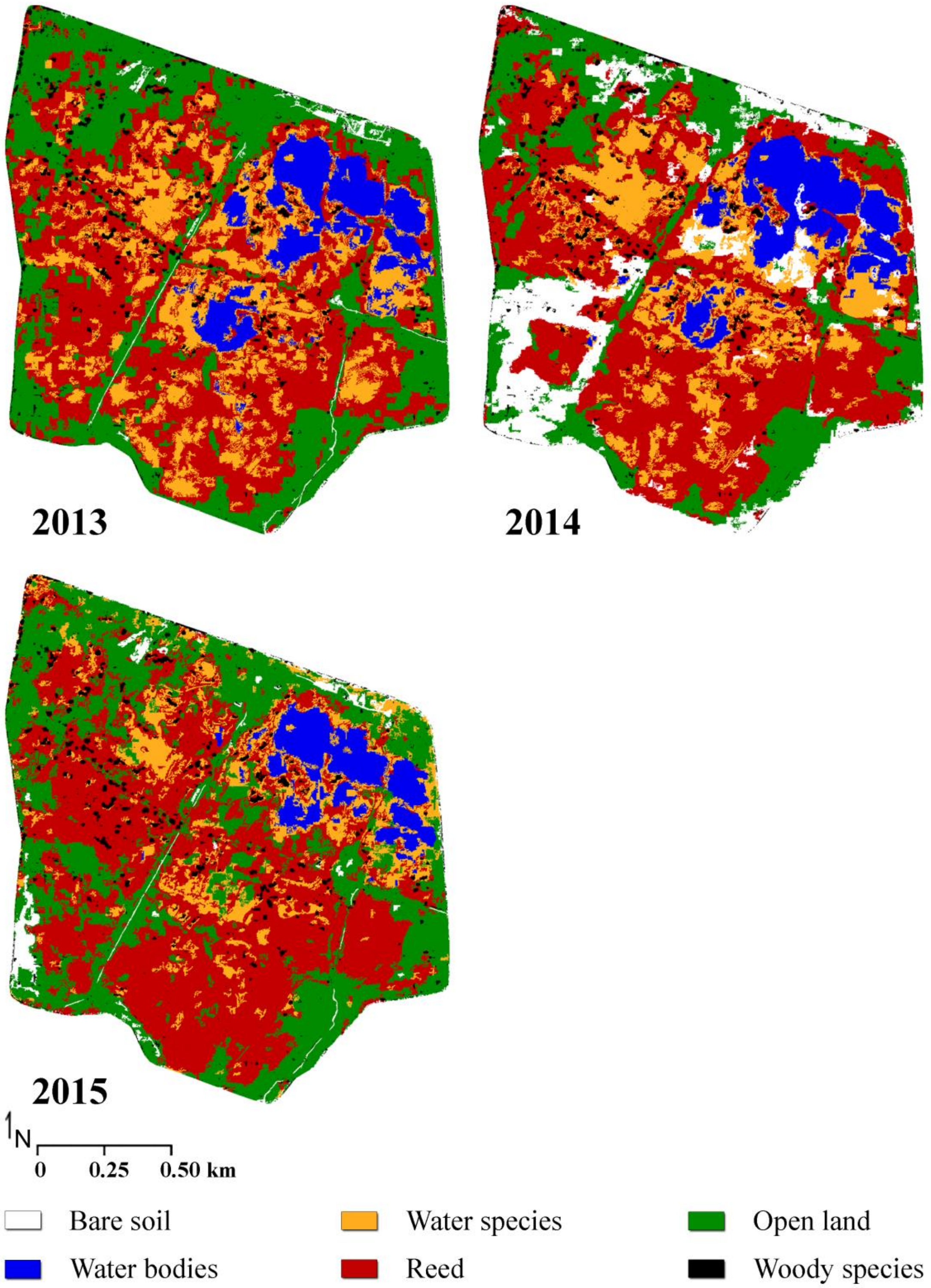

Figure 39. Classified maps for September months (2013, 2014 and 2015).

Appendix D. Classified maps for year 2015

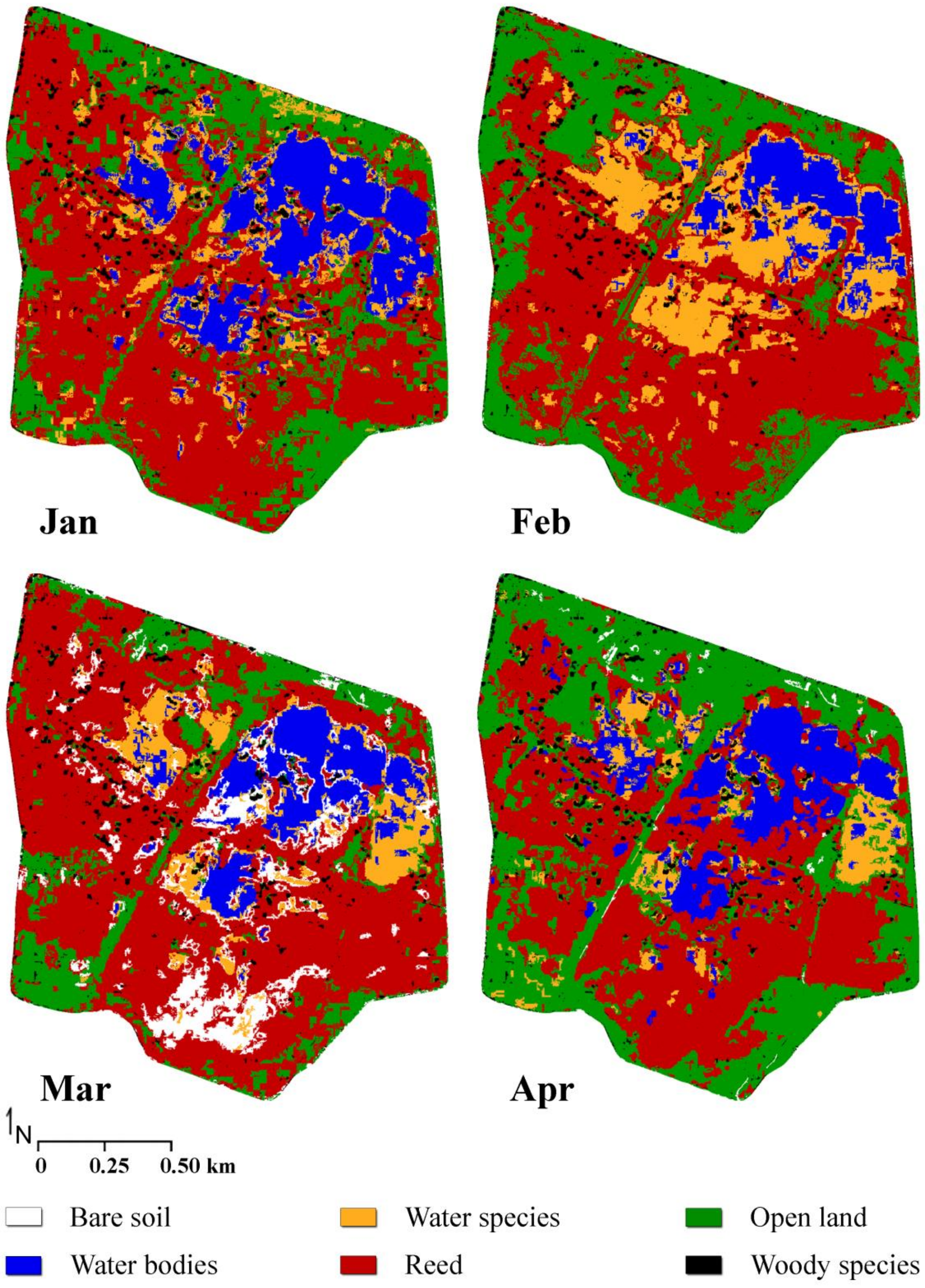

Figure 40. Classified maps for year 2015 (January, February, March and April).

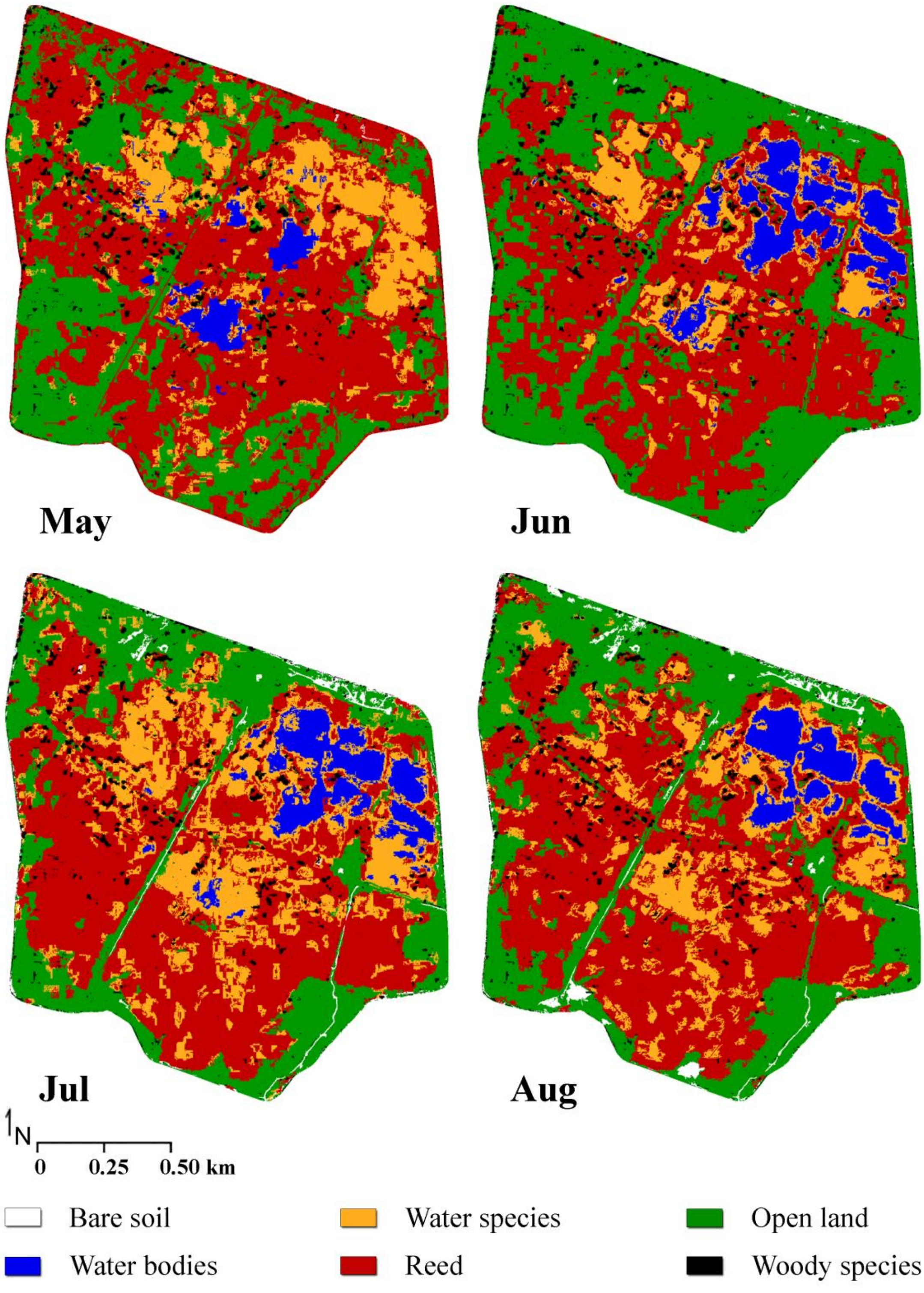

Figure 41. Classified maps for year 2015 (May, June, July and August).

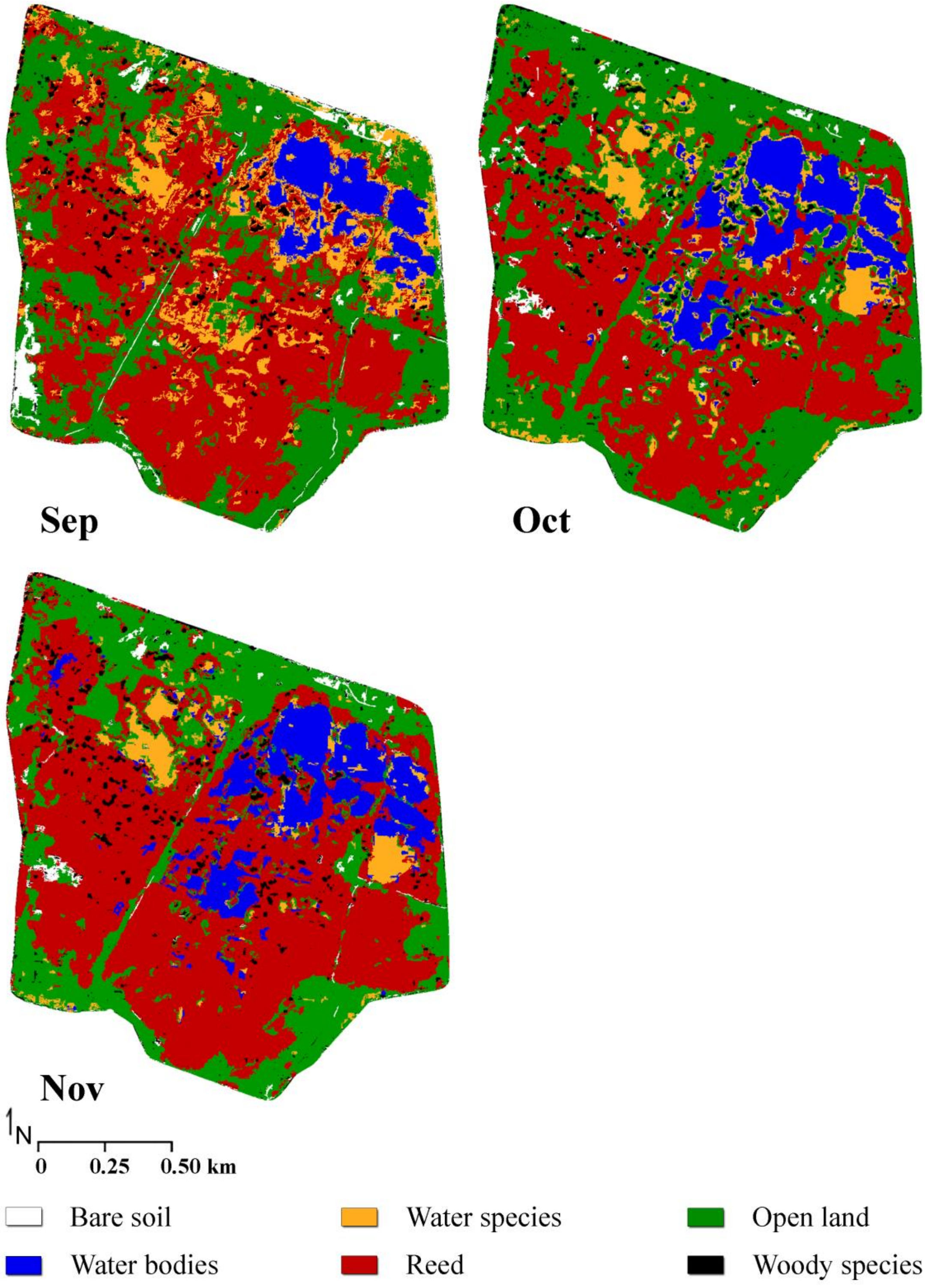

Figure 42. Classified maps for year 2015 (September, October and November).

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