Chapter 3

Using Geospatial Technologies in Mapping the Distribution and Quality of Ecosystems

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Abstract In the context of present environmental changes, human society is continuously looking for ways to evaluate the status of ecosystems and determine human-induced modifications on their structure and functionality. A clear overview of ecosystems is fundamental in choosing the appropriate measures in our search for sustainability and improving the quality of life. The aim of the chapter is therefore to underline how geography can respond to the need of mapping the distribution and quality of ecosystems. This is easily done by using geospatial technologies, helping to a better understanding of the relation between the spatial distribution and management of ecosystems. The chapter presents the main types of data required by geospatial technologies and the data sources for mapping ecosystems. Challenges in gathering reliable data are also presented besides various methods of overcoming the difficulties. There is a strong emphasis on differentiating the available geospatial technologies for mapping the distribution of ecosystems and for representing their quality. The use of different geospatial technologies in mapping the distribution and quality of specific ecosystems was highlighted through case studies of urban ecosystems, water bodies and forests. We also aimed to identify the causes that determined certain ecosystem approaches, and the potential of geospatial technologies in providing to geographers and other scholars the possibility to explore processes from

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the past, present, or modeling the future. As geographical assessments require a "cause and effect" approach, we aimed to emphasize how geospatial technologies are used in identifying the causes that determined certain planning policies, shaping the current geographical landscape, the effects of these policies, and the future outcomes of newly implemented or proposed planning policies. The current potential of geospatial technologies gives access to complex diachronic analysis, providing the geographers and other scholars the possibility to explore the various processes that occur in the geographical landscape. The chapter demonstrates how geography and geospatial technologies can help policy and decision makers, local administrations, or stakeholders evaluate the distribution and quality of specific ecosystems.

Keywords Geospatial technologies · Mapping · Ecosystems
Environmental changes

3.1 Introduction

Global and local ecosystems are profoundly being changed to cater the growing population and economic development. Technological evolution of human society finds its grounds in the permanent transformation and use of landscape, increasing living standard and comfort. Since the dawn of human society, ecosystems have been under continuous pressure. In this context, the assessment of the human-induced modifications in the structure and functionality of ecosystems is vital in the elaboration of subsequent planning policies, directed to environmental protection.

Policies and strategies were drawn to stop the natural ecosystem degradation. The most ambitious initiative is included in the Convention for Biological Diversity, which specifically refers to vulnerable ecosystems such as protected area, wetlands or aquatic ecosystems (CBD) (UN 1992). In the same direction act the EU Water Framework Directive and the 7th Environmental Action Plan (EC 2013). There are also numerous international projects aiming to conserve biodiversity and reduce habitat loss and ecosystem degradation.

Mapping the distribution and quality of ecosystems (often described by the amount and diversity of ecosystem services) lately represents one of the main focuses in science and policy on a global level (Roussel et al. 2017). Initiatives like IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) and MAES (Mapping and Assessment of Ecosystems and their Services) tried to draw a framework applicable at global, regional, and local level, but there are currently still many issues that must be overcome.

Considering the chosen scale, the spatial representation of ecosystems implies specific challenges and restrictions. For wider scales, continental or global, the mapping and evaluation of the ecosystems reside on the mainland use classes and large structural units, leaving out important ecological characteristics. Therefore, it is recommended to represent ecosystems more thoroughly (Blasi et al. 2017), considering the significant factors that produce discontinuities, properties of the environment (soil type, hydrographical basin), or different spatial relations (home range, species migration). The limits of ecosystems may be established by considering the place where a number of these discontinuities converge.

Ecosystem mapping is mandatory for land use planning, environmental impact assessment, and conservation as they demand spatial outcomes for proper decision-making (Ershov et al. 2016). Maps that represent the relevant ecosystem for the existence of a population will be totally different than maps showing the impact of human activities over the same ecosystem. Since ecosystems are dynamic entities, their morphological and structural evolution through time is meaningful. Land use planning and decision-making are greatly improved by more precise and accurate spatial data regarding ecosystems (Blasi et al. 2017).

Geospatial technologies provide the means to work with multiple layers of information, showing distinctive characteristics of the environment, everything being at the same time accurately represented in space. Contemporary geospatial technologies are extremely well suited to represent ecosystems in their high complexity, not only through simple models. In order to differentiate between ecosystems, we can use key criteria, such as the density of relations, but in practice, apparent homogeneity is a more adequate alternative. If multiple characteristics are to be used at the same time to delimitate the spatial extension of an ecosystem, geospatial technologies can manage information in different layers, representing landforms, soil's category, or vegetation groups but also to produce a composite map by joining the layers using different algorithms.

The chapter presents the main types of data required by geospatial technologies and the data sources for mapping ecosystems. We also provide different examples of how geospatial technologies could be used to emphasize specific features of ecosystems. We focused on emphasizing the differences that occur by using different geospatial techniques to assess similar features, the differences being dependent on the quality of raw data, or the processing solution used in the analysis.

3.2 Data Sources for Mapping Ecosystems

The input data for geospatial technologies are much diversified and may be provided by various sources, from remote sensing (imagery and data collected from space or airborne platforms) to databases created by specialists. The smartphone technology is proving to be a valuable tool for ecosystem data collection by the wide public through applications that use GPS to accurately map the information (Edsall et al. 2015). Data availability, accuracy, and resolution have greatly improved, and further progress is expected to satisfy increasing and more specific needs. Some of these sources provide data at a global scale, while others register detailed aspects of the ecosystems.

At the global level, the most widely used data are the ones provided by satellites systems. They have the advantage of spatial and temporal coverage; the images being generated at global level with a daily frequency. The most used sources for remote sensing are images produced by Landsat-MSS, TM, ETM+ and SPOT-HRV, Aster Terra (Turner 2010). The most important platform for this type of images is the US Geological Survey (https://earthexplorer.usgs.gov/). The main software solutions for image processing is ENVI 5.3, and ArcGis 10.x for spatial analysis. Raw satellite images should be processed through some filters to eliminate some geometrical distortions using software solutions such as ERDAS Imagine before being used for classification (Badar and Romshoo 2008).

For European land use and land change studies, the Corine Land Cover (CLC) database (available at http://www.copernicus.eu/) is widely used by researchers. As it records land cover type from 1990, 2000, 2006, and 2012, the database is a useful product in emphasizing landscape dynamics throughout the continent (Feranec et al. 2010, 2007). However, this dataset is not sensitive for changes that occur within an area of less than 25 ha as this is the minimum mapping unit. For the CLC 1990 and 2000, the satellite data were provided by LANDSAT-5, respectively LANDSAT-7 sensors and the proposed thematic accuracy of at most 85% was achieved only for the 2000 version. For 2006 and 2012 versions, satellite data were provided by SPOT 4/5 and IRS P6 LISS III respectively IRS P6 LISS III and RapidEye sensor and the thematic accuracy has not been checked yet. The Copernicus platform also offers a wide range of products designed for the analysis of specific ecosystems.

Besides the global and regional datasets there are national products that provide land use data generated either from military topographical maps or orthophoto maps. Often, these products are used to calibrate the global and regional datasets as they have a better resolution and accuracy (Pătru-Stupariu et al. 2015; Iojă et al. 2011).

For many years, the main challenge of geospatial data was related with resolution, since the products with 120, 60 or even 30 m resolution do not present enough detail to map distinct ecosystem features, like ecotones between different ecosystems (e.g., the shoreline, urban expansion in protected habitats). Currently, new technologies facilitated the acquisition of images with high spatial and spectral resolution and improved radiometric and temporal coverage. However, as Bishop et al. (2012) underline, sensor improvements rise issues related with data volume, storage capacity, memory and processing speeds, increased information variability, algorithm suitability, data integration, analysis, and visualization. Accuracy and effectiveness of data retrieved from online sources are other issues that permanently occur in spatial analysis. Some online platforms, like Open Street Map, are based on voluntary participation therefore the data quality is not fully validated.

3.3 Geospatial Technologies for Mapping the Distribution of Ecosystems

According to the American Association for the Advancement of Science (2017), geospatial technologies refer to a range of modern tools contributing to the geographic mapping and analysis of the Earth. The main categories of geospatial technologies are related with:

Remote Sensing—images and data which are collected from space or airborne cameras and sensor platforms and are subsequently processed to extract the distribution or quality of different ecosystems or elements like vegetation, water bodies or built areas (United States Geological Survey 2017).

Geographic Information System (GIS) represents an ensemble of software tools which can be used for mapping and analyzing data. The raw data processed through GIS solutions must be georeferenced which means every information has assigned a specific location on Earth.

Global Positioning System (GPS) is a global navigation satellite system owned by U.S. Department of Defense which provides geolocation (position on Earth) and time information for military and civil use. Currently, there operates another satellite system managed by the Russian Federation (GLONASS), while the European Union, China, and Japan are preparing to launch their own systems.

Internet Mapping Technologies comprise software programs like Google Earth and web features like Microsoft Virtual Earth which allow visualization and sharing of geospatial data.

The main characteristic of geospatial data is represented by the spatial reference information assigned to each location which can be represented by geographical coordinates, addresses or other types of spatial attributes.

Accurate and consistent mapping of the distribution of ecosystems must rely on proper definition and classification for the ecosystems themselves. The scope, time frame, and the scale of such classifications are also extremely important for the subsequent mapping of ecosystems distribution.

Scale is relevant when mapping the distribution of ecosystems from several perspectives. Classifications can be done either by subdivision (top-down approach) or by agglomeration (bottom-up approach). From a scale-based reasoning, maps can emphasize from the distribution of major ecosystems (e.g., biogeographical zones), down to the smallest relevant ecosystems (e.g., a pine forest or an oasis). The level of detail is directly dependent on the scale, but adequate geospatial technologies can present the ecosystems at varying scales, depending on the resolution of the input information. Scale is also relevant when trying to establish the limits of an ecosystem.

Mapping the distribution of different ecosystems is best achieved by tools specifically designed for them, since ecosystems are extremely different, with specific key characteristics that need to be properly evaluated (Pagella and Sinclair 2014). Mapping the distribution of forest ecosystems needs a totally different set of indicators than mapping the distribution of river ecosystems (Remmel and Perera 2017). Using the available geospatial techniques greatly improves the efficiency of the ecosystems' distribution mapping, when not trying to differentiate between ecosystems with minor differences. The outcome usually consists of probability maps that need further confirmation through field evaluation.

3.4 Geospatial Technologies for Mapping the Quality of Ecosystems

Geographic Information System (GIS), Global Positioning System (GPS), and Internet Mapping Technologies are primarily used to identify the distribution of ecosystems, while Remote Sensing can also directly provide a great amount of information about their quality. Once identified the distribution, the first three solutions can be used to store different characteristics of the elected elements (in our case categories of ecosystems) and model them through spatial or geostatistical analysis (e.g., modeling the air pollution in relation with the ecosystem services provided by different categories of land cover (Salata et al. 2017) or geo-computation (techniques, including cellular automata, that permit the representation and prediction of complex phenomena (Bishop et al. 2015) like space and time dynamics of a geo-ecosystems in Mediterranean areas (Nainggolan et al. 2012))).

Remote sensing is widely used for mapping natural resources, analyzing land cover and land use dynamics, and assessing ecological, soil, geological, hydrological, and cryosphere systems (Bishop et al. 2015) all of these uses being related with ecosystem mapping.

Among the biophysical properties of vegetation that can be derived through remote sensing, there are some as green biomass, leaf area index, chlorophyll concentration, leaf moisture, biochemical, canopy structure, height, and basal area (Chen et al. 2003) that can be related with the quality of ecosystems (Table 3.1).

Table 3.1 Review of the most common aerial imagery products used for ecosystem assessments

Imagery	No.	Resolution (m)	First launch	Last launch
WorldView (DigitalGlobe)	4	0.31–0.46	2007	2016
IKONOS (DigitalGlobe)	1	0.84–4	1999	–
SPOT (AIRBUS Defence and Space)	7	1.5	1986	2014
LANDSAT-15 m (NASA)	8	15	1972	2013
Sentinel (AIRBUS Defence and Space)	5	10	2014	–
MODIS (Santa Barbara Remote Sensing)	2	250–1000	1999	2011
ALOS (Jaxa)	1	2.5	2006	–

3.5 Using Geospatial Technologies for Mapping Distinct Ecosystems

3.5.1 Forest Ecosystems

Throughout history, forest ecosystems have changed their status, from being natural landscapes features to becoming ecosystems that require special management plans to keep providing the required ecosystem services (Pukkala 2013). The Food and Agriculture Organization of the United Nation (2012) considers **forest** as "*land spanning with more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds* in situ". Crown cover percentage or the tree canopy cover (TCC) represents a central element in many definitions given to forest ecosystems. The minimum TCC for considering a landscape to be a forest ecosystem varies for the European countries from 5 to 30% as well as the minimum surface that varies from 0.5 to 2 ha (Kleinn 2001). Choosing a forest definition based upon to assess forest ecosystems can firmly influence the estimates of deforestation and forest degradation areas or the recognition of their drivers (Chazdon et al. 2016). A forest ecosystem must be considered as such, based on more than crown cover, area, or width; it should consider the biodiversity within and the amount of ecosystem services it provides (Thompson et al. 2016).

Forest ecosystems are subject for a complex policy making and management process (Fig. 3.1). The modern management of woodlands consists in assessing their potential to provide ecosystem services and the pressures they face dictate how to exploit the ecosystem services in a sustainable way, what conservation methods are the best for a certain ecosystem, and to establish a monitoring plan for it.

The availability of geospatial technologies towards the large public has made forest management easier and more efficient and in the same time more complex because it has opened the door for other scholars, besides foresters to provide their know-how, making forestry an interdisciplinary domain (Cushing et al. 2008). These technologies have taken the woodland analyses and management from a local perspective to a national and even a global perspective, by enhancing the possibility to process huge amounts of data (Hansen et al. 2013). The valuable field observation made by foresters, biologist, or other researchers is now completed with data obtained from remote sensing and GIS techniques.

Geospatial technics have been used to assess the rainforest ecosystems and their resilience mostly towards land use change (Souza et al. 2013; Pinheiro et al. 2016), to emphasize deforestation patterns and trends (Hansen et al. 2010, 2013) due to selective logging and forest fires (Souza et al. 2013; Pinheiro et al. 2016) or to identify driving forces for forest degradation (Morales-Barquero et al. 2015), or just to map the degraded forests by processing several indicators (Pfeifer et al. 2016) or the fragmentation degree (Dong et al. 2014). In the same time, geospatial techniques were also used to map and quantify the amount of ecosystem services provided by forests and elaborating conservation plans for the areas of high natural value (Mura et al. 2015).

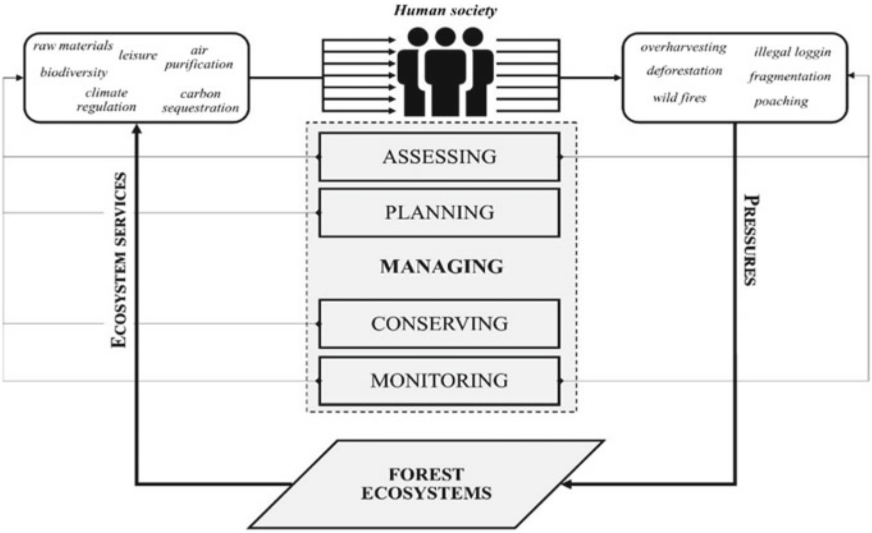

Fig. 3.1 Forest ecosystem management in relation with the society's needs

The contribution of remote sensing procedures and GIS-based solutions in forest ecosystem assessments has encouraged researchers to develop specific tools and indicators. The knowledge about the present challenges, the causes, and their effects over forest quality have increased, enhancing the decision and policy makers to take better measures to maintain and improve the forest ecosystems. Geospatial solutions stood at the roots of several products, commonly used by scholars and different stakeholders in achieving sustainability in regard to forest management. These products cover global, regional, and local scales providing alternatives for their users depending on their objectives.

Shimada et al. (2014) developed a product representing forest and non-forest cover at a global scale using ALOS PALSAR (Advanced Land Observing Satellite—Phased Array Type L-band Synthetic Aperture Radar) data. This product was made available for the wide public thorough JAXA (eorc.jaxa.jp) website. ALOS PALSAR data were used by numerous researchers, focused on regional or local studies such as mapping forest cover (Thapa et al. 2014), mapping forest degradation, and loss (Whittle et al. 2012) or estimating aboveground biomass (Cartus et al. 2012).

Another product that provides tree cover density at global scale is the one generated by using the methods described by Sexton et al. (2013) who developed a 30 m resolution dataset by rescaling MODIS (Moderate-Resolution Imaging Spectroradiometer) vegetation continuous fields (VCF) tree cover layer using LANDSAT images (available on Global Land Cover Facility website glcf.umd.edu/).

Probably the best-known product regrading global forest ecosystems is provided by Hansen et al. (2013) who offer a 30 m resolution datasets recording global forest loss and gain, available on Global Forest Watch online platform (globalforestwatch.org). The product was developed using LANDSAT and MODIS imagery and allows researchers and decision makers to understand the dynamic of forest areas between 2000 and 2012 and to identify the areas that need special attention in terms of conservation and sustainable management.

At European level, the Corine Land Cover dataset classifies forest land cover in broad-leaved forests (code: 311), coniferous forests (code: 312), and mixed forests (code: 313) (Bossard et al. 2000). The limitations related with spatial resolution of the dataset affect less the forest ecosystems than smaller ecosystems, and the errors generally affect the edges.

Through the Copernicus Programme another dataset was elaborated, exclusively for forest ecosystems such as the tree cover density (TCD) from which it derived the forest type (FTY) dataset for the year 2012, having a spatial resolution of 20 m. However, TCD includes land uses that are not considered forests according to the forestry definition such as orchards, parks, and alley trees and group of trees within urban areas (Langanke 2013).

The Joint Research Centre (JRC), European Commission's science and knowledge service has provided forest cover maps for 1990, 2000 and 2006. For 2006, they have also provided forest type datasets. For 1990 and 2000, JRC used the LANDSAT sensors resampled to 25 m resolution and CLC were used as ancillary data and for 2006, they used SPOT-4 sensors instead of the LANDSAT sensor. The methods used to generate the 2000 forest cover map are described by Pekkarinen et al. (2009) where they state that the resulting forest/non-forest map was validated with three independent datasets. The forest cover maps and data are available for download on the European Commission online platform (forest.jrc.ec.europa.eu) along with information and data regarding tree species distribution and projected distribution for the future. JRC also provides data and information about European forests' pattern and fragmentation, forest fires, forest in relation with climate change, forest ecosystem services, or land use change of forest ecosystems.

3.5.1.1 Case Studies

Different datasets providing information about forest ecosystem differ in terms of the same indicator values. For instance, we used several datasets and products to estimate the amount of forest surface for the Romanian Carpathians in accordance with FAO definition (Fig. 3.2). The data were selected to emphasize the forest vegetation cover in 2000 using the JRC and CLC database and the ones proposed by Hansen et al. (2013) and Sexton et al. (2013). The generated maps enhance differences among the four data sources. The JRC and CLC data are more similar as they were resulting using similar base maps and satellite imagery and the same goes for the Sexton and Hansen datasets. The differences in forest vegetation surfaces between the minimum and the maximum value are of 0.75 million ha. As we mentioned before, there is a clear border between what we consider forest and forest vegetation cover. Most of the products generated through remote sensing procedures reveal forest vegetation land cover, which is not the same as the areas considered forest by foresters and

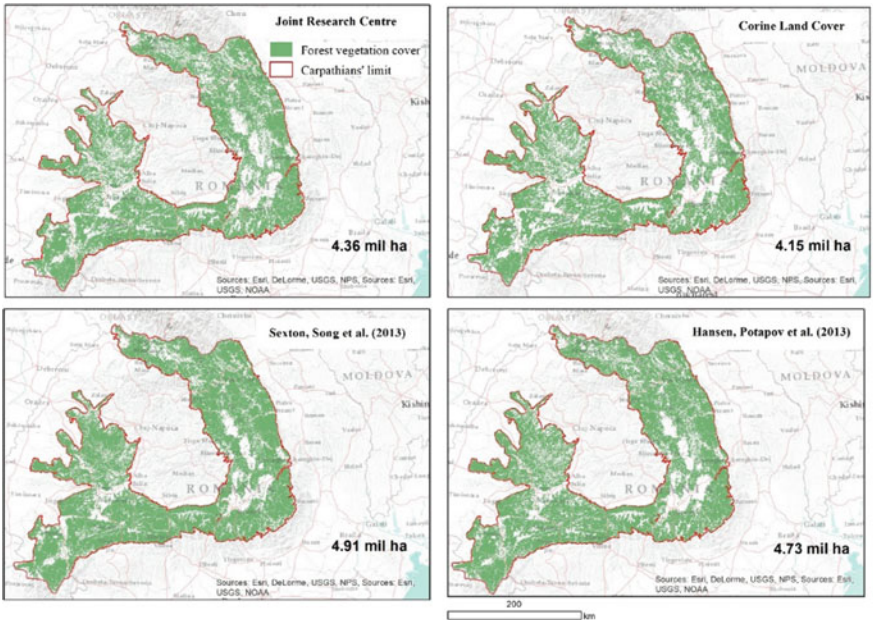

Fig. 3.2 Forest vegetation cover in the Romanian Carpathians extracted from different data sources (2000)

forest managers. This confusion may lead to biased conclusion when referring to deforestation degrees, illegal logging, or forest cover dynamics.

The discrepancy among the surface values provided by the datasets is generated by the resolution of the base maps used to generate these products, whether talking about satellite imagery, orthophoto maps, or high-resolution spatial representation (Table 3.2). However, a preliminary analysis can indicate a pattern regarding the forest vegetation dynamics in the Romanian Carpathians by using all the abovementioned products. By averaging the surface indicated by each product per year, we can draw a preliminary conclusion that forest vegetation cover had a decreasing trend in the last 30 years (Fig. 3.3).

Our aim was to provide a brief review of the available geospatial technologies most commonly used in assessing forest ecosystems and we used the available, scientifically endorsed products to emphasize the dynamics of forest vegetation cover in the Romanian Carpathians. The results have revealed significant differences between different databases, enforcing the need of complementary research method when assessing forest ecosystems. Geospatial technologies should be used along with other specific methods to establish the quality of forest ecosystems. Such examples are provided by several authors that combined field methods and geospatial technologies to assess forest ecosystem in different study areas in the Carpathians (Teodosiu and Bouriaud 2012; Pătru-Stupariu et al. 2015).

Table 3.2 Forest vegetation surfaces from different data sources—forest vegetation in Romanian Carpathians

Sources	Year										
	1990	2000	2005	2006	2007	2008	2009	2010	2012	2015	
DTM	6.38	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	million ha
JRC	*No data*	4.37	*No data*	3.82	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	
Hansen	*No data*	4.73	*No data*	*No data*	*No data*	*No data*	*No data*	4.67	*No data*	*No data*	
Sexton	*No data*	4.91	4.87	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	
CLC	*No data*	4.16	*No data*	2.51	*No data*	*No data*	*No data*	*No data*	3.07	*No data*	
ALSPLS	*No data*	*No data*	*No data*	*No data*	4.60	4.70	4.67	4.88	*no data*	4.75	
ORTO	*No data*	*No data*	*No data*	*No data*	*No data*	3.88	*No data*	*No data*	*No data*	*No data*	
Copernicus	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	*No data*	4.37	*No data*	

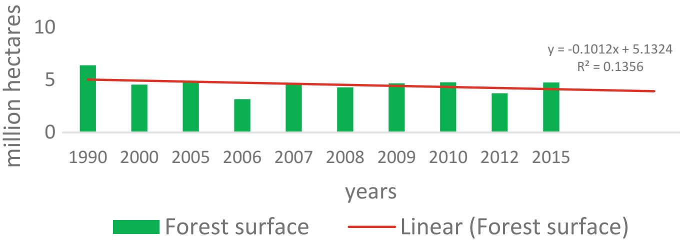

Fig. 3.3 Forest vegetation surface evolution in the Romanian Carpathians—forecast generated through the aggregation of different datasets

We emphasize that using geospatial technologies in forest ecosystem studies has proved to boost the knowledge of these ecosystems. However, the need to crosscheck the accuracy of the results driven by using these technics is crucial for describing certain phenomena occurring in forest ecosystems.

3.5.2 River Ecosystems

River ecosystems have a specific linear topology and their map representation width at certain scales must be exaggerated, in terms of proportionality with reality, to make them visible. To set the limit of an ecosystem, an arbitrary criterion which offers higher contrast is sometimes chosen as the delimitating factor, since the ecosystems do not have clear-cut boundaries.

In some methodologies, the specific criteria used for the ecosystem classification serve to delimitate areas with those ecosystem characteristics (Gao et al. 2015). The set of criteria defining an ecosystem as a classification category is used to find the territories with these characteristics and the proper ecosystem defined as such. Some of these characteristics are inextricably linked to the territory where they appear or are best described through spatial distribution, using maps.

Mapping river ecosystems reveal distinct challenges. Determining the linear pattern and flow direction are among the most important variables. The physical parameters and the composition of the ecosystems are continuously changing along their length. River ecosystems are dynamic since water is in a state of constant movement along the length of the river. Further, water is also changing its properties through interaction with all the other components of the river, such as the stream bed lithology or the vegetation. While along a river there are segments with different properties, resulting in different ecosystems, to establish where one ecosystem ends and another one begins is a more challenging task, since there always is a fading transition between such river ecosystems. Moreover, the water flow keeps transferring some of the energy and matter and thus some characteristics from one river segment to the following. Consequently, the delimitation between the ecosystems of a river must be performed in an arbitrary fashion, considering the variation of a chosen key indicator or through expert opinion.

The Water Framework Directive explicitly emphasizes that the member states shall submit to the Commission a map or maps, in a Geographical Information System (GIS) format, of the geographical location of the types consistent with the degree of differentiation required under systems of classification described in the Directive. The classification of the water bodies in accordance with these criteria can be greatly improved by using geospatial technologies. Some of the indicators can be directly determined or calculated using GIS (e.g., altitude, slope, distance from river source). Satellite images offer opportunities to determine other specific indicators (e.g., mean water depth).

The Water Framework Directive methodology includes not only modalities to classify water bodies but also indicators for evaluating the water ecosystems quality. These indicators quantify the general biological, hydro morphological, physical and chemical, and specific pollutants (synthetic and non-synthetic) properties of the water. Some data cannot be obtained through geospatial technologies and there is the need for field surveys and laboratory analysis. For example, among the quality elements for the river classification of the ecological status, the composition, abundance and age structure of fish fauna is one of the main indicators that cannot be determined but through field sampling. Still, this data can offer more insights if it is collected and treated as spatial data. Further processing is also greatly improved, as it is data presentation through maps.

3.5.2.1 Case Studies

Today, GIS techniques and remote sensing are commonly used in river management. Field data can easily be computed using modern geospatial technologies, emphasizing issues that should be looked upon. We provided an example of how several fundamental characteristics of a river basin can be mapped by using geospatial techniques.

Our case study is represented by the Olt river basin, the major inner river of Romania. We used the digital elevation model (DEM)—20 m resolution to calculate the slope degree and orientation in Olt hydrographic basin (Fig. 3.4). These two characteristics are very useful in river management as a high slope degree means faster water flows, potentially turning into torrential phenomena, leading to floods and material damages. The slope degree and orientation were calculated using ArcGIS 10.3. by using *Slope* and *Aspect* tools from ***Spatial Analyst*** toolbox. Using the data provided by this analysis the decision-making process regarding flood management and river management is streamlined.

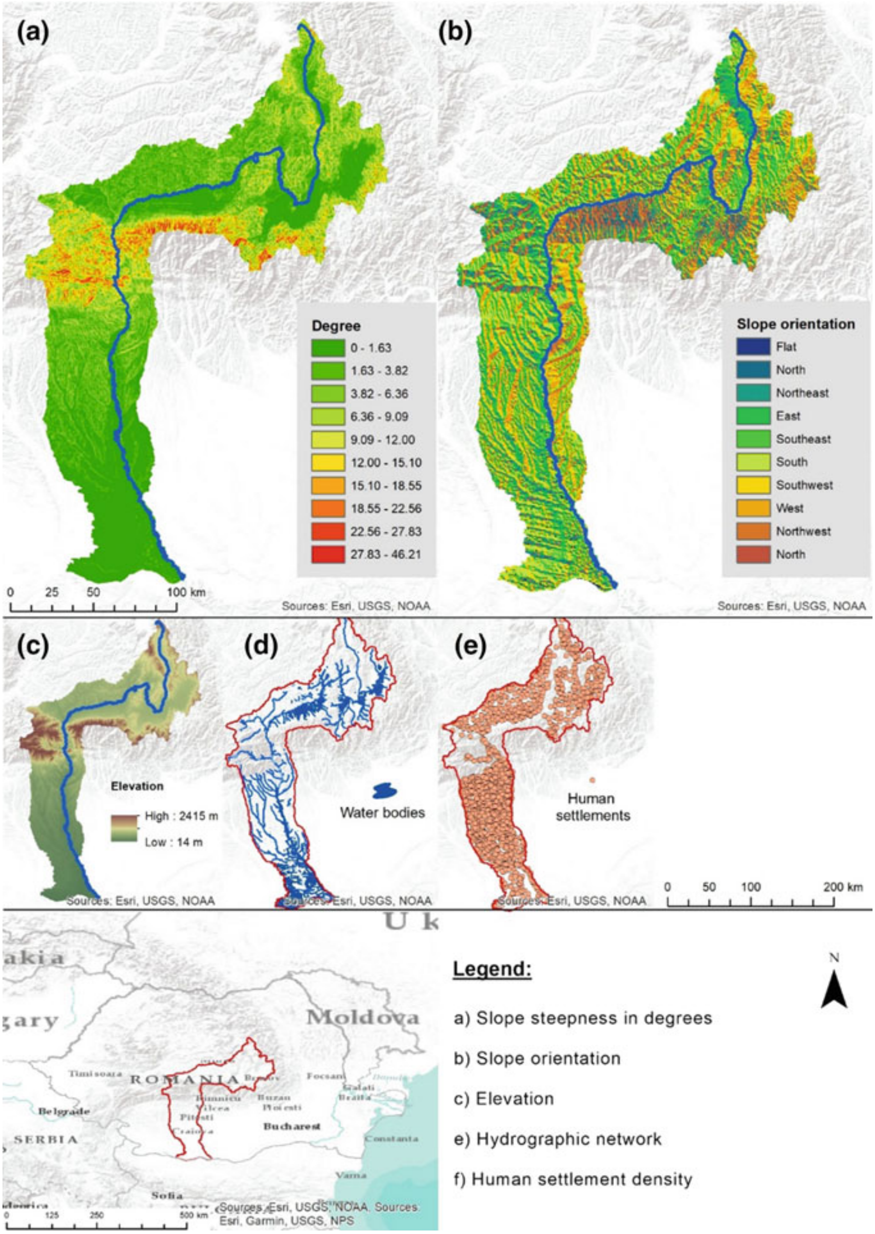

Fig. 3.4 Different characteristics for Olt hydrographic basin represented using geospatial techniques

3.5.3 Lakes Ecosystems

When mapping lake ecosystems, as it is also the case of the river ecosystems, there should be made the distinction between the actual water ecosystem and the riparian ecosystem that is usually found in the proximity. The riparian ecosystem is strongly integrated with the water ecosystem it borders, influencing the functional processes and the structure of the aquatic communities, extending for 50 m or more from the water surface (Angradi et al. 2016).

Mapping and evaluating the spatial variability of the lake ecosystems can be achieved efficiently by using habitat distribution maps at different scales, from 1: 50000 to 1:5000 and satellite imagery. When using satellite imagery to establish the distributions and the extension of the lake ecosystems, filed validation is necessary.

Besides Corinne Land Cover, a suitable database for mapping lake ecosystems is Copernicus Pan-European High-Resolution Permanent Water Bodies, available on the Copernicus official web platform (land.copernicus.eu). It contains five land use categories, at 20 m resolution, Lambert projection, ETRS-8: forest, pastures, water bodies, wetland, and built area. Using this database to delimitate ecosystems needs a pixel-by-pixel validation stage based on satellite imagery in order to eliminate errors that might have been generated when the initial processing was performed (EEA 2016). The CLC dataset cannot record water bodies with surfaces below 0.25 ha, and for more detailed analysis, more accurate datasets are required.

CORINE database is not sensitive whether the lake ecosystem is natural or artificial, such as sewage or industrial water basins. The input data for Copernicus is IRS-P6/Resourcesat-2, SPOT 4 and 5 satellite images, further improved using IRS, SPOT and Landsat 7 ETM+ satellite images. Compared to the CORINE, the Copernicus dataset is much more detailed and the number of identified lakes is much larger (Fig. 3.5).

Evaluating the degradation of aquatic ecosystems through remote sensing and GIS techniques is proving to be a useful approach (Gao et al. 2016; Al-Fahdawi et al.

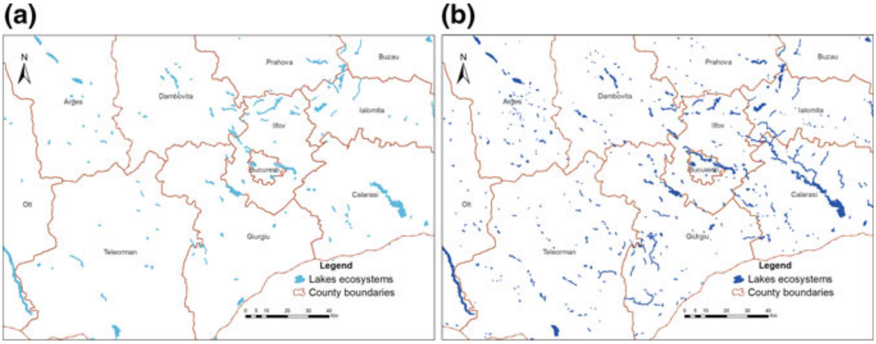

Fig. 3.5 Lake ecosystems in South of Romania: CLC 2012, code 512 (**a**) and Copernicus databases (**b**)

2015). Also, identifying and delimiting aquatic ecosystems, including the lakes, through remote sensing methods such as Multiband Spectral Relationship, Normalized Difference Water Index (NDWI), and Tasseled Cap transformation (Gao et al. 2016) is proving to be successful in many situations. To extract lake position and extension, Landsat-8 OLI imagery offers good results, by processing an initial binary image and further applying a Normalized Difference Water Index (NDWI) (McFeeters 1996), eliminating by supervised classification the adjacent surfaces (Gao et al. 2016).

A series of 30 m resolution satellite images that can also be used for lake ecosystem analysis are accessible by USGS Global Visualization Viewer (Turner 2010). These data provide good territorial coverage and are available in the form of different periods of time datasets. They offer information for areas with limited accessibility and allow for comparative analysis in time. Remote sensing and satellite imagery are cost and time saving, considering the amount of data produced (Al-Fahdawi et al. 2015). Spatial resolution is still a limitation in the case of the aquatic ecosystems (Hestir et al. 2015). The size of the image pixel, compared with the size of the covered habitat is extremely important (Hestir et al. 2015).

3.5.4 Urban Ecosystems

Urban ecosystems can be defined as an integrated ensemble of connected built (sharing built or paved infrastructures) and green infrastructures (Burkhard and Maes 2017). Geospatial technologies have a critical role in the analysis of urban ecosystems quality since they can be used for mapping, spatial analysis and modeling. The diversity of databases, available in the last decade, and the high quality of sensors, and improved image resolution offer the opportunities in urban ecosystem assessment and sustainable urban planning for the future.

As more land is being urbanized and natural landscapes are shrinking, sustainability in urban planning has become a common topic within the scientific community (Gavrilidis et al. 2017). The complexity of "urban ecosystems" entails advanced methods for assessing the relations and process within a city. Geospatial technics have proved to be useful for a wide range of urban studies related to planning, environmental, or social issues. Remote sensing analysis and GIS technics used in urban analysis enhanced the role of geographers in this field of research.

Remote sensing has a critical role to play in the analysis of the interactions that occur between people and urban environments that may help shape our understanding of humans and the principle environment in which they live. Improved sensors, more exacting resolutions, the rapid convergence of earth observation systems, geographical information systems, and spatial statistics have expanded the scale and scope of remote sensing applications across human geography, the social sciences, and in the real world of public policy (Gatrell and Jensen 2008). The availability of geospatial technologies made possible different approaches in assessing urban sprawl and acknowledge when this phenomenon occurs in the world's cities. Bhatta et al. (2010) examined several methods based on remote sensing technics and their suitability for sprawl measurements, concluding that some of the methods borrowed from other research domains are not as efficient in urban sprawl assessments. Even though the topic regarding urban sprawl is highly theorized, the use of geospatial technologies has enhanced the measurements of the phenomenon (Grădinaru et al. 2017; Jaeger and Schwick 2014).

Geospatial technologies have been used to assess, measure, and map different processes and phenomena within the urban settlements and their surrounding such as air pollutants dispersion (Fishman et al. 2008) and sources of pollution (Wang et al. 2013), built-up dynamics (Gavrilidis et al. 2015), occurring environmental conflicts and functional incompatibilities (Iojă et al. 2014b; Niţă et al. 2013), assessing and mapping urban landscape and urban landscape features (Inostroza 2017; Gavrilidis et al. 2016), planning and assessing urban green infrastructures (Gavrilidis et al. 2017; Iojă et al. 2014a), or assessing and mapping of the ecosystem services generated by different urban features (Burkhard and Maes 2017; Cvejić et al. 2015). High-resolution satellite images have been very useful in extracting information about different urban land covers. These images have often been used to extract data about urban green areas or areas covered with vegetation. Mathieu et al. (2007) mapped the private gardens from Dunedin (New Zeeland) using the technique of object-oriented classification on multispectral Ikonos images. The authors were among the first researchers to reach this degree of detail analysis as previous studies focused over the large green urban areas. Since present days, satellite imagery resolution evolved simultaneously with the assessment methods.

Air quality assessment is usually done by using in situ measured data at ground level in monitoring networks, by satellite measurements or modeling, or by a combination of the measurements and modeling approaches. Satellite data due to their large space coverage provide information on the distribution of pollutant concentrations (Fishman et al. 2008), estimation of the pollutant emission (Streets et al. 2013) and for air quality applications (Duncan et al. 2014).

Urban green infrastructures are a modern concept that assesses urban green space in an integrated way, in accordance with the amount and variety of ecosystem services they provide. From emphasizing the diversity of urban green infrastructures (Badiu et al. 2014), through assessing the connectivity within an urban green infrastructure (Niță et al. 2018) and finally to plan increasing and improving an urban green space network based on the human needs (Gavrilidis et al. 2017; Cucu et al. 2011), geospatial technologies have provided an useful tool for researchers focusing on urban environments.

3.5.4.1 Case Studies

Multiple studies that assessed urban dynamics or urbanization processes included land use and land cover analysis. Gavrilidis et al. (2015) emphasized the influence that a raw resource can have over the urbanization process of a city by correlating the land use and land cover changes with the dynamics of the economic activities in the

Table 3.3 Green space and built-up dynamics between 2005 and 2010 in Ploiesti (Romania)—data extracted from aerial images

Year	Green spaces	Percent of administrative area (ha)	Built-up area	Percent of administrative area (ha)	Administrative area
2005	416.6	8.10	2229.71	43.37	5140.66
2010	693.87	11.47	2500.04	41.34	6047.84

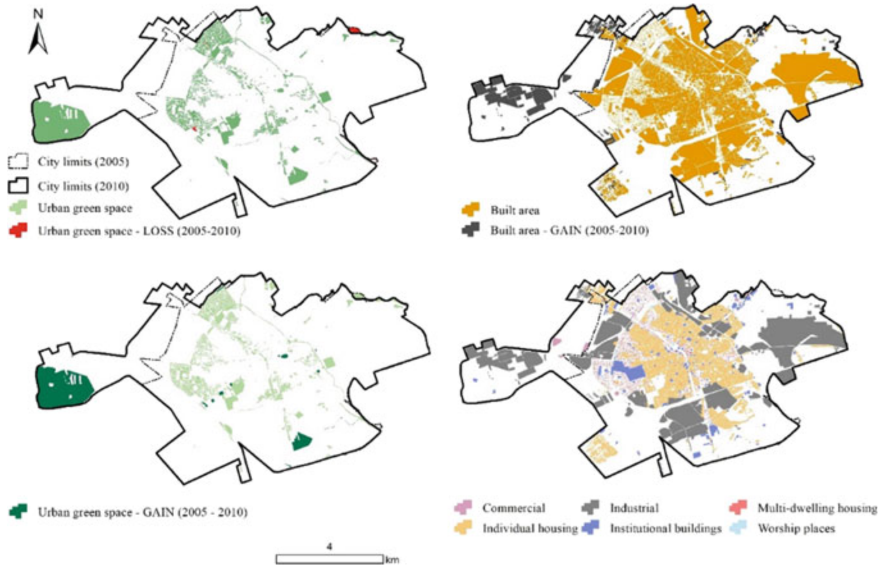

Fig. 3.6 Green areas and built-up areas land cover distribution in Ploiesti (Romania)—extracted from aerial imagery (2005 and 2010)

last 100 years. Several studies have used the land use and land cover dynamics for assessing the sprawling patterns of cities (Sperandelli et al. 2013), as the information used for establishing a certain land use or land cover type were extracted from various base maps such as old topographical maps or aerial images. However, these studies are relevant only to settle landscape change patterns and they cannot be used for detailed analysis. For detailed scale analysis, high-resolution maps or imagery are required and for assessing land use and land cover dynamics at a precise level, same scale base maps are required too (Table 3.3; Fig. 3.6).

As emphasized in the examples above, using geospatial technologies to spot a certain dynamic of the urban land cover patterns generates "three-dimensional" results, providing spatial, quantitative, and qualitative outcomes that further can be developed, offering more depth to the analysis of urban areas and their surroundings. The availability and use of geospatial technics in urban planning have opened the door for participatory planning, thus the stakeholders, local authorities, citizens, and researchers can express themselves towards the processes that occur in an urban landscape.

3.6 Conclusion

Mapping different processes, phenomena or *status quos* helps indicated the spatial location of an issue, making the intervention process easier. Geospatial technics made mapping more accurate and easier, being a tool used not also by geographers, but also by scholars from different domains. As all geospatial technics assumes geographical knowledge, this new technological age in which location tagging and mapping became widely used is the perfect time for skillful geographers to prove their inputs in other research domains.

However, the use of geospatial techniques in ecosystem assessments could become biased without field data and observation to confirm the processed findings. This could be considered an important challenge for geography and geographers in future decades as the need to achieve results very fast in order to respect multiple deadlines. Thus, field observation could become more and more neglected and the dependency on geospatial techniques to provide field observation can alter the reality and further the effects of the decision-making process. We conclude this chapter by underling that geospatial techniques are useful tools in modern analysis that provide useful outcomes, improving the management of ecosystems but the development of these technologies should not substitute the classic assessment techniques, especially field observation which represents the basis of geographic research.

References

Al-Fahdawi AA, Rabee AM, Al-Hirmizy SM (2015) Water quality monitoring of Al-Habbaniyah Lake using remote sensing and in situ measurements. Environ Monit Assess 187(6):367–378

American Association for the Advancement of Science (2017) What are geospatial technologies. https://www.aaas.org/content/what-are-geospatial-technologies

Angradi TR, Launspach JJ, Bolgrien DW, Bellinger BJ, Starry MA, Hoffman JC, Trebitz AS, Sierszen ME, Hollenhorst TP (2016) Mapping ecosystem service indicators in a Great Lakes estuarine Area of Concern. J Great Lakes Res 42(3):717–727

Badar B, Romshoo SA (2008) Assessing the pollution load of Dal lake using geospatial tools. In: Sengupta MDR (ed) Proceedings of Taal 2007: The 12th World Lake Conference, pp 668–679

Badiu D, Chincea I, Ioja C, Niculae M, Nita M, Patroescu M, Vanau G (2014) The diversity of urban green infrastructures in a former industrial city in Romania. Case study–Resita. In: 14th SGEM geo conference on ecology, economics, education and legislation 2 (SGEM2014 conference proceedings, June 19–25, 2014, vol 2, 703–710 pp. ISBN 978-619-7105-18-6/ISSN 1314-2704

Bhatta B, Saraswati S, Bandyopadhyay D (2010) Urban sprawl measurement from remote sensing data. Appl Geogr 30(4):731–740

Bishop MP, Dobreva ID, Houser C (2015) Geospatial science and technology for understanding the complexities of the critical zone. In: Giardino J, Houser C (eds) Principles and dynamics of the critical zone. Elsevier

Bishop MP, James LA, Shroder JF Jr, Walsh SJ (2012) Geospatial technologies and digital geomorphological mapping: concepts, issues and research. Geomorphology 137:5–26

Blasi C, Capotorti G, Alós Ortí MM, Anzellotti I, Attorre F, Azzella MM, Carli E, Copiz R, Garfì V, Manes F, Marando F, Marchetti M, Mollo B, Zavattero L (2017) Ecosystem mapping for the implementation of the European Biodiversity Strategy at the national level: the case of Italy. Environ Sci Policy 78:173–184

Bossard M, Feranec J, Otahel J (2000) CORINE land cover technical guide: Addendum 2000

Burkhard B, Maes J (2017) Mapping ecosystem services. Pensoft Publishers, Sofia

Cartus O, Santoro M, Kellndorfer J (2012) Mapping forest aboveground biomass in the Northeastern United States with ALOS PALSAR dual-polarization L-band. Remote Sens Environ 124:466–478

Chazdon RL, Brancalion PH, Laestadius L, Bennett-Curry A, Buckingham K, Kumar C, Moll-Rocek J, Vieira ICG, Wilson SJ (2016) When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. Ambio 45(5):538–550

Chen JM, Liu J, Leblanc SG, Lacaze R, Roujean JL (2003) Multi-angular optical remote sensing for assessing vegetation structure and carbon absorption. Remote Sens Environ 84(4):516–525

Cucu A, Ciocănea CM, Onose DA (2011) Distribution of urban green spaces—an indicator of topophobia—topophilia of urban residential neighborhoods. Case Study of 5th District of Bucharest, Romania. Forum geografic Studii şi cercetări de geografie şi protecţia mediului 10(2):276–286

Cushing JB, Parker GG, Ford ED, Stallman C, Nadkarni NM (2008) The international canopy network: a pathway for interdisciplinary exchange of scientific information on forest canopies

Cvejić R, Eler K, Pintar M, Železnikar Š, Haase D, Kabisch N, Strohbach M (2015) A typology of urban green spaces, ecosystem services, provisioning services and demands. GREEN SURGE

Dong J, Xiao X, Sheldon S, Biradar C, Zhang G, Duong ND, Hazarika M, Wikantika K, Takeuhci W, Moore B III (2014) A 50-m forest cover map in Southeast Asia from ALOS/PALSAR and its application on forest fragmentation assessment. PLoS ONE 9(1):e85801

Duncan BN, Prados AI, Lamsal LN, Liu Y, Streets DG, Gupta P, Hilsenrath E, Kahn RA, Nielsen JE, Beyersdorf AJ (2014) Satellite data of atmospheric pollution for US air quality applications: examples of applications, summary of data end-user resources, answers to FAQs, and common mistakes to avoid. Atmos Environ 94:647–662

EC (2013) Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Program to 2020 'Living well, within the limits of our planet'. Eur Comm Off J Eur Union. L 354

Edsall RM, Barbour L, Hoffman J (2015) Complementary methods for citizen mapping of ecosystem services: comparing digital and analog representations. In: Robbi Sluter C, Madureira Cruz CB, Leal de Menezes PM (eds) Cartography—maps connecting the world: 27th international cartographic conference 2015—ICC2015. Springer International Publishing, Cham, pp 295–307. https://doi.org/10.1007/978-3-319-17738-0_20

EEA (2016) High resolution layer: permanent water bodies (PWB)

Ershov DV, Isaev AC, Lukina NV, Gavrilyuk EA, Koroleva NV (2016) Assessment of biodiversity in Central Federal District using satellite-based maps of terrestrial ecosystems. Contemp Probl Ecol 9(7):791–804. https://doi.org/10.1134/s1995425516070040

FAO (2012) FRA 2015 terms and definitions. The forest resources assessment (FRA) working paper series. Food and Agriculture Organization of the United Nations, Rome

Feranec J, Hazeu G, Christensen S, Jaffrain G (2007) Corine land cover change detection in Europe (case studies of the Netherlands and Slovakia). Land Use Policy 24(1):234–247

Feranec J, Jaffrain G, Soukup T, Hazeu G (2010) Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data. Appl Geogr 30(1):19–35

Fishman J, Al-Saadi JA, Creilson JK, Bowman KW, Burrows JP, Richter A, Chance KV, Edwards DP, Martin RV, Morris GA (2008) Remote sensing of tropospheric pollution from space. Bull Am Meteor Soc 89(6):805–821

Gao J, Lv S, Zheng Z, Liu J, Zou C, Yang Z, Chen L, Fu B, Su C, Li W (2015) Classification and research methods of ecosystem. In: Li W (ed) Contemporary ecology research in China. Springer, Berlin, Heidelberg, pp 109–131. https://doi.org/10.1007/978-3-662-48376-3_6

Gao H, Wang L, Jing L, Xu J (2016) An effective modified water extraction method for Landsat-8 OLI imagery of mountainous plateau regions. In: IOP conference series: earth and environmental science, vol 1. https://doi.org/10.1088/1755-1315/34/1/012010

Gatrell JD, Jensen RR (2008) Sociospatial applications of remote sensing in urban environments. Geogr Compass 2(3):728–743

Gavrilidis A, Alexandru Grădinaru S, Raluca Iojă IC, Cârstea E, Maria Pătru-Stupariu I (2015) Land use and land cover dynamics in the periurban area of an industrialized East-European city. An overview of the last 100 years. Carpathian J Earth Environ Sci 10:29–38

Gavrilidis AA, Ciocănea CM, Niţă MR, Onose DA, Năstase II (2016) Urban landscape quality index–planning tool for evaluating urban landscapes and improving the quality of life. Procedia Environ Sci 32:155–167

Gavrilidis AA, Niță MR, Onose DA, Badiu DL, Năstase II (2017) Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure. Ecological Indicators

Grădinaru SR, Kienast F, Psomas A (2017) Using multi-seasonal Landsat imagery for rapid identification of abandoned land in areas affected by urban sprawl. Ecological Indicators

Hansen MC, Stehman SV, Potapov PV (2010) Quantification of global gross forest cover loss. Proc Natl Acad Sci 107(19):8650–8655

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova S, Tyukavina A, Thau D, Stehman S, Goetz S, Loveland T (2013) High-resolution global maps of 21st-century forest cover change. Science 342(6160):850–853

Hestir EL, Brando VE, Bresciani M, Giardino C, Matta E, Villa P, Dekker AG (2015) Measuring freshwater aquatic ecosystems: the need for a hyperspectral global mapping satellite mission. Remote Sens Environ 167:181–195

Inostroza L (2017) Informal urban development in Latin American urban peripheries. Spatial assessment in Bogotá, Lima and Santiago de Chile. Landscape Urban Plann 165:267–279

Iojă I, Onose D, Nita M, Vanau G, Patroescu M, Gavrilidis A, Saghin I, Zarea R (2011) The conversion of agricultural lands into built surfaces in Romania. Recent Res Urban Sustain Green Dev 6:115–120

Iojă CI, Grădinaru SR, Onose DA, Vânău GO, Tudor AC (2014a) The potential of school green areas to improve urban green connectivity and multifunctionality. Urban Forest Urban Greening 13(4):704–713

Iojă CI, Niţă MR, Vânău GO, Onose DA, Gavrilidis AA (2014b) Using multi-criteria analysis for the identification of spatial land-use conflicts in the Bucharest Metropolitan Area. Ecol Ind 42:112–121

Jaeger JAG, Schwick C (2014) Improving the measurement of urban sprawl: weighted urban proliferation (WUP) and its application to Switzerland. Ecol Ind 38:294–308

Kleinn C (2001) A cautionary note on the minimum crown cover criterion in forest definitions. Can J For Res 31(2):350–356

Langanke T (2013) GIO land (GMES/Copernicus initial operations land) high resolution layers (HRLs)—summary of product specifications. European Environment Agency

Mathieu R, Freeman C, Aryal J (2007) Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. Landscape Urban Plann 81(3):179–192

McFeeters SK (1996) The use of the normalized difference water index (NDWI) in the delineation of open water features. Int J Remote Sens 17(7):1432–1452

Morales-Barquero L, Borrego A, Skutsch M, Kleinn C, Healey JR (2015) Identification and quantification of drivers of forest degradation in tropical dry forests: a case study in Western Mexico. Land Use Policy 49:296–309

Mura M, McRoberts RE, Chirici G, Marchetti M (2015) Estimating and mapping forest structural diversity using airborne laser scanning data. Remote Sens Environ 170:133–142

Nainggolan D, Termansen MFL, Hubacek K, Reed MS, de Vente J, Boix-Fayos C (2012) What does the future hold for semi-arid Mediterranean agro-ecosystems? Exploring cellular automata and agent-based trajectories of future land-use change. Appl Geogr 35 (1–2):474–490

Niţă MR, Iojă IC, Rozylowicz L, Onose DA, Tudor AC (2013) Land use consequences of the evolution of cemeteries in the Bucharest Metropolitan Area. J Environ Plann Manag (ahead-of-print):1–17

Niță MR, Năstase II, Badiu DL, Onose DA, Gavrilidis AA (2018) Evaluating urban forests connectivity in relation to urban functions in Romanian cities. Carpathian J Earth Environ Sci 13:291–299. https://doi.org/10.26471/cjees/2018/013/025

Pagella TF, Sinclair FL (2014) Development and use of a typology of mapping tools to assess their fitness for supporting management of ecosystem service provision. Landscape Ecol 29(3):383–399. https://doi.org/10.1007/s10980-013-9983-9

Pătru-Stupariu I, Stupariu M-S, Tudor CA, Grădinaru SR, Gavrilidis A, Kienast F, Hersperger AM (2015) Landscape fragmentation in Romania's Southern Carpathians: testing a European assessment with local data. Landscape Urban Plann 143:1–8

Pekkarinen A, Reithmaier L, Strobl P (2009) Pan-European forest/non-forest mapping with Landsat ETM+ and CORINE Land Cover 2000 data. ISPRS J Photogrammetry Remote Sens 64(2):171–183

Pfeifer M, Kor L, Nilus R, Turner E, Cusack J, Lysenko I, Khoo M, Chey V, Chung A, Ewers R (2016) Mapping the structure of Borneo's tropical forests across a degradation gradient. Remote Sens Environ 176:84–97

Pinheiro T, Escada M, Valeriano D, Hostert P, Gollnow F, Müller H (2016) Forest degradation associated with logging frontier expansion in the Amazon: the BR-163 region in Southwestern Pará, Brazil. Earth Interact 20(17):1–26

Pukkala T (2013) Multi-objective forest planning, vol 6. Springer Science & Business Media

Remmel TK, Perera AH (2017) Mapping forest landscapes: overview and a primer. In: Remmel TK, Perera AH (eds) Mapping forest landscape patterns. Springer, New York, pp 1–62. https://doi.org/10.1007/978-1-4939-7331-6_1

Roussel F, Schulp CJE, Verburg PH, van Teeffelen AJA (2017) Testing the applicability of ecosystem services mapping methods for peri-urban contexts: a case study for Paris. Ecol Ind 83:504–514

Salata S, Ronchi S, Arcidiacono A (2017) Mapping air filtering in urban areas. A land use regression model for ecosystem services assessment in planning. Ecosystem Services

Sexton JO, Song X-P, Feng M, Noojipady P, Anand A, Huang C, Kim D-H, Collins KM, Channan S, DiMiceli C (2013) Global, 30-m resolution continuous fields of tree cover: Landsat-based rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. Int J Digital Earth 6(5):427–448

Shimada M, Itoh T, Motooka T, Watanabe M, Shiraishi T, Thapa R, Lucas R (2014) New global forest/non-forest maps from ALOS PALSAR data (2007–2010). Remote Sens Environ 155:13–31

Souza CM Jr, Siqueira JV, Sales MH, Fonseca AV, Ribeiro JG, Numata I, Cochrane MA, Barber CP, Roberts DA, Barlow J (2013) Ten-year Landsat classification of deforestation and forest degradation in the Brazilian Amazon. Remote Sens 5(11):5493–5513

Sperandelli DI, Dupas FA, Dias Pons NA (2013) Dynamics of urban sprawl, vacant land, and green spaces on the metropolitan fringe of São Paulo, Brazil. J Urban Plann Dev 139(4):274–279

Streets DG, Canty T, Carmichael GR, de Foy B, Dickerson RR, Duncan BN, Edwards DP, Haynes JA, Henze DK, Houyoux MR (2013) Emissions estimation from satellite retrievals: a review of current capability. Atmos Environ 77:1011–1042

Teodosiu M, Bouriaud OB (2012) Deadwood specific density and its influential factors: a case study from a pure Norway spruce old-growth forest in the Eastern Carpathians. For Ecol Manage 283:77–85

Thapa RB, Itoh T, Shimada M, Watanabe M, Takeshi M, Shiraishi T (2014) Evaluation of ALOS PALSAR sensitivity for characterizing natural forest cover in wider tropical areas. Remote Sens Environ 155:32–41

Thompson JR, Lambert KF, Foster DR, Broadbent EN, Blumstein M, Almeyda Zambrano AM, Fan Y (2016) The consequences of four land-use scenarios for forest ecosystems and the services they provide. Ecosphere 7(10)

Turner D (2010) Remote sensing of chlorophyll a concentrations to support the Deschutes Basin lake and reservoir TMDLs. Technical Report to EPA

UN (1992) Convention on biological diversity (Ch_XXVII_8, Chapter XXVII), vol 2. Environment, United Nations. https://treaties.un.org/doc/Treaties/1992/06/19920605%2008-44%20PM/Ch_XXVII_08p.pdf. Accessed 20 Nov 2017

United States Geological Survey (2017) What is remote sensing and what is it used for? https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used-0?qt-news_science_products=7#qt-news_science_products

Wang J, Hu Z, Chen Y, Chen Z, Xu S (2013) Contamination characteristics and possible sources of PM10 and PM2. 5 in different functional areas of Shanghai. China Atmos Environ 68:221–229

Whittle M, Quegan S, Uryu Y, Stüewe M, Yulianto K (2012) Detection of tropical deforestation using ALOS-PALSAR: a Sumatran case study. Remote Sens Environ 124:83–98