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From the Russian/Soviet landscape concept to the geosystem approach to integrative environmental studies in an international context

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Acknowledgements I thank José Muñoz-Rojas and two anonymous reviewers for their constructive comments.

Abstract

Context The geosystem paradigm emerged in the USSR in the 1960s and offered improved operational tools for landscape assessment. However, its contributions to integrative environmental studies have yet to be widely recognized at an international level.

Objectives The first objective of this paper is to describe the conceptual origins of the geosystem approach to resource management and its evolution in an international context. The second objective is to discuss its potential for enriching other methodologies used in integrative environmental studies.

Methods The paper is based on a review of the European and Latin American literature on the geosystem concept and its use in integrative territorial and environmental studies. It traces the historic, epistemic and sociocultural trajectories of this paradigm. It also identifies some of the opportunities it offers and some of its weaknesses, and the problems that the geosystem paradigm can help to identify and resolve in contemporary integrative environmental studies.

Results The trajectory of the geosystem paradigm in Russia and the USSR and its adaptation in several countries have demonstrated its usefulness for integrative territorial and environmental studies in different contexts and its complementarity with other scientific frameworks, such as Ecosystem Services and Landscape Ecology.

Conclusions Geosystem-based approaches can contribute to international Landscape science and integrative socio-ecological and territorial frameworks with the theoretical and methodological findings made over its more than fifty-year history. The lessons learned from the evolution of the geosystem scientific paradigm will be useful for further studies and actions on environmental sustainability.

Keywords Epistemology, Geosystem paradigm, Integrative territorial approaches, International perspective, Landscape

Introduction

The concept of geosystem is a central issue in various academic papers and books most of which were either not published in English (e.g. Sochava 1963; Bertrand 1968; Rougerie and Béroutchachvili 1991; Bertrand and Bertrand 2002; Frolova 2007) or were only translated into English several decades after they were originally published (e.g. Wiens et al. 2006). However, despite widespread use of the geosystem's scientific paradigm in various scientific schools of geography and Landscape science, its contributions to integrative environmental studies are not widely recognized internationally.

Recent research in the English-speaking world (Shaw and Oldfield 2007; Angelstam et al. 2013; Bastian et al. 2015; Oldfield et al. 2015; Oldfield and Shaw 2016) reflects a growing interest in the specific Russian/Soviet tradition of integrative environmental studies. Both landscape and geosystem concepts were closely linked to this tradition in Russia. International English-language papers on geosystem usually present it as a scientific framework that developed within Russian/Soviet and Eastern European physical

geography (Angelstam et al 2013; Bastian et al. 2015). However, this paradigm was not only characteristic of Eastern Europe, but was also adapted to integrative environmental and landscape-related studies by various scientific schools in the Western Europe (in particular in France and Spain due to the influence of French geographer Georges Bertrand and his school) and in Latin America (inspired by the Cuban and French schools of landscape studies), making a broader international comparative analysis of the geosystem paradigm necessary. Western scholars (Shaw and Oldfield 2007; Oldfield and Shaw 2015; Oldfield et al. 2015; Oldfield and Shaw 2016) have examined the origins of Russian Landscape science and compared its development with Western conceptions of landscape during the first half of the 20th century, although their research does not explore its relationship with the geosystem paradigm, which emerged in the 1960s. Bastian et al. (2015) focused their research on the significance of the geosystem paradigm for the assessment of Ecosystem Services, but paid little attention to the historic, epistemic and sociocultural trajectories of the Soviet geosystem paradigm.

The first objective of the paper is to analyse the historic, epistemic and sociocultural trajectories of the integrative scientific framework of geosystems for natural (landscape and territorial) resource management. The historical and sociocultural dimensions of this paper focus on the evolution of Landscape science and the geosystem paradigm in different sociocultural contexts, while its ‘epistemic’ focus is linked to its scientific origins, including Russia’s intellectual traditions of environmental studies, in particular Russian Landscape science, and the subsequent development of the geosystem paradigm in different regional scientific contexts. This paper also compares the contributions made by geographers to the study of geosystem at an international level (Eastern and Southern Europe, Latin America). The second objective of the paper is to critically examine the advantages and weaknesses of this approach and its potentialities for integrative environmental resources and landscape studies. It also looks at the lessons that can be learned.

Methodology

The paper is based on a review of the European (particularly Russian, French and Spanish) and Latin American (particularly Cuban and Brazilian) literature on the geosystem paradigm and its use in landscape-related and integrative environmental resources studies. This paper uses the term ‘paradigm’ in the sense defined by Kuhn (1970), namely as an overarching set of ideas that structures the intellectual work within a scholarly field, in this case that of landscape and environmental resources studies.

The vision of the role of the geosystem paradigm within integrative landscape studies is traditionally very positivist. In spite of all its contributions to geography, this scientific model, like many others, has its limits and has been criticized for quite a few decades by geographical scientists. Thus, according to Acot (1999), scientists that create models and concepts are not free of ideological influences, prejudices and ideas disseminated in non-scientific discourses and worldviews. In addition, the appearance of one or other model is often linked to a social project implemented in a particular place and time. The study of the epistemic trajectories of scientific concepts can therefore help us to understand better both their

limitations and the contributions they can make. It is therefore important to bear in mind the broad set of historical, cultural, political and social conditions in which the geosystem paradigm appeared and evolved.

This paper reviews the literature in Russian, French, Spanish, English and Portuguese on theoretical aspects of the geosystem paradigm in order to trace its historic, epistemic and sociocultural trajectories. Its opportunities and weaknesses are also identified, along with the challenges that the geosystem paradigm can help to identify and resolve in contemporary integrative studies of landscape and environmental sustainability.

The emergence of Landscape science in Russia and USSR

Russia has a long tradition in holistic systems for studying environmental resources and the landscape, as part of an attempt to understand the interrelations between the different biophysical elements of landscape and human activity. The first integrative studies within the framework of Landscape science appeared in Russia at the beginning of the 20th century (Berg 1913; Ramenski 1938), although the Russian soil scientist V.V. Dokuchaev established the principle of the integrative analysis of a territory some time earlier (Dokuchaev 1899, 1948). The holistic environmental approach emerged as a response to the challenges for which Dokuchaev was seeking a solution. These included the devastating effects of the droughts of 1877-1878 in terms of forest regression and soil exhaustion, affecting 29 provinces of European Russia (Dokuchaev 1948; Valebny 1998). The serious consequences of the drought caused him to reflect on the best ways to prevent the damage to harvests caused by natural catastrophes. This new approach sought to clarify the interactions between vegetation, relief, geology, climate and human activity, driving Russian geographical sciences towards the synthetic analysis of the geographic environment (Dronin 1999). On the basis of the phenomena observed in the steppes, Dokuchaev proposed a revolutionary theory that considered the soil as an independent 'body' which develops in the process of interaction between the abiotic and biotic components of a spatial unit that is also influenced by human activity (Dokuchaev 1948; see also Oldfield and Shaw 2015). He also proposed a historic approach to the study of soils and of natural 'zones' in general (equivalent of 'biomes'). For Dokuchaev, soil is both a natural and a historic element, with each 'natural' zone representing the genesis of each soil type. This novel framework was used for landscape and integrative resources studies in the 20th century not only by Dokuchaev's disciples (G.N. Glinka, A.N. Krasnov, G.F. Morozov, G.I. Tanfiliev, V.I. Vernadsky, G.N. Vysotski), but also in various physical geography-research studies conducted in Russia (Dronin 1999; Frolova 2000; Shaw and Oldfield 2007; Oldfield and Shaw 2015).

It is paradoxical that even though Dokuchaev did not use the term *Landschaft* to materialize this approach, he is generally considered as one of the founders of Russian Landscape science. Around 1910, in an attempt to promote geography as an independent science, another Russian geographer, L.S. Berg developed ideas similar to those of Dokuchaev, presenting landscape as an interaction between biophysical and anthropic characteristics of the environment (Fig. 1). Berg's ideas were also based on works by the German geographer Alfred Hettner and his vision of geography as a chorological or place-based science. He viewed *Landschaft* as the integrative subject of Geography, which endowed the discipline with a specific

nature distinct from other disciplines, and which was the purpose or objective of its studies (Berg 1915, 1947; see also Shaw and Oldfield 2007; Oldfield and Shaw 2015). From the second decade of the 20th century, landscape was gradually established in Russia as the basic objective in studies of Physical Geography, and Landscape science (*Landshaftovedenie*) was defined as a sub-field of Geography (Frolova 2006). The geosystem concept became a fundamental part of Landscape science in the 1960s.

Fig. 1 Relation between the integrative environmental approach of V.V. Dokuchaev, focusing on soils and natural-historic zones (a), and the landscape concept of L.S. Berg of the 1930s (b), in which he included interaction of people with natural elements of landscape

At the turn of the 20th century, Russian integrative studies of environmental resources and landscapes were still permeable to all things anchored in the culture and history of the relationship between society and nature. This was true of Dokuchaev himself, who described the “genetic interaction, which has always existed between nature and its imaginary ‘master’, man, and all his material and spiritual life” (Dokuchaev 1899: 19), something which is manifested in ‘natural-historic zones’.

Other Russian natural scientists at that time were also engaged in research into human influence on the environment. The climatologist Alexandre Voyeikov (1910) published a series of articles in which he analyzed the different aspects of the anthropization of nature. Likewise, Andrei Krasnov, a noted geographer and botanist, studied the effects of Russian colonization on the transformation of vegetation and soils in the subtropical Caucasus in research published in 1895 (Krasnov 1956), in which he suggested that colonization posed many problems which would nowadays be termed “ecological”. He showed that instead of implementing their own agricultural methods and experiences imported from the plains of Central Russia, the colonists should have noticed that traditional agriculture adapted well to local geographical conditions and analyzed the reasons why. Influenced to some extent by the ideas of environmental determinism popular at that time he blamed the initial failures of the colonization of the subtropical Caucasus on a lack of research into the ‘ancestral relationship’ between the local peoples and their environment (Krasnov 1915; see also Frolova 2006). These approaches were similar to the line of thought developed in the second half of the 19th century by Italian geologist Stoppani (1973) on the ‘anthropozoic era’ (Steffen et al. 2011) and by George Perkins Marsh (1864, 1874), although Russian geographers of this period focused their holistic studies on interlinkages between the different biophysical elements of landscapes and the analysis of their modification under human influence, in particular Russian colonization. Finally, in 1920-1930s Vladimir Vernadsky (1924, 1926) in his works (1924, 1926) stated that human activity played such an important role in the processes of energy and biogeochemical exchange that it should be considered alongside and on a level with geological and geochemical forces (Vernadsky 1997; see also Steffen et al. 2011). The creator of biogeochemistry and “long neglected father of the science of biosphere (later called global ecology)” (Steffen et al. 2011:844) Vernadsky developed the concept of noosphere originally proposed by Edouard Le Roy (1928) and Pierre Teilhard de Chardin (1966). Vernadsky defines noosphere as the sphere of knowledge, of reason, of the transformation of the

environment by human civilization, which exists on the same level as the biosphere and the lithosphere (Vernadsky 1997).

Berg's conceptualization of landscape also linked natural and cultural elements of landscape: he introduced the concept of cultural landscape to Russian geographers in 1915 and in his first publications examined the ways in which patterns of human settlements, activity, customs and ways of life interact with the environment in different geographical contexts (Fig. 1 (b)) (Frolova 2000; Shaw and Oldfield 2007). Nonetheless, as the 20th century advanced the role of human activity was pushed progressively into the background within integrative Russian/Soviet studies of landscape due to the ideological changes that took place after the Russian revolution in 1917 and the appropriation of Landscape science and the concept of *Landschaft* by physical geographers in the Soviet Union. The term 'cultural landscape', which had been widely used in Russian landscape geography between the 1920s and the 1950s disappeared from Soviet geographers' vocabulary for the following two decades.

The socialist revolution of 1917 brought about significant changes in the development of Russian and Soviet geography, due in part to the enormous shifts that took place at an economic and an ideological level. The implementation of a centrally planned economy, the collectivization of agriculture and the disappearance of the private sector created demands for a science that was oriented towards national goals (Oldfield and Shaw 2015). The applied nature of Russian research on the environment and landscape was strengthened during the Soviet period, in which all the resources of Soviet science were "called on to aid in the great campaign of industrialization and militarization" (Shaw and Oldfield 2007: 118). Soviet landscape geographers also progressively rejected social analyses and denounced the classical, descriptive approach to geography, which was especially preminent in the regional tradition within French geography. It was within this new ideological and economic context that the study of nature came to the fore in Landscape science, placing new demands on this discipline to provide analytical tools with which to create the conditions to ensure the self-sufficiency of the USSR in terms of resources. The need to present Russia's geographic space at different scales spurred the development of ideas as to how to fit the landscape units at different scales into maps for spatial planning and governmental decisions.

At the same time from the 1930s, a materialist conception of science came to the fore, according to which the basis of knowledge lies in matter -the objective reality perceived by our senses. This doctrine, which regards our senses as effective means of discovering the objectivity of the material world, had to be accepted by Soviet geographers as an absolute truth. It is important to make clear however that this doctrinal shift, which some consider a "result" of communism, coincided in many ways with a general trend in the evolution of geography and landscape research in the 1960s and 70s, when a deductive, rationalistic and quantitative approach had dominated (Antrop 2005), although the 'objectivization' of geography in the USSR took place earlier and was not questioned until the 1980s (Frolova 2006).

The outcome was that landscape studies increasingly put the emphasis on physical geography, such that Landscape science, once presented as the core of geography, was no longer able to unite geographers from the different specialist fields and came to be viewed as a discipline within physical geography, and human aspects were deleted from descriptions of the landscape. The neglect of the human

dimensions of landscape in favor of an applied, essentially technocratic approach has been considered one of the most significant gaps in Russian/Soviet Landscape science (Dronin 1999; Shaw and Oldfield 2007).

In this context, a well-known Soviet landscape geographer from Moscow State University, N. A. Solntsev (1949), carried out research into the morphology of landscape. He and his pupils focused their studies on mapping natural landscapes at different scales. Although this approach was linked to the earlier works of Russian geographers it became dominating due to its applied character and its consideration as a response to the demands placed on Soviet geography for a pragmatic representation of landscape that could be applied in spatial planning (see Dronin 1999). Solntsev defined landscape as a “genetically uniform territory, with regular and typical repetition of some interrelated combinations of geological structures, landforms, surface and groundwater, microclimates, soil types, phytocoenoses and zoocoenoses” (Fig. 2 (a)) (Solntsev 1948; see also Bastian et al. 2015: 1147). Each landscape unit is made up of different morphological parts: *facies* (elementary natural territorial complex), *podurochishche* (spatial combination of *facies*), *urochishche* (series of genetically and dynamically linked *facies* and *podurochishche*), *mestnost'* (a part of a landscape with a certain combination of main *urochishchya*) (Solntsev 1948; Bastian et al. 2015; Gómez-Zotano et al. 2018). At the same time, landscape is just one part of the higher scale taxonomic units (regional or planetary) in which landscape is individualized by differentiation criteria.

Although from the 1940s to the 1960s Landscape science in the Soviet Union was dominated by Solntsev's morphology of the natural landscape, which viewed landscape as a static, discontinuous concept, some Soviet scientists began to highlight a more dynamic, more continuous dimension. For example, in the early 20th century the geochemist V.I. Vernadsky proposed the idea of the continuity of environmental processes and stressed the importance of the interactions between living phenomena (biosphere) and abiotic matter (atmosphere, hydrosphere, lithosphere) that take place through flows of energy and matter (Vernadsky 1926). The geobotanist B.B. Polynov (1925) adapted Vernadsky's ideas about the interaction of the different elements in the environment to the landscape scale, introducing the idea of a 'geochemical landscape', which he defined as a natural, territorial complex whose components are related both genetically and by the migration of chemical elements. As a result, landscape is not merely composed of visually established static elements and instead its components are joined by the processes at work, which express the dynamic nature of the environment.

Fig. 2 Relation between the landscape concept of N.A. Solntsev (a) and the geosystem approach (b). V. Sochava incorporates time and vertical spatial dimension to the static and deterministic horizontal model of natural landscape as interconnected elements, typically repeated in space. Although in his first researches he does not include technical and socio-cultural subsystems, in his later works and in approaches developed in 1980s-2010s they took relevance in the geosystem's model

This approach met with some resistance within the field of landscape studies and landscape was generally presented in the works of Soviet landscape geographers as an objective, organized and deterministic spatial construction with static boundaries that were easily detectable through field studies (Pedroli 1983; Frolova 2007; Shaw and Oldfield 2007). Although this approach had been widely used for

natural resource exploration and for planned economic activities and planning within the former Soviet Union and Russia (Bastian et al. 2015), the Soviet scientific community manifested several methodological problems relating to its applicability and its practical use in landscape management (Khoroshev et al. 2006).

As A. Reteyum (1977) pointed out, it is difficult to establish divisions between these territorial units as the frontiers between them are blurred and there are no common criteria to highlight the active factors responsible for their genesis, except perhaps for the zonal and azonal factors.

In fact, the concept of landscape was addressed by Soviet geographers in a very specific and contingent context, namely the relatively uninhabited plains in the middle latitudes of European Russia, but Soviet geographers assumed *a priori* that the studies of all types of landscapes could be based on the same principles. The result was that the territorial model they created was very difficult to apply in studies of other contexts such as mountains (Frolova 2006) or highly urbanized regions. A further problem was that the model had been conceived for natural landscapes and proved very difficult to apply in environments that had been severely altered by human activity.

Another difficulty was that relief and geology were considered of crucial importance for landscape genesis because landscape classifications were originally linked to geomorphological studies, in particular of quaternary deposits. In addition, the specific character of the Central Russian landscapes analyzed as a basis for this classification seemed to justify a deterministic vision of a ‘natural territorial complex’ as a uniform pattern which lies within a single form of relief, with a uniform microclimate and particular vegetation association (Frolova 2007; Gómez-Zotano et al. 2018). Nowadays this focus is widely applied in Russia for landscape mapping, land evaluation and management, spatial planning and sustainable use of natural resources (Angelstam et al. 2013) and is often justified by the low levels of human intervention in large parts of Russia (Bastian et al. 2015). However numerous other studies have revealed that landscape genesis could be the product of several different factors acting simultaneously, given that its biotic and abiotic elements are formed as a result of very different processes and under very different conditions. In this way, external elements such as water, glaciers, air masses, living organisms and human activity may be just as important for the landscape as relief, and certain landscape elements may evolve without any changes taking place in the lithological base (Reteyum 1977).

The methodological problems encountered by Soviet geographers who were studying mountain landscapes in the 1950s and 1960s are a significant example of these difficulties (Frolova 2006). Shchukin and Shchukina (1967: 10) emphasized: “Although Soviet geographers have advanced in the regionalization of plains, we are still at the beginning of resolving problems regarding the regional division of mountain areas”. Even though many physical geographers considered relief and geology as the most important mountain landscape differentiation drivers, some empirical studies demonstrated that certain ‘external factors’ were also very important in shaping the character of the landscape, emphasizing that some landscape elements (such as vegetation) were independent of relief, but were extremely dependent on factors such as the insolation regime, latitude, slope exposure, valley width and season (Reteyum 1977).

This conception of landscape was considered contradictory to the canons of the pragmatic, applied studies required by Soviet geographers, several of whom rejected it (Gerasimov 1966). However, the

demand for integrated analyses of the environment and the landscape that were less descriptive and more applied increased, so leading to a rethinking of research methods.

Paradigm shift: the geosystem theory

The renewal of Soviet landscape science in the 1960s is often attributed to the introduction of geosystem theory into landscape interpretation by Viktor Sochava (Sochava 1963). A renowned geographer and botanist, Sochava was the founder of the Siberian geographical school. His interdisciplinary scientific background and his participation in numerous multidisciplinary scientific expeditions all over Russia in the 1920s and 30s led him to focus his research on integrated analysis of the environment.

In the wake of Sochava's research, new methods, tools and techniques for studying landscape began to appear during the second half of the 20th century. These included mathematical modelling, system and ecological approaches and landscape geochemistry (derived from Vernadsky's works (1924, 1998)). These methods opened new perspectives for a holistic approach to the study of landscape and environmental resources.

Geosystem theory was an original Russian contribution to the integrative, geo-ecological study of environmental and territorial resources. It was based on General System Theory (von Bertalanffy 1968) and on certain aspects of geochemistry and geophysics¹. It has developed in parallel with an integrated ecological approach to the landscape proposed by Carl Troll (Troll 1939, 1966), although the geosystem approach had its own particularities compared to Landscape ecology.

The paradigm of geosystem, a system of spatially localized natural elements, was proposed in the 1960s as a result of a search for solutions to the methodological problems encountered in Russian and later Soviet Landscape science (Sochava 1963, 1978). Sochava's approach was closely connected to earlier work by Dokuchaev and the concept of landscape proposed by Berg, and focused on integrative analysis of the environment, based on spatial studies of the interactions between vegetation, relief, geology, climate and human influence (Fig. 2 (b)).

Sochava defined geosystems as "terrestrial spaces of varying dimensions (ranging from the geographical environment as a whole to an elementary physical-geographical *geofacies*), where the individual components of nature are in a system connection with one another and as a definite entirety, interacting with the cosmic sphere and with human society" (Sochava 1963, 1978). Geosystems are "open, hierarchically organized dynamic systems, and each level of their hierarchy represents a dynamic integrity with an intrinsic geographical organization which includes their differentiation, integration, development and the functioning sustaining them" (Semenov and Snytko 2013: 197-198). The geosystem is characterized by:

¹ The term "geosystem" in Russian was suggested by V.B. Sochava in 1963. It appeared in English in 1967 (Stoddart 1967), in French in 1968 (Bertrand 1968) and in German in 1967 (Neff 1967).

- its morphology, i.e. its vertical (geohorizon²) and horizontal (geofacies) spatial structures
- its dynamics, which cover the whole set of transformations linked to solar or gravitational energy, the cycles of water, the bio-cycles, the movements of air masses and the geomorphogenetic processes
- specific changes in its functioning, in other words, an analysis of the changes in state that affect the geosystem within a particular time sequence (Beroutchachvili and Bertrand 1978; Beruchashvili 1983, 1986).

The geosystem paradigm enriched the methodologies applied in the study of integrative environmental resources and landscape in the Soviet Union. This paradigm enabled time and dynamics to be integrated into landscape research and science, and offered improved operational tools for landscape assessment for the study of landscape scale, landscape classification and landscape genesis (Bastian et al. 2015).

Although both the geosystem approach and the ecosystem approach are applications of general systems theory and of the systematic modeling of the environment, there are two essential differences between them. The first difference is that the ecosystem approach is a biocentric one, in which the non-living elements in the medium are subordinated to the living organisms. By contrast, the geosystem approach is a territorial one, in which *a priori* no element, of either biotic or abiotic origin, is treated preferentially. Another important difference is that in its initial stages of development ecosystems ecology was site- or species-limited and only shifted its focus onto spatial patterns and scale in the 1980s (Golley 1989), while spatial patterns and scale (ranging from global to local level) have always been the core issues of landscape research, as based on the geosystem paradigm.

In parallel with the introduction of the geosystem paradigm in research into integrative environmental resources and landscape in Russia there was an important change in the methodology deployed. Up until the 1950s the traditional method of landscape study was via scientific expeditions and fieldwork of relatively short duration. In the 1950s and 60s the first “seasonal” studies were held. These involved repeated analyses of the dynamism and functioning of landscapes over a long period of time and focused on identifying the connections between varying physical characteristics of soils and vegetation, on the one hand, and biological, biochemical, geochemical and hydrological characteristics of geosystems, on the other (Semenov and Snytko 2012). All these field study approaches were conceived for regions with very low populations and it was assumed *a priori* that the landscapes being studied were natural.

The studies that viewed the functioning of the landscape as a group of flows of matter, energy and information made clear that it was impossible to establish a hierarchically rigid “pyramid”: *facies – urochische – mestnost’* -, etc. (Isachenko 1997). In addition, the new form of Landscape science based on the geosystem paradigm tried to clarify the ambiguous issue of landscape genesis and of the factors responsible for its structure. In the 1980s and 90s, V.S. Preobrazhenski (1983) formulated the principle of the polystructuralism of the geosystem, in other words, its definition as a ‘system of sub-systems’ as

² Vertical geosystem layers named after their dominant component: lithological, bio-edaphological, bio-aerial, etc.

opposed to the ‘system of components’ proposed by Sochava. As a result, there was no longer any point in the discussions about the factors responsible for the structure of the landscape. The analysis of the dynamics of the landscape over different periods of time at the Soviet physical geography stations highlighted the fact that each component of the landscape evolved at different rates of change (Beruchashvili 1983). In this way, many Russian landscape geographers rejected the deterministic conception of the “absolute correlation” between the components of the landscape and its genesis as the main criterion for its differentiation in space. Finally, the geosystem approach also gave rise to the idea of “oscillating” stochastic relations between the components of the landscape, relations that change over time.

The findings of Landscape ecology research all over the world have also enriched approaches to geosystems analysis. Several studies have recognized that different environmental processes tend to prevail in different domains and scalar levels in time and space. This makes the extrapolation of information across diverse scales more complicated, thus emphasizing the need for a multiscale approach in Landscape science (Wu 1999; Hay et al. 2001; Khoroshev et al. 2006; Gómez-Zotano et al. 2018)

Nonetheless, certain methodological problems of Landscape science based on the geosystem paradigm were still unresolved. On the one hand Soviet Landscape science was focused on natural landscapes, and only rarely and with great difficulty applied their geosystem methods to the study of anthropic environments such as cities (Preobrazhenski 1983). Any elements of human origin, even if they were physically present within the landscape, were not included in landscape or geosystem-based maps which as a result did not show the real landscapes, and instead presented the landscapes as they theoretically would have been if no human interference had taken place (Angelstam et al. 2013). The impacts of socioeconomic systems on natural systems were normally studied as a separate issue. At the same time, geosystem methods excluded all the sociocultural phenomena and the subjective phenomena involved in the perception of the landscape in spite of the development of the anthropogenic landscape concept³ by the geographer from the University of Voronezh F.N. Milkov (1973). Although Milkov added anthropogenic elements to the ‘natural’ landscape, his interpretation remained mainly biophysical (Angelstam et al. 2013). It was not until the end of the 20th century that Russian geographers finally shook off their ideological doctrines, so allowing them to start looking at the relationship between society and its environment (Kalutskov 2000; Nikolayev 2003; Vedenin 2003; Frolova 2006), not only from a pragmatic and ideological point of view but also from a social and cultural perspective. This evolution coincided in many ways with that of European Landscape ecology, which until the end of 1990s did not consider intangible elements such as cultural and other values as part of the landscape (Field et al. 2003).

Finally, some geosystem-related methodologies were excessively complicated, demanding and time consuming (Bastian et al. 2015). They required the collection of large amounts of data, something that could only be achieved using copious amounts of material resources which although previously available to Soviet geographic institutions are no longer accessible in Russia today (Frolova 2007).

³The concept of anthropogenic landscape centered on material products of human activities in a landscape originates in the German *Landschaftskunde* (Schlüter 1920).

Some of these problems have been resolved. Geographers in several European and Latin American countries have managed to simplify and adapt geosystem-based methodologies to the needs of landscape and environmental resources studies and have combined them with different national traditions of integrative studies to improve their methods and results.

The diffusion of the geosystem approach in Europe and Latin America

The geosystem approach became an important scientific framework in Russia and other post-Soviet countries (Azerbaijan, Armenia, Georgia and Ukraine) for solving a wide range of problems ranging from landscape degradation and human impacts on landscapes, to landscape management and forecasts regarding its future development (e.g. Beroutchachvili 1995; Chistiakov and Kaledin 2010; Bastian et al. 2015; Merekalova and Khoroshev 2016).

The geosystem approach was also rapidly adapted to the needs of environmental resources and landscape studies by geographers in several European countries (for Slovakia, France, Germany, Poland and Spain see Bertrand 1968; Demek 1978; Richling 1983; Muñoz Jiménez 1989; de Bolós i Capdevila 1992; Miklós and Izakovičová 1997; Jiménez Olivencia 2000; Bertrand and Bertrand 2002; Bastian et al. 2015) and in Latin America (for Cuba, Mexico and Brazil see Mateo et al. 1985; Salinas 1994; García Romero 1998; Figueiredo Monteiro 2000; Salinas Chávez and Franco do N. Ribeiro 2017; das Neves and Salinas 2017), by underpinning the specific regional and national approaches to the integrated management of territorial and natural resources by a common scientific and operational framework.

While the geosystem paradigm for integrative studies used in Eastern European countries is very similar to that applied in Russian and Soviet Landscape science, in Germany national traditions of holistic environmental research based on natural landscapes units were developed in the 1950s and 1960s (Neef 1967; Bastian 2000) by merging with ecosystem and geosystem-based concepts (Bastian et al. 2015).

In France in the 1960s and 1970s, the geosystem concept was introduced into geographical studies of the environment within the context of the renovation of physical geography, which until then had been dominated by geomorphology, which was considered as the physical base of geography, ignoring other aspects of the natural environment. In France, geography was not a science that studied the physical environment explicitly and directly, and instead did so through a variety of detailed sectorial analyses which ran more or less in parallel to each other but which rarely resulted in an overall understanding of the environment (Bertrand and Bertrand 2002).

Two scientific schools of environmental studies emerged in France during this period, the school of Toulouse and the school of tropical environment studies⁴. These were inspired both by the Soviet geosystem paradigm and by French biogeographical and/or phytosociological studies. The founder of the Toulouse landscape school, the biogeographer Georges Bertrand, proposed his own methodology for the geographical study of the environment, which was inspired partly by the Soviet geosystem concept and

⁴The last one was formed by researchers from *Office de la Recherche Scientifique et Technique Outre-Mer* (ORSTOM) and Institute of Tropical Geography of the University of the Ivory Coast.

partly by Carl Troll's Landscape ecology (Bertrand 1968). Although the term and some of its main features were borrowed from the Soviet quantitative and naturalist model, Bertrand and his scientific school of geography (e.g. Briane and Cabrol 1986) adapted the concept of geosystem to a different reality, that of Western Europe, where landscapes were extremely anthropic. He also adapted the methodology to the limited material resources available in French geography lab sin the 1970s, which at that time were far inferior to those of the Soviet Union, simplifying it and proposing a more qualitative, open model about the complex relations between the environment and human society.

In his first publications Bertrand treated the geosystem both as a model for a general approach to integrative environmental resources studies and as a hierarchical level of a taxonomy of territorial units. Under this approach the geosystem unit varied in size from a few square kilometers to several hundred square kilometers. According to Bertrand (1968), most of the interactions between the different elements of landscape took place at this more local scale, as did their evolution. This meant that the geosystem provided a good base for studies of territorial organization and planning.

While in his works he presented the geosystem approach as "self-sufficient" for studying the dynamics of landscape and territorial planning, in his work over the last two decades Bertrand has made clear that the geosystem paradigm must be used in combination with other frameworks that address complex historic interactions between society and nature (Bertrand and Bertrand 2002, 2016). In his work with Claude Bertrand, Georges Bertrand states that geosystem is a naturalist concept that "allows us to analyse the structure and the biophysical functioning of a geographic space as it functions today, in other words, with its degree of anthropization". However, he goes on to add that for the studies of the territorial impacts and the sociocultural aspects of social and economic systems, other concepts must be used (Bertrand and Bertrand 2002: 281).

As for the French school of Tropical Environments Studies founded by researchers from Paris, Montpellier and Abijan in the 1970s, its research was based on phytosociology and several concepts drawn from Soviet Landscape science, in particular the geosystem concept (Filleron and Richard 1974; Riou 1980; Richard 1985; Rougerie and Beroutchachvili 1991). Unlike Bertrand's first works in which the geosystem concept was used to design a hierarchical level of horizontal morphological units, this school also focused on the study of vertical structures of geosystems introducing the concept of geohorizons widely used in Soviet geosystem studies (Rougerie and Beroutchachvili 1991). This concept was especially suitable for studies of an important element of vegetation of tropical forest and this holistic approach enabled them to better understand the dynamics and evolution of tropical landscapes under anthropic influence.

Although the geosystem approach was not widely adopted within the French geographic community, it has been applied in a great deal of landscape research in Spain strongly influenced by the French geographical school of Georges Bertrand (Muñoz Jiménez 1989; Jiménez Olivencia 1991-1992; de Bolós i Capdevila 1992; Gómez Zotano 2000; Pérez-Chacón 2002) and Brazil (Figueiredo Monteiro 2000). As in Bertrand's early works the term 'geosystem' was used above all to describe a particular hierarchical level of the taxonomy of territorial units for landscape classification and mapping (Jiménez Olivencia 1991-1992; Bolós i Capdevila 1992). During last two decades Spanish geographers have been combining geosystem framework with land use change analysis in their studies of landscape dynamics or landscape

assessment for land planning (Jiménez Olivencia 2000; Gómez Zotano 2000; Jiménez Olivencia and Porcel Rodríguez 2008).

In Latin America, the “geosystem” concept is used in integrated studies of the environment and territory in a very similar way as it is used today in Russia, due to the fact that it was disseminated by Cuban geographers who were strongly influenced by Soviet Landscape science or directly educated in the USSR. For Cuban scientists (Salinas 1994; Mateo 2008; Miravet-Sánchez et al. 2014) geographical landscape is a synonym of geosystem and is a general scientific category of a transdisciplinary nature which is conceived as an open, complex, spatial-temporal system that originates and evolves in the interface between nature and society, in a constant state of exchange of energy, matter and information, in which its structure, functioning, dynamics and evolution reflect the interaction between the natural (abiotic and biotic), technical, economic and sociocultural components.

The geosystem approach was applied not only to the study of environments as natural units, but also to urban landscapes, albeit less frequently (Neves et al. 2015; Martínez Serrano 2017). For example, Neves et al (2015) showed its usefulness in the analysis of the process of environmental degradation due to urban expansion in environmentally fragile riverbed areas in the municipality of Urucui-Pi and its consequences for local landscapes and urban population.

Although there were some variations from country to country, the major accomplishments of the introduction of the geosystem approach into environmental resources and landscape studies in Latin America were as follows:

- Orientation of national landscape schools to holistic studies of environmental resources
- Improvement of operational tools for landscape assessment, in particular for landscape mapping at different scales and landscape classification
- Integration of environmental dynamics into landscape research
- Focus on the interaction between the natural (abiotic and biotic) and socioeconomic components of geosystems

Therefore geosystem-based approaches were used in many of these countries for environmental diagnoses and territorial planning. In Latin America the definition, classification and mapping of geosystems (often used as synonyms for the term “landscape”), complemented with the use of Geographic Information Systems (GIS) and various other concepts drawn from ecology, became the basis for research into environmental and territorial administration and planning, frequently referred to as “geoecological studies” (Silva et al 2007; Marques Neto 2016; das Neves and Salinas 2017; Salinas Chávez and Franco do N. Ribeiro 2017). In Cuba, for example, environmental and territorial planning is conceived in a similar way as in the Soviet tradition, “from the study of the properties and characteristics of landscape units, which enables us to propose the most suitable forms of using them from the perspective of the rational and diversified use of the territory” (Miravet-Sánchez et al. 2014: 54; see also Salinas 1994). As in Spain, geosystem methodology was frequently combined in Cuba with analysis of land use change in order to assess anthropic impacts on landscape changes.

In Brazil the geosystem approach is used above all in studies of the transformation and fragmentation of landscapes at local and regional scale. The geosystem paradigm was applied in the study

and mapping of landscapes and territorial units, in particular of river watersheds as a basic unit for public policies for environmental planning and management in Brazil (e.g. Soares 2006; Silva and Corrêa 2007; Ribeiro et al. 2010; Marques Neto et al. 2014; Souza 2014). The success of geosystemic studies of river watersheds was attributed both to the close relationship between geosystem theory and the general theory of hydrological systems and to the fact that it is relatively easy to combine biotic and abiotic environmental factors and human activity within this scientific framework (das Neves and Salina 2017).

Its main weakness is that it is difficult to study anthropic landscapes with all their technical, social and cultural elements, using geosystem methodologies derived from physical geography. Therefore, although the geosystem concept has proved useful for interpreting the dynamics of periurban landscapes in Brazil and Mexico, and of the changes in flows of matter and energy that take place within them, especially in their relations with river watersheds (Neves et al. 2015), the results of the study of its anthropic elements and urban landscape mapping are rather poor (e.g. Martínez Serrano 2017). It is often based on less complex methodologies that combine data on elevation, soils, waters, biotopes or land cover through the use of Geographic Information Systems.

Another problem of this framework is that the terms related with the geosystem paradigm are complex and thus not easy to communicate to practitioners involved in land use and landscape management in different countries. Therefore geosystem terms were often replaced by the term ‘landscape’ which offers a much more comprehensible framework than geosystem for most people wishing to interpret the relations between society and the environment (Termorshuizen and Opdam 2009; de Groot et al. 2010; Setten et al. 2012; Albert et al. 2014).

Geosystems versus other methodologies for integrative environmental studies

How can the geosystem paradigm enrich other methodologies for integrative environmental resources and landscape studies? In the previous sections it was shown that one of the strong points of the geosystem framework is its focus on the spatial dimension of environmental systems, which permits relatively easy mapping of its object of study. In addition, the spatial scale used in the majority of geosystem studies is more operational than that used in other holistic frameworks such as ecosystem. As J. Wu (2013: 1000) shows while comparing scales of landscape and ecosystem, “local ecosystem-based studies tend to be too small in spatial extent to incorporate the environmental, economic, and social patterns and processes relevant for sustainable development”. However, “a landscape or region, consisting of multiple ecosystems, represents a pivotal scale domain for research and application of sustainability” (Idem.). Similarly, the geosystem scale covers most of the interactions between the biotic, abiotic and anthropic elements of landscape and their evolution and offers a solid base for spatial planning and for the management of natural resources (Bertrand 1968). In addition, the geosystem-based approach is ‘holistic’, i.e. it is not biocentric and it encompasses the complexity of the biophysical and human components of landscapes and a wide range of their different characteristics.

All these qualities mean that the geosystem-based approach is an excellent complement to other integrative approaches, such as for example Landscape ecology and Ecosystem Services (ES)⁵. In fact, in Post-Soviet Russia, some East European and Latin American countries geosystem-based approaches were successfully combined with Landscape ecology concepts for regional planning and environmental management (e.g. Diakonov 2011; Miravet-Sánchez et al. 2014; Halada et al. 2016; Marques Neto 2016; das Neves and Salinas 2017).

While approaches such as geosystem and Landscape ecology contribute to transdisciplinary environmental research by identifying measurable variables for different pillars of sustainability, they need to be complemented by social science approaches developed by applied demography, human ecology and rural community studies (Field et al. 2003; Angelstam et al. 2013) to make the knowledge useful in practice (e.g. Kates 2011). The different approaches to integrative environmental and landscape studies can be used as a foundation to combine a suite of theoretical frameworks within human and natural science that enable certain aspects of landscapes and the environment to be measured from a holistic perspective (Angelstam et al. 2013).

In this context the important strength of the geosystem-based approach is its close relationship with landscape-based researches. The previous sections of this paper showed the interrelations between the concepts of landscape and geosystem, both of them based on the integrative analysis of the environment and on spatial studies of interactions between vegetation, relief, geology, climate and human influence.

Since one of the weaknesses of the geosystem framework was the difficulty to study non-natural landscapes with methodologies derived from physical geography it needed to open up to other perspectives to take into account the social and cultural dimensions of the relation between people and their environment.

The geosystem framework has however shown great potential for integrating the complexity of human culture and its history into its methodologies. For example, numerous geosystem-based studies of human-dominated landscapes provided new methodologies that combine the geosystem framework with other more socioculturally-oriented perspectives, such as historical (e.g. Bertrand 1984; Isachenko 1998; Jiménez Olivencia and Porcel Rodríguez 2008) or ‘ethno-cultural’ landscape analysis (Kalutskov 2000). In this way the transdisciplinary, applied and spatial nature of the geosystem approach allows us to shift away from the abstract theoretical model focused on physical and ecological elements of the environment to more pluralistic and project-oriented perspectives. These lessons learnt from the evolution of the geosystem-based approaches show that geo-ecological methodologies must be used in combination with other kinds of instruments that take into account the complex interactions between society and nature and the sociocultural perspectives of these interrelations. In fact, the ES framework has recently been undergoing a process of this kind. For example, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) focused its definition of ES on ‘nature’s benefits to people’ (Diaz et al. 2015) and

⁵ The concept of ES first appeared at the beginning of the 1980s as a pedagogical instrument to raise social awareness of the wide range of services that ecosystems provide to people, so justifying the need to protect them. Since the Millennium Ecosystem Assessment (2005), it has become a very widely used and politicized tool for decision-making processes in the field of environmental conservation.

included viewpoints from the social sciences in order to strengthen its analytical capacity for understanding human-nature relations (Berbés-Blázquez et al. 2016).

Another way the geosystem framework can be used to bridge the gaps in integrative environmental resources studies is with the tools it offers for landscape and ES assessment. For example, Bastian et al. (2015) detected a gap in ES research in the use of simplistic proxy methods for mapping ES based on land use and land cover. These methods helped raise policy awareness on ES supply and values but ignored the more complex ecological reality, posing serious risks in terms of the possible adverse effects of policies. The geosystem-based approach can therefore be very useful for predicting, monitoring and enhancing ecosystem services, in that it encompasses the complexity of environmental systems and their abiotic, biotic and even socioeconomic characteristics, a problem yet unresolved in the ES framework (Norgaard 2010). In addition, a territorial approach made up of geosystem-based methods is particularly useful for ES mapping, since ecosystem services are place-based, and could be easy to assess, maintain, enhance and restore if their location is known (Iverson et al. 2014; Fu and Forsius 2015; Bastian et al. 2015).

Ecosystem services are spatially heterogeneous and interactive (Termorshuizen and Opdam 2009) and different ecosystem services could prevail in different domains and scales in time and space. However, the concept of ES focuses mainly on the ecosystem individually and does not consider its spatial contexts and interactions (Wu 2013). The consideration of spatial interactions between different hierarchical levels of the geosystem or its sub-systems could therefore be helpful for detecting and “spatializing” ecosystem services in different environmental and territorial contexts.

Finally, both Soviet Landscape science and Ecosystem services have had difficulties in integrating time and dynamics into their analysis. Geosystem-based mapping and modelling methods for the analysis of environmental dynamics offer solid tools based on numerous empirical studies on landscape and geosystem monitoring, modeling and mapping over the last half century which can help advance ES research.

Concluding remarks

There is a long tradition in Russian and Soviet Landscape science regarding the use of holistic approaches to environmental and integrative territorial studies. One of its important contributions was the geosystem paradigm. This new paradigm enabled geographers to move towards a more interactive, dynamic, globalizing view of landscapes, leaving behind the static determinist model that had dominated and still remains important in Russian geography. Geosystem-based methodologies provided operational tools for spatial planning and studies of environmental resources dynamics not only in Russia but also in several European countries and in Latin America.

This framework has proved highly adaptable to different geographical, cultural and political contexts throughout its more than fifty years of history. The trajectories of the geosystem paradigm in several other countries apart from Russia have demonstrated its usefulness for integrative territorial and environmental studies in diverse sociopolitical and environmental situations, and its compatibility and complementarity with other scientific frameworks such as Ecosystem Services or Landscape ecology. Its

strength lies in its focus on the spatial and temporal dimension of ecosystems and the fact that it encompasses a wide range of facets, including human elements. The geosystem framework has gradually evolved over several decades, during which time its close links with landscape-based studies and its potential for integrating nature-human relations have also become clear.

There is evidence to suggest that Russian Landscape science and the development of the geosystem framework in different countries have much to contribute to further progress of integrative environmental studies (Shaw and Oldfield 2006, 2007; Angelstam et al. 2013; Bastian et al. 2015). This is not only due to the large amount of data on landscape classification, analysis, evaluation, monitoring, modeling and mapping accumulated since the beginning of the last century, but also thanks to the long Russian tradition of philosophical and sociological debate regarding the significance of environment and landscape (Shaw and Oldfield 2007; Oldfield et al. 2017).

Geosystem-based approaches must be combined with other approaches for unravelling the relationships between human beings and the environment so as to enable the creation of an international framework of integrative studies on environmental sustainability. This will allow experts working in the different traditions of integrative environmental and territorial approaches to combine their interests and efforts to fill the gap between societal and environmental studies.

References

- Acot P (1999) *L'histoire des sciences*. Presses Universitaires de France, Paris
- Albert C, Aronson J, Fürst Ch, Opdam P (2014) Integrating ecosystem services in landscape planning: requirements, approaches, and impacts. *Landscape Ecol* 29:1277–1285. <https://doi.org/10.1007/s10980-014-0085-0>
- Angelstam P, Grodzynski M, Andersson K, Axelsson R, Elbakidze M, Khoroshev A, Kruhlov I, Naumov V (2013) Measurement, Collaborative Learning and Research for Sustainable Use of Ecosystem Services: Landscape Concepts and Europe as Laboratory. *Ambio* 42(2):129–145. <https://doi.org/10.1007/s13280-012-0368-0>
- Antrop M (2005) From holistic landscape synthesis to transdisciplinary landscape management. In: Tress B, Tress G, Fry G, Opdam P (eds.) *From Landscape Research to Landscape Planning – Aspects of Integration, Education and Application*. Springer, Dordrecht, pp 27-50
- Bastian O (2000) Landscape classification in Saxony (Germany) — a tool for holistic regional planning. *Landscape and Urban Plan* 50:145-155. [https://doi.org/10.1016/S0169-2046\(00\)00086-4](https://doi.org/10.1016/S0169-2046(00)00086-4)
- Bastian O, Grunewald K, Khoroshev AV (2015) The significance of geosystem and landscape concepts for the assessment of ecosystem services: exemplified in a case study in Russia. *Landscape Ecol* 30 (7):1145–1164. <https://doi.org/10.1007/s10980-015-0200-x>
- Berbés-Blázquez M, González JA, Pascual U (2016) Towards an ecosystem services approach that addresses social power relations. *Curr Opin Environ Sustain* 19:134-143. <https://doi.org/10.1016/j.cosust.2016.02.003>

- Berg LS (1913) An attempt to divide Siberia and Turkestan into landscape and morphological regions. In Festchrift in honor of D. N. Anuchin's seventieth birthday. Izdatel'stvo Imperatorskogo obshchestva Lyubitelei Estestvoznaniya, Antropologii i Etnografii pri Moskovskom universitete, Moscow, pp 117–151 (In Russian)
- Berg L S (1947) Geographical zones of the Soviet Union, Vol. 1, OGIZ, Moscow (In Russian)
- Berg LS (1915) The objectives and tasks of geography. In: Proceedings of the Imperial Russian Geographical Society 51:463–475 (in Russian). Also in: Wiens JA, Moss M, Turner MG, Mladenoff DJ (eds.) (2006) Fundamental papers in landscape ecology. Columbia University Press, New York, pp 11–18
- Beroutchachvili N, Bertrand G (1978) Le géosystème ou “système territorial naturel”. *Revue géographique des Pyrénées et du Sud-Ouest* 49 (2):167-180
- Beroutchachvili N (1995) The Caucasus: Landscapes, Models, Experiments. UNEP, GRID-Arendal and World Bank, Tbilisi (In Russian)
- Bertrand G (1968) Paysage et géographie physique globale. Esquisse méthodologique. *Rev géographique des Pyrénées et du Sud-Ouest* 49 (2):167-180.
- Bertrand G (1984) Apogée et déclin d'un géosystème sylvo-pastoral (Montagne de León et de Palencia, Espagne du nord-ouest). *Rev géographique des Pyrénées et du Sud-Ouest* 55(2):239-248
- Bertrand Cl, Bertrand G. (2002) Une géographie traversière: L'environnement à travers territoires et temporalités. Editions Arguments, Paris
- Bertrand Cl, Bertrand G (2016) La naturaleza-artefacto, entre antropización y artialización. La experiencia del sistema GTP (geosistema-territorio-paisaje). In Frolova M (ed) *Relación entre la sociedad y el medio ambiente en geografía moderna*. Universidad de Granada, Granada, pp 9-25
- Beruchashvili NL (1983) Methodology of geographical landscape studies and mapping of states of natural territorial complexes. Publishing House of Tbilisi State University, Tbilisi (In Russian)
- Beruchashvili NL (1986) Four dimensions of landscape. Mysl, Moscow (In Russian)
- Beruchashvili NL, Zhuchkova VK (1997) Methods of complex physical geographical research. Publishing House of Moscow State University, Moscow (In Russian)
- Briane G, Cabrol J-L (1986) L'abeille dans le géosystème: essai de cartographie des ressources mellifères. *Rev géographique des Pyrénées et du Sud-Ouest. Sud-Ouest Européen* 57 (3):363-373
- Chistiakov KV, Kaledin NV (eds) (2010) Mountains and people: landscape changes and ethnos of intercontinental mountains of Russia. Saint-Petersburg State University-Russian Geographical Society, Saint-Petersburg (in Russian)
- das Neves CE, Salinas E (2017) A Paisagem na Geografia Física Integrada: Impressões Iniciais Sobre sua Pesquisa no Brasil entre 2006 e 2016. *Revista de Departamento de Geografia, Universidade de São Paulo* 6: 124-137
- de Bolos i Capdevila M (ed) (1992) *Manual de Ciencia del paisaje: Teoría, métodos y aplicaciones*. Masson, Barcelona
- de Groot RS, Alkemade R, Braat L, Hein L, Willemsen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol Complex* 7(3):260–272. <https://doi.org/10.1016/j.ecocom.2009.10.006>

- Demek J (1978) The Landscape as a Geosystem. *Geoforum* 9:29-34
- Dempsey J, Robertson MM (2012) Ecosystem services: Tensions, impurities, and points of engagement within neoliberalism. *Prog in Hum Geography* 36 (6):758-779. <https://doi.org/10.1177/0309132512437076>
- Diakonov KN (ed) (2011) Recent problems of landscape planning, Publishing House of Moscow State University, Moscow (in Russian)
- Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR, Arico S, Báldi A et al. (2015) The IPBES Conceptual Framework — connecting nature and people. *Curr Opin Environ Sustain*, 14:1-16. <https://doi.org/10.1016/j.cosust.2014.11.002>
- Dokuchaev V (1899) Report to the Transcaucasian Statistic Committee on soil evaluation in general and in particular of horizontal and vertical zones of soils in the Caucasus. *Tip. Kants. Glavnonach. Grayd. Chasti na Kavkaze*, Tiflis (in Russian)
- Dokuchaev V (1948) Toward the study of natural areas. OGIZ, Moscow
- Dronin NM (1999) Evolution of the Russian concept in Russian and Soviet physical geography. GEOS, Moscow
- Field DR, Voss PR, Kuczenski TK, Hammer RB, Radeloff VC (2003) Reaffirming social landscape analysis in landscape ecology: A conceptual framework. *Society & Natural Resources* 16: 349–361. <https://doi.org/10.1080/08941920390178900>
- Figueiredo Monteiro CA (2000) Geosistemas: a historia de uma procura. Contexto, São Paulo
- Filleron JC, Richard JF (1974) Recherches sur les paysages subsoudanais. Les géosystèmes de la région d'Odiénne. *Annales Univ Abidjan VI*:103-168
- Frolova M (2000) Le paysage des géographes russes: l'évolution du regard géographique entre le XIX et le XX siècle. *Cybergéo: European Journal of Geography* (online) 143. <https://doi.org/10.4000/cybergeogeo.1808>
- Frolova M (2006) Les paysages du Caucase: l'invention d'une montagne. Centre des Travaux Historiques et Scientifiques, Paris
- Frolova M (2007) Desde el concepto de paisaje a la Teoría de geosistema en la Geografía rusa: ¿hacia una aproximación geográfica global del medio ambiente? *Ería* 70:225-235
- Fu B, Forsius M (2015) Ecosystem services modeling in contrasting landscapes. *Landscape Ecol* 30:375–379. <https://doi.org/10.1007/s10980-015-0176-6>
- García Romero A (1998) Geoecología del paisaje vegetal en el occidente de la Ciudad de México. *Anales de Geografía de la Universidad Complutense* 18:115-137
- Gerasimov IP (1966) Constructivist geography: objectives, methods, results. *Izvestia Geograficheskogo Obshchestva SSSR* 98(5):389-403 (in Russian)
- Golley FB (1989) Paradigm shift. *Landscape Ecol* 3 (2):65-66. <https://doi.org/10.1007/BF00131170>
- Gómez Zotano J (2000) El paisaje integrado de las montañas andaluzas. *Análisis de la metodología experimentada. Cuadernos Geográficos* 30:445-467
- Gómez-Zotano J, Riesco-Chueca P, Frolova M, Rodríguez-Rodríguez J (2018) The Landscape Taxonomic Pyramid (LTP): a multi-scale classification adapted to spatial planning. *Landscape Res.* <https://doi.org/10.1080/01426397.2017.1404021>

- Halada L, Bača A, Boltížiar M (eds) Landscape and Landscape ecology. Proceedings of the 17th International Symposium on Landscape ecology. Institute of Landscape ecology, Slovak Academy of Sciences, Nitra
- Hay GJ, Marceau DJ, Dubé P, Bouchard A (2001) A multiscale framework for landscape analysis: Object-specific analysis and upscaling. *Landscape Ecol* 16:471-490. <https://doi.org/10.1023/A:1013101931793>
- Isachenko GA (1997) Discontinuity and continuity in Landscape science theory. In: Structure, functioning, evolution of natural and anthropogenic landscapes. Izdatelstvo RGO, Moscow-Saint-Petersbourg, pp 23–25 (in Russian)
- Isachenko GA (1998) “Window to Europe”: History and Landscapes. Publishing House of the University of Saint-Petersbourg, Saint-Petersbourg (in Russian)
- Iverson L, Echeverria C, Nahuelhual L, Luque S (2014) Ecosystem services in changing landscapes: an introduction. *Landscape Ecol* 29:181–186. <https://doi.org/10.1007/s10980>
- Jiménez Olivencia Y (1991-1992) Esquema metodológico para un análisis del paisaje orientado a la planificación de un espacio natural protegido: Sierra Nevada (España), Cuadernos geográficos de la Universidad de Granada 20-21:29-36
- Jiménez Olivencia Y (2000) De los complejos naturales a los paisajes: el modelo de Sierra Nevada, Cuadernos geográficos de la Universidad de Granada 30:347-364
- Jiménez Olivencia Y, Porcel Rodríguez L (2008) Metodología para el estudio evolutivo del paisaje: aplicación al Espacio Protegido de Sierra Nevada, Cuadernos geográficos de la Universidad de Granada 42:151-179
- Kalutskov VN (2000) Bases of an ethno-cultural Landscape science. Izdatelstvo Moskovskogo Universiteta, Moscow (in Russian)
- Kates RW(2011) What kind of science is sustainability science? *Proceedings of the National Academy of Sciences United States of America* 108: 19449–19450
- Khoroshev AV, Puzachenko YuG, Diakonov KN (2006) Recent stage of the Landscape Ecology, *Izvestia RAN, ser. geogr.* 5:12-21 (in Russian)
- Krasnov AN (1915) Southern Colchis. Izdatelstvo PP Soikin, Saint-Petersbourg (in Russian)
- Krasnov AN (1956) Under the tropics of Asia. Geografiz, Moscow (in Russian)
- Kuhn Th S (1970) The Structure of scientific revolutions. 2nd Edition, University of Chicago Press
- Le Roy É (1928) Les Origines humaines et l'évolution de l'intelligence. Boivin & Cie., Paris
- Marques Neto R (2016) Geomorfologia e geossistemas: influências do relevo na definição de unidades de paisagem no maciço alcalino do Itatiaia (MG/RJ). *Revista Brasileira de Geomorfologia* 17(4):729-742
- Marques Neto R, Perez Filho A, Oliveira TA (2014) Geossistemas na Bacia do Rio Verde (MG): Propuesta de mapeamento de sistemas ambientais físicos em escala regional. *Geografia, Rio Claro* 39 (2):321-336
- Marsh GP (1864) Man and nature; or, physical geography as modified by human action. Reprinted 1965. Belknap Press of Harvard University Press, Cambridge
- Marsh GP (1874) The earth as modified by human action: new edition of ‘Man and Nature’. Scribner, Armstrong & Co., New York (reprinted by Arno Press 1970)

- Martínez Serrano A (2017) Zonificación geoecológica, un criterio para la interpretación y el análisis espacial del paisaje urbano de la ciudad de Morelia. *Boletín de la Asociación de Geógrafos Españoles* 73:343-367
- Mateo J (2008) *Geografía de los Paisajes*. Editorial Universitaria, La Habana
- Mateo J, Guzman JL, Salinas E (1985) El Análisis de los paisajes como fundamento para la Planificación de los Territorios. Primera Jornada sobre Planificación Regional y Urbana. IPF-JUCEPLAN, La Habana
- Merekalova K, Khoroshev A (2016) Trends in inter-component relationships during the recovery of disturbed landscapes. In Halada L, Bača A, Boltížiar M (eds) *Landscape and Landscape ecology. Proceedings of the 17th International Symposium on Landscape ecology*. Institute of Landscape ecology, Slovak Academy of Sciences, Nitra, pp 132-140
- Miklós L, Izakovičová Z (1997) The landscape as a geosystem. VEDA, Bratislava (in Slovak)
- Millennium Ecosystem Assessment (ed) (2005) *Ecosystems and Human Well-being: Synthesis*. Island Press
- Milkov FN (1973) The man and landscapes. Sketches of anthropogenic landscape studies. Mysl, Moscow (in Russian)
- Miravet-Sánchez BL, García-Rivero AE, Salinas-Chávez E, Cruañas-López E, Remond-Noa R (2014) Diagnóstico Geoecológico de los paisajes de la cuenca hidrográfica Ariguanabo, Artemisa, Cuba. *Ciencias de la Tierra y el Espacio* 15 (1):53-66
- Muñoz Jiménez J (1989) Paisaje y Geografía, *Arbor* 518/519:219-233
- Neef E (1967) *Die theoretischen Grundlagen der Landschaftslehre*. H. Haack, Gotha, Leipzig
- Neves SM, Barbosa AMF, Souza RM (2015) Análise geoambiental do município de Uruçuí-PI. *Revista de Geografia* 32 (1):151-166
- Nikolayev VA (2003) *Landscape science: aesthetics and design*. Aspent Press, Moscow (in Russian)
- Norgaard RB (2010) Ecosystem services: From eye-opening metaphor to complexity blinder. *Ecol Economics* 69:1219–1227. <https://doi.org/10.1016/j.ecolecon.2009.11.009>
- Oldfield JD, Shaw DJB (2015) A Russian Geographical Tradition? The Contested Canon of Russian and Soviet Geography, 1884-1953. *J of Historical Geography* 49:75-84. <https://doi.org/10.1016/j.jhg.2015.04.015>
- Oldfield JD, Lajus J, Shaw DJB (2015) Conceptualizing and Utilizing the Natural Environment: Critical Reflections from Imperial and Soviet Russia. *Slavon and East Eur Rev* 93 (1): 1-15
- Oldfield JD, Shaw DJB (2016) *The Development of Russian Environmental Thought: Russian Geographical Perspectives on the Natural Environment, 1880s-1960s*. Routledge, London
- Pedroli B (1983) Landscape concept and landscape and rangeland surveys in the Soviet Union. *ITC J*, 4:307-321
- Pérez-Chacón E (2002) Unidades de paisaje: Aproximación científica y aplicaciones. In: Zoido Naranjo F, Venegas Moreno C (eds) *Paisaje y ordenación del territorio*. Consejería de Obras Públicas y Transportes, Seville, pp 122-135
- Polynov BB (1925) Landscape and soil. *Priroda* 1:74-84 (in Russian)
- Preobrazhenskiy VS (1983) Geosystem as an Object of Landscape study. *GeoJournal* 7 (2):131-134

- Ramenski LG (1938) Introduction to complex soil and botanic territorial research. Selkhozgiz, Moscow (in Russian)
- Reteyum AY (1977) About the factors and forms of spatial organization of the earth's envelope, *Voprosy geografii* 104:84-95
- Ribeiro SC, Lima FJ, Marçal MS (2010) O enquadramento paisagístico como contribuição aos estudos da sub-bacia do Rio Salgado/CE: do domínio morfoestrutural ao sgeossistemas. *Revista de Geografia, Recife* 2:121-135
- Richard JF (1985) La science du paysage ; relations, dépendences et autonomies. *Rev géographique de l'Est* 4:347-353
- Richard JF, Béroutchachvili N (1996) Vers l'élaboration d'un système d'information sur les paysages du monde. *Cahiers des Sciences Humaines de l'Orstom* 32(4):823-842
- Richling A (1983) Subject of Study in Complex Physical Geography (Landscape Geography). *Geo Journal* 7 (2):185-187. <https://doi.org/10.1007/BF00185166>
- Riou G (1980) Étude intégrée des milieux naturels et organisation de l'espace sahélien, DGRST-CEGET, Talence
- Rougerie G, Beroutchachvili N (1991) Géosystèmes et paysages. Bilans et méthodes. Armand Colin, Paris
- Salinas E (1994) El ordenamiento geoecológico en la planificación regional en Cuba. *Medio Ambiente y Urbanización* 49:89-99
- Salinas Chávez E, Franco do N. Ribeiro Á (2017) La cartografía de los paisajes con el empleo de los Sistemas de Información Geográfica: Caso de estudio Parque Nacional Sierra de Bodoquena y su entorno, Mato Grosso do Sul, Brasil. *Geografía y Sistemas de Información Geográfica (GEOSIG)*
- Schlüter O (1920) Die Erdkunde in ihrem Verhältnis zu den Natur- und Geisteswissenschaften, *Geographischer Anzeiger* 21(7/8):145-152
- Semenov YuM, Snytko VA (2013) The 50th Anniversary of the Appearance of V. B. Sochava's First Article on the Geosystem. *Geography and Natural Resources* 34 (3):197-200
- Setten G, Stenseke M, Moen J (2012) Ecosystem services and landscape management: three challenges and one plea. *International J of Biodivers Sci, Ecosyst Services & Manag* 8 (4):305-312. <https://doi.org/10.1080/21513732.2012.722127>
- Shaw DJB, Oldfield JD (2007) Landscape Science: A Russian Geographical Tradition. *Annals of the Association of Am Geographers* 97 (1):111-126. <https://doi.org/10.1111/j.1467-8306.2007.00526.x>
- Shchukin IS, Shchukina OE (1967) About problems of physical-geographic regionalization of mountain regions. *Vestnik MGU, ser. V*, 6:10-19 (in Russian)
- Silva FLM, Corrêa ACB (2007) Relações entre geossistemas e usos da terra em microbacia hidrográfica semi-árida: o caso do Riacho Gravatá/Pesqueira – PE. *Revista de Geografia, Recife* 24 (1): 174-191
- Soares FM (2006) As paisagens da Bacia Hidrográfica do Rio Curu: exploração de um campo de estudo da Geografia Física integrada, *Mercator* 5(9):96-104
- Sochava VB (1963) The definition of some concepts and terms in Physical Geography. *Doklady Instituta geografii Sibiri i Dal'nego Vostoka* 3:50–59 (in Russian)
- Sochava VB (1978) Introduction to the study of geosystems. Nauka, Novosibirsk (in Russian)

- Solntsev NA (1948) The natural geographic landscape and some of its general rules. In: Proceedings of the Second All-Union Geographical Congress, vol 1. OGIz, Leningrad, pp 258–269 (in Russian). Also in: Wiens JA, Moss MR, Turner MG, Mladenoff DJ (eds) (2006) *Fundamental papers in landscape ecology*. Columbia University Press, New York, pp 19–27
- Solntsev NA (1949) About the morphology of geographical landscape, *Voprosy geografii* 16: 61-86
- Souza JCO Análise geossistêmica na bacia hidrográfica do Rio São Miguel, Alagoas: estudo e interpretação de paisagens hidrogeomorfológicas, *Revista Brasileira de Geografia Física* 7(5):880-890
- Steffen W, Grinevald J, Crutzen P, McNeill J (2011) The Anthropocene: conceptual and historical perspectives. *Phil Trans R Soc A* 369:842-867. <https://doi.org/10.1098/rsta.2010.0327>
- Stoddart DR (1967) Organism and Ecosystem as Geographical Models. In: Chorley RJ, Haggett P (eds) *Models in Geography*. Methuen CO & LTD, London, pp 511–548
- Stoppani A (1973) *Corso di geologia*, vol. II. G. Bernardoni e G. Brigola, Milan
- Teilhard de Chardin P (1966) *The vision of the past*. Collins, London
- Termorshuizen JW, Opdam P (2009) Landscape services as a bridge between landscape ecology and sustainable development. *Landscape Ecol* 24:1037-1052. <https://doi.org/10.1007/s10980-008-9314-8>
- Troll C (1939) *Luftbildplan und ökologische Bodenforschung*. F. Steiner Verlag, Wiesbaden
- Troll C (1966) *Landschaftsökologie als geographisch-synoptische Naturbetrachtung*. In: Troll C (ed.) *Ökologische Landschaftsforschung und vergleichende Hochgebirgsforschung*. F. Steiner Verlag, Wiesbaden, pp 1-13
- Valebný VV (1998) Scientific naturalism and the Landscape science emergence. In: *Cultural landscape: theoretical and methodological questions*. Izdatelstvo SGU, Moscow-Smolensk: 14-25 (in Russian)
- Vedenin YuA (2003) The informational bases of study and formation of the cultural landscape as heritage object. *Izvestiya Akademii Nauk, ser. geogr* 3:7-13 (in Russian)
- Vernadsky V (1924) *La géochimie*. Librairie Félix Alcan, Paris
- Vernadsky VI (1926) *The biosphere*. NJTI-NTO-VSMJ, Leningrad (in Russian). Translated into English as Vernadskii VI (1998) *The biosphere*. Copernicus, New York
- Vernadsky VI (1997) *Scientific Thought as a Planetary Phenomenon*. V.I. Vernadsky Foundation, Moscow
- Voyeikov AI (1910) Land improvements and their relation with climate and other natural conditions. *Iezhegodnik otdelenia zemelnykh uluchsheniy*, Saint-Petersbourg, pp 91-115 (in Russian)
- von Bertalanffy (1968) *General System Theory. Foundations, Development, Applications*. George Braziller, New York.
- Wiens JA, Moss MR, Turner MG, Mladenoff DJ (eds) (2006) *Fundamental papers in landscape ecology*. Columbia University Press, New York
- Wu J (1999) Hierarchy and scaling: Extrapolating information along a scaling ladder. *Canadian J of Remote Sens* 25:367-380. <https://doi.org/10.1080/07038992.1999.10874736>
- Wu JG (2013) Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape Ecol* 28(6):999-1023. <https://doi.org/10.1007/s10980-013-9894-9>