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THE MANAGEMENT OF ECOSYSTEM SERVICES VERSUS TIME IN ECOSYSTEMS

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ZARZĄDZANIE USŁUGAMI ŚRODOWISKA, A WYMIAR CZASU W EKOSYSTEMACH

STRESZCZENIE: Makrosystem społeczeństwo-gospodarka-środowisko funkcjonuje i rozwija się z wykorzystaniem zasobów naturalnych usług środowiska przyrodniczego.
W teorii ekonomii przede wszystkim analizowano zasoby naturalne, a usługi środowiska są stosunkowo nową kategorią ekonomiczną, szczególnie w aspekcie wymiaru czasu. Teoria ekonomii powinna szerzej uwzględniać założenia ekonomii ewolucyjnej oraz różne interpretacje czasu i korzystać z nich w analizach zjawisk ekonomicznych, w tym związanych z gospodarowaniem usługami środowiska. Celem pracy jest analiza roli czasu w ekosystemach w zrównoważonym gospodarowaniu usługami środowiska przyrodniczego – ze szczególnym uwzględnieniem badań polskich przedstawicieli ekonomii ekologicznej i zrównoważonego rozwoju. Czas w ekosystemach jest nierozerwalnym elementem oddziaływującym na zjawiska i procesy gospodarowania w postaci czwartego wymiaru czasoprzestrzeni lub logicznego następstwa zdarzeń. Problemy badawcze nie powinny koncentrować się na pytaniu, czy uwzględnić jego rolę w procesach gospodarowania, szczególnie w odniesieniu do zrównoważonego gospodarowania usługami środowiska, tylko na pytaniu, jak ten czas rozumieć i w jaki sposób wprowadzić go do teorii ekonomii i praktyki gospodarczej.

SŁOWA KLUCZOWE: ekosystem, ekonomia ekologiczna, ekonomia ewolucyjna, ekonomia zrównoważonego rozwoju, usługi środowiska, gospodarka oparta na wiedzy, czas w ekosystemach

Introduction

Society-economy-environment macrosystem functions and develops with the use of natural resources and ecosystem services. The theory of economics has primarily analysed natural resources, while ecosystem services, particularly in temporal aspect, are a relatively new economic category. Time is present in every activity of a contemporary man, both scientific and non-scientific, including philosophy, religion, life sciences, history and psychology. Time, as a form of matter, energy and information existence, is a universal manifestation of economic activities and functioning of the economic system.[1]

The theory of economy should consider the assumptions of evolutionary economics and various time interpretations more thoroughly and use them in analysing economic phenomena, including the ones concerning ecosystem services. In fact, real economic systems without the supporting role of ecosystem services do not exist. The management of ecosystem services is based on their conscious and unconscious use. Knowledge-based economy should be aimed at fully conscious management of ecosystem services, which takes account of time in ecosystems. The aim of the present paper is to analyse the role of time in ecosystems in sustainable management of ecosystem services – with particular attention to the researches by Polish representatives of ecological economics and sustainable development. The introduction of this topic to the theory of economics is to increase the effectiveness and efficiency of economizing processes and the implementation of sustainable development in society-economy-environment macrosystem.

Economic category of ecosystem services

The concept development of ecosystem services has been clearly noticeable since 18th century.[2] The economic category of ecosystem services appeared in 1981.[3] The article of 1997 is a significant publication concerning the issue of ecosystem services. It presents 17 global scale functions of natural environment, attributed with material and non-material services. Their value was estimated at over 33 bln USD.[4] The beginning of 21 century brought a number of reports providing classification systems, evaluations and assessments of ecosystem ser-

[1] S. Czaja, *Czas w ekonomii*, Wydawnictwo Uniwersytetu Ekonomicznego, Wroclaw 2011; *see Time in Economic Theory*, ed. S. Zamagni, E. Agliardi, Edward Elgar Publishing, New York 2005.
[2] E. Gómez-Baggethun, R. de Groot, P.L. Lomas, C. Montes, *The history of ecosystem services in economic theory and practice: from early notions to markets and payments schemes*, „Ecological Economics" 2010 No. (69)6, p. 1209-1218.
[3] H.A. Mooney, P.R. Ehrlich, *Ecosystem services: A fragmentary History*, in: *Nature's Services: Societal Dependence on Natural Ecosystems*, ed. G.C. Daily, Island Press, Washington 1997, p. 11-22.
[4] R. Costanza et. al., *The value of the world's ecosystem services and natural capital*, „Nature" 1997 No. 387, p. 253-260.

vices. The reports include: Ecosystems and Human Well-being: Synthesis in 2005, The Economics of Ecosystems and Biodiversity in 2008, The Economics of Ecosystems and Biodiversity. Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB in 2010. Polish authors have also reviewed international and Polish researches on ecosystem services, which were the main topic of the first issue of *Ekonomia i Srodowisko* (*Economics and Environment*) in 2010.[5]

The most popular system of ecosystem services classification was presented in the report Ecosystems and Human Well-being. It distinguishes four groups of ecosystem services:

- provisioning services – include medicinal plants, genetic resources, ornamental resources,
- regulating services – refer to the benefits from regulatory properties of ecosystems, e.g. climate and air quality regulation, water purification, waste utilization,
- cultural services – non-material benefits from the functioning of ecosystems, e.g. natural and cultural heritage, leisure and recreation, creative inspiration, ecological education,
- supporting services – a group of services that are necessary for rendering other services, e.g. soil formation, water circulation, nutrient cycling, photosynthesis.[6]

Polish literature on the subject uses the classification by Kosmicki. It also distinguishes four groups of ecosystem services:

- raw material, production and transformation services – oxygen production, water circulation and purification, food production, gene pool as a reserve for the future, medical resources, material production for clothes and household industries, materials for construction and other branches of economy, biochemical production, fuel and energy production, fodder and fertilizers production,
- regulating and utilizing services – protection against harmful background radiation, regulating local and global energy balances, regulating chemical composition of the atmosphere and oceans, water flow man-

[5] e.g. A. Mizgajski, *Świadczenia ekosystemów jako rozwijające sie pole badawcze i aplikacyjne*, „Ekonomia i Środowisko" 2010 No. 1(37), p. 10-19; B. Poskrobko, *Usługi środowiska jako kategoria ekonomii zrownoważonego rozwoju*, „Ekonomia i Srodowisko" 2010 No. 1(37), p. 20-30; T. Żylicz, *Wycena uslug ekosystemow. Przeglad wynikow badan swiatowych*, „Ekonomia i Srodowisko" 2010 No. 1(37), p. 31-45; J. Famielec, *Korzysci i straty ekologiczne w ekonomii sektora publicznego*, „Ekonomia i Srodowisko" 2010 No. (1)37, p. 46-63; A. Graczyk, *Świadczenia ekosystemow jako dobra ekonomiczne*, „Ekonomia i Srodowisko" 2010 No. (1)37, p. 64-76; A. Michałowski, *Ocena działań na rzecz zachowania świadczeń ekosystemów na etapie programowania rozwoju jednostek organizacyjnych*, „Ekonomia i Środowisko" 2010 No. (1)37, p. 98-113; see R. Costanza, I. Kubiszewski, *The authorship structure of „ecosystem services" as a transdisciplinary field of scholarship*, „Ecosystem Services" 2012 No. 1(1), p. 16-25.

[6] *The Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis*, Island Press, Washington 2005.

agement, flood prevention, water retention, underground water supply, prevention of soil deterioration, humus formation and fertility maintenance, solar energy absorption and biomass production, recycling of organic matter and nutrients, accumulation and recycling of anthropogenic waste, regulation of biological control mechanisms, life space maintenance for the purpose of reproduction, socialization and mobility, biodiversity maintenance, stabilization of ecosystems,
- services of space preparation for the anthropogenic use – settling, cultivation, energy use, leisure and tourism,
- information services – aestheticism of nature, stimulation and reward patterns in society, sense and socialization patterns, gene pool for agriculture and medicine, historical information, cognition patterns.[7]

Constant development of environment economy and economic research on sustainable development[8] forces modification and supplementation of different economic categories, including ecosystem services[9]. Graczyk emphasizes the fact that in order to define ecosystem services, one has to adopt the point of view of a microeconomic entity that makes choices in their economic activities. Such entities include companies and households (consumers). Environment functions that are significant from their perspective might be limited to the following three dimensions:
- environment as a supplier of production factors – it is a function of supplying production factors as primary goods (e.g. raw materials, fish) and the goods that result from intended actions of men (e.g. cultivated plants),
- environment as a service – environment is a system that facilitates the transfer of costs and benefits by the collection of wastes and pollutants and by generating direct benefits,

[7] E. Kośmicki, *Globalne zagrozenia bioroznorodnosci a problem swiatowego kierowania*, in: *Teoretyczne aspekty ekonomii zrownowazonego rozwoju*, ed. B. Poskrobko, Wydawnictwo Wyższej Szkoly Ekonomicznej, Bialystok 2011, p. 34-58.

[8] e.g. H. Rogall, *Nachhaltige Okonomie. Okonomische Theorie und Praxis einer Nachhaltigen Entwicklung*, Metropolis Verlag, Marburg 2009; *Ekonomia zrównoważonego rozwoju. Zarys problemów badawczych i dydaktyki*, ed. B. Poskrobko, Wydawnictwo Wyższej Szkoly Ekonomicznej, Białystok 2010.

[9] e.g. R. Muradian, E. Corbera, U. Pascual, N. Kosoy, P.H. May, *Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services*, „Ecological Economics" 2010 No. (69)6, p. 1202-1208; R.B. Norgaard, *Ecosystem services: From eye-opening metaphor to complexity blinder*, „Ecological Economics" 2010 No. (69)6, p. 1219-1227; I.J. Bateman, G.M. Mace, C. Fezzi, G. Atkinson, K. Turner, *Economic Analysis for Ecosystem Service Assessments*, „Environmental and Resource Economics" 2010 No. 48, p. 177-218; A. Balmford, B. Fisher, R.E. Green, R. Naidoo, B. Strassburg, R.K. Turner, A.S.L. Rodrigues, *Bringing Ecosystem Services into the Real World: An Operational Framework for Assessing the Economic Consequences of Losing Wild Nature*, „Environmental and Resource Economics" 2010 No. 48, p. 161-175; B. Fisher, S. Polasky, T. Sterner, *Conservation and Human Welfare: Economic Analysis of Ecosystem Services*, „Environmental and Resource Economics" 2010 No. 48, p. 151-159; A. Michałowski, *Przestrzenne usługi środowiska w świetle założeń ekonomii zrównoważonego rozwoju*, „Problemy Ekorozwoju"/"Problems of Sustainable Development" 2011 No. 6(2), p. 117-126.

- environment as a state – this perspective considers environment as a generator of conditions that are necessary to perform actions, i.e. a possibility to do activities that contribute to better prosperity.[10]

The above perspectives correspond to conscious and unconscious requirements of different subjects and consumers. Meeting those requirements by the environment generates benefits, while ecosystem devastation results in obtaining insufficient profits. Therefore, the entities that plan to undertake their activities should consider changes in the intended features of natural environment which form the intended functions of their economic objectives. From the economic point of view, ecosystem services may be defined as performing service functions (transferring costs and benefits) and the functions of state (generating conditions for activities) by the ecosystems.

Poskrobko notices that ecosystem services may be interpreted from two perspectives: bio-ecological and socio-economic.[11] The former considers ecosystem services as all natural processes that form a developmental niche for a man and ensure evolution-driven quality of life basis. The latter approach interprets ecosystem services as those ecosystem processes that have significant impact on economic activities, e.g. the functioning of nutrient circulation or plant pollination. According to this view, services should be regarded as values, powers and natural processes, along with their effects which generate non-resource economic values, necessary for the development of society-economy-environment macrosystem and the functioning of production processes. Anthropogenic infringement upon ecosystem services forces incorporation of ecosystem services into economic analyses, as it deteriorates natural foundations of human life and increases the manufacturing costs. The problem of understanding and defining ecosystem services needs to be discussed more deeply.

Considering the foundations of contemporary ecology and the results of the quoted researches and reports as well as their discussions, ecosystem services – according to the author – may be defined in the following way: ecosystem services include all the processes in ecosystems supplied by living organisms and geophysical powers which process the matter, energy and information in a positive manner from the perspective of socio-economic processes and the development of society-economy-environment macrosystem. On the basis of the above definition, the author distinguishes the following main streams of ecosystem services:

- material – as temporary economic effects of processing matter in the society-economy-environment macrosystem, e.g. biomass production, waste decomposition,

[10] A. Graczyk, *Swiadczenia ekosystemów jako dobra ekonomiczne*, „Ekonomia i Środowisko" 2010 No. (1)37, p. 64-76.
[11] B. Poskrobko, *Kategorie: gospodarowanie, bogactwo i kapital w ekonomii zrownowazonego rozwoju*, in: *Ekologiczne uwarunkowania rozwoju gospodarki oraz przedsiebiorstw*, ed. J. Famielec, Uniwersytet Ekonomiczny, Kraków 2011, p. 21-40.

- energetic – as temporary economic effects of processing energy in the society-economy-environment macrosystem, e.g. solar energy accumulation in living organisms' tissues, transferring energy from the Earth's interior,
- information – as temporary economic effects of processing information in the society-economy-environment macrosystem, e.g. scientific and artistic inspiration, beauty of the nature, genetic information.

The function of total stream of ecosystem services can be expressed in the following formula: $ES(t) = F[ES_M(t), ES_E(t), ES_I(t)]$, where $ES(t)$ – total stream of ecosystem services, $ES_M(t)$ – stream of material ecosystem services, $ES_E(t)$ – stream of energetic ecosystem services, $ES_I(t)$ – stream of information ecosystem services. The analysis of constant time, provides a possibility to define the density of total stream. It is a derivative of a given function, under condition that the function is constant and differentiable. The density of stream at *t* point is defined with the following formula: $ES'(t) = F'(t)/dt$. Different types of ecosystem services can be distinguished in different groups of streams. Their further classification entails further theoretical work and empirical experiments on ecological economics and sustainable development with consideration to time in ecosystems. All ecosystem services have their spatial dimension.[12]

The proper interpretation of ecosystem services requires the researcher to employ the perspective of analyzing natural environment as a basis of all nations' wealth. From the most general perspective, wealth is a factor satisfying needs and wants. It is differently perceived by people in different social situations. In the mainstream theory of economics, wealth does not have a status of an economic category. Instead, the terms capital and added value are used and the wealth of a nation is measured in its domestic product. It seems that the largest mistake of classical economics was regarding natural resources as free goods which gained value only when acquired. Such an approach has led to colonization of the nature as purposeful interaction of a man with ecosystems and their processes regardless of the outcomes. Colonization of the environment brought significant changes in the circulation of matter, energy flows and information transfer in ecosystems. The present generation lives and develops at the cost of the coming generations. The economy of environment and sustainable development should lead to decolonization of natural environment, what requires new rules of functioning for the economic system and measuring the effects of developmental activities. Considering natural environment as a basic component of nations' (countries') wealth should become a key assumption.[13]

The author believes that ecosystem services should be analysed and researched in dynamic perspective with an account of temporal category. Special

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[12] see A. Michałowski, *Przestrzenne usługi środowiska...*, op. cit.; A. Michałowski, *Ekonomiczne podstawy usług srodowiska*, „Optimum. Studia Ekonomiczne" 2011 No. 6.

[13] B. Poskrobko, *Filary ekonomii zrównoważonego rozwoju,* in: *Ekonomia zrownowazonego rozwoju. Materiały do studiowania*, ed. B. Poskrobko, Wydawnictwo Wyzszej Szkoly Ekonomicznej, Bialystok 2010, p. 132-160; see e.g. E. Kośmicki, *Główne zagadnienia ekologizacji społeczeństwa i gospodarki*, Agencja Wydawnicza Ekopress, Bialystok 2009.

attention must be paid to economic consequences of the manifestations of time in ecosystems. Full understanding of the role of time in ecosystems is possible by comprehending the dynamics of species that take part in the process. Changeability of stand composition is an important feature of secondary succession. It results from regression of certain species and progression of others. These mechanisms are of strictly demographic character. Dynamic analysis of ecosystem phenomena cannot neglect the role of distribution and relocation of specimens in space. In succession processes the relations of a population to space change, especially the frequency of occurrence and the means of filling the space. They can have different character – certain species increase their frequency in time and space, others appear exclusively in selected places. The time and means of filling the space by a given species can influence significantly the organization and dynamics of ecosystem and the quality of ecosystem services streams.

The conditioning of time in ecosystems

In the theory of ecosystem service management temporal conditions refer primarily to the problem of natural resource exploitation, especially to renewable resources. They encompass those which can be reused after procession and use. From the perspective of human life in a sense of real time, renewable resources can be reused without any temporal limitations. The theory of economics offers a number of analytical approaches to temporal aspects of renewable and non-renewable natural resource management. One of the solutions is basing natural resource management on classical optimization harvesting, and particularly on the concept of Maximum Sustainable Yield (MSY). It offers a formal model that clearly explains the relations in renewable resources exploitation. However, it has a disadvantage related to the fact that renewable resource exploitation rarely means harvesting only one species. This brings the problem of weight definition, which is crucial in estimating the significance of other variables in the model. Another disadvantage of the concept is model sustainability which is exceptionally rare in real natural systems. Gordon's theory of rent-seeking is closer to reality. According to the theory, the balance between the industry and renewable resources will take place at the moment of equating streams of incomes with the level of costs. At the moment when income increases, the exploitation of outsiders starts, whereas in reverse situation there is a flow of capital to other branches of production. Moreover, the concept epitomizes the possibility of total exploitation of resources. The use of both concepts gives foundations to modeling the methods of natural resource preservation in a form of public goods, e.g. biodiversity or species population. The concepts can also be used with regards to ecosystem services.[14]

[14] see S. Czaja, *Czas w ekonomii...*, op. cit.

Temporal aspects of non-renewable resource management also generate significant problems related to the time range of their exploitation and allocation. From an economic point of view, Malthus's and Ricardo's paradigms influence the solution of these problems to largest extend. According to the former, there is an absolute limitation of resources, while in the latter there is no absolute exhaust of resources but the increase of exploitation costs resulting from the decrease of income. Malthus's approach does not account for the shift of temporal limitation of resources in the processes of new discoveries, technological development and changes of resource consumption. Ricardo's approach allows overcoming the limitations of Malthus's paradigm. Additionally, it is more flexible in analysing time range of non-renewable resource exploitation. Other problems arise with regards to non-renewable resource exploitation. They derive from the approach proposed by Hotelling. While traditional approach assumes the criterion of economic surplus maximization in microeconomic calculations, Hotelling's model makes assumption that the owner of natural resource deposits is the price taker and aims at maximization of the current value that is understood as the sum of discounted allowances from the resource exploitation. The allowance is a difference between what the purchasers want to pay for a unit of the resource and what the seller has to charge for delivering the unit to the market. Contemporarily, Hotelling's rule accounts for a few additional elements, including technological advancement, discovering new resource deposits and external costs in the light of preserving optimization conditions. Another problem is the inter-period allocation of resources. The problem appeared in the theory of economics with the publication by Ramsey[15] who rejected the idea of time discounting as unethical. Other opponent of discounting such as Arrow, Solow, Rawls and Sena also refer to Ramsey's point of view. Supporters of discounting emphasise, among other arguments, the consequences for man's survival and life opportunities for the future generations. As far as natural environment is concerned, the problems of discounting and monetary evaluation refer to legitimacy of the valuation of biotic and abiotic elements of ecosystems and the advisability of protection policy. Binding the issues of ethical with temporal reference facilitated the search for appropriate means of natural resource exploitation, on the other hand, it complicated the problem, particularly with reference to sustainable development and fighting with global ecological problems, including the decrease of ecosystem service quality.[16]

One of the most vital problems of sustainable development and ecosystem service management is to clearly understand the range and time frame of developmental processes. All dynamic phenomena, including sustainable development, function in cyclic systems. The most broadly discussed cycles in economics include civilization cycle, Kondratiev cycle, and business cycle. Society-economy-environment macrosystem is at different phases of known and unknown developmental cycles at a given moment. Each of the systems in society,

[15] F. Ramsey, *A Mathematical Theory of Savings*, „The Economic Journal" 1928 No. 38, p. 543-559.
[16] S. Czaja, *Czas w ekonomii...*, op. cit.

economy and environment changes in a specific developmental cycle.[17] Economic system develops at a very fast rate. Environmental system is based on differentiated natural cycles, which are very difficult to control. The development of the society is a resultant of changes in economy and in the society. Consequently, the macrosystem that is not in the dynamic equilibrium can be on the way to it. Therefore, the evaluation of the level of sustainable development implementation can be performed in suitably long time perspective. With regards to ecosystem service management the evaluation should consider the range of time in ecosystems.

Borys identifies boundary conditions for the economics of sustainable development. They have the characteristics of time in ecosystems. They should also constitute a basis for the sustainable ecosystem service management in dynamic approach to ecological processes, as they reflect the developmental properties of ecosystems. The most important temporal ranges of boundary conditions in society-economy-environment macrosystem should include the rules of development durability, rules of development sustainability, rules of development maintenance, integrated order and the rule of responsibility.[18]

Durability rules correspond to its specific variants and are assigned to defined ethical areas. They reflect different levels of social, economic and ecological reference and the existing conflict between conservative and expansive ways of management. Durability is graded according to restrictiveness of natural capital retention rules, which reflect the transition from ideal capital substitution to their increasing complementarity and domination of nature capital. The development that executes weak rule of durability (based on ideal capital substitution) means preserving the whole capital, regardless of its structure – nature capital, anthropogenic capital, human capital. Such a development is typically conventional and considers the most obvious requirements concerning resource management and ecosystem services. The development based on sensible and moderate rule of durability require the preservation of total capital with defined values of its individual elements. The development that executes strong rule of durability requires the preservation of each component of capital separately, because nature capital, anthropologic capital and human capital do not substitute one another. It has particular significance with relation to ecosystem services. From this perspective, maintaining nature capital and high level of ecosystem service quality are the key conditions of development. The development can be based on even more restrictive rule of durability that prohibits any exploitation of non-renewable resources, while renewable resources can be used to such a degree that allows for their renovation in the subsequent periods.

[17] B. Poskrobko, *Cykliczność, trwałość i równoważenie rozwoju*, in: *Zrównoważony rozwój. Wybrane problemy teoretyczne i implementacyjne w świetle dokumentów Unii Europejskiej*, ed. B. Poskrobko, S. Kozłowski, Wydawnictwo Wyższej Szkoły Ekonomicznej, Bialystok 2005, p. 19-36.

[18] T. Borys, *„Warunki brzegowe" ekonomii zrównoważonego rozwoju*, in: *Ekonomia zrównoważonego rozwoju w świetle kanonów nauki*, ed. B. Poskrobko, Wydawnictwo Wyższej Szkoły Ekonomicznej, Bialystok 2011, p. 51-68.

The rules of sustainability bring balance to preservation of anthropogenic, human and natural environments. The emphasis the necessity to improve life quality of the present and future generations by shaping proper proportions between different components of the total capital, including ecosystem services.

The rules of development self-maintenance emphasise inter-generation and intra-generation justice. Their manifestation is related to the drive to satisfy the needs of the present and future generations and to improve broadly understood life quality as a supreme objective. Positive evaluation from at least anthropocentric system of values is a significant feature of development self-maintenance.

Integrated order is a positive ultimate objective of temporal developmental changes. It is a landmark for the changes characterised by the strong rules of durability, sustainability and self-maintenance. It means coherent and simultaneous formation of social, economic and environmental order. There are two approaches to integrated order: hierarchical and the one that does not differentiate the importance of each order. The former is characteristic for traditional developmental paradigms, while the latter – for the new paradigm of sustainable development. Hierarchical approach puts emphasis on the superiority of environmental order over economic or social one.

The rule of responsibility is one of the central categories of general ethics and axiology. Responsibility forms the basis of man's genuine identity and his/her awareness of the role they play in the economy. It can be referred to all activities in institutions and organizations, including entities of the economy, business and its sectors, the country and politics. In socio-economic practice, there are three approaches to responsibility, which also have time in ecosystems dimension. The first two approaches are characteristic for old economic paradigms, while the third one is an axiological boundary condition for sustainable economy. According to this condition, a man is good by nature; however, in the moments of weaknesses he rejects his nature as a result of mistakes in his upbringing or the pressure from his environment. Responsibility is represented in a number of dimensions: legal, economical and financial, social and ecological. In ecosystem service management these dimensions must be analysed in the perspective of time in ecosystems.

Czaja emphasises two basic interpretations of temporal dimension with relation to sustainable development strategy – epistemological and implementational.[19] Both of them are significant in sustainable ecosystem service management with regards to time in ecosystems. The former interpretation concerns abstract time, while the latter adopts real, astronomical or calendar dimension. In epistemological interpretation time is related to the essence of sustainable development and its attributes, considering time as a limited dimension and the evolution of sustainable development objectives. The use of implenetational interpretation is concerned with the possibility to control the pace of processes in time, their temporal coordination and time range of sustainable development strategy. The issues get even more complicated when dynamic ecosystem processes in

[19] S. Czaja, *Czas w ekonomii...*, op. cit.

ecosystem services are taken into account. Vast majority of them is of chaotic character, their trajectories and paces change in a completely different manner than on the basis of simplified models of traditional economics. Therefore, a system of gathering, processing and utilizing information on dynamic ecosystem processes should be constructed. With regards to research, it is necessary to broaden their scope by randomness – risks and uncertainty in the scale of time in ecosystems and changes in pace.

Sustainable ecosystem service management requires considering broader range of information about dynamic processes in ecosystems. It is in line with the foundations of sustainable economy and knowledge-based economy. The processes of ecosystem service management occur in the circumstances of increasing ecosystem complication in time during primary succession (which takes place in primary ecosystems) and secondary succession (in devastated ecosystems). The continuity of fauna and flora in a given ecosystem leads to qualitative and quantitative biodiversity, whose condition corresponds to a given set of ecosystem service streams and their density – expressed in natural or monetary units.

The main disorders of relations in ecosystems trigger succession, which is a form of their regeneration. Along with succession, the reconstruction of biocenoses occurs, including animal and plant species. The theory of ecology proves that such process does not equal the return to the conditions from before the devastation. This results from the decrease of species diversity and reconstruction of food chains that is based on their shortening. The share of smaller organisms with short life cycles and quick metabolism increases. The share of big organisms characterised with slow development decreases. Succession processes can be quickly broken by environment management. One of the examples is cultivation of annual plants. Succession may also proceed uninterrupted, as it is in case of forest planting and agricultural cultivation with limited ploughing. Succession changes in individual groups of organisms have different speed and pace. The development of flora is long if compared with the speed of changes that take place in organisms whose life is measured in days or hours. These differences clearly explain the lack of concordance between the diversity of autotrophic and heterotrophic organisms. For instance, the research conducted in prairie for many years showed the contradiction between the world of animals and plants. In the period of decreased plant diversity during the development of high prairie and the increase of plant biomass, a reverse tendency was observed in the group of invertebrates. In the grazing prairies as little as half of the number of arachnids were found, in comparison with non-grazing prairies. Similar results were obtained in research on prairie insects and mammals, which obviously prefer high trees to grazing low-prairie communities. Birds, however, behave in an opposite way to the rest of animals. They favour open plant communities in low grazing prairies, where they find better conditions for nesting and gathering food. The presented contradiction in the development of biodiversity constitutes a significant obstacle in ecosystem service management as far as the choice of priorities and streams is concerned.

Sustainable environment service management with regards to time in ecosystems includes interaction with succession processes. The theory of biodiversity exposes practical problem of ecosystem management that concerns the appearance of new species in the time space. It can be analysed in three dimensions:

- the appearance of new species which can settle ecological niches – this is a natural phenomenon of biodiversity change and increase in time,
- reintroduction of species which disappeared for various reasons – it allows to accelerate succession or facilitate the appearance of new species which are suppressed by natural ecological barriers; it leads to changes in the increase of biodiversity,
- the appearance of species that are stranger to their native habitat, e.g. from other areas of Europe and the continents – it is related to introduction and bringing in alien species, what can cause the displacement of native species from the ecosystems; alien species usually demolish existing relations and facilitate the introduction of other new species into ecosystems.

Disturbances and regressions of ecosystems lead to regeneration of the state similar to the previous or the formation of the system with different biodiversity, which conditions ecosystem service streams. In the first stage of succession this can refer to regeneration of natural processes of ecosystem services, e.g. energetic, which are based on a simplified internal structure. However, previous elements or even redundant structures that extensively secure the same processes may not regenerate. In sustainable ecosystem service management it is indispensible to maintain the critical structures that secure certain sets of streams. Maintaining all redundant structures generates the increase of costs. The objectives of ecosystem service management should be based on scientifically proven social, economic and ecological justification with regards to biodiversity and its changes in different scales of time in ecosystems and various ecosystems. The need to optimize the stability in local and global service management should be accepted. Their maintenance may be self-excluding in the static approach, however, in the dynamic analysis of time in ecosystems, the set of service streams may be evaluated and valued (including monetary valuing) in a given time frame, e.g. 100 years. The selection of management methods becomes more flexible with the adoption of time in ecosystems in sustainable environment service management. However, such a process entails providing significant amount of information and basing all the environment management processes, including those unregistered by the market, on knowledge.

The problem of time in ecosystems in ecosystem service management is closely related to changes in biodiversity. According to Odum[20] and Margalef's[21]

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[20] E.P. Odum, *The strategy of ecosystem development*, „Science" 1969 No. 164, p. 262-270; see e.g. F.E. Clements, *Plant succession and Indicators*, H.W. Wilson, New York 1928; H.R. Delcourt, P.A. Delcourt, *Quaternary landscape ecology: Relevant scales in space and time*, „Landscape ecology" 1988 No. 2(1), p. 23-44; K. Falinska, *Ekologia roslin*, PWN, Warszawa 2004.

[21] R. Margalef, *Perspectives in Ecological Theory*, University of Chicago Press, Chicago 1968.

theory, the biodiversity indicators increase from initial stages of succession to the final ones. More detailed elaborations on selected groups show that the increase of biodiversity is not monotonous because the indicators can reach higher values also in transitory stages. The relation between qualitative and quantitative states of biodiversity with ecosystem stability is one of the controversial issues. It is not clear whether biodiversity leads to the stability or if it is the other way round.[22] One should, however, notice that in more diverse ecosystems there are more alternative elements that process matter, energy and information, what ensures the maintenance of ecosystem services with lower risks and uncertainty.

Keeping appropriate set of ecosystem service streams is an important problem in environment management. They are results of ecosystem processes performed by species diversity. Ecologists proved that certain moderate ecosystem disorders change and increase biodiversity. Numerous disturbing agents are also neutral, e.g. appearance of herbivores, natural gaps in the forests, fires, fallen trees, boar rooting, cracking. There is a model in the theory of ecology in which ecosystem diversity is closely related to environmental stress – mowing, grazing, water and food availability.[23] According to this model, ecosystems with very low and very high stress are the habitat of very few species, while moderately stressed areas are biologically more diversified. Appropriate timing of mowing, grazing or removing fallen trees can maintain proper biodiversity from the point of view of a selected set of ecosystem service streams. It is achieved by suppression of more vigorous species i.e. potential dominators, and generating opportunities for other species. Properly selected environment management processes can lead to the preservation of service stream's data at a given spatial-temporal section. One should remember that ecosystem management at early stages of succession allows for easier and more profitable generation of particular streams of ecosystem services. All of the analysed problems of time in ecosystems require incorporating knowledge-based economy, the theory of ecological economy and sustainable development, especially with regards to the category of ecosystem services.

Final remarks

Time in ecosystems is an inseparable element influencing the phenomena and management processes in a form of a fourth dimension of the space-time or a logical consequence of events. The research problems should not focus on questioning whether to consider the role of time in ecosystems in management processes, especially with reference to sustainable management of ecosystem

[22] *Rożnorodność biologiczna: pojęcia, oceny, zagadnienia ochrony i kształtowania*, ed. R. Andrzejewski, R.J. Wiśniewski, Komitet Naukowy przy Prezydium PAN Człowiek i Środowisko, Zeszyty Naukowe No. 15, Instytut Ekologii PAN, Oficyna Wydawnicza, Dziekanów Leśny 1996; see A. Richling, J. Solon, *Ekologia krajobrazu*, PWN, Warszawa 2002.

[23] e.g. *Uwarunkowania ochrony rożnorodności biologicznej i krajobrazowej*, ed. L. Ryszkowski, S. Balazy, Zakład Badań Środowiska Rolniczego i Leśnego PAN, Poznan 1999.

services, but on the defining how the time must be understood and how to incorporate it to the theory of economics and economic practices.

In dynamic and mathematical approach, ecosystem can be defined as a deterministic mathematical formula which defines its evolution in the function of time. Time can be a constant or discrete variable expressed in integral values. In case of constant time, it can be expressed with a vectorial formula: $dE(t)/dt = F[E(t)]$, where E is a n-dimensional vector, dynamic ecosystem because for an initial state E(0) there is a possibility to solve the equation, with the aim to obtain future states of ecosystem $E(t)$ for $t > 0$. In order to make this vectorial (differential) equation describe dynamic ecosystem additional assumptions need to be taken for the existence and explicitness of Couchy's equation for $t \in [0, \infty]$[24]. The path of ecosystem evolution is its trajectory. Such dynamic models can be used to research three interesting economical problems: model stability (ecosystem), connection link between the states of dynamic equilibrium and comparative dynamics. They should be related to the practical problem of the optimization of ecosystem service streams in society-economy-environment macrosystem in the light of the properties of time in ecosystems. Sustainable ecosystem service management must be based on dynamic economical and ecological models. Designing them is a challenge in terms of theory and implementation in ecological and sustainable economy.

[24] S. Czaja, *Czas w ekonomii*, op. cit.