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Dragan Petrović, Zorana Filipova

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UVOD / INTRODUCTION

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Tabela 1 - Rezultati eksperimentalnih merenja

Ispod ilustracije treba da stoji objašnjenje, npr.: *Slika 1 - Rezultati simulacije procesa*

Nazive tabela i grafikona takođe dati na srpskom i engleskom jeziku.

Formule numerisati rednim brojevima u malim zagradama. Pozivanje na formule u tekstu vrši se navođenjem odgovarajućeg rednog broja u malim (okruglim) zagradama:

$$\overline{R_u} = L_4 + L_3 F_x \left(\frac{\overline{U_{pm}} - \overline{U_{gm}}}{\overline{U_{pm}^2}} \right) \quad (1)$$

U ovom odeljku se takođe vrši upoređenje rezultata koje su dobili autori s podacima iz radova navedenih u spisku referenci, što predstavlja osnovu diskusije.

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LITERATURA / REFERENCES

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Petrović, S. (2019). *Zaštita vodnih resursa*, Naučna knjiga, Beograd, 403 str.

Smith, G. (2020). Title of the article, *Chem. Phys.*, 65 (4), pp. 19-35.

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Reevaluation of economic growth through the prism of natural capital sustainability

Preispitivanje ekonomskog rasta kroz prizmu održivosti prirodnog kapitala

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Abstract: This paper explores the messages of various economic growth policies through the lens of the imperative of natural capital sustainability. It highlights the key differences between the policy of green growth and the recommended policies of stagnation and deceleration of economic growth, as advocated by the Degrowth and Post-growth concepts. These differences are evident in the fact that the green growth concept and the associated greening policies are based on the assumption that future economic growth is feasible if measures related to increased use of renewable energy, extensive recycling, and the transition from linear to circular production are implemented. In other words, proponents of green growth do not consider fundamental changes in economic systems necessary to address global environmental issues such as climate change, the biodiversity crisis, and other problems associated with the unsustainable exploitation of natural capital. Conversely, the critique of green growth from the Degrowth and Post-growth perspectives argues that such policies cannot achieve a decoupling of production increases from the consumption of natural capital. Consequently, these concepts critique not only economic growth as a central macroeconomic category but also challenge the potential of green growth to ensure sustainable global production and consumption in the future.

Keywords: Natural capital, Green Growth, Greening policies, Degrowth, Post-growth.

Sažetak: Ovaj rad istražuje različite politike ekonomskog rasta kroz sočivo imperativa održivosti prirodnog kapitala. Ističu se ključne razlike između politike zelenog rasta i preporučenih politika stagnacije i usporavanja privrednog rasta, koje zagovaraju koncepti odrasta i post-rasta. Te se razlike očitavaju u činjenici da se koncept zelenog rasta i povezane politike ozelenjavanja temelje na pretpostavci da je budući ekonomski rast izvodljiv ako se preduzmu i implementiraju mere vezane za povećano korišćenje obnovljive energije, ekstenzivno recikliranje i prelazak s linearne na kružnu proizvodnju. Drugim rečima, zagovornici zelenog rasta ne smatraju da su fundamentalne promene u ekonomskim sistemima neophodne za rešavanje globalnih ekoloških problema kao što su klimatske promene, kriza biodiverziteta i drugi problemi povezani sa neodrživom eksploatacijom prirodnog kapitala. Nasuprot tome, kritika zelenog rasta iz perspektive odrasta i post-rasta tvrdi da takve politike ne mogu postići razdvajanje povećanja proizvodnje od potrošnje prirodnog kapitala. Shodno tome, ovi koncepti kritikuju ne samo ekonomski rast kao centralnu makroekonomsku kategoriju, već i dovode u pitanje potencijal zelenog rasta da obezbedi održivu globalnu proizvodnju i potrošnju u budućnosti.

Ključne reči: prirodni kapital, zeleni rast, politike ozelenjavanja, odrast, post-rast.

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INTRODUCTION

The origins of modern criticism of economic growth, particularly in the context of increasingly evident negative environmental externalities and the overexploitation of natural resources, can be traced back to the 1972 Club of Rome report, *The Limits to Growth*. This report emphasized the necessity for economic analysts to consider the physical dimensions of the economy and its functioning in accordance with the basic laws of thermodynamics (Meadows et al., 1972). Despite its shortcomings, the report highlighted a paradox in development economics: the notion of limitless production growth on a finite planet.

Brundtland's 1987 report, *Our Common Future*, introduced the concept of sustainable development, defining it as the capacity to meet current human needs without compromising the ability of future generations to meet their own needs. Overall, sustainable development underscores the need to balance economic, social, and environmental goals (Our Common Future, 1987).

Criticisms of economic growth policies that promote unlimited growth without adequate consideration of the limits imposed by natural capital sustainability have led to the emergence of alternative frameworks and development policy tools. While many criticisms remain theoretical, a smaller subset provides concrete guidance for policy-makers.

The most common critique of conventional economic growth policies centers around the sustainability of natural capital as a driver of unlimited growth, and the increasing inequalities in the distribution of newly created value and wealth. This paper focuses particularly on the first aspect, examining how different critiques address the issue of natural capital sustainability.

The scope and messages of criticisms regarding the feasibility of unbridled economic growth in the context of natural capital sustainability vary significantly. These range from advocating minor adjustments to GDP calculations, without questioning the central role of growth in policy-making, to supporting continued growth with reduced natural capital consumption through green economy measures, and even to more radical positions advocating for the curtailment and slowdown of economic growth.

The main debates over growth policies in the past decade have revolved around the concepts of Green Growth, Degrowth, and Post-Growth. However, the essential differences between these concepts and their implications for development policy are not always sufficiently highlighted in the literature on economic growth and sustainable development. Therefore, this paper aims to explain the messages of different economic growth approaches from the perspective of natural capital sustainability.

The structure of the paper includes three sections. Following the introduction, the second section provides a descriptive analysis of Green Growth and its key criticisms from the perspective of natural capital sustainability, focusing on Degrowth and Post-Growth concepts. The third section interprets the results of this descriptive analysis, primarily assessing their implications for contemporary macroeconomic development policies.

1. MATERIALS AND METHODS

1.1. Natural Capital as an Engine of Economic Growth

From a broad perspective, economic growth represents a holistic view of the world, reflecting the rise of modern industrialized societies and dominant modes of production and consumption. In macroeconomic terms, economic growth is seen as the main driver of wealth creation, new investments in physical and educational infrastructure, and improvements in innovation at all levels.

Economic growth is most often measured by Gross Domestic Product (GDP), which quantifies the total value of produced and marketed goods and services within a country over a year. The GDP per capita is commonly used to illustrate the standard of living of the population. It is therefore not surprising that GDP growth is associated with solving a wide range of economic and political problems, including increased employment, higher incomes, and improved social outcomes in education and healthcare. Since the mid-20th century, many countries have focused their development policies on economic growth. However, over the past twenty years, this focus has been increasingly criticized as an insufficient measure of economic and social progress. A significant issue is the neglect of the serious consequences of human activities on the excessive consumption of natural capital.

Natural capital encompasses all renewable and non-renewable natural resources and environmental functions essential for human life and economic activity. In other words, it includes natural resources, both renewable and non-renewable, the environment, and land as a production factor for agriculture. Natural capital has four primary functions for humans: it provides raw materials for economic goods, serves as a waste repository, supplies natural goods, and supports life. Created or produced capital represents everything humans have made, while human capital refers to the total knowledge, education, and skills possessed by individuals.

Although natural capital has been recognized as an input in production, it has long been absent from economic growth models. When incorporated, it was generally based on the premise of substitutability between natural and created capital. In other words, it was assumed that a reduction in natural capital could be offset by an increase in created or human capital, keeping the final output constant (Costanza & Daly, 1992).

Neoclassical economic theory assumes that natural and created capital are almost perfectly substitutable. Nobel laureate Robert Solow argues that this substitution occurs over time: current generations consume natural capital but leave a greater volume of created and human capital for future generations (Solow, 1993). This idea is based on two important assumptions: that technological progress will enable the transformation of natural capital and that market mechanisms will effectively allocate resources. Consequently, the need to incorporate environmental values into the market through the internalization of external effects has become increasingly evident.

If we assume that it is sufficient to maintain the sum of all types of capital constant, then addressing the preservation of nature and its functions would be unnecessary. It would be sufficient to increase created capital proportionally to the destruction of natural capital. From a neoclassical perspective, the weak sustainability approach is considered acceptable. Hartwick's rule, for instance, posits that consumption can remain constant or increase if the rent from non-renewable resources is reinvested in renewable capital (Hartwick, 1977).

The neoclassical assumption of perfect substitutability between natural and created capital has faced significant criticism. Critiques commonly question why so much natural capital has historically been converted into created capital if they are true substitutes (Daly, 2007). Natural capital is essential for producing created capital, suggesting that they are not true substitutes. Moreover, while the destruction of created capital is not irreversible, the loss of certain plant and animal species, as well as non-renewable fossil fuels, is often irreversible. Additionally, if created capital was a true substitute for natural capital, it would be unclear why increasing created capital is necessary when natural capital is abundant (Costanza & Daly, 1992). Unlike created capital, natural capital can, in some cases, renew itself (Farley & Daly, 2006). Therefore, while there may be some degree of substitutability between labor and created capital or between different types of natural capital, perfect substitutability between created and natural capital is not feasible.

If natural and created capital are complementary, then economic growth is constrained by the type of capital that is in the shortest supply. Historically, when the production subsystem was relatively small compared to the global ecosystem, created capital was the limiting factor. Today, with exponential population growth and accelerated economic development, natural capital has become the limiting factor.

The fact that economic growth can no longer be considered without acknowledging the constraints imposed by the finite nature of natural resources and the capacity of ecosystems to absorb environmental pollutants is frequently overlooked. This oversight is often viewed as an inevitable consequence of expanding economic activities. Within this framework, discussions about economic growth have increasingly centered on the tension between production and consumption growth and the sustainability of natural capital. This tension highlights the challenges and potential scope of the concept of green growth.

1.2. The Essence of the Green Growth Concept

At the core of the green growth concept is the belief that it is possible to achieve economic growth while maintaining a stable or preferably declining trend in the exploitation of natural capital. Green growth aims to address long-standing economic and environmental challenges while promoting new forms of growth. This involves stimulating production through reduced consumption of natural resources and energy and minimizing pollution per unit of final output (Loiseau et al., 2016).

Analytically, the idea of green growth can be related to the Environmental Kuznets Curve. According to this model, economic growth initially leads to environmental degradation, but beyond a certain level of development, a turning point occurs where economic growth becomes decoupled from environmental harm (Figure 1). In the context of economic growth analysis, this concept of decoupling should be understood in two dimensions: first, as the separation of economic growth from the use of natural resources, and second, as the separation of economic growth from environmental pollution.

The concept of decoupling is crucial because humanity's tendency to intensify economic growth and improve human well-being often implies increased consumption of natural resources. According to neoclassical mainstream principles, this consumption typically has serious negative consequences for the environment and human health. The decoupling of economic growth from natural resource consumption and the impact of production growth on environmental degradation could, all else being equal, positively influence human well-being (Wood et al., 2018; Charlier & Fizaine, 2023). Therefore, in evaluating the success of the transition from traditional production models to green economy, it is important to consider not only GDP growth rates, natural resource use, and pollutant emissions but also indicators of human well-being growth.

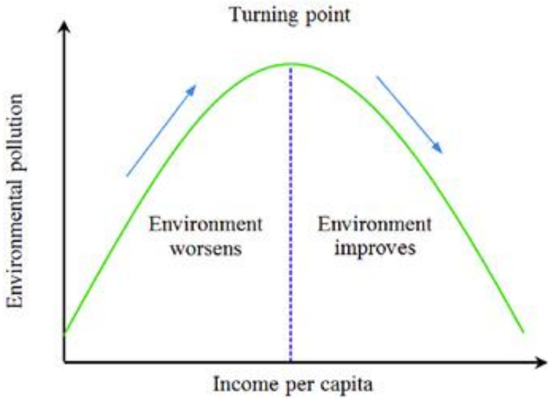

Figure 1: Environmental Kuznets Curve
Source: Karić et al., 2023

Proponents of green economic growth continue to view growth as a central policy goal but advocate for various adjustments to make growth more sustainable and inclusive. Examples of green growth policy instruments include environmental taxes, decarbonization measures, and other similar initiatives. Essentially, green growth is a key component of the green economy and a fundamental premise for achieving sustainable development goals. It fundamentally refers to economic growth driven by resource-efficient and cleaner production practices.

1.3. Critiques of Green Growth: Degrowth and Postgrowth Concepts

Criticisms of the green growth concept often highlight that many of the so-called planetary boundaries have already been exceeded, resulting in a high risk of generating large, sudden, or irreversible changes in the natural environment. In 2009, the Thomson Reuters Foundation introduced the framework of 'planetary boundaries,' assessing anthropogenic impacts on nine biophysical processes critical for maintaining the state of the planet necessary for modern human society. The 2009 report indicated that three of these planetary boundaries had been surpassed (Rockström et al., 2009). A subsequent study published in September 2023 found that six of the nine planetary boundaries had now been exceeded (Richardson et al., 2023). These processes are interdependent and can disrupt each other, leading to significant uncertainty. Scientists believe that the boundary for climate change has been most critically surpassed (Figure 2).

Critics of green economy policies argue that their proponents fail to fully address the fundamental changes required in economic systems to resolve critical issues such as the climate crisis, biodiversity loss, and various forms of environmental degradation. Instead, these critics advocate for alternative frameworks that propose significant economic transformations, including the cessation of economic growth. Among the approaches that question the efficacy of green growth policies in addressing escalating environmental challenges are the concepts of Degrowth and Post-growth.

Proponents of the Degrowth concept assert that a declining economy could potentially address ecological limits and social issues. This perspective advocates for profound structural reforms and proposes several policy options, including the cessation of fossil fuel extraction and consumption, restrictions on advertising, a focus on community practices and the sharing of goods, shorter working hours, and the implementation of a universal basic income.

The central motive behind the Degrowth concept is to enhance quality of life and promote environmental sustainability. Degrowth advocates for a shift in societal priorities from relentless economic growth and production to a focus on sustainability, well-being, environmental stewardship, and cooperation. It is a framework that mobilizes numerous researchers and activists to challenge the dominance of economic growth, arguing for a radical societal reorganization that significantly reduces the use of natural resources and energy as a necessary, albeit challenging, option (Kallis, 2018).

The current form of economic growth in industrialized countries is deemed unsustainable. Even if this growth is characterized as "green" - part of a transformative agenda investing heavily in renewable energy and sustainability - industrialized countries cannot rapidly reduce their negative impacts on natural capital while their economies continue to expand (Schmelzer et al., 2022: 11). Thus, transforming industrial production in economically developed countries is crucial for mitigating environmental damage and excessive resource consumption (Klein, 2019). Supporters of Degrowth argue that it is not only feasible but highly desirable to live well without continuous growth, aiming to create a more just, democratic, and truly prosperous society. This perspective is driven by issues such as inequality in value distribution, exceeding biophysical limits of natural capital, work overload, and rising living costs (Demaria et al., 2013). Achieving this requires a fundamental political and economic restructuring to overcome the structural dependence on growth embedded in capitalist economies, from industrial infrastructure to social systems and ideological growth myths (Jackson, 2017).

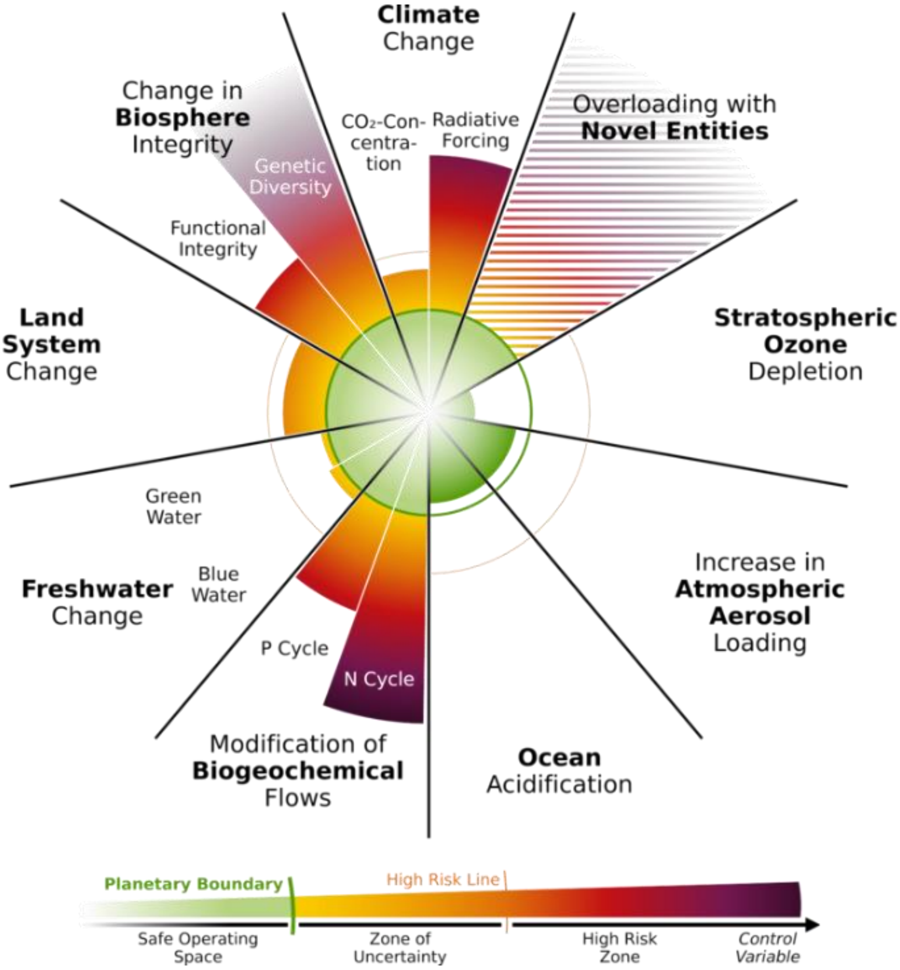

Figure 2: Current status of control variables for all nine planetary boundaries.
Source: Richardson et al., 2023

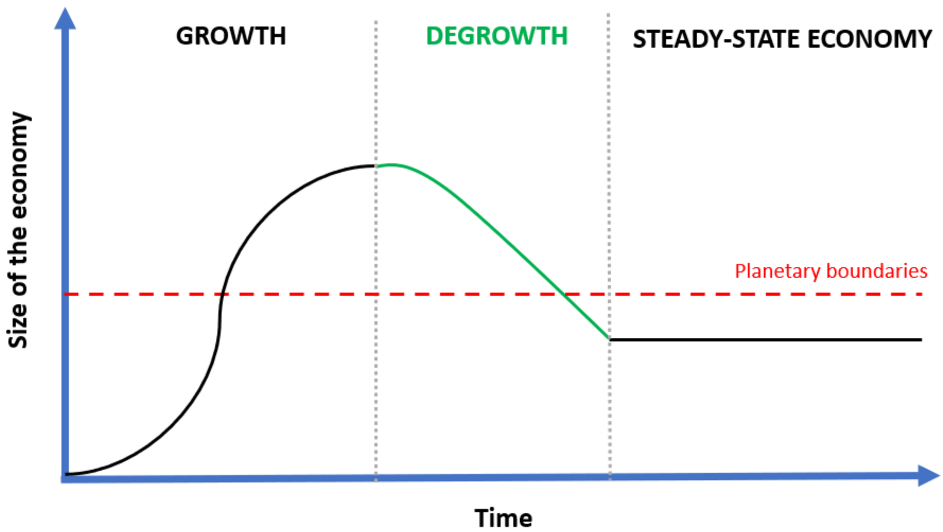

Figure 3: Steady State Economy
Source: Authors

Degrowth rejects the conventional growth theory notion that crises are resolved by recession and reduced savings, advocating instead for new approaches to sustainable production and demand. Evidence increasingly suggest that economic growth is not a sufficient condition for improving quality of life (Schmelzer et al., 2022). In essence, Degrowth represents a targeted reduction in economic activity and consumption in high-income countries to foster a more socially sustainable society. While certain economic sectors, such as renewable energy and public transportation, must grow to ensure a sustainable future, other sectors that primarily boost corporate profits and consumption among the wealthiest have minimal impact on overall human well-being (Hickel, 2020). The constant pursuit of economic growth, critics argue, benefits only a small portion of the population and incurs substantial social and environmental costs. The challenge is to halt the unending quest to increase global production and consumption and instead create socio-ecological conditions that support meaningful, fulfilling lives for all. The core idea of Degrowth is living well with less, which can be achieved by prioritizing welfare, justice, and sustainability through transformative strategies that allow societies to decelerate (Kallis et al., 2020). This approach envisions a post-capitalist economy that is more socially responsible, focusing on improving human well-being and preventing ecological collapse. By consuming less from nature, it is possible to achieve more, with proponents advocating for the abandonment of growth as the primary economic goal and reorganizing economies to enhance well-being rather than capital accumulation.

The Post-growth concept challenges the established economic position that a higher GDP per capita invariably indicates greater human well-being (Wiedmann et al., 2020). This approach suggests that wider economic justice, enhanced social well-being, and ecological regeneration can be achieved without the continuous intensification of economic growth. Economies function within a physical environment and depend on the ongoing use of natural capital. Natural resources, whether non-renewable or renewable at a rate limited by environmental capacity, inherently limit future economic growth. Similarly, the environment's capacity to absorb waste and pollution is strained by continually growing production and consumption. Evidence from the late 20th century indicated that the rate of natural resource consumption outpaced renewal rates, while waste emissions exceeded the environment's capacity to manage them.

Supporters of the Post-growth concept argue that it is possible to structure the economy so that production remains within the limits imposed by available natural capital. They emphasize that human activities and flawed production-consumption patterns place significant pressure on a planet with limited resources. Future economic and social development should focus on operating within natural limits, with waste production matching environmental absorption capacities. Technological advances alone cannot overcome physical limits, such as finite oil reserves. Therefore, future economic policies must be more committed to addressing natural capital sustainability. Post-growth advocates believe that respecting natural capital constraints requires rejecting the paradigm of unlimited economic growth. Existing societies, economies, and cultures, however, promote consumption expansion and inhibit necessary social changes due to the growth imperative in competitive market economies (Wiedmann et al., 2020).

2. DISCUSSION

The preceding descriptive and graphical analysis of economic growth sustainability, considering the limitations imposed by natural capital, leads to the following conclusions:

Green Growth Perspective: Proponents of Green Growth assert that it is possible to achieve increased production while avoiding transgression of planetary boundaries, thanks to the decoupling of economic growth from environmental degradation. This concept hinges on the idea that economic expansion can be reconciled with environmental sustainability through efficient resource use and technological innovation.

Criticism of Green Growth: Critics argue that natural capital is fundamentally the limiting factor for economic growth, making indefinite production increases unfeasible. They contend that the neoclassical view of substituting natural capital with other forms of capital in the production process is unrealistic. This necessitates a qualitatively new approach to understanding the future possibilities of economic growth, recognizing the intrinsic limits of natural resources.

Degrowth and Post-growth Alternatives: In contrast to the Green Growth paradigm, which is rooted in sustainable development, the Degrowth and Post-growth concepts offer alternative visions of "development without growth." These perspectives suggest that development must occur within the constraints imposed by finite natural capital. They argue that a future perspective on development should focus on satisfying needs within the limits of natural resource availability, advocating for a reduction in economic activity and consumption as a path to sustainability.

This discussion underscores the critical debate on how economic growth interacts with environmental sustainability and the need for innovative approaches to reconcile human development with ecological limits.

CONCLUSION

Degrowth and Post-growth represent intersecting philosophies that underscore the necessity for profound socio-ecological transformation. They both recognize the inherent limits to growth, emphasizing the need to safeguard planetary boundaries and societal well-being to mitigate potential trade-offs.

Degrowth advocates for a fundamental shift in societal priorities from relentless economic growth and production to a focus on sustainability, well-being, environmental stewardship, and cooperation. Proponents argue that the continuous expansion of production and consumption, whether measured by GDP or other metrics, is untenable on a finite planet.

Post-growth offers a fundamentally different approach compared to Green Growth. While Green Growth focuses on integrating green technologies to achieve sustainable development within the current growth paradigm, Post-growth challenges the very premise of continuous economic expansion. According to Post-growth advocates, the primary challenge lies not in implementing green technologies but in rethinking and transforming the relationship between society, the economy, and the environment.

Together, these concepts highlight the urgent need to reassess how economic activities align with ecological limits and social needs, advocating for transformative changes that prioritize ecological balance and human well-being over unchecked growth.

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Tariffs, affordability and sources of financing of investment projects for environmental protection

Cene, pristupačnost i izvori finansiranja investicionih projekata u oblasti zaštite životne sredine

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Abstract: The objective of this paper is to analyze the impact of an investment project on tariffs, affordability and sources of financing. EU candidate countries on the Balkan Peninsula are required to implement various projects in water sector in order to protect its environment. The preparation and implementation of large investment projects require careful planning as well as financial and economic analysis. By applying European Commission methodology for assessing financial feasibility, financial analysis is performed in order to assess the impact of project implementation on prices of services, the ability of population to pay for new services and possible sources of financing. The conclusions of the analysis could be useful for institutions that should secure financing of such projects as well as the operators.

Keywords: financial analysis, tariffs, affordability, investment project, environmental protection.

Sažetak: U radu se analiza uticaj implementacije investicionog projekta u oblasti zaštite životne sredine na cene, pristupačnost i izvore finansiranja. Zemlje kandidati za članstvu u EU na Balkanu treba da implementiraju značajan broj projekata u oblasti zaštite voda. Priprema i realizacija velikih investicionih projekata podrazumeva pažljivo planiranje kao i sprovođenje finansijske i ekonomske analize. Primenom metodologije Evropske komisije za ocena finansijske izvodljivosti sprovedena je finansijska analiza sa ciljem da se oceni uticaj implementacije projekta na cene usluga, sposobnost stanovništva da plati novu uslugu i moguće izvore finansiranje. Zaključci ovakve analize mogu biti od koristi institucijama koje treba da obezbede sredstva za finansiranje ovakvih projekata kao i pružaoce usluge odnosno javna komunalna preduzeća.

Ključne reči: finansijska analiza, cene, pristupačnost, investicioni projekat, zaštita životne sredine.

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INTRODUCTION

Environmental protection includes protection of water as well as the treatment of wastewater that requires significant investments and adjustments of tariffs. Countries of the Balkans are preparing and implementing investment projects in this area and will face challenges with regards to possible sources of financing and tariff policy that may impact the ability of households to pay for new services.

Water is essential for human health and survival, playing a critical role in supporting sustainable ecosystems and driving socio-economic development, as numerous industries rely on it (Jokar et al., 2021; Mauchauffee et al., 2012). The main legal frameworks supporting the EU's commitment to enhance the quality of Europe's water resources include the Water Framework Directive (WFD; Directive 2000/60/EC), the Urban Wastewater Treatment Directive

(Council Directive 91/271/EEC), and the Drinking Water Directive (Council Directive 98/83/EC). Nika et al. (2020) stated that in the environment, water undergoes a cycle sustained by natural processes, including precipitation, infiltration, evapotranspiration and condensation. On the other hand, water resources are unevenly distributed in space and time, and are increasingly under pressure due to population growth and the growing global economy (Voulvoulis, 2018).

Due to climate change and low degree of resilience of water resource supply system, increased competition for water resources is expected globally (Rossi et al., 2023). In recent years, the growing pressure on water resources has reached a critical point, with declining water availability and deteriorating water quality. As a result, water has become unsuitable for use by both humans and ecosystems (Şahin and Manioglu, 2019). To address water scarcity, the principle of the circular economy (CE) could be applied (International Water Association). By transferring waste to the next cycle of the production process through the "product-waste-product" model the use of new resources is reduced thereby achieving socio-economic benefits (Stoimenov, Jevtić, 2023).

The objective of the paper is to analyze the impact of an investment project on tariffs, affordability and sources of financing. The preparation and execution of large investment projects demand thorough planning, along with comprehensive financial and economic analysis. Using the European Commission's methodology for evaluating financial feasibility, a financial analysis is conducted to assess the effects of project implementation on service prices, the population's ability to afford new services and potential financing sources (Economic appraisal vademecum, 2022; EC Guide, 2014). The findings from this analysis can provide valuable insights for institutions responsible for securing project financing, as well as for the project operators.

1. MATERIALS AND METHODS

The analysis was performed using data from financial statements and reports from a public utility company and municipality. The data includes water consumption and wastewater figures, invoiced quantities, current prices, current and historic operating and depreciation costs related to water and wastewater services, collection rates, estimated capital expenditures and operating expenditures. The methodology is based European Commission guidelines to cost-benefit analysis (2014) and Economic appraisal vademecum (2022) which require the implementation of full-cost recovery principle. The costs, tariffs and household disposable income are analyzed to determine if new service is affordable for the citizens of the agglomeration. By applying funding-gap calculation possible sources of financing are assessed.

The sources of financing are calculated based on the EC Guide to CBA (2014). The level of Community assistance is based on the "funding gap" rate of the project, i.e. the share of the discounted cost of the initial investment not covered by the discounted net revenue of the project. The funding gap is determined using an incremental approach. Specifically, the financing gap is calculated by subtracting the costs and revenues of the "without project" scenario from those of the "with-project" scenario. In line with requirements, the financing gap is calculated excluding contingencies, meaning that contingencies are not included in the discounted investment cost or in the discounted residual value of investments. The residual value of the investment at the end of the reference period is treated as revenue.

2. RESULTS AND DISCUSSION

The financial analysis includes affordability assessment based on the available income which is exogenous to analysis and future tariffs which are determined in the context of project characteristics. The approach to future tariff calculation included calculation of the current share of household income which is spent on water-related services and the minimum required revenue which is supposed to cover for "the operating costs and the rising portion of the depreciation charge" to satisfy the cost-recovery principle of investment projects prescribed by the Guide to Cost-Benefit Analysis of Investment Projects. The Table 1 summarizes the current tariffs for water and wastewater services.

The tariff system consists of separate tariffs for drinking water, wastewater collection and wastewater treatment service. The affordability criterion requires that the overall wastewater tariffs which include both wastewater collection and wastewater treatment do not exceed the maximum of 3% of available household income. It is assumed that the wastewater tariff should not be significantly different from the other two tariffs already introduced. Its introduction should not impose a large combined immediate financial burden for households. Apart from that there is the objective of full-cost recovery suggested by the Guide for Cost-Benefit Analysis of Investment Projects (2014) which requires that the revenues cover 100% of operating cost and an increasing portion of depreciation cost over the investment horizon. In this case, the immediate operating cost is fully ensured, while the depreciation costs coverage starts at 0% in first year of operation and then increases gradually to the level of 100% by the end of the reference period.

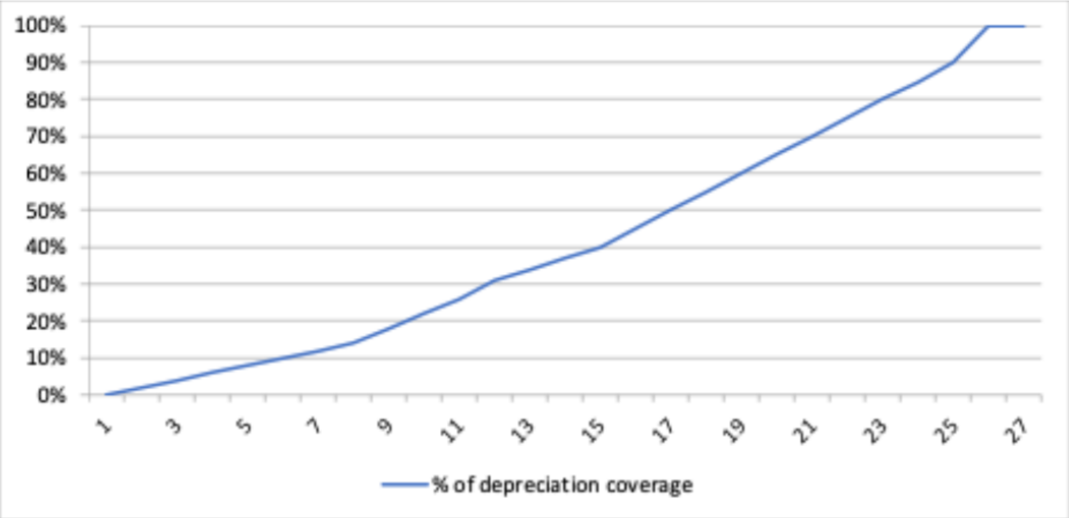

Figure 1: Depreciation coverage throughout investment horizon
Source: Author's calculation

One of the assumptions is that the current water and wastewater tariffs were sufficient to cover the existing costs. Relying on such assumption may not lead to the objective of achieving financial sustainability. Therefore, the water and wastewater costs during the last three years were analyzed and compared to the current tariffs.

Table 1: Water and wastewater costs in EUR

Water service	2021	2022	2023
Variable costs			
Maintenance	440.000	450.000	460.000
Electricity	65.000	70.000	75.000
Other variable costs	150.000	140.000	160.000
Fixed costs			
Wages/Salaries	550.000	590.000	600.000
Depreciation	370.000	380.000	400.000
Financial costs	16.000	18.000	19.000
Overhead costs	3.000	7.000	8.000
Other fixed costs	3.500	2.000	5.000
TOTAL	1.597.500	1.657.000	1.727.000
Wastewater service			
Variable costs			
Maintenance	14.000	11.000	13.000
Electricity	2.400	2.100	2.200
Other variable costs	24.000	20.000	19.000
Fixed costs			
Wages/Salaries	115.000	118.000	119.000
Depreciation	29.000	30.000	34.000
Financial costs	3.500	2.500	1.600
Overhead costs	750	710	650
Other fixed costs	965	210	650
TOTAL	189.615	184.520	190.100
TOTAL WATER AND WASTEWATER	**1.787.115**	**1.841.520**	**1.917.100**

Source: Author's calculations

The analysis show that current tariffs are not sufficient to cover the existing costs. Given the change in market price of electricity in 2022 and 2023, existing connection rates and revenue collection rate of 85% current tariffs should be increased by 30% on average in order to cover all existing water and wastewater costs (see Table 2).

Table 2: Tariffs for services, EUR/m^3

Type of service	Customer group	Current tariff	Proposed tariff
Water provision	households	0,60	0,78
Water provision	companies	1,00	1,30
Wastewater collection	households	0,10	0,13
Wastewater collection	companies	0,12	0,16
Wastewater treatment	households	/	0,30
Wastewater treatment	companies	/	0,30

Source: Author's calculation

In addition to what is stated above, the proposed future tariff is a result of the following set of assumptions. The tariffs gradually eliminate the difference in the population and industry water tariff by assuming that the ratio will gradually drop. The tariff system also gradually reduces the difference in the population and industry wastewater tariff. The assumed revenue collection rate starts at 85% in year 1 of the reference period and then slowly increases reaching 95% by the end of investment horizon. Following the start of wastewater treatment services, new wastewater treatment tariff should be EUR 0,30 m^3. Currently, the total cost of services provided is equal to 1,82 EUR/m^3 while the total cost of the proposed tariffs including wastewater services would be 2,97 EUR/m^3. Consequently, an average household bill would increase by 63% which may affect the ability of population to pay for the services.

In order to estimate the current share of household income the average annual amount of water billed to the households with access to water supply system is considered. The calculation takes into account tariffs for both water and wastewater services as presented in Table 2. The results are presented in the following chart (Figure 2).

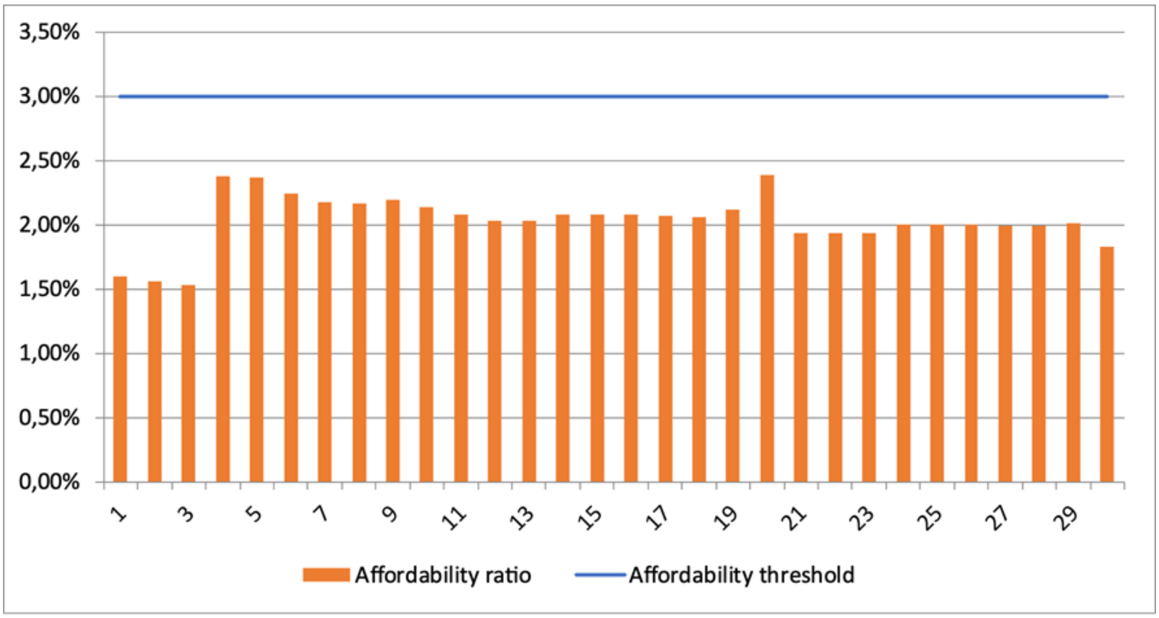

Figure 2: Estimated share of average household income spent on water and wastewater services
Source: Author's calculation

The construction period is three years and current affordability ratio of 1,6% is significantly below the threshold of 3%. During the first year of project operation, the affordability ratio would be at the level of 2,4%. The maximum ratio is reached in years 4 and 5 reaching 2,44% which is below the affordability threshold of 3%. One of the reasons for the decreasing affordability ratio are very high industry tariffs and the intense cross-subsidization in the early years of project life while the ratio between household and industry tariffs is allowed to converge to one (Васић и др., 2024).

Table 3 summarizes the funding gap calculation and possible sources of financing.

Table 3: Funding gap calculation

Parameter		
Reference period (years)	30	
Financial discount rate (% real)	4,00%	
Total investment costs, TC	35.000.000	
DIC = Discounted investment costs (incl. supervision)		31.125.000
Residual value	7.200.000	
Residual value discounted		2.650.000
Revenues discounted		17.500.000
Operating cost discounted		15.300.000
DNR = Discounted net revenue		4.850.000
Eligible expenditure, EE = MIN(DIC,(DIC-DNR))		26.275.000
Funding gap rate R = EE/DIC, %	84,42%	
Decision amount DA = EC (incl. contingencies)•R	29.546.185	
Maximum IPA Co-funding rate, %	85,00%	
IPA Co-funding amount = DA•85.00%	25.114.257	
Memo: R•Maximum IPA Co-funding rate, %	71,76%	

Source: Author’s calculation

The undiscounted investment cost is EUR 35 million with the residual value of EUR 7,2 million. Given the discounted revenues, operating costs and residual vale the discounted net revnue equal to EUR 4,85 million. Since revenues are modelled to satisfy the full-cost recovery principle, the discounted net revenues are positive. Hence, the funding gap rate is considerably less than 100% and it is at the level of 84%. IPA co-funding rate of 85% is applied on the funding gap rate resulting in maximum IPA co-funding rate of 72%. Given the assumed investment cost of EUR 35 million up to 72% of the investment cost could be financed by EU funds, while at least 28% of the investment cost should be covered by national budget and debt financing. These calculations are highly important for budget preparation process as they indicate the figures that should be budgeted over a three-year period.

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Nuclear accidents: past, present and maybe the future

Nuklearni akcidenti: prošlost, sadašnjost, a možda i budućnost

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Abstract: Radioactive contamination is the unintentional and undesirable presence of radioactive elements on surface or within organism. Such contamination can be result of technological developments, peaceful nuclear energy use, experimental nuclear activities, and the use of nuclear weapons in warfare. To mitigate the risk of radioactive contamination, protective measures are being implemented. During the period from 1945 to 1987, 28 accidents occurred due to human actions. Before the Chernobyl accident (26.04.1986, Ukraine), there were three notable cases of unintentional radioactive leakage from nuclear power plants: Kyshtym (1957), Windscale (1957), and Three Mile Island (1979). The incident at the Lenin nuclear power plant in Chernobyl resulted in global environmental contamination, with cesium residues are still present in Serbia to this day. At 1999 southern Serbia experienced contamination with long-lived radionuclides from depleted uranium used in the bombings. The Fukushima nuclear incident in Japan (2011) did not result in significant contamination in Serbia due to the considerable distance. Regardless of their development level, all states face common threats and risks in economic, informational, technological, biological, and nuclear security, which could potentially lead to new nuclear accidents.

Key words: radioactivity, nuclear accidents, radioaktive contamination, Chernobyl.

Sažetak: Radioaktivna kontaminacija je neplanirano i nepoželjno prisustvo radioaktivnih elemenata na površini ili unutar organizma. Može da nastane usled tehnološkog razvoja, mirnodopskog korišćenja nuklearne energije, eksperimentalnih nuklearnih proba, kao i usled primene nuklearnog oružja u ratnim sukobima. U cilju sprečavanja radioaktivne kontaminacije stanovništva sprovode se mere zaštite. Čovekovim delovanjem u periodu od 1945. do 1987. godine desilo se 28 akcidenata. Do akcidenta u Černobilju (26.04.1986, Ukrajina) zabeležena su tri slučaja ispuštanja značajne radioaktivnosti iz nuklearnih elektrana u okolinu: Kištim (1957), Vindskejl (1957), Ostrvo Tri Milje (1979). U nuklearnoj elektrani Lenjin u Černobilju, desio se akcident koji je doveo do globalne kontaminacije životne sredine, pa i Srbije. Na teritoriji Republike Srbije i danas su prisutne rezidue ^{137}Cs. Teritorija juga Srbije je 1999. godine dodatno kontaminirana dugoživećim radionuklidima u napadima agresora koji je koristio municiju sa osiromašenim uranijumom. Nuklearni akcident u Fukušimi (Japan) desio se 2011. godine, ali na sreću zbog velike udaljenosti nije doveo do kontaminacije životne sredine u Srbiji. Sve države se, bez obzira na stepen razvijenosti, suočavaju sa zajedničkim pretnjama i rizicima u oblasti ekonomske, informacione, tehnološke, biološke i nuklearne bezbednosti, koji mogu da dovedu do novih nuklearnih akcidenata.

Ključne reči: radioaktivnost, nuklearni akcidenti, radioaktivna kontaminacija, Černobilj.

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THE RADIOACTIVITY CONCEPT AND RADIONUCLIDE TYPES

Radioactivity and ionizing radiation were present even before the formation of planets and life on Earth. All organisms on planet Earth are exposed to radiation, which according to their place of origin, can be divided into: radiation of terrestrial and cosmic origin. Sources of ionizing radiation according to their genesis and occurrence in the environment can be divided into: natural (primordial or terrestrial, cosmogenic and cosmic radiation); anthropogenic (radioactive fallout and medical technology) and radioactive waste (Dangić, 1995).

Primordial radionuclides (^{235}U, ^{238}U, ^{232}Th, ^{226}Ra, ^{222}Rn, ^{40}K and others) are the most important sources of ionizing radiation in the environment. They have a long physical half-life (10^5-10^{16} years) and differ significantly in their physical and geochemical properties, types of radioactive decay (alpha, beta and gamma), radiation intensity, isotopic abundance, mode of occurrence, migration and geochemical cycles (Dangić, 1995).

Factors that affect the intensity of natural radiation are: the type of cosmic radiation, altitude, latitude and longitude, the content of natural radioactive elements in the biosphere and the geological characteristics of the soil. Natural radionuclides in the soil (formed in the process of nucleo synthesis, billions of years ago) make the largest contribution to gamma radiation (96%) in the environment. Natural radioactivity is part of the environment. It changes from place to place and affects the population over a very long period of time. According to the UNSCEAR report, the average mass concentrations (concentration range) of uranium, radium, thorium and potassium in the world's soil are: 2.82 (1.29-8.87) mg/kg; 3.18 (1.53-5.45) mg/kg; 7.32 (2.68-15.61) mg/kg and 1.54 (0.54-3.28) (%), respectively (UNCSEAR, 2000). Araxá in Brazil, Kerala and Madras in India, and Ramsar in Iran are examples of geographical areas on Earth where radiation doses up to 800 times higher than average have been measured (UNCSEAR, 2000).

Cosmogenic radionuclides (^{3}H, ^{7}Be, ^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl and others) due to their low concentrations, relatively short half-lives and low radiation intensities, have little significance in the total irradiation of the population.

Generated or anthropogenic radionuclides (^{3}H, ^{131}I, ^{129}I, ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{239}Pu, and others) have been amplified or created by human activity. They have different half-lives and emergencies. Contamination with these radionuclides is mainly regional in nature, but it can also be on a wider scale in the case of powerful nuclear explosions (Aakrog, 1988). Radioactive contamination of the environment with artificial radioactive elements occurs by: accidental release of radioactive effluents from nuclear power plants, accidents at nuclear facilities, discharge of waste from research laboratories and hospitals, inadequate disposal of nuclear waste or testing of nuclear weapons.

RADIOACTIVE CONTAMINATION

Radioactive contamination represents the unplanned and undesirable presence of radioactive elements on a surface or inside an organism. Radioactive contamination of certain parts of the environment can occur in several ways: due to technological development, peaceful use of nuclear energy, experimental nuclear tests, as well as due to the use of nuclear weapons in war conflicts. Regardless of the origin and manner in which radioactive substances are released into the environment, radionuclides pose a threat to the radiation safety of the population.

CONTAMINATION WITH ANTHROPOGENIC RADIONUCLIDES

Nuclear weapons testing and accidents at nuclear installations represent the main sources of contamination of the atmosphere by artificial radionuclides. There are two types of nuclear weapons: fissional or atomic bombs, in which nuclear energy is released by fission of uranium or plutonium nuclei, and fusion bombs (also called thermonuclear or hydrogen bombs), in which the atomic bomb is the trigger that causes the fusion of tritium and deuterium nuclides. Atmospheric testing of fission bombs leads to contamination of the atmosphere with fission products. Fusion bombs contaminate the atmosphere with ^{3}H, ^{14}C and other radioactive elements. They also release fission products, due to the use of fission material as a trigger for the explosion.

Radioactive elements that enter the environment, whether air, water or soil, begin their migration through the ecosystem and food chain and contribute to the overall irradiation of living beings occupying a certain territory. The behavior of radionuclides in the environment, their migration degree and inclusion in the food chain depends on: the manner of introduction into the environment, climatic factors, geographical characteristics of regions, physico-chemical characteristics of the soil and physiological-morphological characteristics of plants animals and mineral fertilizer (Čučulović et al., 2024). The migration of radionuclides through different ecosystems and links in the food chain is called the biological cycle of radionuclides. Radioactive elements of fission origin, which are easily incorporated and migrate through the food chain and pose a danger to all living things, are called biologically significant radionuclides. In order for a radioactive element to belong to this group, it is necessary: that it is formed in large quantities during nuclear fission, that it has a sufficiently long half-life, that it is present in large quantities in food and water, that it is easily absorbed in the body, that it has its own chemical analogue or stable isotope in the body and that it is excreted from the body in a short period of time and in large quantities. The most important biologically significant radionuclides are ^{134}Cs, ^{137}Cs, ^{89}Sr, ^{90}Sr and ^{131} (Mitrović, 2021).

The radioisotopes ^{134}Cs (physical half-life ($T_{1/2}$) = 2.06 years) and ^{137}Cs ($T_{1/2}$ = 30.17 years) are fission elements, beta and gamma emitters, whose radioactive decay produces stable isotopes ^{134}Ba and ^{137}Ba. Both radionuclides are present in the fuel elements of a nuclear reactor, from which they are released into the environment. An example of this is the behavior of ^{137}Cs. In the case of a nuclear bomb explosion, ^{137}Cs is initially present in the atmosphere in negligible quantities, after 2 months it is represented by 0.1%; after 9 months with 1%; after 2 years at 4%; and 20 years later, by 22 %. Due to its long half-life, it stays in the stratosphere for a long time and then gradually reaches the troposphere (Simon, 1971). The cesium ion is a chemical and biochemical homologue of potassium and follows its metabolism in the body. It is completely soluble in body fluids and is evenly distributed throughout the body. Because of this property, there is no critical organ for cesium and it is an organotropic radionuclide. Radiocesium is an extremely toxic element, and its physicochemical characteristics are such that it actively participates in the human and animal food chain through plants, because it metabolically replaces potassium. A biokinetic model of cesium in the human body shows that 10% of total cesium has a half-life of 2 days, and 90% has a half-life of up to 110 days. It is estimated that 80% of cesium is eliminated from the body in the urine (ICPR Publication, 1979). Cesium uptake processes from the external environment include: physical and chemical sorption and ion exchange. Radiocesium most often reaches plants through dry or wet rainfall. Sorption of radiocesium by vascular plants can be through the crown, stem or root system (Melnikov, Zanoni, 2010).

^{131}I is a biologically important radionuclide for the population. It is produced in significant quantities during nuclear fission or accidents at nuclear reactors and appears in elemental form or in the form of iodide, to a lesser extent directly from the air (as a radioactive aerosol), and mostly indirectly through green food and vegetables that are radioactively contaminated with atmospheric precipitation. The physical half-life of ^{131}I is 8 days. The biological half-life of ^{131}I varies in mammals, differing between species, but also within species. Absorbed from food, about 90% of ^{131}I reaches the bloodstream, from where 30-50% of it is taken up by the thyroid gland and fixed to its saturation, and the remaining amounts are excreted from the body through urine and feces (Drozdovitch, 2021).

NUCLEAR TESTS AS A SOURCE OF CONTAMINATION BY ANTHROPOGENIC RADIONUCLIDES

The Trinity test, the first nuclear test, was conducted in 1945 by the United States in New Mexico. The era of the use of nuclear weapons began in the same year, when the first atomic bombs were dropped on the cities of Hiroshima and Nagasaki (Japan), when more than 200,000 people died (were killed) almost instantly.

In the periods from 1954 to 1958, from 1961 to 1962, and from 1972 to 1982, the United States, the Soviet Union, and the United Kingdom conducted intensive tests (air, ground, underground, and underwater) of nuclear weapons. During the tests, hundreds of thousands of tons of earth was torn out, scorched, sucked into a fireball, quickly spreading into mushrooms and clouds, from which large pieces of various materials (soil, construction of buildings) fell to the ground, covering a surface similar to a circle (direct radioactive fallout). Local radioactive fallout occurs between 10 and 20 hours after the explosion and consists of large particles, larger than 5 μm in diameter, that fall from the atomic cloud into a confined space of ellipsoidal shape, forming "islands" of greater contamination. Smaller particles that entered the troposphere in the next 2 to 3 weeks after the explosion gradually fall to the earth's surface. This precipitation is called tropospheric radioactive fallout (semi-global or continental). Depending on the direction of the winds, it spreads around the Earth, making a full circle in 4 to 7 weeks. Stratospheric or global radioactive fallout is made up of very tiny particles that enter the stratosphere. Annually, about 10% of these particles are deposited on the ground. Radioactive elements that are deposited on the ground by radioactive fallout begin their migration process through the food chain and lead to irradiation and contamination of all living beings in the area (Simon, 1971). When nuclear bombs explode, the total precipitation is spread over large areas and significant amounts of radioactive particles fall into the world's seas. In 1963, the United States, the USSR and Great Britain signed an agreement in Moscow to partially ban nuclear tests in the atmosphere, oceans and space. Between 1972 and 1982, 20 above-ground tests were carried out (6 in the Northern Hemisphere and 14 in the Southern Hemisphere) (Jovanović, 1983). The consequences of these experimental nuclear explosions are manifold, the dangers are diverse and in many cases unpredictable. Between 1945 and 1990, about 540 atmospheric and 1,900 underground nuclear tests were conducted, while between 1945 and 1975, about 800 nuclear tests were carried out, with a cumulative strength of 325045 kT trinitrotoluene (TNT) (Mitrović, 2021).

NUCLEAR ACCIDENTS AS A SOURCE OF CONTAMINATION BY ANTHROPOGENIC RADIONUCLIDES

To meet the energy demands of humanity, nuclear power plants have been built, which, in normal operation, would contribute very little to the exposure of the population to radiation. Thus, in 1956, the first nuclear power plant, Colder Hall, with a capacity of 50 megawatts, was put into operation in Great Britain. Until then, both the United States and the USSR had their own reactors, but their power was negligible (only 2.4 MW and 5.0 MW respectively). By 1997, 442 power generation reactors had been built in 34 countries, with an installed capacity of 350825 MW. The construction of another 36 reactors with a capacity of 27678 MW was planned (IAEA Bulletin, 1997). By 2021, there were more than 400 nuclear power plants in the world distributed in thirty-one countries (Mitrović, 2021).

A nuclear accident is an unexpected event, human error, equipment failure and other irregularities whose consequences or possible consequences are not negligible from the point of view of protection against ionizing radiation, nuclear or radiation safety or security. Accidents at nuclear facilities can lead to regional, semi-global or global environmental contamination. Between 1945 and 1987, there were 28 accidents involving 272 exposures to excessive radiation and 35 deaths. Of the 27 accidents prior to the Chernobyl accident, only three cases resulted in significant releases of radioactivity into the environment: Kishtim - USSR (September 29, 1957), Vindscale - Great Britain (October 8, 1957), Three Mile Island - USA (March 28, 1979). The accident in Kishtim (southern Urals) discharged 49×10^{15} Bq ^{144}Ce; 19×10^{15} Bq ^{95}Zr and ^{95}Nb; 4.0×10^{15} Bq ^{90}Sr and 2.7×10^{15} Bq ^{106}Ru. Only 0.027×10^{15} Bq of radiocesium-137 was released. About 740 PBq radionuclides are thought to have been released into the atmosphere. The Vindscale accident contaminated the territory of Great Britain and Europe. On that occasion the following was released: 0.74×10^{15} Bq ^{131}I; 0.022×10^{15} Bq ^{137}Cs; 0.003×10^{15} Bq ^{106}Ru; 1.2×10^{15} Bq ^{133}Xe and 0.0088×10^{15} Bq ^{210}Pb. The accident at the Three Mile Island nuclear power plant (USA) emitted the most noble gases: about 370×10^{15} Bq (mostly ^{133}Xe) and 0.55×10^{15} Bq ^{131}I (Bennett, 1995; Kirchmann, 1997; Wirght et al. 1999).

In order to assess the accident extent and its consequences for human health and the environment, the International Radiation Protection Agency (IAEA) has adopted criteria for classifying them into seven safety categories or levels, known as the International Nuclear and Radiological Event Scale (INES scale). Events are classified into seven levels, of which levels 0 to 3 are considered incidents and levels 4 to 7 are considered accidents.

The accident that marked the 20th century was an accident at the Lenin nuclear power plant in Chernobyl, then the Soviet Union, now Ukraine, on the border with Belarus and Russia. The accident that occurred on April 26, 1986 at 01:23 a.m. once again pointed to the human factor as an always possible source of errors with catastrophic consequences. With their unfortunate manipulations, the operators of the power plant caused insufficient heat dissipation from the reactor core. Overheating of fuel elements, sudden production of steam and a chemical explosion produced a shock wave whose power was equal to several hundred kilograms of TNT explosives. As a result of the accident, a high-energy boiling reactor, with a power of 1 million watts and the production of 7.4×10^{19} Bq of various radionuclides, was destroyed, and the consequences of this accident were felt throughout the Northern Hemisphere and affected millions of people. The composition of the released material depended on the stage at which it was released. There were four characteristic periods of radionuclide emission from the damaged reactor: 1. explosion on April 26, 1986 (mechanical ejection of materials with iodine, tellurium, cesium and inert gases); 2. From 26 April to 2 May 1986, due to the covering of the reactor with about 5000 tons of boron, lead, dolomite and sand, the release of radioactivity decreased; 3. From May 2 to May 5, 1986, there was again an increase in the release of radioactivity, because there was an accumulation of heat in the reactor and thus an increase in the emission of volatile fission products, primarily iodine; and 4. After May 6, 1986. due to the measures taken, a decrease and termination of radionuclide discharge from the damaged reactor was observed.

The most significant and dangerous radionuclides released into the atmosphere were ^{131}I, ^{134}Cs and ^{137}Cs. About 12x10^{18} Bq of radioactive materials was released into the environment. About 85% of the released material originated from radionuclides with a half-life of less than one month (^{85m}Kr, ^{87}Kr, ^{88}Kr, ^{133}Xe, ^{135}Xe, ^{132}Te, ^{131}I, ^{132}I, ^{135}I, ^{140}Ba, ^{239}Np); 13% of radionuclides with a half-life of several months (^{95}Zr, ^{95}Nb, ^{103}Ru); 1% of radionuclides with a half-life of about 30 years (^{137}Cs, ^{90}Sr) and about 0.0001% with a half-life of over 50 years (^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{242}Cm) (Xavkes et al., 1987). The data show that in the period from 1945 to 1980, nuclear tests released about 6500 TBq of ^{239}Pu and 4300 TBq of ^{240}Pu into the atmosphere, and the Chernobyl accident released only 70 TBq of these radionuclides.

The dispersal of the ejected material, and therefore territorial pollution was largely due to meteorological conditions. At the time of the first explosion, in which the column of ejected material reached its highest height, local winds of variable direction were blowing over Chernobyl. They propelled the radioactive material to the north and east, rotating in the direction south of Chernobyl. Thus, the material first reached Scandinavia and Finland. During all this time, the radioactive cloud was mainly circling over the USSR and on April 28 its trajectory was diverted to the west and south, and a day later in the direction of Germany and France. On April 30, a southern direction developed: through Hungary, Austria and Yugoslavia, towards Greece and even western Turkey, where increased activity was observed from May 1 to May 5, 1986. Eventually, this material again reached Poland and Scandinavia.

As a result of the accident, countries outside the Soviet Union received more radiocesium than the Soviet Union itself. Of the 1.5x10^{17} Bq emitted in total ^{134}Cs and ^{137}Cs, 45x10^{15} Bq was deposited in the Soviet Union, while most of the activity of ^{90}Sr and transuranic elements was kept within the borders of the USSR (Battiston et al., 1987).

Most deposits of the activities were mainly in the central, northern and southeastern parts of Europe, at a distance of 2000 km from Chernobyl. Comparing the precipitation from nuclear weapons testing, the total ^{137}Cs released by the Chernobyl accident was an order of magnitude smaller, while its radioecological impact was 30% greater than that of radiocesium-137 resulting from nuclear tests. This is explained by the fact that Chernobyl activity was deposited in densely populated areas with relatively high agricultural production (Aakrog, 1988). In the accident, 237 people were highly irradiated, and 32 died during the first weeks of the accident as a result of radiation. All of the highly irradiated were members of the intervention teams that were engaged in cooling the crashed reactor and extinguishing the fire in the initial phase of the accident. The intervention teams were made up of operating and firefighting personnel.

According to UNSCEAR, the radioactive cloud affected the territory of Yugoslavia in two waves. It is estimated that during 1986, about 2.4% of the total radionuclides (excluding inert gases) were deposited on the territory of Yugoslavia, i.e. about 5% of ^{131}I and about 10% of ^{137}Cs (Savezni komitet za rad, zdravstvo i socijalnu zaštitu, 1987). In 1996, an estimated 80x10^{15} Bq of long-lived radionuclides, mainly ^{137}Cs and ^{90}Sr, were present in Europe.

In the laboratory of Institute for the Application of Nuclear Energy, INEP, immediately after the accident in May 1986, high levels of total gamma activity were measured in grass (30.6 kBq/kg) and soil of Belgrade (6.8 kBq/kg), while the activity levels of ^{137}Cs were 5.3 kBq/kg and 1.6 kBq/kg, respectively. (Stanković, Stanković, 1999). In the immediate aftermath of the accident, animal fodder was heavily contaminated with ^{134,137}Cs. Compared to other bulky, grainy and concentrated foods, alfalfa was the most contaminated (up to 6,234 Bq/kg was found in in alfalfa flour in 1986) (Stanković, Stanković, 1999). As a result of the contamination of animal feed, in 1986, high levels of ^{137}Cs activity were measured in meat (537 Bq/kg in sheep meat) (Mitrović, 1995). INEP measured high levels of ^{137}Cs activity in milk in the first half of 1986 that amounted to 292 Bq/kg. (Stanković, Stanković, 1996). In the INEP laboratory, high levels of ^{137}Cs activity were measured in the period from 1986 to 1991, in the meat of snails (521 Bq/kg, 1987) and game, deer (up to 60 Bq/kg, in 1986). These levels of activity are much lower than the ones determined in the meat of roe deer from Northern European countries, which suggests that the territory of Yugoslavia suffered less from the Chernobyl accident than the countries of Northern Europe (Stanković, Stanković, 1998; Stanković, Stanković, 1996). Medicinal plants were also heavily contaminated with ^{137}Cs. In 1986, Asperula (*Herba asperulae*) was the most contaminated with measured 4190 Bq/kg, while in 1987 hawthorn (*Sumitates crataegi*) exhibited 5579 Bq/kg. (Stanković et al., 1993). Immediately, after the accident the activity levels of ^{137}Cs in bioindicators were high: in mushrooms - morels it was up to 2389 Bq/kg, in lichen *Cladonia fimbriata* from the mountain Sinjajevina (Montenegro) it was 13610 Bq/kg. Moss was also contaminated immediately after the Chernobyl accident (Stanković, Stanković, 1996; Čučulović et al., 2014).

Today, in Serbia, the activity levels of ^{137}Cs in meat samples of domestic and wild animals, milk, dairy products, are less than 1.0 Bq/kg. Radioactive residues of ^{137}Cs can still be found on the territory of Serbia in bioindicators: fungi (< 20 Bq/kg), lichens and mosses, but these are values that would correspond to the values before the Chernobyl accident (Čučulović et al., 2020).

At the beginning of 1999, depleted uranium ammunition was used on the territory of Serbia and Montenegro, which caused contamination of the attacked territory: Pljačkovica, Borovac, Bratoselce, Bukurevac, Reljan (Serbia) and Cape Arza (Montenegro). After the launch of depleted uranium missiles, environmental pollution with depleted uranium can be: 1) carried by the wind; 2) transport by insects, war and human activities; (3) biological and chemical corrosion processes, and (4) rain, surface water and groundwater, which become secondary sources of uranium pollution. Studies have shown that in air samples (filters) taken in the given areas, the activity level of ^{238}U ranged from 1.99 to 42.1 μBqm^{-3}; ^{234}U from 0.96 to 38.0 μBqm^{-3} and ^{235}U from 0.05 to 1.83 μBqm^{-3} (Jia et al., 2005).

Prior to the Fukushima disaster, one of the world's 25 largest nuclear power plants, Japan had 55 nuclear reactors. The Fukushima nuclear accident (Okuma, Futaba Area, Japan, March 11, 2011) was one of the largest since the Chernobyl accident, but less dangerous for the local population, as much smaller amounts of radioactive materials were released. It included a series of nuclear accidents and device failures that occurred as a result of a large and strong earthquake (9 on the Richter scale). The plant consisted of six 4.7 GW BWR nuclear reactors. At the time of the earthquake, reactors 1, 2 and 3 were automatically shut down, while reactors 4, 5 and 6 were not operational. After the earthquake, a large tsunami struck reactors 1, 2 and 3 and flooded the entire area. As a result, the diesel generators that powered the reactor cooling pumps were left without electricity. Over the next few days, there was a partial meltdown of the core of reactors 1, 2 and 3 and a hydrogen explosion that destroyed the roofs of the building where reactors 1, 3 and 4 are located. The explosion damaged the container of reactor 2, and several fires also damaged reactor 4. Due to fears of the spread of radiation, the population was evacuated from an area of 30 km around the nuclear power plant. No one was killed in the disaster. Radioactive particles were released from the reactor into the external environment, the most important of which was ^{131}I, and prophylactic iodine tablets were distributed to the population. In addition to ^{131}I, ^{134}Cs and ^{137}Cs, highly radioactive plutonium, were released from the reactor. The accident was at level 7 on the INES scale out of a possible 7, the same as the Chernobyl accident, except that the radiation released was less than 10% of the radiation from Chernobyl.

The Chernobyl accident led to global environmental contamination. On the territory of the Republic of Serbia, ^{137}Cs originating from Chernobyl is still present in the environment, especially in hilly and mountainous regions. The accident in Fukushima, due to its long distance, did not lead to significant contamination of the environment of the Republic of Serbia.

In the Republic of Serbia, the construction of nuclear power plants, nuclear fuel production plants and spent nuclear fuel processing plants is prohibited by law, so these activities, as well as the mining and processing of uranium ore, do not contribute to additional irradiation of the population on our territory.

LEGISLATIVE BODIES AND LEGAL REGULATIONS AT THE GLOBAL AND NATIONAL LEVEL

In 1925, the first international congress of radiologists was held in London, where the need for the formation of a radiation protection committee was discussed. In 1928, the International Commission on Radiological Protection (ICRP) was founded in Stockholm and today it is an international organization whose recommendations are adopted by: the International Atomic Energy Agency (IAEA), the UN FAO (Food and Agriculture Organization of the United Nations) and the World Health Organization (WHO).

The first rulebook on protection measures when working with X-ray devices and radioactive substances in the Federal People's Republic of Yugoslavia was adopted in 1947, and in 1959 the Law on Protection against Ionizing Radiation was passed. In 1965, the Basic Law on Protection against Ionizing Radiation was adopted in the Socialist Federal Republic of Yugoslavia. Protection against ionizing radiation was the responsibility of the Federal Commission for Nuclear Power, the Federal Institute for Health Protection and the Federal Committee for Health and Social Protection. In the period from 1970 to 1987, the Federal Committee for Health and Social Protection published the results of measurements of radioactivity in the environment once a year in the publication "Radioactivity of the Environment in Yugoslavia". In 2009, the Agency for Radiation Protection and Nuclear Safety was established in the Republic of Serbia in order to provide conditions for the quality and efficient implementation of measures of protection against ionizing radiation and nuclear safety measures in the performance of radiation activities and nuclear activities. In 2018, the Agency changed its name to the Directorate for Radiation and Nuclear Safety and Security of Serbia.

The Yugoslav Radiation Protection Society was founded on October 11, 1963 in Portorož during the Yugoslav Symposium on Radiological Protection. In 1969, the Society became a full member of the International Commission on Radiation Protection (ICRP). In the period from 1972 to 2003, the Society changed its name to the Yugoslav Radiation Protection Society, and in 2005 it was renamed the Radiation Protection Society of Serbia and Montenegro.

FUTURE

We live in a world where the actions of some states are directly aimed at undermining legitimate authorities, social stability and traditional values, and eroding trade and cultural ties. Developed and underdeveloped countries face common threats such as terrorism, organized crime, drug trafficking, illegal migration, radicalism and extremism, as well as economic, informational, technological and biological security risks. We live in a world full of strained relations and the opening of new conflicts in a number of regions, new confrontations in which civilians are primarily killed. Are we on the brink of World War III? Are we so negligent of ourselves, our descendants, the environment in which we live in to use nuclear warheads? Can there be new nuclear accidents? The answer is yes if we don't come to our senses.

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Perspektive organske poljoprivrede u Srbiji, Hrvatskoj, Bosni i Hercegovini i Severnoj Makedoniji

Perspectives of organic agriculture in Serbia, Croatia, Bosnia and Herzegovina and North Macedonia

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Sažetak: Organska poljoprivreda ne podrazumeva samo izbegavanje hemijskih materija u agrarnoj proizvodnji, već i prilagođavanje poljoprivrednih aktivnosti okolini i živom svetu u okrženju. Stanje zemljišta je jedan od glavnih faktora za organsku poljoprivredu, kao i za biodinamičku poljoprivredu koja uključuje organsku poljoprivredu. Organska poljoprivreda je sistem koji počinje da razmatra potencijalne ekološke i društvene uticaje eliminacijom upotrebe sintetičkih inputa, kao što su sintetička đubriva i pesticidi, veterinarski lekovi, genetski modifikovano seme i rase, konzervansi, aditivi i zračenje. Organska poljoprivreda podrazumeva holistički sistem upravljanja proizvodnjom hrane koji promoviše i poboljšava zdravlje agroekosistema: biodiverzitet, bilološke cikluse i biološku aktivnost zemljišta. Za Srbiju kao zemlju u razvoju, organska poljoprivreda predstavlja priliku i dalju razvojnu šansu, kao i za ostale obuhvaćene zemlje. Udeo organske proizvodnje prema zvaničnim podacima u agraru Srbije je poslednjih godina u porastu. Ovaj rad se bavi analizom stanja organske poljoprivrede i istražuje perspektive razvoja organske poljoprivrede u Srbiji i zemljama regiona Bosni i Hercegovini, Hrvatskoj i Severnoj Makedoniji.

Ključne reči: Poljoprivreda, agrar, održivost, proizvodnja hrane, Evropski zeleni dogovor.

Abstract: Organic agriculture does not only mean the avoidance of chemical substances in agricultural production, but also the adaptation of agricultural activities to the environment and the living world in its surroundings. Soil condition is one of the main factors for organic farming, as well as for biodynamic farming that includes organic farming. Organic agriculture is a system that begins to consider potential environmental and social impacts by eliminating the use of synthetic inputs, such as synthetic fertilizers and pesticides, veterinary drugs, genetically modified seeds and breeds, preservatives, additives, and radiation. Organic agriculture implies a holistic food production management system that promotes and improves the health of the agro-ecosystem: biodiversity, biological cycle and soil biological activity. For Serbia as a developing country, organic agriculture represents an opportunity and a further development chance, as well as for the other covered countries. According to official data, the share of organic production in Serbian agriculture has been increasing in recent years. This paper is the analysis of the state of organic agriculture and explores the perspectives of the development of organic agriculture in Serbia and the countries of the region: Bosnia and Herzegovina, Croatia and North Macedonia.

Keywords: Agriculture, Agrar, Sustainability, Food production, European Green Deal.

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UVOD / INTRODUCTION

Za razliku od konvencionalne poljoprivrede koju karakteriše upotreba većih količina đubriva, pesticida, pojačivača zemljišta, biostimulatora, biljnih hormona i niza drugih hemikalija, razvoj organske poljoprivrede doprinosi očuvanju prirodnih resursa, pre svega vode i zemljišta i direktno utiče na razvoj brojnih dopunskih aktivnosti u ruralnim područjima.

Koncept kvaliteta zemljišta kao osnove održivog razvoja i organske poljoprivrede nastao je od ranih 90ih godina prošlog veka, kao rezultat brojnih naučnih rasprava, studija i analiza. Reč je o konceptu koji integriše osnovne komponente: održivu biološku proizvodnju, kvalitet životne sredine, zdravstveno stanje biljaka i životinja. Američko društvo za nauku o zemljištu (SSSA) daje definiciju kvaliteta zemljišta kao sposobnosti određene vrste zemljišta da funkcioniše unutar prirodnih ili ekonomskih granica ekosistema, održava produktivnost biljaka i životinja radi očuvanja ili povećanja kvaliteta vode i vazduha i podržava zdravlje i humane standarde. Pojavljuje se sve više izazova kada je u pitanju poljoprivreda i proizvodnja hrane (Janković i dr., 2023). Neki autori, kao što su He i dr., smatraju da je zbog preterane upotrebe hemijskih sredstava u poljoprivredi hitno potrebna strategija za njeno smanjenje, koja će, s jedne strane, osigurati produktivnost, ali i očuvati životnu sredinu (He i dr., 2023). Ona se zamenjuju praksama upravljanja specifičnim za lokaciju koja se održava, povećavaju dugoročnu plodnost zemljišta i suzbijaju štetočine i bolesti (FAO, 2002). Organska poljoprivreda mogla bi se ispostaviti kao deo jedne takve strategije, a takvu tendenciju pokazuju podaci Organizacije za hranu i poljoprivredu (FAO) koji govore da je u poređenju s 2000. godinom, kada je 20 miliona hektara bilo organsko, organsko poljoprivredno zemljište povećano više od pet puta (2022.) na globalnom nivou. Kada je u pitanju tržište organskog sektora, ono je u istom periodu (2000-2022) sa 15.1 milijardi evra dostiglo vrednost od 134.8 milijardi evra. U Evropi, organska poljoprivreda pokriva 3.7 % poljoprivredne površine (EU: 10,4 %).

Prema podacima Republičkog zavoda za statistiku za 2023. godinu Srbija ima 3.94 miliona hektara ukupnog raspoloživog poljoprivrednog zemljišta (RZS, 2023), što predstavlja dobru osnovu za razvoj poljoprivrede, kako tradicionalne tako i organske. Uloga koju javni sektor ima u razvoju organske poljoprivrede je nedovoljna. Zainteresovane strane sugerišu da civilno društvo može uravnotežiti nedostatak podrške nadležnih kroz kolektivne akcije i podizanje svesti o ljudskom zdravlju i održivom razvoju (Moreno-Pérez i Blázquez-Soriano, 2023). Rešenje se može naći organizovanjem organskih poljoprivrednih udruženja konkurentne produktivnosti, koja imaju za cilj da organskom poljoprivredom pokriju 25% poljoprivrednih površina, prema Evropskom zelenom dogovoru. Da su evropske zemlje povoljno tlo za aktivnosti organske poljoprivrede i da donete regulative imaju efekte govori i podatak da su među deset zemalja s najvećim površinama organskog zemljišta čak četiri evropske zemlje: Francuska (2.88 miliona ha), Španija (2,68 miliona ha), Italija (2.35 miliona ha) i Nemačka (1.68 miliona ha). Nastavak dobre evropske prakse i velika razvojna šansa za organsku poljoprivredu kada su u pitanju balkanske države je Zelena agenda za zapadni Balkan koja se oslanja na Evropski zeleni dogovor. Prelazak s konvencionalne na organsku poljoprivredu može se postići samo premošćavanjem jaza u profitabilnosti između dva proizvodna sistema (Martín-García i dr., 2023).

Organska poljoprivreda u Srbiji je prepoznata zakonima i propisima - u prvom redu regulativama Ministarstva poljoprivrede, ali i međunarodnim praksama. Biodinamička federacija Demeter International je krovna organizacija koji se sastoji od 48 organizacija članica posvećenih biodinamičkoj poljoprivredi, koja u svom osnovnom pojmu podrazumeva i orgasku agrarnu praksu. Prisutna u 36 zemalja širom sveta, osnovana je pre četiri godine s primarnim ciljevima ujedinjenja, promovisanja i jačanja globalnog, održivog poljoprivrednog pokreta. Biodinamička federacija Demeter International je jedino ekološko udruženje koje je uspelo da uspostavi mrežu za individualnu sertifikaciju biodinamičkih poljoprivrednih praksi širom sveta (Willer i dr., 2024). Demeter Inernational sertifikacija počiva na 7 osnovnih principa: plodnost zemljišta je ključna, zdrave biljke – poljoprivreda bez GMO, poštovanje za prirodu životinja, biodiverzitet nema cenu, garancija najvišeg organskog kvaliteta, ekološka odgovornost i društvena odgovornost. Napredak po ovom pitanju uočava se i u zemljama koje su predmet ove studije slučaja, pa je tako prepoznato 117 ha na ovaj način sertifikovanog zemljišta u Bosni i Hercegovini, 57 ha u Srbiji, 9 ha u Hrvatskoj, dok u Severnoj Makednoji još nije sprovedena Demeter-sertifikacija (Biodynamic Federation Demeter International, 2023).

Sistem pravnih okvira u organskoj proizvodnji u odabranim zemljama je uspostavljen ili delimično uspostvaljen. Srbija koristi uspostavljene domaće propise na osnovu Zakona o organskoj proizvodnji iz 2010. godine kao i njegovih izmena i dopuna iz 2019. Bosna i Hercegovina nema u potpunosti implementiran sistem sertifikacije, međutim zakonodavni okvir postoji – Zakon o poljprivrednoj organskoj proizvodnji iz 2016. godine. U Severnoj

Makedoniji nacionalno zakonodavstvo o organskoj poljoprivrednoj proizvodnji obezbeđuje Ministarstvo poljoprivrede, šumarstva i vodoprivrede i koriste se domaći propisi. Hrvatska kao članica Evropske Unije (EU) jedina od posmatranih zemalja koristi domaću i međunarodnu regulativu, odnosno propise EU koji su nastavak nacionalnih regulativa: Zakon o organskoj proizvodnji i obeležavanju organskih proizvoda iz 2010. godine (u nadležnosti Ministarstva poljoprivrede) kao i EU Reg Akcioni plan za organsku proizvodnju EU 2021-2027.

1. MATERIJALI I METODE / MATERIALS AND METHODS

U ovom radu je korišćena deskriptivna, analitička metoda i metoda komparativne analize kroz izveštaj The World of Organic Agriculture. Statistics and Emerging Trends 2024 Research Institute of Organic Agriculture FiBL, Frick, and IFOAM (Willer et al., 2024) i zvaničnih nacionalnih statistika i podataka. Komparativna analiza sprovedena je kroz istraživanje organske poljoprivrede u zemljama okruženja na prostoru Balkana (Hrvatska, Bosna i Hercegovina, Makedonija).

2. REZULTATI I DISKUSIJA / RESULTS AND DISCUSSION

Sprovedeno je istraživanje indikatora organske proizvodnje u posmatranim državama Srbiji, Bosni i Hercegovini, Hrvatskoj i Severnoj Makedoniji. Analizirani su indikatori organske poljoprivrede:

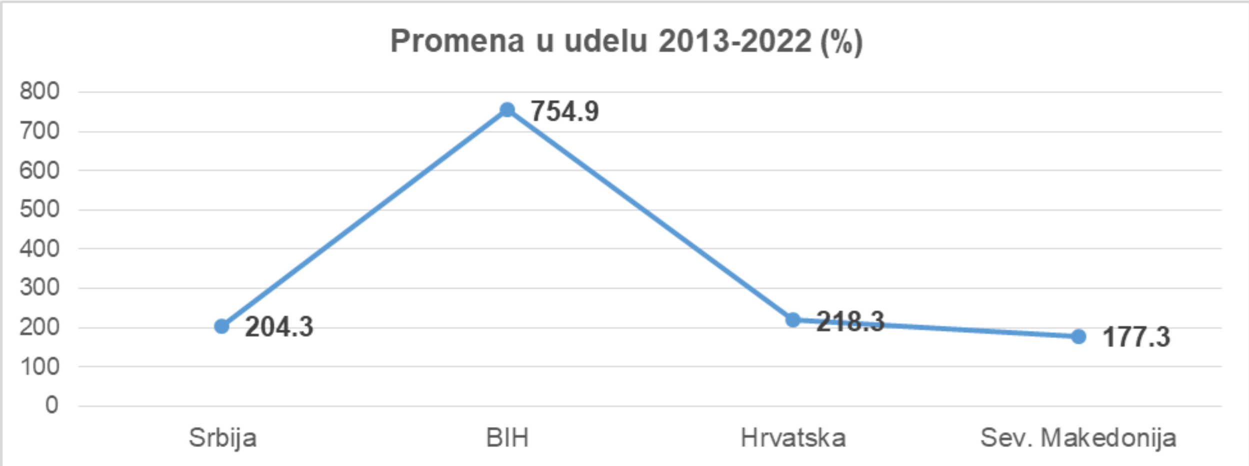
Organsko poljoprivredno zemljište (veličina u ha, udeo organske proizvodnje u %, promene u udelima i površinama); Status konverzije zemljišta (u potpunosti konvertovano, u konverziji); Upotreba zenmljišta u oragnskoj proizvodnji; Broj proizvođača, prerađivača, uvoznika i izvoznika. Tržišna komponenta je analizirana je kroz podatke o izvozu.

Tabela 1: Organsko poljoprivredno zemljište
Table1: Organic agricultural land

Država	Organsko poljoprivredno zemljište (ha)	Udeo organske proizvodnje (%)	Promena u udelu 2013-2022 (%)	Promena u površini 2021-2022 (ha)
Srbija	25035	0.7	204.3	+1508
Bosna i Hercegovina	2495	0.1	754.9	0
Hrvatska	129374	8.6	218.3	+7450
Severna Makedonija	8724	0.7	177.3	+930

Izvor: Autorska sistematizacija na osnovu Willer et al., 2024
Source: Author's systematization based on Willer et al., 2024

Najveće organsko poljoprivredno zemljište, udeo organske proizvodnje i promene u površini (2021-2022) ostvarila je Hrvatska, dok je najveću promenu u udelu (2013-2022) ostvarila Bosna i Hercegovina.



Grafikon 1: Promena u udelu organske proizvodnje 2013-2022 u %
Chart 1: Change in the share of organic production 2013-2022 in %
Izvor: Autorski prikaz / Source: Author's figure

Tabela 2: Status konverzije zemljišta
Table 2: Land conversion status

Država	U potpunosti konvertovano (ha)	U procesu konverzije (ha)
Srbija	16503	8533
Bosna i Hercegovina	2082	413
Hrvatska	92959	36415
Severna Makedonija	6594	2130

Izvor: Autorska sistematzacija na osnovu Willer et al., 2024
Source: Author's systematization based on Willer et al., 2024

Veličina konvertovanog zemljišta je veća u svim posmatranim državama, u odnosu na zemljište koje je u konverziji. U Srbiji je to oko polovine, u Hrvatskoj i Severnoj Makedoniji oko trećine, dok je zemljište u konverziji u Bosni i Hercegovini petina od raspoloživog u potpunosti konvertovanog.

Tabela 3: Upotreba zemljišta u organskoj proizvodnji
Table 3: Land use in organic production

Država	Oranice (ha)	Stalni pašnjaci i livade (ha)	Trajni usevi (ha)
Srbija	19412	-	5623
Bosna i Hercegovina	1532	-	159
Hrvatska	49068	62591	17715
Severna Makedonija	4592	3376	755

Izvor: Autorska sistematzacija na osnovu Willer et al., 2024
Source: Author's systematization based on Willer et al., 2024

U Hrvatskoj i Severnoj Makedoniji primećeni su stalni pašnjaci i livade u sistemu organskog zemljišta, dok se u Srbiji i Bosni i Hercegovini takva upotreba zemljišta ne beleži. Trajnih useva u Hrvatskoj je najviše, zatim sledi Srbija dok su u Bosni i Hercegovini i Severnoj Makedoniji trajni usevi rasprostranjeni na manje od 1000 ha.

Kvalitet i sastav zemljišta imaju važnu ulogu u proceni mogućnosti za upotrebu zemljišta za konverziju u cilju organske proizvodnje. Kako vidimo iz tabele 4, Srbija ima veći procenat kvalitetnog zemljišta (černozem, kambisol i fluvisol) nego Hrvatska. S druge strane, Hrvatska za razliku od Srbije ima manji procent solončaka, nepogodnog za konverziju u organsko zemljište.

Tabela 4: Poređenje sastava i kvaliteta zemljišta u Srbiji i Hrvatskoj (wrb)
Table 4: Comparison of composition and quality of soil in Serbia and Croatia (wrb)

WRB naziv	Srbija	Hrvatska
Kambisol	27,99	8,80
Černozem	17,68	0,93
Fluvisol	7,58	2,50
Leptosol	15,90	0,60
Luvisol	2,38	12,60
Solonec / Solončak	*1,43*	0,22
Vertisol	8,32	5,37

Izvor: Autorska sistematzacija
Source: Author's systematization

Tabela 5: Proizvođači, prerađivači, uvoznici i izvoznici
Table 5: Manufacturers, processors, importers and exporters

Država	Proizvođači	Prerađivači	Uvoznici	Izvoznici
Srbija	513	154	66	88
Bosna i Hercegovina	90	51	-	20
Hrvatska	6132	380	11	-
Severna Makedonija	890	18	5	1

Izvor: Autorska sistematzacija na osnovu Willer et al., 2024
Source: Author's systematization based on Willer et al., 2024

Kada su u pitanju učesnici aktivnosti u organskoj poljoprivredi u broju proizvođača prva je Hrvatska, zatim Severna Makedonija i Srbija, a najmanji broj proizvođača ima Bosna i Hercegovina. Uzrok ovome može se potražiti i u neimplementiranoj regulativi u potpunosti u ovoj državi.

Broj proizvođača je jedan od najvažnijih, ali za razvoj organske poljoprivrede u posmatranom regionu je značajan i broj izvoznika, s obzirom da su lokalna tržišta možda nedovoljna za ostvarivanje profita. Hrvatska svoje organske proizvode plasira u okviru EU i s obzirom na njeno članstvo u istoj ne klasifikuje se kao izvoznik ka zemljama EU.

Severna Makedonija ima značajan broj proizvođača, ali su organski posedi rasparčani (do 2 ha). Na taj način smanjuje se kapacitet izvoza.

S druge strane za ostavarivanje punog profita broj prerađivača je ključni indikator. Hrvatska je prva u posmatranom regionu sa 380 prerađivača, dok je prati Srbija sa 154. U Bosni i Hercegovini postoji 51 prerađivač, dok ih je u Severnoj Makedoniji 18. U slučaju Srbije, s aspekta razvoja organskog agrara negativnu pojavu predstavlja veliki broj uvoznika (66), dok je s tačke gledišta razvoja tržišta ovo pozitivan podatak.

Tabela 6: Podaci o izvozu
Table 6: Export data

Država	Izvoz (tona)	Izvoz (milliona evra)
Srbija	14285.8	-
Bosna i Hercegovina	10489.8	6.3
Hrvatska	20.8 (USA)	2.9
Severna Makedonija	447.1 (EU)	-

Izvor: Autorska sistematzacija na osnovu Willer et al., 2024
Source: Author's systematization based on Willer et al., 2024

U slučaju Hrvatske, podaci se odnose na izvore SAD, dok promet u okviru EU koja je glavni konzument organskihih proizvoda nije obuhvaćen. Podaci Severne Makedonije odnose se na izvoz isključivo u EU. Za Srbiju i Severnu Makedoniju nisu obuhvaćeni podaci o iznosu izvezenih količina organskih proizvoda. Prema dostupnim izvorima, Srbija prednjači u izvezenim količinama organskih proizvoda u posmatranom regionu.

ZAKLJUČAK / CONCLUSION

U odnosu na podatke iz razvijenih evropskih zemalja kada je organska poljoprivreda u pitanju, stiče se utisak da je organska proizvodnja zanemareni potencijal na Balkanu u nekada agrarnim državama.

Posmatrane zemlje svakako pokazuju interesovanje i tendenciju povećanja poljoprivrednih aktivnosti u organskom sektoru. Proizvodnja Srbije, Hrvatske, Bosne i Hercegovine i Severne Makedonije pretežno je usmerena na izvoz organskih proizvoda u druge zemlje EU, obzirom na to da su lokalna tržišta mala i nedovoljno obuhvaćena marketinškim aktivnostima usmerenim na širenje potrošačkih navika u sferi skupljih organskih proizvoda koji uz to i teže dostupni nego proizvodi iz konvencionalne poljoprivrede.

Podaci o prerađivačima pokazuju da je prerađivačka aktivnost u okviru organske proizvodnje nedovoljno razvijena, uprkos mogućnosti ostvarivanja dodatnog profita u odnosu na samu proizvodnju neprerađene organske hrane.

Proizvodnja prerađivanih produkata predstavlja izazov za prerađivače zbog velikih investicija u opremu i složenosti procesa koji su fokusirani na visok kvalitet i bezbednost proizvoda i minimalnu štetu po životnu sredinu.

Ulaganjem značajnih dodatnih napora u razvoj organske proizvodnje i sledeći evropske regulative i smernice, ali i primere dobrih praksi razvijenih zemalja koje mogu poslužiti dobrom osnovom za mnoge druge zemlje Balkana, moguće je ostvariti ciljeve neophodne za proizvodnju i preradu organske hrane u skladu s Evropskim zelenim dogovorom. Hrvatska je već postigla značajne rezultate po usklađivanju zakonske regulative sa drugim zemljama Evropske unije u sektoru organske proizvodnje.

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Uticaj insekticida na životnu sredinu i ekološki prihvatljive mere remedijacije

Impact of insecticides on the environment and environmentally acceptable remediation measures

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Sažetak: Insekticidi (odnosno antiektoparazitici) imaju veoma značajnu ulogu u zaštiti ljudi, životinja i biljaka od brojnih insekata ili ektoparazita. Zahvaljujući primeni ovih sredstava iskorenjene su razne zarazne bolesti, olakšano je suzbijanje i lečenje ektoparazitoza kod ljudi i životinja, te je unapređena i povećana poljoprivredna proizvodnja. Iako su postignuti, (može se slobodno reći) grandiozni rezultati u suzbijanju zaraznih bolesti, nažalost još uvek postoje određeni regioni u svetu, gde neke zarazne bolesti (malarija) odnose veliki broj ljudskih života. Insekticidi su (kao što je već rečeno) značajno doprineli i povećanju poljoprivredne proizvodnje. Zbog toga se danas često može čuti mišljenje da je poljoprivredna proizvodnja postala praktično nemoguća bez primene pesticida. To je svakako uticalo da se ova sredstva danas, takoreći masovno koriste širom sveta. Upravo navedene činjenice, odnosno ovakva primena insekticida, koja je često i neracionalna, izaziva sve veću zabrinutost. Jedan od najvažnijih razloga za to, jeste svakako porast razvoja rezistencije kod insekata, a time i smanjenje efikasnosti insekticida. Pored toga, ne manji značaj ima i sve veće zagađenje životne sredine. O tome se takođe u poslednje vreme sve više priča i u našoj zemlji, pa će se u budućnosti morati voditi više računa. Ovo pre svega iz razloga, što primena insekticida (naročito ukoliko je neracionalna) može delovati štetno, ne samo na neciljne, odnosno korisne insekte, kao što su pčele, već i druge organizme, a posebno one u zemljištu i vodi. Ako se ovom doda i činjenica da može nastati i potencijlna kontaminacija lanca ishrane, onda su to svakako faktori koji mogu dovesti do poremećaja ravnoteže u pojedinim ekosistemima. Cilj ovog rada je bio da ukaže na moguće štete neracionalne primene insekticida, da se istakne značaj razumne primene insekticida i predlože mere za njenu primenu.

Ključne reči: pesticidi, insekticidi, antiektoparazitici, insekti, poljoprivreda, ekosistem.

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Abstract: Insecticides (i.e. agents against ectoparasites) play a very important role in protecting humans, animals and plants from numerous insects or ectoparasites. Thank you to the use of these agents, various infectious diseases have been eradicated, the control and treatment of ectoparasitoses in humans and animals has been facilitated and agricultural production has been improved and increased. Although great success has been achieved in the fight against infectious diseases, there are unfortunately still certain regions of the world where some infectious diseases (malaria) claim a large number of lives. Insecticides have (as already mentioned) contributed significantly to the increase in agricultural production. As a result, one often hears the opinion today that agricultural production has become practically impossible without the use of pesticides. This has certainly influenced the fact that these products are now used on a massive scale all over the world. The facts just mentioned, that is, this kind of application of insecticides, which is often irrational, is causing increasing concern. One of the most important reasons for this is certainly the increase in the development of resistance in insects, and thus the decrease in the effectiveness of insecticides. In addition, the growing pollution of the environment is of no less importance. This has also been talked about more and more recently in our country, so more care will have to be taken in the future. This is primarily due to the fact that the application of insecticides (especially if it is irrational) can have a harmful effect, not only on non-target, that is, beneficial insects, such as bees, but also on other organisms, especially those in the soil and water. If we add to this the fact that potential contamination of the food chain can occur, then these are certainly factors that can lead to a disturbance of the balance in certain ecosystems. The aim of this paper is precisely to point out the possible harms of irrational application of insecticides, to emphasize the importance of reasonable application of insecticides and to propose measures for its application.

Key words: pesticides, insecticides, antiectoparasitics, insects, agriculture, ecosystem.

UVOD / INTRODUCTION

Danas se insekticidi najčešće koriste u poljoprivredi i komunalnoj higijeni za suzbijanje i kontrolu brojnih insekata. Osim toga, određen broj ovih sredstava je našao svoju primenu i veterinarskoj medicini, gde se koriste kao antiektoparazitici. Od svih navedenih namena, poljoprivredna proizvodnja je ipak na prvom mestu. Naime, u cilju zaštite useva i postizanja maksimalnih prinosa (pored ostalih „agro" mera) insekticidi su postali jedan od ključnih faktora za povećanje prinosa u poljoprivrednoj proizvodnji. Drugim rečima, oni su postali neophodni za savremenu poljoprivredu, odnosno poljoprivredna proizvodnja je postala praktično nemoguća bez njihove primene. Ovo pre svega iz razloga što se pokazalo da gubici u prinosima mogu da iznose i do 45% (na godišnjem nivou), ukoliko se ne koriste insekticidi. Takođe, treba istaći da su insekticidi odigrali veliku ulogu, a i danas je imaju u preventivnoj zaštiti ljudi, od brojnih bolesti (na prvom mestu malarije) (Sharma et al., 2019; Gardarin et al., 2022).

Udeo insekticida u ukupnoj potrošnji pesticida i njihov odnos danas izgleda ovako: najviše se koriste herbicidi (47,5%), na drugom mestu su insekticidi (29,5%), a tek na trećem fungicidi (17,5%). Za kategorizaciju pesticida koristi se niz faktora (Grondona et al., 2023). Najćešći kriterijumi za klasifikaciju su: put ulaska pesticida u životnu sredinu, njihov hemijski sastav i vrsta organizma, na koje deluju. S druge strane Svetska zdravstvena organizacija (SZO) i globalno harmonizovani sistem (GHS) dali su prioritet javnom zdravlju (odnosno stepenu toksičnosti ili štetnim efektima, koje neki pesticid poseduje, odnosno izaziva) i ovaj kriterijum su stavili kao najvažniji, koji treba uzeti u obzir, kada je u pitanju klasifikacija pesticida, a time i insekticida (Barathi et al., 2023).

Azija spada među regione s najvećom potrošnjom pesticida. Kina i Indija su dve zemlje s izuzetno velikom potrošnjom insekticida i ukupno gledano svih pesticida. Indija je posle Kine, najveći proizvođač insekticida u Aziji, a na 12. mestu u svetu je po upotrebi, tj. potrošnji insekticida (Shahid & Khan, 2022). Inače, udeo insekticida u ukupnoj potrošnji pesticida u Indiji je drugačiji od onog u drugim zemljama. Naime, u Indiji najveći broj pesticida čine insekticidi (62,2%), na drugom mestu su fungicidi (19,2%), a tek na trećem mestu su herbicidi (14,4%) i potom slede ostali pesticidi (4,2%). Ima više od 200 fabrika za proizvodnju pesticida i preko 4000 objekata za proizvodnju aktivnih supstancija, dok u Kini ima preko hiljadu fabrika za proizvodnju pesticida. Za uspešno suzbijanje insekata danas se koristi veliki broj insekticida. Prema nekim podacima u svetu je danas komercijalno dostupno nekoliko desetina hiljada hemijskih supstancija, različitih hemijskih grupa (Rajmohan et al., 2020). Već pre desetak godina bilo ih je u svetu preko 80.000 (Ansari et al., 2014).

Međutim, sve češće smo svedoci da se insekticidi prilično neracionalno koriste, te da je njihova primena dramatično porasla poslednjih godina. Ovo se odnosi pre svega na SAD, Kinu, Argentinu, Brazil, Rusiju, Kanadu, Australiju, Kolumbiju, Francusku i Indiju. Pokazalo se da ovakva primena može imati i neželjene posledice, naročito na neciljne organizme. Stradaju, pre svega korisni insekti, kao što su pčele, ali se neželjeni, odnosno toksični efekti mogu ispoljiti i na ekosisteme (i organizme u njima), kao što su zemljište i voda, te na divlje životinje (Ren et al., 2023). U Južnoj Koreji, Južnoj Africi, Kanadi, Turskoj, Indiji, Tanzaniji i drugim zemljama, zabeleženi su čak smrtni ishodi akutnog trovanja insekticidima kod dece (Islam et al., 2022).

To je svakako uticalo da se donesu određeni propisi koji se odnose na registraciju, upotrebu, uvoz i izvoz insekticida. Tako je na primer (usled toksičnih efekata, ali i neurokognitivnih problema i oštećenja mozga kod dece), povučena upotreba hlorpirifosa u Evropskoj uniji, 2020. godine, a dve godine kasnije i u SAD (Raj et al., 2023).

1. ŠTETNI EFEKTI INSEKTICIDA NA ŽIVOTNU SREDINU / HARMFUL EFFECTS OF INSECTICIDES ON THE ENVIRONMENT

Usled preterane i često neracionalne potrošnje insekticida, poslednjih godina sve više se razmatra i analizira koliki je potencijal ovakve primene insekticida za kontaminaciju zemljišta, podzemnih i površinskih voda, te životne sredine. Studije su pokazale da Azija (s površinom od 1,9 miliona kvadratnih milja) i u njoj Kina (koja čini preko 50% od ove površine), predstavlja danas najveći region u svetu s najvećim rizikom od zagađenja životne sredine. Naučnici se sve više opravdano brinu da će prekomerna upotreba insekticida (ako se ovako nastavi) uskoro preokrenuti ravnotežu na vagi, u pravcu značajnijeg razaranja ekosistema, a time i oštećenja, pre svega kvaliteta vode, koja je (kao što znamo) neophodna za opstanak ljudi i životinja (Tang et al., 2021). Stoga je, u cilju zaštite svojih građana od štetnog dejstva insekticida, vlada u Kini donela strožije zakone o primeni insekticida i uspostavila preporučene standarde (Malla et al., 2023).

Inače, široka primena insekticida i drugih nerazgradivih toksičnih supstancija u poljoprivredi u poslednjih nekoliko decenija izazvala je (negde više, a negde manje) kontaminaciju podzemnih voda i zemljišta, što svakako predstavlja važnu opasnost za ekološku poljoprivredu, a time i zdravlje ljudi (Chandran et al., 2020).

2. MERE I STRATEGIJE U CILJU ZAŠTITE ŽIVOTNE SREDINE / MEASURES AND STRATEGIES FOR ENVIRONMENTAL PROTECTION

Zbog svega navedenog, veoma je važno da se u cilju postizanja održive poljoprivredne proizvodnje, napravi strategija upravljanja primenom insekticida i drugih pesticida. U skladu s tim veoma je važno zaštiti i (usled toga) očuvati zdravlje zemljišta, te okolinu oko poljoprivrednih površina. Jedna od mera, koja se preporučuje i koja je ekološki prihvatljiva strategija za kontrolu insekata i drugih štetočina u poljoprivredi, jeste i ona koja zagovara upotrebu insekticida na bazi mikroorganizama (Archana et al., 2022). Ovo tim pre, jer se pokazalo da korišćenje mikroorganizama u polju, deluje stimulativno na rast biljaka, pre svega olakšavanjem rastvorljivosti fosfora (Zhu et al., 2023), ali i većom produkcijom hidrolitičkih enzima i povećanjem rastvorljivosti cinka (Kour et al., 2019). Mikroorganizmi su odgovarajući bioresursi i u redovnim, kao i abiotičkim stresnim stanjima (Kour et al., 2019), prirodnoj fiksaciji azota (Barathi i ar., 2023) i rastvorljivosti kalijuma (Kour et al., 2022). Mikroorganizmi, takođe pomažu lišću u prevazilaženju abiotičkih stresova, kao što su slani rastvori, niska temperatura i nekoliko drugih faktora, u cilju postizanja održive poljoprivredne proizvodnje (Barathi i ar., 2023). Osim toga, što mikroorganizmi povećavaju godišnji prinos, oni pomažu i u poboljšanju kvaliteta poljoprivrednih proizvoda. U poslednje vreme upotreba prirodnih proizvoda na bazi mikroorganizama za kontrolu i suzbijanje insekata, sve više privlači pažnju brojnih farmera širom sveta. Ipak, korišćenje mikroorganizama, kao insekticida još uvek izaziva određenu zabrinutost, zbog mogućeg uticaja pre svega na neciljne organizme, što naravno zahteva dalja ispitivanja i poboljšanja u ovom pogledu. Zato su biološki-zasnovane degradacije insekticida, svakako alternativno sredstvo za prevazilaženje ovih ograničenja, iako za sada još uvek predstavljaju improvizovanje u upravljanju suzbijanja štetočina u poljoprivrednom polju. U svakom slučaju, proces smanjenja zagađenja insekticidima na ekološki prihvatljiv način, odnosno dugoročnu ekološku korist predstavlja upravo biorazgradnja insekticida. Mikroorganizmi su prepoznati po svom uticaju i brojnim primenama u unapređenju dobrobiti ljudi i igraju značajnu ulogu u razgradnji insekticidnih jedinjenja. Nedavna istraživanja su pokazala da pojedinačni mikroorganizmi ili grupe mikroorganizama, izolovani sa mesta kontaminiranih insekticidima ili vode mogu razgraditi insekticide. Među njima se nalazi nekoliko sojeva bakterija i gljivica, aktinomiceta, algi i drugih mikroorganizama. Dakle, u svetu se danas vrše brojna ispitivanja u cilju smanjenja mogućeg zagađenja insekticidima, a jedan od njih je svakako i napred navedeni način razgradnje uz pomoć mikroorganizama. Radi uklanjanja i smanjenja koncentracije insekticida u životnoj sredini u svetu se danas donose i drugi planovi i strategije na globalnom nivou. A jedan od njih je i promovisanje održive poljoprivredne proizvodnje, bez primene sintetičkih insekticida (Barathi et al., 2023). U tom pravcu brojna ispitivanja se vrše manipulacijom genima i molekulima kod insekata. Naime, da bi se insektima dale željene karakteristike, uvode se specifični geni u njihove genome. Sve ovo ima za cilj da se razviju ekološki prihvatljivi insekticidi (Yang et al., 2023; Barathi et al., 2024).

Takođe, ne mali značaj ima i sinteza sve većeg broja biosenzora za detekciju insekticida u životnoj sredini i njenim pojedinim ekosistemima (Aguilar-Perez et al., 2020).

3. BIOSENZORI ZA DETEKCIJU I ODREĐIVANJE KONTAMINACIJE INSEKTICIDIMA / BIOSENZORI ZA DETEKCIJU I ODREĐIVANJE KONTAMINACIJE INSEKTICIDIMA

Danas su u fokusu interesovanja i biosenzori za identifikaciju prisustva neke hemikalije, odnosno agro-zagađivača, odnosno zagađivača životne sredine. Da bi opravdali svoju primenu, oni moraju ispunjavati određene uslove, u pogledu osetljivosti, granica detekcije i stabilnosti. Posebno su interesantni oni koji bi se koristili na udaljenim lokacijama (Aguilar-Perez et al., 2020).

Dakle, direktno otkrivanje zagađivača, kao što su teški metali, pesticidi i toksini iz otpadnih voda, te praćenje stanja vode i zemljišta, danas predstavljaju značajan izazov u oblasti životne sredine i analitičke hemije. Trenutne tehnike primenjene za analizu u realnom vremenu i praćenje kontaminiranih uzoraka su ograničene, zbog nedostatka opreme s niskim granicama detekcije i skupe laboratorijske opreme. S tim u vezi, različite istraživačke grupe su poslednjih godina ulagale napore u razvoj senzorskih tehnologija. Ustvari, potrebni su isplativi, kompaktni i ekološki prihvatljivi senzori. Pokazalo se da nanotehnologija obezbeđuje vodeće biosenzore, koristeći nove tehnike nanoproizvodnje i zelene sinteze. Nano biosenzori, koji se koriste za detekciju zagađivača pokazuju ultra-osetljivost i brzo vreme detekcije u realnom vremenu. Pored toga, granice detekcije zagađivača na nanomolarnom do pikomolarnom nivou su već objavljene u literaturi (Perez et al., 2020).

Kao što je već rečeno, poslednjih godina se (naročito u nekim delovima sveta) kvalitet vode i poljoprivrednih zemljišta značajno pogoršao, zbog kontaminacije izazvane jedinjenjima antropogenog porekla (Guerra et al., 2018). Iz ovih razloga, upotreba nanomaterijala (npr. metalne nanočestice, polimeri, nanokompoziti, ugljene nanocevi itd.) je pokazala prednosti u dijaganozi kontaminacije, tj. otkrivanju i praćenju kontaminacije otpadnih voda (Aguilar-Perez et al., 2020). Nanomaterijali imaju prosečnu veličinu od 1 do100 nm i odlikuju se svojim jedinstvenim strukturama i svojstvima (mehanička, optička i električna) s obzirom na njihov veliki odnos između površine i zapremine (Rasheed et al., 2020). Upotreba bio-elemenata u kombinaciji sa zelenom komponentom nanomaterijala omogućava proizvodnju nano-bio-senzora za praćenje monitoringa životne sredine. Izvanredne karakteristike nano-biosenzora u poređenju s tradicionalnim metodologijama čine ih veoma osetljivim i isplativim instrumentima za praćenje životne sredine i detekciju zagađivača. Oni su široko klasifikovani u dve kategorije, to jest, na bio-receptore i pretvarače. Bio-receptori se kao biosenzori dalje kategorišu u enzime, proteine, antitela, bakterije i DNK. Na osnovu transdukcionih metoda, biosenzori se kategorišu u elektrohemijske, optičke, kalorimetrijske i biosenzore zasnovane na masi (Hernandez-Vargas et al., 2018).

4. ZELENA SINTEZA NANO-BIO-MATERIJALA / GREEN SYNTHESIS OF NANO-BIO-MATERIALS

Nanomaterijali se mogu sintetizovati različitim hemijskim, fizičkim, biološkim i hibridnim tehnikama. Međutim, biološkim metodama, proizvodni procesi olakšavaju upotrebu biljnih ekstrakata, mikroorganizama (npr. bakterija i gljivica), algi, enzima, biomolekula i industrijskog ili poljoprivrednog otpada. Kombinacija svojstava nanomaterijala s biomolekulima rezultiraju sinergističkim efektom, koji je pomogao za postizanje, odnosno dobijanje kompetentnih nano-bio-senzora (Cardoso, 2022; Gall, 2021).

5. SINTEZA NANO-BIO-MATERIJALA KORIŠĆENJEM BILJAKA / SYNTHESIS OF NANO-BIO-MATERIALS USING PLANTS

Alkaloidi, proteini, ugljeni hidrati i fenolna jedinjenja su najčešći sekundarni metaboliti koji se koriste za dijagnozu kontaminacije životne sredine. Važno je napomenuti da je sinteza nano-bio-materijala zasnovana na ovim metabolitima sačinjena od mešavine metalnog prekursora (tj. zlata (Au) i srebra (Ag) s nekim biljnim ekstraktom). Formiranje nanočestica je otkriveno promenom obojenosti rastvora usled procesa nukleacije metalnih atoma (promena oksidacionog stanja u nulto valentno stanje) (Akhtar et al., 2013). Utvrđeno je da od oblika nanočestica zavisi sposobnost ekstrakta da stabilizuje nanočesticu (Shah, et al., 2015).

6. SINTEZA NANO-BIO-MATERIJALA KORIŠĆENJEM MIKROORGANIZAMA / SYNTHESIS OF NANO-BIO-MATERIALS USING MICROORGANISMS

Biološka sinteza nanočestica putem mikroorganizama sastoji se od uzimanja ciljnih jona iz svog okruženja pomoću mikroorganizama i pretvarajući ih u metalne jone preko biomolekula kao što su enzimi, šećeri i proteini koje luče (Prabhu & Poulose, 2012). U zavisnosti od lokacije sinteze nanočestica, ona se može klasifikovati kao intracelularna i ekstracelularna sinteza (Arun et al., 2013; Selvakumar et al., 2011). Veličina i morfologija nano čestice zavise od mikroorganizma i faktora kao što su pH ili temperatura.

7. SINTEZA NANO-BIO-MATERIJALA KORIŠĆENJEM BIOMOLEKULA / SINTEZA NANO-BIO-MATERIJALA KORIŠĆENJEM BIOMOLEKULA

Generalno, glavni biomolekuli koji se koriste u sintezi nano čestica su mali molekuli kao što su ugljeni hidrati (npr. glukoza i galaktoza), aminokiseline i kratki peptidi, koji se koriste kao reduktori, što omogućava specifičnu detekciju mete ili cilja (Tan et al., 2010; Kunoh et al., 2018; Care et al., 2015; Jia, 2019). Ovaj proces zavisi od sposobnosti biomolekula da aktiviraju razvoj nanočestica (Saha et al., 2010; Care et al., 2015). Postoji nekoliko studija koji govore i o upotrebi monosaharida (β-D-glukoze) i polisaharida (rastvorljivi skrob) za sintezu srebra (Ag) i zlata (Au) nanočestica (Yang et al., 2019).

ZAKLJUČAK / CONCLUSION

Da bi se obezbedila zaštita useva i optimalni prinosi, primena insekticida je danas takoreći neophodna za savremenu poljoprivredu. Međutim, njihova prekomerna upotreba sve više izaziva zabrinutost, kako zbog mogućeg štetnog uticaja, na same poljoprivredne kulture, tako i na životnu sredinu, odnosno neciljne organizme, uključujući ljude i domaće životinje. Osim toga, pokazalo da prekomerna primena insekticida neminovno dovodi i do razvoja rezistencije kod insekata, što opet iziskuje povećanje potrošnje ovih hemikalija. Zato se danas širom sveta predlažu brojne mere i strategije za smanjenje upotrebe ovih sredstava. Pored stalne i kontinuirane edukacije farmera, iznalaze se rešenja za održivu primenu insekticida, odnosno (gde je to moguće) traže se zamene za njihovu primenu. Isto tako, u tom pravcu se razvijaju i metode za utvrđivanje kontaminacije ekosistma, pre svega zemljišta i vode, uz pomoć nano-bio-materijala, koji služe kao benzori.

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Green franchising: connecting sustainability and franchising

Zeleni franšizing: povezivanje održivosti i franšizinga

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Abstract: Green franchising means ecologically sustainable and fair franchising, including franchise companies that behave environmentally friendly. Due to the increased awareness of sustainability, ecology, and fairness, "green" is also becoming a more and more prominent topic in franchising. Green franchising aims to find balanced and sustainable economic, ecological and social solutions. Green franchising aims for franchise systems to operate sustainably and in an environmentally and socially compatible manner over the long term. Green franchising also sees the sustainability of the franchise system itself as one of the critical success factors. The binding power and duration of franchise partnerships depend on the quality of the concept and, on the other hand, essentially on the quality of the relationships. The paper's main aim is to investigate green franchising from the research point of view and to see whether there is an opportunity for such franchise systems not only in Croatia. The paper is based on global green franchising development data and the unique features of green franchising. The paper will present case studies of the Croatian green franchises. Based on the research, the conclusion will offer proposals for increasing possibilities for such franchise systems.

Keywords: green franchising, sustainability, environment, opportunity in Croatia.

Sažetak: Zeleni franšizing znači ekološki održivi i pošteni franšizing, uključujući franšizne kompanije koje se ponašaju ekološki prihvatljivo. Zbog povećane svesti o održivosti, ekologiji i pravičnosti, „zeleno" takođe postaje sve istaknutija tema u franšizingu. Zeleno franšizing ima za cilj pronalaženje uravnoteženih i održivih ekonomskih, ekoloških i društvenih rešenja. Zeleno franšizing ima za cilj da sistemi franšize funkcionišu održivo i na ekološki i društveno kompatibilan način na duži rok. Zeleno franšizing takođe vidi održivost samog franšiznog sistema kao jedan od kritičnih faktora uspeha. Obavezujuća snaga i trajanje franšiznog partnerstva zavise od kvaliteta koncepta i, s druge strane, suštinski od kvaliteta odnosa. Glavni cilj rada je istražiti zeleni franšizing sa istraživačke tačke gledišta i vidjeti postoji li mogućnost za takve franšizne sisteme u Hrvatskoj. Rad se zasniva na podacima o razvoju zelene ekonomije u svetu, jedinstvenim karakteristikama zelenog franšizinga i statističkim podacima Međunarodne asocijacije za franšizing i Svetskog saveta za franšizing o razvoju zelenog franšizinga. U radu će biti predstavljena studija slučaja jedne hrvatske franšize. Na osnovu istraživanja, zaključak će ponuditi predloge za povećanje mogućnosti za ovakve franšizne sisteme.

Ključne reči: zeleni franšizing, održivost, okoliš, prilike u Hrvatskoj.

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INTRODUCTION

One of the trends in the modern world is environmental protection. The governments of the world's leading powers are taking initiatives to reduce the negative consequences of climate change, especially those related to the problem of global warming. Many households and businesses in most developed Western countries have begun to focus on recycling (where possible) and reusing goods (separate waste collection, recycling containers, furniture restoration, etc.), installing solar panels in their homes and opting for the benefits of electric vehicles. In this context, the search for new business areas focusing on green, sustainable development and creating a "green" planet is becoming increasingly important. Another reason for opting for this trend is that looking for entirely new business niches is unnecessary. It is enough to reform existing areas of activity and give them a touch of environmental friendliness. It is essential to choose the right time to enter the market and to find someone who "understands" the modern challenges of the time regarding sustainable development issues. The company can become an innovator in these modern business realities. The franchise business is an excellent example of an organic "transformation" from traditional sectors to resource-saving, environmentally friendly and "green" technologies.

The second part of the article explains the global place of green franchising. The third part describes the types of green franchising. The fourth part presents the franchising situation in Croatia and two cases of green franchising. The paper concludes with final reflections and suggestions for further research.

1. GREEN FRANCHISING

A green economy is a fast-growing economic development that prevents global warming, pollution, resource depletion and environmental degradation, creates jobs and promotes economic growth (Zhang et al., 2022). Addressing economic development and environmental concerns is critical as global warming and other environmental issues continue to threaten the world (Acheampong & Opoku, 2023).

Despite the difficult economic conditions in the world and the many external challenges faced by entrepreneurs in recent years, specific business sectors have managed not only to lose their customers but also to gain new customers and significantly strengthen their position in the business world (Berger, 2020). So, 2020 has undoubtedly been one of the most unexpected and challenging years for everyone. The extent of the impact of Covid-19 could neither be predicted nor prevented. Businesses, including franchise networks, apparently believed that consumer demand for goods and services would fall significantly (Rosado-Serrano & Navarro-Garcia, 2022). This was especially true for companies that offered so-called "green" products and services because they thought consumers would want to keep their jobs stable or stick to something familiar in their consumption preferences.

In most cases, the exact opposite was found. Research has shown (Povlitz, N/A) that the pandemic has forced many people to rethink their career choices and explore other opportunities to earn more money and improve their lifestyle. The author further noted that this is reflected in a 67 increase in requests for goods and services in the "eco" category in 2020 compared to 2019. In addition, significant growth was noted not only among consumers but also among business partners. For example, in 2020, the number of companies willing to invest in franchises specializing in "green" technologies increased by 60% (Shahzad et al., 2022).

The concept of modern franchising has been around since the 19th century (Erceg, 2017). Franchising allows individuals to own and operate their business using a parent company's established brand, support and resources (Ziolkowka & Erceg, 2016). Franchising is usually associated with the fast food, hospitality and retail industries (Mickovski et al., 2024).

However, a new wave of franchises has emerged in response to growing environmental concerns focusing on sustainability and environmentally conscious practices (Revolution Brands, 2023). These franchise systems emphasize eco-friendly practices, and products gain traction as they meet customer demand for sustainable products and the need for companies to decrease their environmental footprint. The adoption of green technologies can be seen everywhere - from existing franchises going greener to those gearing their entire concept toward protecting the environment (Campisi, 2024). The green trend has been spreading for around 25 years, but only recently has it become mainstream (Franchise Direct, 2023). As for eco-business franchises directly, they are now presented in several ways (Salisbury, 2015; Franchise Direct, 2023; Campisi, 2024):

- rental and sale of electric vehicles - for example, in Italy, the franchisor company offers a business for the rental and sale of electric bicycles and additionally develops ecotourism in the country (bicycle excursions),
- sale of goods powered by solar and other types of energy,

- selling goods and opening direct catering restaurants based on organic farming products,
- installation of energy-saving windows and spray systems (made from limestone and other environmentally friendly materials),
- consulting (analysis of household energy consumption, drawing up a plan for reducing consumed resources, assistance in sorting waste, etc.),
- training in the field of ecology.

Due to the increased awareness of sustainability, ecology and fairness, "green" is also becoming an increasingly important topic in franchising. Green franchising usually refers to ecologically sustainable and fair franchising. On the other hand, it includes franchise companies that act environmentally friendly and eco-friendly (Martius, 2010). Green franchising aims to find balanced and sustainable economic, ecological and social solutions (Salisbury, 2015; Faster Capital, 2024). Bellone and Matla (2012) state that the franchise structure is predestined for the integration of the three-pillar model of sustainability - namely economic, social and ecological sustainability (Figure 1).

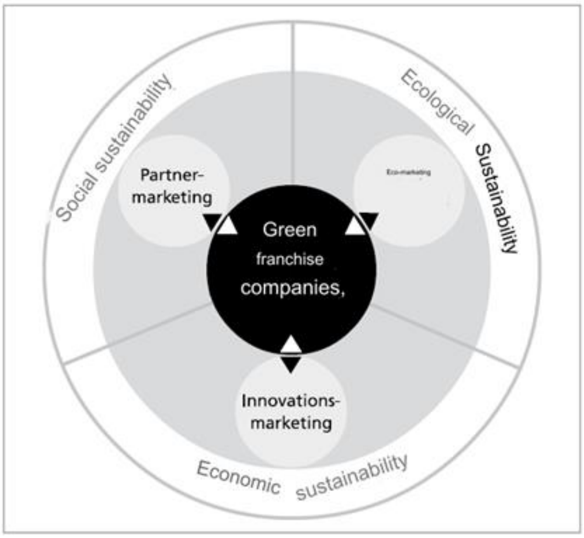

Figure 1: Green franchising principle
Source: adapted from (Bellone and Matla, 2012:13)

Green franchising aims to ensure that franchise systems operate sustainably and in a long-term environmentally and socially compatible way (Martius, 2010). The author says that green franchising considers the franchise system sustainability one of the most critical success factors. The strength and duration of franchise partnerships depend on the concept's quality and the relationships' quality. Bellone and Matla (2012) conclude that green franchising should not be seen as a new type of franchising but rather as a behavioral indicator of sustainable franchising. Green franchising refers to franchisors providing their franchisees with know-how in reducing pollutant emissions and whose codes of conduct require franchisees to obey specific ecological standards (Landini, 2016). In response to the "green" economic growth, more and more franchises are offering "green" goods and services and introducing environmentally friendly practices into their business to reduce the potential negative impact of their technologies, products or waste on the environment (Maltius, 2010). With eco-business franchises, you can today (Revolution Brands, 2023):

- work in a market segment with low competition,
- create a market segment for a potentially new audience of consumers,
- save resources, and at the same time minimize business costs,
- attract more customers to the business thanks to an additional flow organized by fashion trends,
- receive high profits.

Although it is impossible to determine which type of franchising is best suited for its "greening" due to the different needs and goals of every kind of business, it is nevertheless possible to identify five trends in the field of eco-franchising that are receiving close attention from potential partners. These franchising business categories aim to go green, preserve natural resources, and limit waste emissions and energy use, and they include (Salisbury, 2015):

- Organic or healthy food - organic and/or fresh food restaurants, delivery and vending machines.
- Green Home - landscaping solutions, pest control, lighting and duct cleaning.
- Transport - enterprises focused on using bicycles in their activities and even environmentally friendly car washes.
- Green business products and services - consulting companies that increase awareness or help companies become green while improving their performance. Companies focus not only on consumption and energy use but also on the products used in the office and how they are recycled.
- Organic or recycled furniture and clothing - repurposing and upcycling redundant or unnecessary items rather than throwing them away.

- Repair of electric vehicles and batteries for electric vehicles.

When speaking of a “green franchise”, one might think that the company manufactures a product or offers consumers an ecologically friendly service (Salisbury 2015). However, remembering that a franchise can be deemed green if it has adopted environmental practices at its headquarters and altered how it does business (Bellone & Matla, 2010). This could imply a recycling program or limiting waste (e.g., not printing out every email, thereby saving paper; recycling, etc.); energy-efficient lighting options that require employees to turn off computers and electronics when they leave the office; having a water conservation system in place; or implementing other types of energy-efficient systems. Potential franchisees should approach these green opportunities with their eyes wide open. Sound business practices cannot be ignored because a company is considered “green” (Berdin & Berdina, 2022). They have to be wary of so-called “greenwashing” - companies that claim to be environmentally friendly but do not have the proof for those claims. Alternatively, worse, what they do might harm the environment (de Freitas Netto et al., 2020). One must beware of these pretenders, companies that claim to be green, to capitalize on the increasing interest and demand for environmentally friendly companies and business practices, but they are not green (Berdin & Berdina, 2022). Green franchising is best described by Libawa (2010), who stated that to qualify as green, they must do more than recycle paper or use eco-friendly cleaning supplies. They need to make sure, step by step, that the company is committed to environmentally friendly practices.

2. GREEN FRANCHISING RESEARCH

As we prepared this paper, we searched Clarivate Web of Science, Scopus and Google Scholar databases for scientific papers about green franchising using the search words “green” and “franchising”. There were not many scientific papers, i.e., six papers in Web of Science, five in Scopus database and a similar number in Google Scholar. All the scientific papers found were published in the last ten years, and we have only one researcher who is the author of more than one paper. This shows that the research on green franchising is still not a hot topic in the franchising research community. One of the problems with this could be the name of this type of franchising. Some call it green franchising (Berdin & Berdina, 2022), some eco-franchising (Nikolaychuk, 2020), and some sustainable franchising (Jang & Park, 2019). Still, most franchising studies do not make any difference within these terms and do not research them separately. In none of the found papers, there is no green franchising in the name or keywords, but it can be found in the paper itself. The main topic of most recent research about franchising is the topic of sustainability in franchise systems and the impact of sustainability on potential competitive advantage (Calderon et al., 2017).

This shows that there is no separate type of franchising but that sustainability and being green in doing business are accepted. We can expect more papers about sustainability in the “regular” franchise chains like Mcdonald's, Burger King, Subway etc., as they accept the circular economy importance as was researched in several scientific papers (e.g., Dada et al., 2024; Perrigot et al., 2021).

3. CHOOSING GREEN FRANCHISES

Choosing a franchise is always tricky, and selecting a green franchise is no different. A potential franchisee intending to become part of a genuinely green franchise network must objectively analyze the franchisor's green business capabilities (Belloni & Matla, 2010). To wisely choose a green franchise and protect themselves (both the franchisor and the franchisee) from possible risks and implementation failures in practice, the parties need to analyze and consider the following conditions (Franchise Direct, 2023; Salisbury, 2015; Revolution Brands, 2023):

When considering a green franchise, a prospective franchisee should decide whether to join a franchise system that directly supports environmental initiatives (such as clean energy or solar panel installation) or one that incorporates green technologies and is committed to environmental sustainability.

Verification of adherence to green standards is essential. In the USA, the Green America Seal of Approval (Green America, N/A) certifies that a company has completed a selection process and is recognized as socially and environmentally responsible.

When selecting a green franchise, ensuring it genuinely practices sustainability is essential. Greenwashing occurs when franchisors exploit environmental trends for profit without genuinely committing to green practices. Sometimes, a franchisor might allocate its entire environmental budget to promoting its green image rather than implementing sustainable practices.

The prospective franchisee should confirm that the franchisor offers comprehensive training for new franchisees and their employees. This training should cover the fundamentals of franchise management and educate employees on the environmental technologies and business practices that must be consistently applied across the franchise.

Franchisees need to know the costs of operating a green franchise or transitioning to green practices. It is crucial for a potential franchisee to thoroughly research the franchise network they are interested in to ensure they are making a sound investment in a truly green franchise.

Participants in a franchising network can realize their eco-opportunities in business in any way if the franchisor and franchisees use truly green technologies. There is no clear list of those areas of activity where it is possible to use elements of green franchising. Franchise Direct (2023) states that green franchises are i) ones that directly aid the environment and ii) that employ green practices and technology. In the first group are companies from solar panel installation to consultants for energy conservation. The second group comprises companies from different industries, from retail and fast-food franchises to consulting and auditing franchises. Among the most popular franchise networks from multiple industries that have introduced environmental technologies and programs in their activities, the following groups can be distinguished: a) retail franchises, b) car franchises, c) franchise delivery and d) printing franchises.

While the benefits of green franchising systems are substantial, they are not without their challenges. Here are some common obstacles these businesses may encounter (Faster Capital, 2024):

- *Initial investment* - green franchises may demand a higher upfront investment than traditional franchises (Figure 2). The costs associated with eco-friendly technologies, sustainable materials, and necessary certifications can contribute to increased startup expenses. Beyond the initial investment, green and traditional franchises require ongoing payments, including royalties and marketing fees.
- *Consumer education* - Educating consumers about the advantages of green products and services can be challenging (Nekmahmud et al., 2022). Green franchises often need to invest in marketing efforts to raise awareness among potential customers about their eco-friendly offerings.
- *Supply chain sustainability* - Ensuring a steady supply of sustainable materials and products can be difficult, mainly if the franchise operates in regions with limited eco-friendly options.
- *Competitive market* - As demand for sustainable products and services grows (Figure 3), more companies enter the market, intensifying competition. Green franchises must consistently innovate and distinguish themselves to maintain a competitive edge.
- *Changing regulations* - Ecological regulations can differ across regions and are often subject to change. Compliance with these evolving regulations can be a complex challenge for green franchises.

Figure 2: Initial investments in some of the green franchises
Source: (Franchise Direct, 2023)

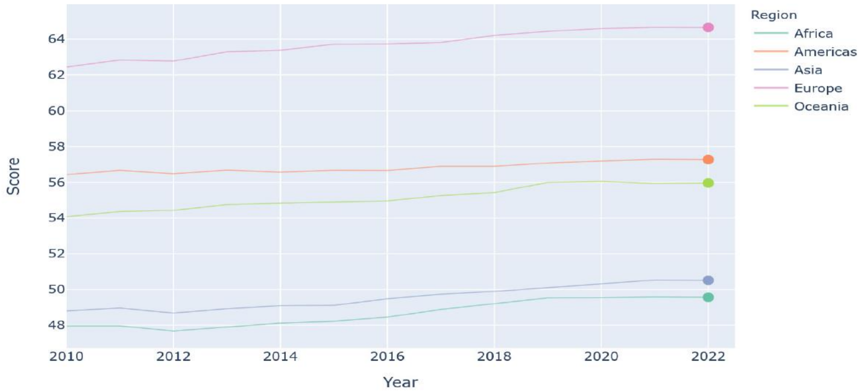

Figure 3: Trend in green growth index by region
Source: (Global Green Growth Institute, 2024)

In the general franchising system, there is an actively growing movement towards environmentally friendly business (Berdin & Berdina, 2022). While ten years ago, for potential franchisees, it was possible to find only a few business options that would fall under the "green" category, today there are already many options among various types of business where one or another green technology can be implemented (Franchise Direct, 2023; Salisbury 2015).

4. GREEN FRANCHISING IN CROATIA

The franchise business in Croatia, which has been in operation since the 1960s, has been looking for a stable place on the market for a long time. In the past three years, there has been significant growth in this sector, especially in the domain of domestic franchises (Erceg et al., 2023; Kukec, 2024). This growth testifies to the Croatian market's adaptability and innovation and entrepreneurs' growing interest in the franchise business model. The franchise sector in Croatia is characterized by high dynamics, which is evident from the significant number of brands entering and exiting the market. In contrast to larger markets, where the closure of one location may remain unnoticed due to the number of others, in the relatively smaller Croatian market, any closure of one area of a prominent brand becomes very noticeable.

According to data from the Hrvatska udruga za franšizno poslovanje (Kukec, 2024), 248 franchise systems operate in Croatia at 4,500 locations, employing around 20,000 people. In the last three years, the share of domestic franchise systems has grown, accounting for 29% of the total number of franchises. In the Republic of Croatia, the fashion sector has the largest share of 43%, followed by the food and beverage sector with a share of 12%; the education sector occupies an important place with a share of 8% in the market, the transport sector, i.e., rent-a-car franchises, has a share of 6%. In comparison, the health and beauty sector occupy 5%. As far as franchising statistics are concerned, there is no data about green franchise systems in Croatia.

The Croatian franchise sector has significant potential for further growth and development, especially in the context of global trends and the adaptability of the local market to international business models. In 2024, the franchise sector will be characterized by several key trends providing challenges and opportunities for growth and development. Technology will continue to play an essential role in the franchise sector, focusing on automating business processes and artificial intelligence (Kukec, 2024). This will lead to greater efficiency, higher customer satisfaction and better decision-making for the franchise business. As people increasingly emphasize health and wellness, the demand for franchise concepts in the wellness sector, including fitness, nutrition, mental health and wellness centers, will increase. Alongside these developments, franchises must continually adapt to the changing needs and expectations of consumers, with a focus on digital experiences, personalization and sustainability.

While researching for this paper, we examined all franchises in Croatia to check if they are franchises that directly aid the environment or employ green practices and technology. Most Croatian franchise systems employ green practices (e.g., McDonald's Croatia, Burger King, etc.). However, it was hard to find the "real" green franchises that operate in Croatia and are of Croatian origin. However, there has been recent progress in this area, as a new green franchise concept has emerged in the Croatian market. This franchise specializes in the repair of electric vehicles and their batteries, which is still a completely new niche, not only in Croatia but across Europe. Given the high demand for their services globally, they have created a franchise and are negotiating their first franchise agreement. With the growing number of electric vehicles on the road, many of which are coming out of their yearly warranty periods, this niche has enormous potential (Katić, 2024).

As with international franchises, the statistical data shows no division between "green" and "no-green" franchises. For the research on the green franchises in Croatia, we have searched the databases and data from Hrvatska udruga za franšizno poslovanje (Kukec, 2024), Colak Franchising Consulting Group (2023) and Croatian Chamber of Commerce (2024). Based on the available data, two green Croatian franchises with already established franchise networks were identified. In the next part of the paper, we will present their business models.

4.1. Biomania - Croatian "green" franchise

BioMania's journey began in 2018, driven by a vision to change the perception of healthy eating and sustainable living. The brand aims to inspire individuals and the industry to live harmoniously with our planet.

BioMania emerged as a pioneer in the restaurant industry with a vision to combine culinary excellence with environmental sustainability. BioMania Bistro and BioMania Street Food were founded on the ethos of offering 100% organic and plant-based cuisine to challenge conventional food norms and provide a sustainable alternative that promotes healthy living and responsible entrepreneurship. The founding principle was to create a culinary gem that satisfies the palate and contributes positively to the planet, reflecting a broader commitment to a sustainable future.

This innovative approach has quickly propelled BioMania to the forefront of the global restaurant scene. BioMania is among the top 1% of restaurants worldwide and the top 10 vegetarian and vegan restaurants. BioMania's reputation for quality and sustainability speaks volumes about its impact. This recognition is a testament to BioMania's success in combining eco-friendly practices with culinary artistry, which has resonated with a diverse and growing customer base.

A deep-rooted commitment to environmental stewardship is at the heart of BioMania's operating philosophy. The franchise greatly emphasizes using local, seasonal and organic ingredients, significantly reducing its ecological footprint. By prioritizing ingredients sourced from local farmers, BioMania supports the local economy and reduces the carbon emissions of transporting food over long distances. Furthermore, using organic ingredients ensures the food is free from harmful pesticides and chemicals, promoting healthier lifestyles and sustainable farming practices.

BioMania's franchising model is designed to replicate this winning formula across multiple locations, providing franchisees with comprehensive support through culinary philosophy training and ongoing operational guidance. The franchise offers street food and bistro formats, each tailored to different market needs while still following the basic principles of sustainability. The strategic franchise fee structure enables a mutually beneficial partnership and ensures a sound investment with significant return opportunities.

BioMania's commitment to sustainability goes beyond its culinary activities. The franchise appeals to a broad spectrum of customers, including health-conscious individuals, environmentally conscious consumers and those new to plant-based eating. This inclusive approach expands its market reach and is critical in educating the public about the benefits of a sustainable lifestyle. Through its activities, BioMania not only enhances the dining experience of its customers but also promotes greater environmental awareness.

In summary, BioMania is a prime example of how sustainable business practices can seamlessly integrate into the culinary world to create a profitable and environmentally friendly franchise model. The franchise's journey from a novel idea to a leader in the eco-friendly restaurant industry illustrates the transformative power of combining business goals with environmental and social responsibility. As BioMania continues to expand, it redefines the standards of food service and sets a precedent for the role of sustainability in shaping the future of global entrepreneurship.

4.2. EcoPoint - green story from Rijeka

In 2009, Rijeka's author duo Bunek and Raspor, noticing several existing problems, designed a simple modular cabinet which, when implemented in residential buildings, serves as (i) an adequate and tidy space for storing advertising brochures of shopping centers that are delivered to residential buildings almost every day often in or on mailboxes and other inadequate places; (ii) an information space that is available to tenants and visitors of buildings from 0-24 hours every day, with important information such as address, manager, authorized person, telephone numbers of emergency, public, communal and on-call services; (iii) info area about various frequently or occasionally needed services and services; and (iv) a place for the primary selection of waste paper generated in households and its removal for recycling.

Eco Point is a multi-award-winning innovation that, after its commercialization in 2010, became a desirable element in residential buildings due to the range of benefits it provides. It enables innovative advertising with a solid positive ecological environmental impact. After many years of successful business, the desire to expand to other cities and interest in the product from various parties led to the fact that 2015, the company was adjusted, and the franchise business concept was established.

Eco Point franchise is a young brand under construction that provides the franchisee with a profitable turnkey business with a well-chosen niche in the indoor advertising marketing industry. Several reasons why it is good to become a franchisee of an Eco Point franchise: (i) the possibility of earning a monthly income of EUR 2.000 to EUR 3.000; (ii) operating costs are meager and are reduced to mandatory contributions and tax payments, accounting, telephone and internet costs, fuel and monthly royalties in the amount of 10% of turnover; (iii) the franchisee does not have to work 0-24, that is, after establishing the business properly, the time he will set aside for performing the necessary activities is very short; (iv) there are no high investments in shopping and expensive arrangement of business space, apart from investment in equipment and procurement of infrastructure on which the business is based; (v) territorial exclusivity.

The total investment to start the business of the Eco Point franchise does not exceed EUR 21,000, which in the world of franchises is relatively low on the scale of investments in starting a business. Although everyone who becomes an entrepreneur does so for their profit, with the Eco Point franchise, it is possible to raise the quality of housing in the urban environment of residential buildings and exert a strong influence on the preservation of the environment. By increasing the amount of high-quality, valuable secondary raw material and recycling it, the franchisee will also influence the reduction of air pollution and the preservation of water resources. That is why Eco Point is one of the rare so-called green franchises.

Franchisees are fully supported from the start. After signing the franchise agreement, the Eco Point cabinet production process is started, and the training and field preparation process begins so that everything is ready to set up the infrastructure with which the franchisee generates income. When agreeing on locations and installing cabinets, the franchisee has full support from the franchisor and assistance in the field. When everything is set, the franchisee is qualified to generate income. The franchisor ensures the complete transfer of knowledge and experience in business.

Eco Point lockers enable constant income because advertising areas on the front of the lockers are rented, which is extremely attractive. According to the data so far, the fluctuation in advertising space is not significant and satisfied clients stay for long periods and return periodically if there are available spaces.

Although they are currently oriented towards local advertising and local clients, and with the franchisee from Varaždin, they have common clients, Eco Point cabinets are also becoming an exciting advertising medium for national clients. With more franchise units and new franchisees, the franchisor will be able to jointly perform on the entire market of the Republic of Croatia, as it will be more attractive for large advertisers as well. Over time, the franchisor plans to expand internationally to become the most famous and leading chain in the indoor advertising sector in Europe.

5. DISCUSSION

The previous two examples of green franchising in Croatia show two approaches to this type. Biomania is a green franchise in several areas, ranging from sustainable business practices in all segments - such as waste reduction, energy efficiency, carbon emission reduction, water management, recycling, and more - to the ingredients they use for their vegan dishes, which are locally and organically grown. Ecopoint is a franchise whose business concept is based on sustainability. Both companies used franchising to expand their businesses. The following can be stated if we examine these two franchises based on potential obstacles that green franchises encounter.

Regarding the initial investment, both franchises are within the range of the “traditional” franchises, especially Biomania, whose investment is relatively high because it is a restaurant and needs to be within specific safety regulations. On the other hand, the Eco Point initial investment is not too high, but it is within the range of investments for similar businesses. So, the franchisees considering these franchises must find additional benefits when deciding.

The second is consumer education. In Croatia, the ecological movement is high, and people recognize the need to care for the environment and act sustainably. Therefore, this does not represent an obstacle for Croatia, but it is probably an additional benefit of having this business.

The third potential obstacle is the sustainability of the supply chain. Since Biomania uses organic food in the restaurant, it may have a problem with the supply chain and possibly scarcity of ingredients in the domestic market, which may cause problems. Eco Point has no issues with the supply chain because it collects waste (mostly paper) and has a constant supply of raw materials.

The fourth potential obstacle is the competitive market, and this is something that both franchises are facing. Every city has a lot of restaurants and other food places, so Biomania has a significant number of competitors, some of which are offering the same type of products as (organic-grown raw materials). Eco Point is also facing huge competition because, in every city, there is a company collecting waste; the other problem is that this is a regulated business. This is probably the biggest obstacle for both companies.

The last potential obstacle is changing regulations, as with every other company and not only franchises. Due to the increased environmental attention in modern life, the rules are constantly being evaluated and, if necessary, changed.

Based on the potential obstacles examined, it can be concluded that although there are obstacles, they don't significantly influence franchise growth potential. Therefore, franchisors must continue developing their franchises, and success will come.

CONCLUSION

As governments worldwide introduce stricter environmental regulations, companies already adopting sustainable practices will likely have a competitive advantage. This regulatory environment and the growing demand for environmentally friendly products and services make eco-franchises a promising and forward-looking investment opportunity.

As awareness for the preservation of planet Earth has increased significantly today and the SDGs of the United Nations have been adopted accordingly to achieve a sustainable future on a global level by 2030, more and more companies are focusing intensively on their implementation in business. This is precisely why the business model of a green franchise is becoming even more attractive. As mentioned, one of the most important segments that can be described as a green franchise is using renewable energy sources. The seventh UN SDG talks precisely about the fact that energy should be affordable and clean. The ninth UN SDG refers to Industries, Innovations and Infrastructure, which can also be observed within the franchise business model. For example, McDonald's is introducing sustainable and environmentally friendly processes into its business. The eleventh goal, Sustainable Cities and Communities, is closely related to the example of the Croatian franchise EcoPoint described earlier in the paper. The thirteenth UN SDGs dealing with climate protection can be linked to the franchise company BioMania, which has also been described in detail above. Of course, other UN SDGs can also be linked to this topic, but we have selected those directly impacted here.

In a world where environmental issues are becoming increasingly pressing, eco-franchises are proving that it is possible to run a successful business while positively impacting the planet. With their innovative approaches to sustainability and commitment to social responsibility, these franchises set the standard for a new era of green business practices.

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Ekoturizam u funkciji održivosti

Ecotourism in a function of sustainability

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Sažetak: Ekoturizam predstavlja oblik turizma koji sve više raste i dobija na značaju zbog svog održivog pristupa, pažnje prema prirodi i kulturi i podrške lokalnoj zajednici. U sklopu ekoturizma, tradicija ima važnu ulogu koja doprinosi autentičnosti iskustava turista, očuvanju kulturnog identiteta i promociji lokalne kulture. Očuvanje i promocija tradicije unutar ekoturizma ne samo što obogaćuje turistička iskustva, već i doprinosi održivom razvoju turizma, zaštiti kulturnog nasleđa i podršci ekonomskom razvoju, naročito ruralnih predela. Edukacija igra ključnu ulogu u ekoturizmu jer pruža posetiocima, lokalnom stanovništvu i turističkim operaterima znanje, svest i razumevanje o važnosti očuvanja prirode, podrške lokalnoj zajednici, promovisanju održivog turizma i zaštite okoline. Kreiranje i razvoj održivih turističkih proizvoda i usluga u ekoturizmu ključni su za promovisanje održivosti, zaštitu prirode i podršku lokalnoj zajednici. Postoji nekoliko značajnih sertifikata i certifikacija za ekoturizam koje prepoznaju i promovišu održive prakse u turizmu. Uspostavljanje sertifikacije za ekoturizam u Srbiji, slične onoj Ecotourism Australia, zahteva temeljno planiranje, saradnju s relevantnim stejkholderimaima i usklađivanje s međunarodnim standardima održivog turizma. U radu se predlaže pokretanje projekta za uspostavljanje sertifikacije „Ekoturizam Srbija“. Na osnovu sagledanih činjenica, razvojnih dokumenata, svetskih trendova i situacije na terenu, autori preporučuju mere i aktivnosti za unapređenje ekoturizma u Srbiji.

Ključne reči: Ekoturizam, priroda, kultura, održivi razvoj.

Abstract: Ecotourism is a form of tourism that is growing and gaining importance due to its sustainable approach, attention to nature and culture, and support to the local community. Within ecotourism, tradition plays an important role that contributes to the authenticity of tourists' experiences, the preservation of cultural identity and the promotion of local culture. The preservation and promotion of tradition within ecotourism not only enriches tourist experiences, but also contributes to the sustainable development of tourism, the protection of cultural heritage and the support of economic development, especially in rural areas. Education plays a key role in ecotourism because it provides visitors, local residents and tourism operators with knowledge, awareness and understanding of the importance of nature conservation, support for the local community, promotion of sustainable tourism and environmental protection. The creation and development of sustainable tourism products and services in ecotourism are key to promoting sustainability, protecting nature and supporting the local community. There are several notable certifications and certifications for eco-tourism that recognize and promote sustainable practices in tourism. Establishing a certification for ecotourism in Serbia, similar to that of Ecotourism Australia, requires thorough planning, cooperation with relevant stakeholders and alignment with international standards of sustainable tourism. In the paper, it is proposed to launch a project for the establishment of "Ecotourism Serbia" certification. Based on the observed facts, development documents, world trends and the situation on the ground, the authors recommend measures and activities to improve eco-tourism in Serbia.

Key words: Ecotourism, nature, culture, sustainable development.

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UVOD / INTRODUCTION

Ekoturizam predstavlja oblik turizma koji sve više raste i povećava učešće u ukupnoj turističkoj razmeni zbog svog održivog pristupa, pažnje prema prirodi i kulturi i podrške lokalnoj zajednici. U sklopu ekoturizma, tradicija ima važnu ulogu jer doprinosi autentičnosti iskustava turista, očuvanju kulturnog identiteta i promociji lokalne kulture. Ljudi odlaze u prirodu kako bi pronašli inspiraciju, odmor, povezanost s prirodnim svetom i povratak svojim korenima. Ekoturizam, koji promoviše očuvanje prirodnih resursa, zaštitu divljih životinja, podršku lokalnim zajednicama i edukaciju posetilaca, ključan je alat za promovisanje održivosti u turizmu i zaštite prirode. Kroz integraciju ekoturizma u destinacije, možemo stvoriti pozitivan uticaj na okolinu, podržati lokalnu ekonomiju i očuvati kulturnu baštinu, postižući time harmoniju između čoveka i prirode. Smatra se da je Hector Ceballos-Lascurain 1987. izneo prvu definiciju ekoturizma. Ovaj meksički arhitekt i ekolog je ekoturizam definisao na sledeći način: „Putovanje u relativno netaknutu i nezagađenu prirodu sa specifičnim ciljevima kao što su učenje, uživanje i divljenje okolini, biljkama i životinjama kao i prošlom i postojećem kulturnom nasleđu određenog područja" (Ceballos-Lascurain, 1987).

Medjunarodno društvo za ekoturizam, TIES, osnovano 1990. godine, definiše ekoturizam kao „odgovorno putovanje u prirodna područja koja čuvaju životnu sredinu, održavaju dobrobit lokalnog stanovništva i uključuju tumačenje i obrazovanje" (Anonimus, 2024). Obrazovanje treba da uključuje i osoblje i goste (Anonimus, 2024a).

Svetska turistička organizacija, UNWTO, definiše ekoturizam na sledeći način: „Ekoturizam je vrsta turističke aktivnosti zasnovana na prirodi u kojoj je suštinska motivacija posetilaca da posmatraju, uče, otkrivaju, doživljavaju i cene biološku i kulturnu raznolikost s odgovornim stavom da se zaštiti integritet ekosistema i unapredi dobrobit mesne zajednice".

Ekoturizam povećava svest o očuvanju biodiverziteta, prirodne sredine i kulturnih dobara, kako među lokalnim stanovništvom tako i među posetiocima, i zahteva posebne procese upravljanja kako bi se smanjio negativan uticaj na ekosistem (Anonimus, 2024b).

WTO je definisala ekoturizam kao oblik turizma sa sledećim karakteristikama:

1. Svi oblici turizma zasnovani na prirodi u kojima je glavna motivacija turista posmatranje i uvažavanje prirode, kao i tradicionalnih kultura koje preovlađuju u prirodnim područjima.

2. Sadrži obrazovne i interpretativne karakteristike.

3. Generalno, ali ne isključivo, organizuju ga specijalizovana i mala lokalna preduzeća za male grupe. Strani operateri različitih veličina takođe organizuju, vode i/ili prodaju ekoturističke ture, uglavnom za male grupe.

4. Minimizira negativne uticaje na prirodnu i socio-kulturnu sredinu

5. Podržava zaštitu prirodnih područja tako što:

– stvara ekonomske koristi za zajednice domaćina, organizacije i organe vlasti koji su odgovorni za očuvanje prirodnih područja;

– otvara radna mesta i mogućnosti prihoda za lokalne zajednice; i

– povećava svest kako među lokalnim stanovništvom tako i među turistima o potrebi očuvanja prirodnih i kulturnih dobara (Anonimus, 2001).

1. ULOGE TRADICIJE U PONUDI RAZLIČITIH SADRŽAJA EKOTURIZMA / THE ROLE OF TRADITION IN THE OFFER OF DIFFERENT CONTENTS OF ECOTOURISM

U ovom delu, istražujemo ulogu tradicije u ponudi različitih sadržaja ekoturizma.Važno je istaći da tradicija igra ključnu ulogu u oblikovanju ponude ekoturizma, jer obogaćuje turistička iskustva posetilaca i pruža im mogućnost da istraže i upoznaju lokalnu kulturu i tradicionalne običaje. Očuvanje tradicije kroz različite aktivnosti ekoturizma, poput poseta tradicionalnim selima, radionicama lokalnih zanata, kulturnim manifestacijama i gastronomskim turama, omogućava posetiocima da se urone u lokalnu kulturu, upoznaju se s običajima i tradicijom te osete duh zajednice koju posećuju.

Tradicija pruža mogućnost da se sačuva kulturni identitet destinacija koje privlače turiste zbog svoje jedinstvene tradicije i nasleđa. Integracija tradicionalnih elemenata u ponudu ekoturizma pomaže u očuvanju lokalnih običaja, jezika, umetnosti i arhitekture, čime se promoviše važnost kulturne raznolikosti i poštovanje tradicije. Posetioci mogu imati priliku da uče o kulturnom nasleđu destinacije, razumeju njenu prošlost i doprinesu očuvanju tradicionalnih vrednosti kroz podršku lokalnoj zajednici.

Takođe, tradicija često služi kao inspiracija i motivacija za aktivnosti unutar ekoturizma koje promovišu održivi razvoj i zaštitu okoline. Kroz tradicionalne metode očuvanja prirode, korišćenje lokalnih resursa, implementaciju ekoloških praksi i podršku lokalnoj flori i fauni, ekoturizam može reflektovati tradicionalne vrednosti održivog života i brige o prirodi. Očuvanje tradicionalnih poljoprivrednih praksi, uzgajanje autohtonih sorti hrane i promocija ekoloških inicijativa u ekoturističkim destinacijama, pruža primer kako tradicija i održivost mogu delovati zajedno.

Tradicija igra važnu ulogu u oblikovanju i obogaćivanju ponude različitih sadržaja ekoturizma. Kroz pažljivo integrisanje tradicionalnih elemenata u turističke aktivnosti, promociju kulturnog identiteta destinacija i podršku očuvanju prirode, ekoturizam postaje više od običnog putovanja - postaje iskustvo koje duboko uranja u kulturu, tradiciju i prirodu destinacije i stvara trajne veze između posetilaca, lokalnog stanovništva i okoline. Očuvanje i promocija tradicije unutar ekoturizma ne samo što obogaćuje turistička iskustva, već i doprinosi održivom razvoju turizma, jača zaštitu kulturnog nasleđa i podžava ekonomski tazvoj, naročito ruralnih predela (Weaver, 2008; Riznić i dr., 2024).

2. ZNAČAJ EDUKACIJE U EKOTURIZMU / THE IMPORTANCE OF EDUCATION IN ECOTOURISM

Edukacija igra ključnu ulogu u ekoturizmu jer pruža posetiocima, lokalnom stanovništvu i turističkim operaterima znanje, svest i razumevanje o važnosti očuvanja prirode, podrške lokalnoj zajednici, promovisanju održivog turizma i zaštite okoline. Ističemo nekoliko ključnih aspekata koji ukazuju na značaj edukacije u ekoturizmu:

1. *Povećanje svesti:* Edukacija o ekoturizmu pomaže povećanje svesti posetilaca o očuvanju prirode, zaštiti divljih životinja, klimatskim promenama i važnosti održivog putovanja. Kroz edukaciju posetioci stiču bolje razumevanje njihovog uticaja na okolinu i mogućnosti koje imaju za podršku održivim praksama.

2. *Podizanje obrazovanja o očuvanju prirode:* Edukacija u ekoturizmu pomaže u podizanju obrazovanja o važnosti očuvanja prirodnih resursa, biološke raznolikosti, zaštite prirodnih staništa te podršci za programe zaštite i obnove prirode. Posetioci imaju priliku da nauče o lokalnoj flori i fauni, geologiji, ekosistemima i ekološkim procesima.

3. *Promovisanje lokalne kulture i tradicije:* Edukacija u ekoturizmu omogućava posetiocima da uče o lokalnoj kulturi, tradiciji, običajima, umetnosti i zanatima. Kroz interakciju s lokalnim stanovništvom i učeći o kulturnom nasleđu destinacije, posetioci dobijaju dublje razumevanje i poštovanje prema lokalnoj kulturi.

4. *Razvoj ekoturističkih veština:* Edukacija takođe pruža priliku da se razvijaju ekoturističke veštine poput planinarenja, observacije divljih životinja, upravljanja otpadom, ekološke izrade, eko-vođenja i promocije održivih proizvoda. Ove veštine pomažu posetiocima da u potpunosti uživaju u ekoturističkim aktivnostima i podrže principe održivosti.

5. *Podsticanje odgovornog ponašanja:* Kroz edukaciju, posetioci su osposobljeni da prepoznaju i primenjuju odgovorne turističke prakse, kao što su smanjenje korištenja plastike, podrška lokalnoj ekonomiji, poštovanje pravila zaštite prirode te promovisanje održivosti putovanja.

Ukupno gledano, edukacija igra ključnu ulogu u ekoturizmu jer doprinosi podizanju svesti, promoviše očuvanje prirode, podržava lokalnu kulturu, razvija turističke veštine i podstiče odgovorno ponašanje putnika. Kroz edukaciju se stvaraju informisani, odgovorni putnici koji su spremni podržati održivi turizam i doprineti zaštiti okoline (Albrecht, 2021; Fennell, 2020).

3. KREIRANJE I RAZVOJ ODRŽIVIH TURISTIČKIH PROIZVODA I USLUGA U EKOTURIZMU / CREATION AND DEVELOPMENT OF SUSTAINABLE TOURIST PRODUCTS AND SERVICES IN ECOTOURISM

Kreiranje i razvoj održivih turističkih proizvoda i usluga u ekoturizmu ključni su za promovisanje održivosti, zaštitu prirode i podršku lokalnoj zajednici. Jedni od najznačajnijih koraka i smernica za uspešno kreiranje održivih turističkih proizvoda i usluga u ekoturizmu:

1. *Identifikacija prirodnih i kulturnih resursa:* Prvi korak u kreiranju održivih turističkih proizvoda je identifikacija prirodnih i kulturnih resursa destinacije. To može uključivati divlje životinje, prirodne parkove, tradicionalne zanate, lokalnu kuhinju, običaje i festivala. Razumevanje bogatstva i posebnosti resursa pomaže u stvaranju autentičnih turističkih iskustava.

2. *Uključivanje lokalne zajednice:* Važno je uključiti lokalno stanovništvo u razvoj turističkih proizvoda i usluga kako bi se osigurala podrška zajednice, poštovanje lokalne kulture i ekonomska dobrobit. Kroz partnerski pristup s lokalnim stanovništvom, turistički proizvodi mogu biti bolje prilagođeni potrebama i interesima zajednice.

3. *Održivi dizajn:* Pri dizajniranju turističkih proizvoda i usluga potrebno je razmišljati o održivosti, uključujući upravljanje otpadom, štedljivu upotrebu resursa, zaštitu prirode i smanjenje negativnog uticaja na okolinu. Uvođenje ekoloških praksi, korišćenje obnovljivih izvora energije i podrška lokalnoj ekonomiji su važni elementi održivog dizajna.

4. *Edukacija i svest:* Edukacija posetilaca i lokalnog stanovništva o važnosti održivog turizma, zaštiti prirode i podršci lokalnoj zajednici ključna je za uspešno implementiranje održivih turističkih proizvoda. Organizovanje edukativnih tura, radionica i programa za posetiocee pomaže u podizanju svesti i podsticanju odgovornog ponašanja.

5. *Monitoring i evaluacija:* Kontinuirano praćenje i evaluacija održivih turističkih proizvoda i usluga važni su za utvrđivanje učinka, identifikaciju mogućih poboljšanja kao i osiguranje da se ispunjavaju ciljevi održivosti. Kroz praćenje zadovoljstva posetilaca, praćenje ekoloških parametara i saradnju s lokalnom zajednicom, turistički proizvodi mogu biti uspešno održivi.

Kroz primenu ovih koraka i smernica za kreiranje održivih turističkih proizvoda i usluga u ekoturizmu, destinacije mogu doprineti zaštiti prirode, promociji kulture i tradicije, podršci lokalnoj ekonomiji i pružiti autentična i odgovorna turistička iskustva turistima. Održivi turizam ne samo što doprinosi očuvanju okoline, već i pozitivno utiče na lokalnu zajednicu i ekonomiju, stvarajući ravnotežu između turizma, kulture i prirode (Harris i dr., 2002).

4. SERTIFIKACIJA ZA EKOTURIZAM / CERTIFICATION FOR ECOTOURISM

U svetu postoji nekoliko značajnih sertifikata i certifikacija za ekoturizam koje prepoznaju i promovišu održive prakse u turizmu. Neke od najznačajnijih sertifikata za ekoturizam uključuju:

1. *Green Key:* Green Key je međunarodni sertifikat za održive hotele, restorane, kamping objekte i druga turistička preduzeća koji je fokusiran na energetsku efikasnost, upravljanje otpadom, vodu i druge ekološke standarde (Anonimus, 2024c).

2. *Travelife:* Travelife je sertifikat koji se dodeljuje turističkim agencijama, hotelima i drugim turističkim preduzećima koji implementiraju održive prakse u svoje poslovanje, uključujući zaštitu okoline, socijalnu odgovornost i ekonomsku održivost (Anonimus, 2024d).

3. *Rainforest Alliance Certified:* Rainforest Alliance sertifikat priznaje turističke objekte koji podržavaju očuvanje ekosistema šuma, zaštitu divljih životinja, promociju lokalne kulture i podršku lokalnim zajednicama (Anonimus, 2024e).

4. *Global Sustainable Tourism Council (GSTC) Certified:* GSTC je globalno priznata organizacija koja identifikuje kriterijume za održivi turizam, a njeni sertifikati prepoznaju turističke destinacije i preduzeća koja primenjuju održive prakse (Anonimus, 2024f).

5. *Ecotourism Australia:* Ecotourism Australia je nacionalna organizacija u Australiji koja dodeljuje sertifikate ekoturizmu, koji prepoznaju turističke operatore koji promovišu očuvanje okoline, podržavaju lokalno zapošljavanje i promovišu odgovorno poslovanje (Ballantyne & Packer, 2013).

Ovo su samo neki od najznačajnijih certifikata za ekoturizam koji pomažu turističkim preduzećima da ostvare održive prakse, pruže transparentnost i odgovornost u svom poslovanju i pruže putnicima pouzdanu informaciju o njihovim održivim praksama.

5. POTENCIJALI SRBIJE U EKOTURIZMU / SERBIA'S POTENTIAL IN ECOTOURISM

Srbija ima mnogo potencijalnih lokacija koje bi se mogle razviti kao održive turističke destinacije. Neke od značajnih lokacija s velikim potencijalom za razvoj ekoturizma u Srbiji:

1. *Nacionalni park Tara:* Nacionalni park Tara u zapadnoj Srbiji nudi očaravajuću prirodu, bogatstvo divljih životinja i brojne aktivnosti poput planinarenja, vožnje kajakom, posmatranja ptica i ekoloških tura.

2. *Nacionalni park Đerdap:* Nacionalni park Đerdap, koji se proteže duž Dunava, nudi jedinstvenu kombinaciju divlje prirode, kulturne baštine i arheoloških nalazišta. Ovaj park privlači ljubitelje prirode, planinare, arheologe i istraživače.

3. *Nacionalni park Fruška Gora:* Nacionalni park Fruška Gora, blizu Novog Sada, karakterišu pitomi pejzaži, planine, manastiri i brojne staze za planinarenje, biciklizam i obilaske prirode.

4. *Stara planina:* Stara planina, takođe poznata kao Balkan, pruža netaknutu prirodu, divlje životinje, planinske vrhove i prekrasne pešačke staze. Ova regija nudi priliku za održivo planinarenje, vožnju biciklom, posmatranje ptica i ekološke ture.

5. *Reka Drina:* Dolina reke Drine, koja se prostire kroz Srbiju, Bosnu i Hercegovinu i Crnu Goru, nudi spektakularan prirodni pejzaž, mogućnosti za aktivnosti na vodi poput raftinga i ribolova, kao i poseut starim selima i kulturnim znamenitostima.

Navedene lokacije predstavljaju samo nekoliko primera mesta u Srbiji s velikim potencijalom za razvoj održive turističke destinacije. Kroz pažljivo planiranje, upravljanje prirodnim resursima, podršku lokalnoj zajednici i promociju održivih praksi, ove lokacije bi mogle postati privlačna odredišta za putnike koji traže autentična prirodna iskustva i podršku očuvanju životne sredine.

Uspostavljanje sertifikacije za ekoturizam u Srbiji

Uspostavljanje sertifikacije za ekoturizam u Srbiji, slične onoj Ecotourism Australia, zahteva temeljno planiranje, saradnju s relevantnim stejkholderima i usklađivanje s međunarodnim standardima održivog turizma. Predlažemo u naznakama nekoliko koraka koji bi mogli biti korisni za uspostavljanje sertifikacije „Ekoturizam Srbija“:

1. *Analiza tržišta i potreba:* Prvi korak je sprovođenje detaljne analize tržišta i potreba kako bi se utvrdila potražnja za sertifikatom za ekoturizam u Srbiji, identifikovali ključni akteri i definisali ciljevi i kriterijumi sertifikacije.

2. *Razvoj standarda i kriterijuma:* Definisanje standarde i kriterijuma sertifikacije koji će obuhvatiti održive prakse u ekoturizmu, uključujući zaštitu okoline, podršku lokalnoj zajednici, kulturnu autentičnost i ekonomsku održivost.

3. *Saradnja s vlastima i turističkim sektorom:* Potrebno je uključiti relevantne državne agencije, turističke asocijacije, predstavnike fakulteta na kojima se izučavaju turizam i ekologija, turističke operatore i lokalne zajednice u proces razvoja sertifikacije ekoturizma kako bi osigurali široku podršku i aktivno učešće.

4. *Obuka i podrška:* Pružanje obuke i edukacije turističkim operaterima, smeštajnim objektima i destianacionim menadžerima o održivim praksama u ekoturizmu, kao i pružanje podrške u implementaciji standarda sertifikacije.

5. *Implementacija i evaluacija:* Implementirajne standarda i kriterijuma sertifikacije u turističke operacije, sprovođenje evaluacije i nadzora kako bi osigurali usklađenost i kontinuirano poboljšanje održivih praksi.

6. *Promocija i marketing:* Promovisanje sertifikata „Ekoturizam Srbija“ kao prepoznatljive oznake kvalitete koja privlači odgovorne putnike i promoviše održive turističke destinacije u Srbiji.

Uspostavljanje sertifikacije ekoturizma u Srbiji zahteva multidisciplinarni pristup, saradnju s relevantnim stejkholderima i predanost održivosti u turizmu. Kroz ovaj proces, Srbija bi mogla da unapredi svoju ponudu ekoturizma, da pruži jasnu prepoznatljivost održivih turističkih praksi i da postane atraktivna destinacija za ekološki odgovorne putnike.

Uspostavljanje sertifikacije „Ekoturizam Srbija“ zahteva kooperaciju s različitim organizacijama i asocijacijama koje imaju interes i ekspertizu u području održivog turizma. Potencijalni partneri koji bi mogli biti ključni za uspostavljanje ove sertifikacije su između ostalih i:

1. *Ministarstvo turizma i Ministarstvo zaštite životne sredine Srbije:* Ministarstvo turizma i Ministarstvo zaštite životne sredine imaju ključnu ulogu u regulisanju turizma i ekološke zaštite te bi mogli pružiti podršku, smernice i regulativne okvire za uspostavljanje sertifikacije.

2. *Turistička organizacija Srbije:* Turistička organizacija Srbije ima značajnu ulogu u promociji turizma u zemlji i inostranstvu. Takođe, može podržati promovisanje sertifikacije i pomoći u uključivanju turističkih aktera u proces.

3. *Turističke asocijacije i udruženja:* Različite turističke asocijacije, udruženja hotela, turističkih agencija i drugih turističkih operatera mogu biti važni partneri u promociji sertifikacije, provođenju obuka i podršci članovima u implementaciji održivih praksi.

4. *Fakulteti na kojima se izučava turizam i ekologija:* Fakulteti mogu pružiti naučnu i ekspertsku podršku procesu modeliranja i realizacije sertifikacije. Partnerstvo sa fakultetima turizma i ekologije koji su u svom radu posvećeni održivom turizmu i na kojima se izučava održivi turizam, mogu pružiti stručnu podršku u razvoju kriterijuma sertifikacije, obuci turističkih operatera i promociji održivih praksi, a posebno u procesu edukacije za primenu sertifikata.

5. *Nevladine organizacije za zaštitu životne sredine:* NGO-i koji se bave zaštitom okoline, očuvanjem prirode i promocijom održivog razvoja takođe mogu biti ključni partneri u uspostavljanju sertifikacije „Ekoturizam Srbija“ kako bi se osiguralo da sertifikat odražava najbolje prakse održivog turizma.

Kroz saradnju s različitim stejkholferima, uključujući vladine institucije, turističke asocijacije, turističke operatere i nevladine organizacije, uspostavljanje sertifikacije „Ekoturizam Srbija“ može postati uspešan projekat koji će podržati održivi turizam, podržavati lokalnu zajednicu i promovisati zaštitu okoline u turističkom sektoru Srbije.

ZAKLJUČAK / CONCLUSION

Na kraju, na osnovu sagledanih činjenica, razvojnih dokumenata, svetskih trendova i situacije na terenu, autori preporučuju sledeće mere i aktivnosti za unapređenje ekoturizma u Srbiji:

1. *Razvoj održivih destinacija:* Srbija treba da razvija destinacije koje promovišu održivi turizam, uključujući zaštitu prirode, očuvanje kulturne baštine i podršku lokalnoj zajednici.

2. *Edukacija i svest:* Potrebno je edukovati turiste, lokalno stanovništvo i turističke operatore o važnosti očuvanja okoline, podržavanju lokalne kulture i promovisanju održivosti kao ključne vrednosti ekoturizma.

3. *Sertifikacija održivosti:* Podržati implementaciju sistema sertifikacije održivosti u ekoturizmu, kroz projekat Ekoturizam Srbija, koji bi osigurali transparentnost i odgovornost u turističkim aktivnostima.

4. *Povećanje investicija u održive projekte:* Podsticanje investicija u održive turističke projekte, poput eko hotela, ekoloških tura, biciklističkih staza i ekoloških centara, koji podržavaju očuvanje prirode i podršku lokalnoj ekonomiji.

5. *Promocija lokalnih proizvoda i kulture:* Podsticanje korišćenja lokalnih proizvoda, hrane, rukotvorina i kulturnih dobara kako bi se podržala lokalna zajednica i očuvala autentičnost destinacija.

6. *Saradnja s lokalnom zajednicom:* Važno je uključiti lokalnu zajednicu u planiranje, razvoj i upravljanje ekoturizmom kako bi se osiguralo da turizam donosi koristi svima u zajednici.

Unapređenje ekoturizma u Srbiji zahteva integrisani pristup koji uključuje saradnju svih relevantnih aktera, obrazovanje i osnaživanje lokalne zajednice, kao i promociju održivih praksi u turističkom sektoru. Kroz ove mere, Srbija može postati još atraktivnija destinacija za ekoturizam, privlačeći ekološki svesne i odgovorne putnike, podržavajući očuvanje prirode i podstičući lokalni ekonomski razvoj.

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Novi pristup dinamičkoj analizi kompeticionog Lotka-Voltera modela: primena na empirijske trofičke mreže

A new aproach to dynamical analysis of competition Lotka-Volterra model: application to empirical food webs

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Sažetak: Razumevanje odnosa između kompleksnosti biosistema i njihove stabilnosti leži u osnovi, kako modeliranja sistema životne sredine, tako i razvoja održivih strategija za njihovo očuvanje i obnovu. Stoga je poznati fenomen međusobne povezanosti kompleksnosti biosistema, u smislu povezanosti funkcionalnih grupa i složenosti povratnih sprega trofičkih interakcija između njih, sa jedne strane i dinamičke nestabilnosti, kao nesposobnosti sistema da se povrati u ravnotežno stanje nakon malih ili umerenih promena u razmeni organske materije, sa druge strane, intenzivno istraživan. Kao jedan od izuzetno uspešnih alata za tu vrstu istraživanja, kao i za mnoge druge, kao što su problem interakcije između biosistema u tlu i iznad njega, problemi vezani za mineralizaciju organske materije i odnos azot : ugljenik u tlu, predviđanje izumiranja vrsta, osetljivost biosistema na funkcionalne promene u trofičkim odnosima, kao i mnoge druge, pokazao se mehanistički model energetskih mreža ishrane, baziran na generalizovanim Lotka-Voltera jednačinama populacione dinamike, prilagođenih fenomenu kruženja organske materije u vidu azota i ugljenika kroz trofičke nivoe, počevši od detritusa, pa do predatora na vrhu lanca ishrane. Tema ovog rada je primena novih, praktično upotrebljivih merila koja omogućavaju opis osetljivosti biosistema, kako na kvanitativne promene nastale u kruženju organske materije, tako i funkcionalne promene u trofičkim interakcijama, usled izmene ponašanja funkcionalnih grupa, radi adaptacije na izmenjene uslove životne sredine. Primer empirijske trofičke mreže tla i njegova dinamička analiza su (do sad nepublikovani) originalni deo doktorske disertacije autora.

Ključne reči: dinamički sistem, Lotka-Voltera model, stabilnost, robusna stabilnost, trofičke mreže.

Abstract: Understanding the relationship between the complexity of biosystems and their stability is the basis of both, the modeling of environmental systems, and the development of sustainable strategies for their preservation and restoration. Therefore, the well-known phenomenon of interconnectedness of the complexity of the biosystem, in terms of the connection of functional groups and the complexity of the feedback loops of trophic interactions between them, on the one hand, and dynamic instability, as the inability of the system to return to an equilibrium state after small or moderate changes in the exchange of organic matter, on the other hand, has been intensively studied. One of the extremely successful tools for this type of research, as well as for many others, such as the problem of interactions between biosystems in and above the soil, problems related to the mineralization of organic matter and the ratio of nitrogen: carbon in the soil, prediction of species extinction, sensitivity of biosystems to functional changes in trophic relationships, like many others, is the mechanistic model of energy food networks, based on the generalized Lotka-Volterra equations of population dynamics, adapted to the phenomenon of the circulation of organic matter in the form of nitrogen and carbon through trophic levels, starting from detritus, and ending with predators at the top of the food chain. The topic of this paper is the application of new, practically usable criteria that enable the description of biosystem sensitivity, both to quantitative changes in the circulation of organic matter, and to functional changes in trophic interactions, due to changes in the behavior of functional groups, in order to adapt to changed environmental conditions. An example of an empirical soil trophic network and its dynamic analysis are the (so far unpublished) original part of the author's doctoral dissertation.

Keywords: dynamical system, Lotka-Volterra model, stability, robust stability, food webs.

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UVOD / INTRODUCTION

Matematički model koji ćemo razmatrati odnosi se na trofičku mrežu od n funkcionalnih grupa živih vrsta sa fondom nežive organske materije, čija je energija protoka približno opisana generalizovanim Lotka-Voltera jednačinama. Ovaj model preuzet je iz knjige (Moore, de Ruiter, 2012).

Da bismo opisali model, uvedimo, najpre, neke oznake.

Za $i \in N := \{1, 2, \ldots, n\}$, sa $x_i(t)$ označimo gustinu biomase i−te funkcionalne grupe u vremenu $t \geq 0$. Za trofičke mreže tla jedinica je obično gram ugljenika (ili azota) po hektaru po centimetru dubine. Gustinu biomase detritusa označimo sa $x_{n+1}(t)$. Skupove indeksa koji odgovaraju sličnim funkcionalnim grupama označimo sa:

- P - primarni proizvođači (biljke, itd.)
- C - primarni potrošači (biljojedi, gljivojedi, bakteriojedi i mesožderi)
- D - detritusožderi (detritus potrošači poput nekih gljivica, bakterija, itd).

Za $i \in P$, sa $g_i > 0$ označavamo stopu rasta tog primarnog proizvođača.

Za $i \in N$, sa $b_i > 0$ označavamo stopu smrtnosti te vrste zbog ne-trofičkih razloga, sa $a_i \in (0, 1)$ njegovu energetsku efikasnost asimilacije, a sa $p_i \in (0,1)$ njegovu efikasnost produktivnosti. Dakle, $a_i p_i$ predstavlja energetsku efikasnost u trofičkoj interakciji.

Napomenimo da su unutrašnja stopa rasta g_i i stopa smrtnosti b_i, po jedinici vremena, osobine funkcionalnih grupa organizama baziranih na njihovom prethodnom ponašanju i/ili njihovoj fiziologiji, dok energetska efikasnost u trofičkoj interakciji $a_i p_i$ predstavlja odnos imobilisane materije ili energije koja formira novu biomasu u obliku rasta i razmnožavanja i količine potrošene materije ili energije. U tom smislu, efikasnost asimilacije se definiše kao količnik asimilovane konzumacije (unosom molekula kroz ćelijske membrane, tako da se mogu koristiti za rast, reprodukciju i održavanje) i ukupne količine potrošene biomase, a efikasnost produktivnosti definisana je kao količnik asimilovane biomase koja se koristi za produkciju (rast i razmnožavanje) i ukupne količine asimilovane biomase.

Konačno, budući da model koji istražujemo uključuje i biomasu nežive organske materije koja ulazi u sistem spolja, definisaćemo $g_D \geq 0$ kao stopu rasta biomase iz takvog alohtonog izvora, po jedinici vremena.

Razmena energije između živih vrsta modelira se pomoću funkcionalnih odgovora. Naime, za svakog predatora $j \in C$, karakteristika koja opisuje kako se on prilagođava promenama u gustini biomase njegovog plena $i \in P$ u momentu t je data sa $f_j(x_i(t))$.

Koristeći uvedene oznake, deterministički sistem jednačina protoka energije u funkcionalnim mrežama ishrane izgleda ovako:

- upravljajući zakon funkcionalnih grupa proizvođača $i \in P$:

$$\dot{x}_i = g_i x_i - \sum_{j \in C} f_j(x_i) x_j - f_i(x_i) x_i \,,$$

- upravljajući zakon funkcionalnih grupa potrošača $i \in C$:

$$\dot{x}_i = a_i p_i \sum_{j \in N \setminus \{i\}} f_i(x_j) x_i - b_i x_i - \sum_{j \in C \setminus \{i\}} f_j(x_i) x_j - f_i(x_i) x_i \,,$$

- upravljajući zakon funkcionalnih grupa detritusoždera $i \in D$:

$$\dot{x}_i = a_i p_i f_i(x_{n+1}) x_i - b_i x_i - \sum_{j \in C} f_j(x_i) x_j - f_i(x_i) x_i \,,$$

- upravljajući zakon detritusa:

$$\dot{x}_{n+1} = g_D + \sum_{j \in N} b_j x_j - b_i x_i - \sum_{j \in C, k \in N \setminus \{j\}} (1 - a_j) f_j(x_k) x_j - \sum_{j \in D} f_j(x_{n+1}) x_j \,.$$

Prateći konvenciju u literaturi, za detritus koristimo indeks D da bismo ga razlikovali od ostalih. Detritus ulazi u sistem spolja (alohtoni izvori) ili iznutra (autohtoni izvori). Alohtoni izvori predstavljeni su izrazom gD. U ovom modelu, mi ih, bez ograničenja opštosti, posmatramo kao jedan izvor. Što se tiče autohtonih izvora, ovaj model identifikuje dva takva izvora:

- $\sum_{j \in C, k \in N \setminus \{j\}} (1 - a_j) f_j(x_k) x_j$, koji predstavlja neasimilovane delove plena koje je predator pojeo i uključuje izmet, otpatke i nepojedene ostatke
- $\sum_{j \in N} b_j x_j$, koji predstavlja leševe koji umiru iz ne-trofičkih razloga.

Konačno, izraz $\sum_{j \in D} f_j(x_{n+1}) x_j$ predstavlja direktnu konzumaciju detritusa.

Naravno, u zavisnosti od tipa funkcionalnog odgovora, zavisiće i složenost samog modela. Najjednostavniji oblik tog funkcionalnog odgovora jeste linearni, koji pretpostavlja da je brzina napada konstantna u odnosu na gustinu plena (ne zavisi od gustine plena), odnosno da je u pitanju linearna zavisnost

$$f_j(x_i(t)) = c_{ij}\, x_i(t),$$

gde $c_{ij} \geq 0$ predstavlja koeficijent konzumacije po jedinici biomase po jedinici vremena. U slučaju kada nema trofičke interakcije, taj koeficijent je jednak nuli. Slično važi i za detritusoždere $j \in D$, pri čemu je

$$f_j(x_{n+1}(t)) = c_{n+1,j}\, x_{n+1}(t),$$

a $x_{n+1}(t)$ je gustina biomase u detritusu u momentu t.

Veoma je važno ponovo napomenuti da za sve funkcionalne grupe organizama $i \in P \cup C \cup D$, uzimamo u obzir i samoograničavajući faktor kao kompeticiju unutar vrste, u smislu negativnog uticaja jedinki na rast i reprodukciju ostalih jedinki u njihovoj funkcionalnoj grupi. Ovaj proces se modelira kao model zavisnosti od gustine istog tipa funkcionalnog odgovora, u našem slučaju, linearnog tipa:

$$f_i(x_i(t)) = c_{ii}\, x_i(t),$$

gde $c_{ii} > 0$ predstavlja stepen kompeticije unutar vrste (intraspecifična kompeticija) i uključuje pribavljanje i korišćenje zajedničkih resursa (plen, prostor, partner, svetlost, bitne hranljive materije, itd.).

U slučaju ovakvih - linearnih funkcionalnih odgovora, dinamika prati sledeći zakon:

$$\dot{x}(t) = \varphi\big(x(t)\big),$$

gde je φ nelinearna funkcija definisana pomoću parametara g_D, b_i, a_i i p_i $(i \in N)$, kao i parametara trofičkih interakcija c_{ij}, obično izraženih matricom C trofičkih interakcija dimenzije $n+1 \times n+1$. Matrica C ima blok formu, zbog podele funkcionalnih grupa vrsta na četiri skupa indeksa C, P, D i $\{n+1\}$, počev od top predatora pa na dole, te se upravljajuća funkcija φ može zapisati po komponentama kao:

$$\varphi_i(x) = (g_i - b_i)x_i - c_{ii}x_i^2 + x_i \sum_{\substack{j=1 \\ j\neq i}}^{n+1} \big(a_i p_i c_{ji} - c_{ij}\big)\, x_j\,, \quad i \in N,$$

$$\varphi_{n+1}(x) = g_D + \sum_{j=1}^{n+1} b_j\, x_j + \sum_{j=1}^{n+1} \sum_{\substack{k=1 \\ k\neq j}}^{n+1} \big(1 - a_j\big) c_{jk}\, x_j x_k - \sum_{j=1}^{n+1} c_{n+1,j} x_{n+1}\, x_j\,,$$

Community matrica je, u stvari, vrednost Jakobijana u ravnotežnoj tački x^*. Vrednost funkcije φ u tački x^* jednaka je nuli, pa za *dopustive* (feasible) tačke ekvilibrijuma, tj. za one za koje je $x^* > 0$, zaključujemo da je community matrica $A = [\alpha_{ij}]$ data sa:

$$\alpha_{ij} = \begin{cases} -c_{ii}x_i^*\,, & i = j \\ -\big(c_{ij} - e_i c_{ji}\big)x_i^*\,, & i \neq j \end{cases} \qquad (i, j \in N)$$

$$\alpha_{i,n+1} = \begin{cases} 0\,, & i \in C \cup P \\ e_i c_{n+1,i} x_i^*\,, & i \in D \end{cases}$$

$$\alpha_{n+1,j} = b_j - c_{n+1,j}x_{n+1}^* + \sum_{k\in N\setminus\{j\}} (1 - a_k) c_{jk} x_k^* \qquad (j \in N)$$

$$\alpha_{n+1,n+1} = -\sum_{k\in N} c_{n+1,k} x_k^*\,.$$

Funkcija evolucije $\phi_A(t)$ community matrice A, dakle, u potpunosti je određena parametrima efikasnosti asimilacije a_i, efikasnosti produktivnosti p_i, matricom parametara trofičkih interakcija C, kao i ravnotežnim gustinama biomase x_i^*. Prema tome, da bismo formirali model primenljiv na realne ekosisteme, neophodno je kalibrisati ove parametre, i to na osnovu empirijskih podataka. Međutim, dok se parametri obe efikasnosti mogu utvrditi na osnovu fizioloških osobina funkcionalnih grupa organizama, a gustine ravnotežne biomase merenjima, veliki izazov za primenu ovog modela predstavljaju vrednosti matrice trofičkih interakcija. Naime, kako su to stope interspecifičnih interakcija, konzumacije po jedinici biomase po jedinici vremena, (vandijagonalni elementi matrice) i stope intraspecifične kompeticije (dijagonalni elementi matrice), utvrđivanje ovih vrednosti, na osnovu realnih podataka, nije direktan postupak. Pratićemo isti metod kao u (Moore, de Ruiter, 2012) i (Neutel et al., 2007), gde je community matrica izvedena iz

- B_i $[g\ C\ ha^{-1}\ cm\ depth^{-1}]$ – izmerene godišnje prosečne biomase za svaku funkcionalnu grupu $i \in N$,
- d_i – stope ne-predatorske smrtnosti u ekvilibrijumu, uključujući smrtnost (koja zavisi od gustine) prouzrokovanu intraspecifičnom kompeticijom za svaku funkcionalnu grupu $i \in N$,
- a_i i p_i – procenjenih fizioloških parametara asimilacione efikasnosti i produkcione efikasnosti, redom, za svaku funkcionalnu grupu $i \in N$, kao i
- γ_{ij} – faktora trofičkih preferencija funkcionalne grupe $j \in N$ prema funkcionalnim grupama $i \in N$.

Sve ove vrednosti se mogu dobiti proučavanjem fiziologije i trofičkog ponašanja organizama, kao i merenjima biomase na terenu, te, stoga, gornji model, u kome je community matrica A izvedena iz navedenih vrednosti, nazivamo *model empirijske* *trofičke mreže*. Sam postupak takvog dobijanja community matrice navodimo u nastavku.

Prvo, za svaku funkcionalnu grupu $i \in N$, sa M_i označimo *godišnju stopu smrtnosti izazvanu predatorstvom*, a sa F_i njenu ukupnu godišnju stopu hranjenja (obe u $g\ C\ ha^{-1}\ cm\ depth^{-1} y^{-1}$). Pretpostavljajući da se sva merenja biomase vrše u toku ekvilibrijumskog stanja ekosistema, možemo zaključiti da važi zakon o bilansu mase u ravnotežnom stanju, koji se da izraziti kao

$$F_j = \frac{d_j B_j + M_j}{a_j p_j} \quad (j \in N)\,.$$

Sa druge strane, ukupna godišnja stopa F_j hranjenja grupe $j \in N$ distribuirana je na tipove plena $i \in N$ na sledeći način:

$$F_{ij} = \frac{\gamma_{ij} B_j}{\sum_{k\in N} \gamma_{kj} B_j}\ F_j \quad (i \in N)\,,$$

gde je F_{ij} godišnja stopa hranjenja grupe j plenom i. Konačno, godišnja stopa smrtnosti izazvane predatorstvom je

$$M_i = \sum_{j\in N} F_{ij} \quad (i \in N).$$

Dakle, da bismo odredili vrednosti F_{ij} godišnjih stopa hranjenja potrošača $j \in C \cup D$ plenom $i \in N \cup \{n+1\}$, na osnovu kojih možemo kalibrisati community matricu A, neophodno je da rešimo gornji sistem jednačina po F_{ij}. S obzirom da su jednačine rekurentno povezane, neophodno je znati odakle početi rešavanje. Odgovor leži u činjenici da trofičke mreže imaju hijararhijsku strukturu po trofičkim nivoima. Naime, najviši trofički nivo čine top predatori, kojima se niko ne hrani. Označavajući sa N_k indekse funkcionalnih grupa koje se nalaze u $k-$tom trofičkom nivou $k = 1, 2, \dots, l$, prateći top-to-bottom poredak, imamo da je

$$M_j = 0 \quad (j \in N_1)\,,$$

na osnovu čega računamo F_j za sve $j \in N_1$, koje potom distribuiramo na niže trofičke nivoe pomoću i dobijamo F_{ij} za sve $j \in N_1$ i sve $i \in N_2 \cup \dots \cup N_l$. Međutim, tada, kako su za sve $j \in N_2$, potrošači koji se hrane $j-$tom funkcionalnom grupom u N_1, dobijamo

$$M_j = \sum_{k\in N} F_{jk} \quad (j \in N_2).$$

Sada čitav postupak možemo nastaviti za trofički nivo N_2, i potom redom za N_3, sve do poslednjeg N_l, u kome se nalaze proizvođači i detritus.

Na ovaj način smo dobili stope hranjenja F_{ij} za svaki trofički odnos funkcionalne grupe j koja se hrani grupom i, što kao stopa po izmerenoj biomasi B_j upravo odgovara vrednosti $c_{ij} x_i^*$, tj. važi

$$c_{ij} x_i^* = \frac{F_{ij}}{B_j} \quad (1 \le i, j \le n+1, i \ne j).$$

Prema tome, uz fiziološke parametre, na osnovu empirijskih podataka su određeni svi elementi community matrice A, osim dijagonalnih $\alpha_{ii} = c_{ii} x_i^*$, $(i \in N)$.

Međutim, intraspecifična kompeticija se može posmatrati kao deo godišnje ne-predatorske stope smrtnosti, u oznaci d_i, $i \in N$, tj.

$$c_{ii} x_i^* = s_i d_i\,, \qquad (i \in N),$$

gde za funkcionalnu grupu $i \in N$, izraz s_i predstavlja deo godišnje ne-predatorske stope smrtnosti d_i, koja je rezultat intraspecifične kompeticije (prirodna smrt) i koja je *nepoznati* parametar.

Pod pretpostavkom da je $s = s_i$ za sve $i \in N$, community matrica A sada zavisi od parametra s, tj.

$$A = A(s) := sD + G\,,$$

gde je $D = diag(d_1, d_2, \dots, d_n, 0)$, $G = [g_{ij}]$, a

$$g_{ij} = \begin{cases} 0, & i = j,\ i \in N \\ \alpha_{ij}\,, & inače \end{cases}$$

Dakle, community matrica $A(s)$ zavisi od intraspecifično kompeticionog faktora s samo na dijagonalnim ne-detritus mestima, dok je ostatak fiksiran empirijskim podacima, pa se taj parametar s koristi za određivanje indikatora stabilnosti za posmatranu trofičku mrežu. Preciznije, ukoliko postoji $s \in (0, 1]$ takvo da community matrica $A(s)$ čini da je posmatrani TIDS u određenom smislu ”lokalno stabilan” (rezilijentan, nereaktivan, robusno nereaktivan, robusno eksponencijalno stabilan, itd.), tada najmanje takvo s predstavlja dovoljan stepen intraspecifične kompeticije (procenat stopa netrofičkih smrtnosti svake od grupa) koji ”stabilizuje” trofičku mrežu u posmatranom smislu. Zato se takvo s može smatrati indikatorom, pri čemu manje vrednosti označavaju ”stabilnije” trofičke mreže, dok vrednosti $s \ge 1$ govore o tome da se posmatrana trofička mreža ne može smatrati ”stabilnom”, tj. da se sistem ne može stabilizovati putem intraspecifične kompeticije (s je, u suštini, procentualna kategorija, pa ima smisla samo za vrednosti između 0 i 1).

Kao što je već rečeno u (Neutel et al., 2007), prednost izražavanja stabilnosti u terminima dijagonalnih elemenata leži u činjenici da, dok sami karakteristični koreni nemaju direktno biološko tumačenje, nivo jačine intraspecifične interakcije (koji se ogleda u s) ima biološko, materijalno tumačenje. U tom smislu, dijagonalni elementi predstavljaju samoregulišući faktor organizama i odnose se na stopu gubitka organizama u stabilnom stanju. On je dinamičko i energetsko ograničenje, pošto se može protumačiti kao gubitak, kroz samoregulaciju, u odnosu na ukupan prirodni gubitak koji sistem može imati (za date ravnotežne stope i stabilnost).

O tome na koje sve načine možemo iskoristiti parametar s kao indikator ekološke stabilnosti trofičkih mreža bavićemo se u nastavku. Najpre ćemo prezentovati u literaturi poznate rezultate, zajedno sa diskusijom o njihovim nedostacima, a zatim ćemo konstruisati nove indikatore, zasnovane na matematičkim razmatranjima u (Cvetković, 2023).

Da bi se razvili indikatori ekološke stabilnosti empirijskih trofičkih mreža, do sada su, koliko je autoru poznato, od navedenih osobina iskorišćene:

- eksponencijalna stabilnost LTIDS (položaj spektra)
- nereaktivnost u maksimum normi (položaj Geršgoprinovog skupa)
- nereaktivnost u euklidskoj normi (numerički raspon)

i to na sledeći način. U (de Ruiter et al., 1995) je za indikator stabilnosti trofičke mreže, predstavljene empirijskim podacima, uzeta vrednost s_∞^*, koja predstavlja najmanju vrednost s, takvu da je community matrica $A(s)$ strogo dijagonalno dominantna (SDD), što je, s obzirom na negativnost njenih dijagonalnih elemenata, ekvivalentno sa činjenicom da njen Geršgorinov skup leži u otvorenoj levoj kompleksnoj poluravni.

$$s_\infty^* \coloneqq inf\{s \geq 0 : \Gamma(A(s)) \subseteq C^-\}.$$

To je ekvivalentno sa

$$s_\infty^* = inf\{s \geq 0 : \nu_{A(s)}^\infty < 0\},$$

gde je $\nu_{A(s)}^\infty$ reaktivnost matrice A u maksimum normi. Iz tog razloga, ovaj indikator nazivamo *indikator nereaktivnosti u maksimum normi.* S obzirom da se parametar s nalazi na svim dijagonalnim mestima matrice, osim na poslednjem, koji odgovara detritusu, jasno je da s_∞^* ne mora postojati u opštem slučaju. Preciznije, ukoliko je

$$|\alpha_{n+1,n+1}| \leq \sum_{j\in N} |\alpha_{n+1,j}|$$

matrica $A(s)$ ne može biti SDD niti za jedno s, što ćemo konvencijom zapisati kao $s_\infty^* \coloneqq +\infty$. U suprotnom, s obzirom da je $\alpha_{ii} = -sd_i$ za $i \in N$, možemo eksplicitno odrediti sve s za koje je svaka vrsta matrice $A(s)$ strogo dijagonalno dominantna. Drugim rečima, indikator s_∞^* ima lepu osobinu da se eksplicitno može zapisati u terminima elemenata matrice $A(1)$:

$$s_\infty^* = \begin{cases} \max_{i\in N}\left\{\frac{1}{d_i}\sum_{j=1,j\neq i}^{n+1} |\alpha_{ij}|\right\}, & |\alpha_{n+1,n+1}| > \sum_{j\in N} |\alpha_{n+1,j}|, \\ +\infty, & inače. \end{cases}$$

Pored toga, u istom radu, s obzirom da je ovakav uslov za nerekativnost community matrice često previše zahtevan za empirijske trofičke mreže, razvijen je i indikator zasnovan na generalizovanim dijagonalno dominantnim (GDD) matricama koji je manje zahtevan, ali se ne može eksplicitno izraziti preko elemenata matrice i stoga ga je neophodno numerički odrediti, što je netrivijalan i računski daleko složeniji i skuplji postupak, te ga ovde izostavljamo.

Na sličan način, razvijen je indikator zasnovan na numeričkom rasponu, tj, nereaktivnosti u euklidskoj normi, ali, kao što je to bio slučaj sa indikatorom zasnovanom na GDD matricama, tako i ovde, postupak izračunavanja mora biti numerički i zapravo je to problem optimizacije najvećeg karakterističnog korena hermitske matrice. Kao takav, ovaj postupak je netrivijalan i numerički zahtevan, te i njega izostavljamo.

Konačno, u (Moore, de Ruiter, 2012) i (Neutel et al., 2007) za indikator stabilnosti trofičke mreže, predstavljene empirijskim podacima uzeta je vrednost s^*, koja predstavlja najmanju vrednost za s takvu da je community matrica $A(s)$ stabilna, tj. da ima sve karakteristične korene u otvorenoj levoj kompleksnoj poluravni. Preciznije,

$$s^* \coloneqq inf\{s \geq 0 : \Lambda(A(s)) \subseteq C^-\}.$$

Slično prethodnom, izračunavanje indikatora s^* je problem optimizacije najdesnijeg karakterističnog korena matrice $A(s)$, što je, s obzirom na njenu (nehermitsku) strukturu, dodatno složeniji numerički postupak od prethodnog slučaja.

Pre nego što pređemo na nove originalne indikatore ekološke stabilnosti trofičkih mreža, kratko ćemo ilustrovati upotrebu indikatora s_∞^* i s^* i ukazati na određene poteškoće koje nastupaju. Posmatrajmo isti primer koji je obrađen i u radu (Neutel et al., 2007). Bez ulaženja u detalje, navedimo samo da za njenu community matricu

$A(s) = sD + G$, dobijamo

$$s_\infty^* = +\infty \quad i \quad s^* = 0.012766.$$

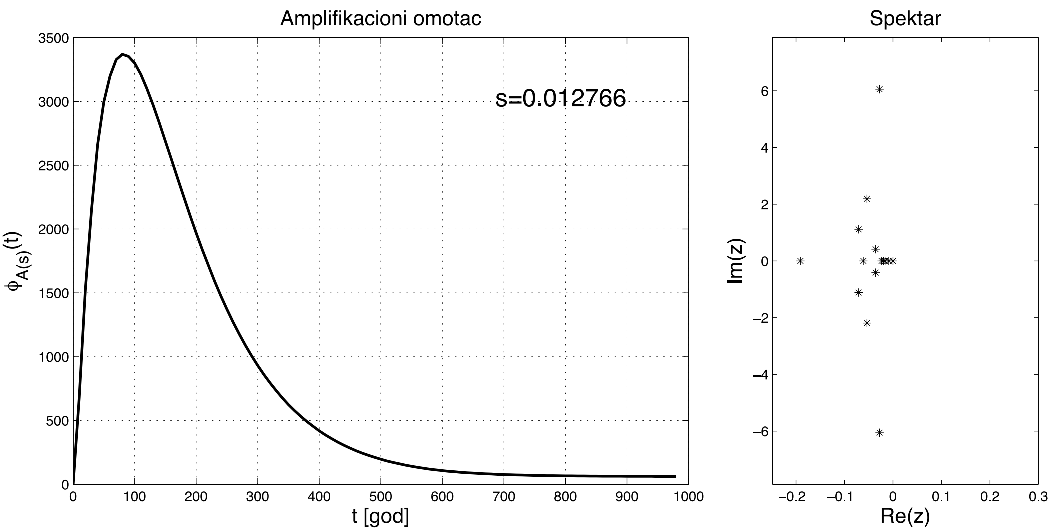
Očigledno, $s_\infty^* > 1$ govori o tome da u maksimum normi ova empirijska trofička mreža mora biti reaktivna, dok $s^* < 1$ predviđa da je možemo smatrati asimptotski stabilnom. Takođe, činjenica $s_\infty^* = +\infty$ znači da poslednja vrsta community matrice nije SDD, tj. da je detritus odgovoran za reaktivnost u maksimum normi, koja se ne može otkloniti intraspecifičnom kompeticijom. Dakle, maksimalno odstupanje od ekvilibrijuma čak i u prisustvu neograničenog spoljnog izvora ishrane, obavezno mora proći kroz amplifikacioni rast, usled dinamike upravljene detritusom.

Na Slici 1 je na desnoj strani prikazan spektar community matrice $A(s^*)$ za $s^* = 0.012766$, a sa leve strane odgovarajući amplifikacioni omotač

$\Phi_{A(s^*)}(t)$. Kao što možemo videti, vreme neophodno da se sistem oporavi nakon perturbacije je više od jednog milenijuma!

Štaviše, pre nego što sistem apsorbuje početnu perturbaciju i vrati se u stanje ekvilibrijuma, u prvih 100 godina, on prolazi kroz fazu svoje tranzicione amplifikacije, koja je veća od 3000. Očigledno, to može biti kritično visoko i može prevazići nosive kapacitete ekosistema. Drugim rečima, ova amplifikacija može da dovede do gubitka funkcionalnog integriteta ekosistema, pre nego što se ispolji efekat asimptotske stabilnosti. Zbog toga je tranziciono ponašanje za izabrano s neophodna informacija za bolje razumevanje dinamičkih ograničenja u strukturi sistema.

U čemu je, zapravo, nastala poteškoća pri formiranju indikatora s^*? Odgovor se ssadrži u činjenici da su predator-plen interakcije među predatorima sadržane u dijagonalnom bloku community matrice koji predstavlja retku matricu, čiji su dijagonalni elementi strogo negativni, a u slučaju kada nema obostranih trofičkih interakcija između predatora, njen donji trougaoni deo je nepozitivan, dok je gornji trougaoni deo nenegativan i numerički značajno manjeg reda. Upravo ovakva struktura community matrice empirijskih trofičkih mreža čini je dalekom od normalne (vidi (Trefethen, Embree, 2005) za detaljni tretman ne-normalnih matrica i ne-normalne dinamike) i zbog toga je odgovorna za to da indikatori stabilnosti izvedeni preko asimptotske stabilnosti najčešće odgovaraju ekstremno dugim vremenskim periodima potrebnim da se sistem vrati u stanje ravnoteže (koje je perturbovano), prolazeći kroz, moguće kritičnu, tranzicionu amplifikaciju.



Slika 1: Tranzicioni rast (levo) i spektralni portret u kompleksnoj ravni (desno) za community matricu $A(s^*)$, za $s^* = 0.012766$

Motivisani ovim razmatranjem, uvodimo drugačiji pristup, koji će obezbediti realističniju interpretaciju.

NOVI INDIKATORI STABILNOSTI / NEW STABILITY INDICATORS

Standardne osobine eksponencijalne asimptotske stabilnosti i nereaktivnosti bili su osnova do sada razvijenih indikatora. Međutim, kao što smo videli, koristeći samo početno ponašanje evolucione funkcije (nereaktivnost) i njeno asimptotsko ponašanje, nismo u stanju da formiramo u potpunosti adekvatne indikatore ekološke stabilnosti. Razlog tome je višestruk:

- Prvo, perturbacije ravnotežnog stanja protoka energije kroz ekosistem u principu nisu samo poremećaji gustine biomase unutar funkcionalnih grupa. Poremećaji mogu biti, a često upravo i jesu, u fiziološkim svojstima organizama, kao i u trofičkom ponašanju.
- Drugo, empirijski podaci, kao takvi, nisu dovoljni da se formira model samo na osnovu njih, usled osetljivosti merenja i stohastičkih fluktuacija.
- Treće, čak i umereno reaktivni asimptotski stabilni LTIDS mogu imati izrazito veliku tranzicionu amplifikaciju, koja može narušiti nosivi kapacitet ekosistema.

Međutim, postoji alat koji otklanja upravo ova tri nedostatka. To je pseudospektar i njegove lokalizacije. Preciznije rečeno, postojeće indikatore možemo unaprediti inkorporirajući perturbacije community matrice u analizu dinamičkih svojstava ekvilibrijuma.

U realnom životu, trofičke mreže su podložne značajnim stohastičkim varijacijama, kako demografskim, tako i varijacijama okoline, vidi (Varughese, Fatti, 2008). Uključivanje tog stohastičkog ponašanja može dovesti do toga da se sistem ponaša značajno drugačije od svog determinističkog duplikata, vidi (Mao et al., 2002).

Poznato je, vidi (Trefethen, Embree, 2005), da je moguća situacija u kojoj karakteristični koreni leže u levoj poluravni, obezbeđujući asimptotsku stabilnost ekvilibrijuma, a da se istovremeno $\varepsilon-$pseudospektar propagira daleko u desnu poluravan, čak i za veoma malo ε, dovodeći do tranzicionog ponašanja. Kada se radi o empirijskim trofičkim mrežama, to znači da, iako je dotični ekosistem ocenjen kao stabilan, na osnovu spektra community matrice, pre nego što asimptotsko ponašanje počne da se manifestuje, može proći više od veka - daleko izvan vremenskog okvira u kome se se linearizacija može smatrati validnom. Još, pri tome, tranziciona amplifikacija može prevazilaziti nosivi kapacitet ekosistema.

Posmatrajući isti problem iz drugog ugla, možemo tvrditi da je ispitivanje stabilnosti samo pomoću spektra ne-normalnih community matrica (što je u praksi najčešći slučaj) u najmanju ruku nedovoljno. Zbog grešaka u merenju i empirijskih nesigurnosti u određivanju fizioloških parametara i gustine biomase, izračunata community matrica biće adekvatna reprezentacija ekološkog sistema samo ako se posmatra zajedno sa granicama nesigurnosti.

Dakle, važno je analizirati kako će se navedeni indikatori stabilnosti ponašati u prisustvu neizvesnosti u modelu empirijskih trofičkih mreža.

Zato, počnimo sledećim pitanjem: *Do koje mere mogu ići nesigurnosti (neizvesnosti) u parametrima koji definišu model v, a da se sačuva indikator stabilnosti?*

Da bismo analizirali ovo pitanje, označimo sa Δ_{ij} nesigurnost empirijskih podataka koji formiraju vrednosti α_{ij} za $1 \leq i,j \leq n+1$. Drugim rečima:

- *empirijska* community matrica je $A(s)$, a
- *tačna* community matrica je $A(s)+\Delta$, pri čemu je $\Delta = [\Delta_{ij}]$ nepoznato.

Ako pretpostavimo da su merenja na terenu i fiziološke studije *razumno* dobre, matrica nesigurnosti Δ ima razumno male elemente.

Neka je $\varepsilon > 0$ nivo nesigurnosti u smislu da je $\|\Delta\| \leq \varepsilon$ i definišemo novi indikator, koji uzima u obzir normu nivoa nesigurnosti ε:

$$s_\varepsilon^* := min\left\{s \geq 0 : \bigcup_{\|\Delta\| \leq \varepsilon} \Lambda(A(s)+\Delta) \subseteq C^-\right\}$$

Nasuprot prethodnih, ovaj novi $\varepsilon-$robusni indikator s_ε^* ima interpretaciju u terminima *tačne* community matrice. Naime, s_ε^* je najmanji deo godišnje stope smrtnosti koja je rezultat intraspecifične kompeticije, a koji garantuje da je tačna community matrica lokalno asimptotski stabilna, ako se baziramo na empirijskim podacima $A(1)$ i nivou nesigurnosti $\varepsilon \geq 0$. Drugim rečima, s_ε^* je najmanja vrednost koja garantuje da su sve matrice $A(s_\varepsilon^*)+\Delta$ lokalno asimptotski stabilne za $\|\Delta\| \leq \varepsilon$. To, naravno, uključuje i tačnu (ali nepoznatu) community matricu.

Prema tome, novi indikator stabilnosti s_ε^*uzima u obzir prirodne stohastičke fluktuacije, netačnosti u merenjima na terenu, kao i moguće strukturalne i fiziološke poremećaje i to u obliku parametra nesigurnosti ε. Ova vrednost, u suštini, odražava najgori scenario, u kome nesigurnosti mogu pomeriti stabilan sistem u nestabilan. Prema tome, s_ε^* treba razumeti kao indikator koji je robustan u odnosu na stohastičke fluktuacije i netačnosti kontrolisane parametrom ε.

Naravno, postavlja se pitanje kako ovakav indikator izračunati. $\varepsilon-$pseudospektar je dobar izbor alata za utvrđivanje spektralnih osobina koje su robusne u odnosu na matrične perturbacije ograničene u datoj normi parametrom $\varepsilon > 0$, pa se indikator s_ε^* može zapisati i kao

$$s_\varepsilon^* = min\{s \geq 0 : \Lambda_\varepsilon(A(s)) \subseteq C^-\}.$$

S obzirom da se radi o nekonveksnom optimizacionom problemu, samo određivanje ovakvog parametra predstavlja veći izazov nego što je to bio slučaj sa nerobusnim indikatorom i moraju se koristiti napredni numerički algoritmi. Međutim, ukoliko se ograničimo na slučaj euklidske norme, možemo formulisati postupak za računje $\varepsilon-$robusnog indikatora stabilnosti s_ε^*, koristeći neke od ideja datih u (Trefethen, Embree, 2005; Byers, 1988; Freitag, Spence, 2011; Kostić et al., 2016; Guglielmi et al., 2015; He, Watson, 1999), prilagođenih našem optimizacionom problemu.

Pošto se pseudospektar u euklidskoj matričnoj normi može evivalentno izraziti preko minimalne singularne vrednosti matrice $A - zE$, pomoću algoritma konstruisanog u radu (Kostić et al., 2016), može se izračunati s_ε^* sa željenom tačnošću. Primenom tog algoritma, dobijamo da $s^* = 0.012766$ odgovara veličini $s_\varepsilon^* = 0.01276599$ za $\varepsilon = 10^{-8}$, što znači da ova izračunata vrednost garantuje stabilnost samo ako su merenja vrlo precizna! Dakle, kao što se pretpostavlja u (Moore, de Ruiter, 2012) i (Neutel et al., 2007), ova vrednost teško može poslužiti kao pokazatelj stabilnosti.

Sa druge strane, vrednost dobijena randomizacijom $s_{rand}^* \approx 0.09$ dobijena u (Neutel et al., 2007) odgovara vrednosti $s_\varepsilon^* = 0.09211586$ za $\varepsilon = 10^{-4}$. Prema tome, sada smo u mogućnosti da zaključimo da ova vrednost može garantovati stabilnost community matrice u uslovima veće nesigurnosti. To potvrđuje zaključak da se situacija popravila korišćenjem randomizacije. Međutim, ova informacija se ne može dobiti Monte Karlo metodom korišćenom u (Neutel et al., 2007).

Važno je takođe naglasiti i to da vreme povratka invarijantno u odnosu na normu (definisano i u (Moore, de Ruiter, 2012) kao recipročna vrednost rastojanja između spektra i imaginarne ose, a u našoj oznaci t_A^{NIRT}) može biti, u slučaju ne-normalnih matrica, značajno manje od vremena povratka u posmatranoj normi. U slučaju s_{rand}^* : $t_{A(s_{rand}^*)}^{NIRT} = 11.61\ godina,$ dok u stvarnosti za takav sistem može biti potrebno $t_{A(s_{rand}^*)}^{2,RT} = 113.5\ godina$ da se oporavi od perturbacija (u terminima euklidske norme). Ta razlika je ovde, očigledno, veoma značajna, pošto će posmatrana trofička mreža za 25 godina promeniti svoj stadijum razvoja, pa, dakle, i svoju strukturu.

Prema tome, ostaje veoma interesantno pitanje koji nivo nesigurnosti treba da izaberemo da bismo dobili pouzdan indikator stabilnosti. Na primer, za $\varepsilon = 10^{-3}$, izračunavamo $s_\varepsilon^* = 0.31742348$ i vidimo da je vremenski rok za takvo s_ε^* mnogo kraći nego u prethodnim situacijama, samo oko 25 godina je potrebno da se ekosistem tla oporavi i vrati u stanje ravnoteže nakon male perturbacije. Takođe, tranzicioni faktor rasta sugeriše da se najveća devijacija u odnosu na stabilno stanje dešava za otprilike 2 godine i da je manja od 200, dok je situacija za randomizovani indikator i originalni spektralni indikator mnogo gora.

Za $\varepsilon = 10^{-2}$, algoritam daje vrednost $s_\varepsilon^* = 2.64613763$. Prateći rezonovanje u (Neutel et al., 2007), zaključujemo da, ako su merenja nesigurna do na $\| \Delta \|_2 \leq 10^{-2}$, dokumentovani trofički odnosi ne garantuju da će se kompenzovati stope gubitka zbog smrtnosti. Sledstveno tome, matematički stabilan ekvilibrijum sa vremenom oporavka manjim od 10 godina, u obliku Lotka-Voltera sistema, će zahtevati postojanje unutrašnje stope rasta određene vrste, što podrazumeva hranjenje iz izvora van sistema.

Očigledno, veće vrednosti za ε odgovaraju većim vrednostima indikatora s_ε^*, manjim maksimalnim amplifikacijama $\phi_{A(s_\varepsilon^*)}^{max}$ i kraćim vremenima povratka $t_{A(s_\varepsilon^*)}^{2,RT}$, što je prikazano u Tabeli 1.

Tabela 1: Indikatori stabilnosti s_ε^* odgovarajuće maksimalne amplifikacije $\phi_{A(s_\varepsilon^*)}^{max}$ i vremena povratka $t_{A(s_\varepsilon^*)}^{2,RT}$ za različite vrednosti ε

$\boldsymbol{\varepsilon}$	$\boldsymbol{s_\varepsilon^*}$	$\boldsymbol{\phi_{A(s_\varepsilon^*)}^{max}}$	$\boldsymbol{t_{A(s_\varepsilon^*)}^{2,RT}\ [god]}$	**Odgovara**
10^{-8}	0.012766	3 000	2 000 000	s^* iz (Neutel et al., 2007)
10^{-4}	0.092116	333	110	s_{rand}^* iz (Neutel et al., 2007)
10^{-3}	0.317424	174	27	-
10^{-2}	2.646138	37	11	-

TRANZICIONO PONAŠANJE I ROBUSNA NEREAKTIVNOST / TRANSITIONAL BEHAVIOR AND ROBUST NON-REACTIVITY

Uvođenjem perturbacija community matrice i pomoću pseudospektra, uspeli smo razviti indikator koji pouzdanije govori o asimptotskoj stabilnosti i pri tome, na određeni način, kontroliše maksimalnu amplifikaciju i vreme povratka koji su od ključnog značaja za ekosisteme.

Po analogiji sa već postojećim indikatorima nereaktivnosti, prvo uvedimo nove robusne indikatore nereaktivnosti. Kako se naš pristup zasniva na posmatranju evolucione funkcije community matrice, on nije invarijantan u odnosu na normu koju koristimo. Ovde ćemo razmatrati slučaj kada ispitujemo maksimalno odstupanje od ekvilibrijuma (maksimum norma). Analogno se razmatra i slučaj kada ispitujemo kvadratno odstupanje od ekvilibrijuma (euklidska norma).

Neka je $\| \cdot \| = \| \cdot \|_\infty$. Definišimo vrednost

$$s_{\infty,\varepsilon}^* := inf\{s \geq 0 :\ \nu_{A(s)}^\infty < -\varepsilon\}$$

koja predstavlja $\varepsilon-$robustan indikator nereaktivnosti i koja se, slično ranijem, može preformulisati u oblik:

$$s_{\infty,\varepsilon}^* = \begin{cases} \max\limits_{i \in N} \left\{ \frac{1}{d_i} \left(\sum\limits_{j=1, j \neq i}^{n+1} |\alpha_{ij}| + \varepsilon \right) \right\}, & |\alpha_{n+1,n+1}| > \sum\limits_{j \in N} |\alpha_{n+1,j}| + \varepsilon , \\ +\infty , & inače. \end{cases}$$

Drugim rečima, indikator nereaktivnosti se malo menja za male promene u community matrici i indikator $\varepsilon-$robusne nereaktivnosti se može eksplicitno zapisati pomoću elemenata matrice i parametra robusnosti. Kako je robusna nereaktivnost zahtevniji uslov za ekvilibrijum od nereaktivnosti, indikator koji smo izveli je često značajno veći od 1, te govori o tome da su empirijske trofičke mreže, u principu, reaktivni TIDS, tj. da uglavnom uvek postoji tranzicioni rast.

Stoga se postavlja pitanje da li možemo još nešto dodatno reći o takvom ponašanju empirijske trofičke mreže u terminima odnosa između dijagonalnih i vandijagonalnih elemenata community matrice A(1) izraženih kroz osobine sličnim strogoj dijagonalnoj dominaciji (SDD), koje imaju "realno" tumačenje. Odgovor leži u lokalicionim oblastim pseudospektra koje smo razvili u (Cvetković, 2017), ali ta tema prevazilazi okvire ovog rada. Zadržimo se samo na komentaru da, zahvaljujući Krajsovoj konstanti, možemo nešto reći i o tranzicionom ponašanju emprijskih trofičkih mreža. Naime, ako imamo lokalizacije ε-pseudospektra, možemo dobiti gornje ocene za ε-pseudospektralnu apscisu, a time i gornje ocene Krajsove konstante. Drugim rečima, maksimalna amplifikacija evolucione funkcije se može ograničiti sa gornje strane upotrebom lokalizacija pseudospektra. Pri tome, ε-pseudo Geršgorinov lokalizacioni skup odgovara slučaju robusne nereaktivnosti, što znači da, kada je takav slučaj na snazi, tu već znamo da je maksimalna amplifikacija manja od 1 (nema tranzicionog rasta), dok za druge lokalizacione skupove ovo ne mora da važi. Međutim, da bismo adekvatno ocenili maksimalnu amplifikaciju treba konstruisati, takođe, i donje granice za Krajsovu konstantu. Stoga ostaje kao interesantno otvoreno pitanje kako se lokalizacije pseudospektra mogu dalje iskoristiti za procenu tranzicionog ponašanja dinamičkih sistema.

ZAKLJUČAK / CONCLUSION

Korišćenje diferencijalnih jednačina za modeliranje trofičkih mreža prisutno je odavno, ali je opšte prihvaćena generalizovana Lotka-Voltera matematička reprezentacija interakcija između vrsta, kako bi se proučavala njihova dinamika. Pri tome je problem stabilnosti jedan od najvažnijih, s obzirom da u terminima populacione dinamike, pitanje stabilnosti, zapravo, znači sledeće: da li, kada je ravnoteža jednom uspostavljenja, mala promena u populacijama čini da se sistem vrati (brže ili sporije, sa ili bez oscilacija, itd.) u narušenu ravnotežu, ili je, pak, ravnoteža takva da jednom kada se i malo naruši, ne može da se povrati. Očigledno, ovo pitanje je jedno od ključnih pitanja u oblasti očuvanja životne sredine.

Pomoću spektra matrice i njegove lokalizacije Geršgorinovim skupom razvijeni su indikatori stabilnosti i to tako što su, najpre, dijagonalni elementi community matrice, koji predstavljaju samoregulišući faktor organizama i odnose se na stopu gubitka organizama u stabilnom stanju, parametrizovani parametrom s, a zatim je taj parametar računat tako da community matrica $A(s)$ za neko $s \in (0,1]$ čini da je posmatrani TIDS u određenom smislu "lokalno stabilan" (rezilijentan, nereaktivan u nekoj od normi). Tada najmanje takvo s predstavlja dovoljan stepen intraspecifične kompeticije (procenat stopa netrofičkih smrtnosti svake od grupa) koji "stabilizuje" trofičku mrežu u posmatranom smislu. Zato se takvo s može smatrati indikatorom, pri čemu manje vrednosti označavaju "stabilnije" trofičke mreže.

Mđutim, u ovom radu uveli smo potpuno nov pristup proučavanju stabilnosti, jer smo koristili teoriju pseudospektra umesto klasičnog spektra. Generalno govoreći, u slučaju kada je matrica posmatranog LTIDS normalna, karakteristični koreni u potpunosti objašnjavaju dinamička svojstva - ne samo asimptotska. Međutim, ukoliko matrica nije normalna, evoluciona funkcija može imati vrlo različito ponašanje, pre nego što se ispolji asimptotika. Osobina matrice koja može objasniti to tranziciono ponašanje je pseudospektar. U terminima LTIDS, to znači da ne posmatramo perturbacije ravnotežnog stanja dinamičkog sistema, već perturbacije upravljajućih zakonitosti! Na primeru populacionih modela, to znači da pored poremećaja u brojnosti pojedinih populacija želimo da tretiramo i poremećaje odnosa između populacija. Svakako, u realnim procesima koji nas interesuju takvi poremećaji ne samo da su mogući, već su, zapravo, od ključnog interesa.

Ovakvim pristupom, na osnovu nove veličine s_{ε}^{*}, pojačali smo zaključke o dinamičkim svojstvima, ne samo u smislu robusnosti, već i u smislu procene stabilnosti koja se uklapa u okvir dopustivog tranzicionog ponašanja organizama, kao takvih, izborom adekvatnog ε parametra.

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