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A Theoretical Framework of Ecological Services: Categories of Nature-Based Services and Their Interrelationships

RAMDEB NASKAR

ASSISTANT PROFESSOR, DEPARTMENT OF GEOGRAPHY, MAGRAHAT COLLEGE

MAGRAHAT, SOUTH 24 PARGANAS, WEST BENGAL

Email ID: ramdeb.bittu@gmail.com

Abstract

The most important benefits that humans gain out of natural systems are the ecological services or ecosystem services. The recent studies in the field of ecology, environmental economics, and sustainability reveal the significance of a comprehensive and theoretically correct comprehension of these services. In spite of improvements, definitions and crosslinking of the types of services have not been well defined. The present paper presents a theoretical construct meant to explain the type of nature-based services as well as demonstrate the dynamic relationships that shape ecological processes, human health, and sustainability into the future. The framework re-examines the conventional division of the ecological services into four primary domains, namely: provisioning, regulating, cultural, and supporting services. Provisioning services include tangible products like food, water, timber, medicinal plants and genetic resources. With the help of controlling services, the environment is stable because of such procedures as preserving the climate, flood control, air cleaning, controlling diseases, and prevention of erosion. The cultural services contain non-material benefits in the form of recreational, aesthetic, spiritual benefits, traditional knowledge and sense of place. The rest of the categories rely on the supportive services which involve nutrient cycling, soil building, primary production and habitat building. The paper analyses the inter-relationship between the ecological classes, based on functional relationships,

feedback, and trade-offs. It also shows how ecological processes provide several services at the same time and how a transformation in one domain, e.g., soil erosion, affects other domains, e.g., crop production. The framework integrates socio-ecological factors where human activities, institutes and governance are emphasized in the sustainability of ecological services. The concept of trade-offs, especially in respect to agricultural intensification and biodiversity, is essential, and ecological services are defined on different levels that should be realized to better ecological evaluation and sustainability planning.

Keywords- Ecological servicesm Nature-based services, Ecosystem functioning, Socio-ecological systems, Trade-offs and synergies, Sustainability framework

1.1 Introduction

It was human society that has always relied on nature to survive and develop, as well as to enrich the culture. It is in the food we eat and the water we drink to climatic stability that agriculture relies upon and aesthetic experiences that give rise to creativity that every aspect of human life is connected to ecological systems. As time progressed, these critical contributions of nature have since then been identified as a holistic concept of ecological services or ecological services. The word as a term became popular in the second half of the twentieth century, but the concept has a long historical spread through civilizations, native systems of knowledge and philosophical traditions, that focus on the peaceful coexistence of human populations and natural habitats. Over the past few decades, increasing international environmental issues, including climate change, biodiversity loss, soil erosion, and a lack of freshwater, have enhanced scholarly interest in the nature, operation, and worth of ecosystem services [1]. This has led to ecological services emerging as a major subject of environmental science, ecological economics, sustainability studies and natural resource management. The increasing importance of ecological services is known to be complicated by their conceptualization which has multiple shapes, functions, and advantages. These services have been categorized in frameworks according to provisioning, regulating, cultural and supporting services, as established in such assessments as the Millennium Ecosystem Assessment (MEA) and the Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services (IPBES). These categories are however not always clear in that many ecological processes provide more than one service at a time; such as forests provide timber and non-timber products (provisioning), assist in carbon sequestration and soil conservation (regulating), provide recreational and spiritual benefits (cultural), and promote biodiversity and nutrient cycling (supporting). Literature on these categories is usually covered individually, and it may not be clear that there are dynamic interrelationships between the ecological processes. With the increasing intensity of the human activities and the heightening necessities of the environmental crises, an atomized perception of the ecosystem services is unsuited in making of the policy and sustainable management. Therefore there is a pressing need to have a theoretical framework which not only explains these categories but also brings out their interrelationships and results to a comprehensive explanation of how ecosystem functions and human influences. Ecological services research has a significant role outside the academic community by guiding land use, conservation agenda, climate change response and economic planning between governments, development agencies, and local communities [2]. The estimation of the controlling services including flood control and groundwater recharge is crucial to the urban planning and climate-resilient infrastructure. In addition, the recognition of cultural services is significant to the conservation of heritage landscape and ecotourism marketing. As the world moves towards sustainable development and solutions with nature as the key, ecological services knowledge can be considered an important instrument to bridge environmental soundness and human wellbeing. Thus, the accurate understanding, measurement, protection, and improvement of nature-based services must be developed on a solid theoretical background. In this study present the detailed theoretical framework of the ecological services development with the focus on their classification and interaction as the integrated socio-ecological systems. It combines knowledge in the various disciplines, such as ecology and sustainability science, and integrates the notion of trade-offs and synergy among ecological services. To illustrate, agricultural expansion can improve the provisioning services in the short-term, but it can also reduce the quality of regulating services such as water quality and pollination [3]. Conversely, there can be a number of positive effects of the restoration of the ecosystem, including the quality of air and biodiversity. The framework puts an importance on researching ecological interactions through different levels including local, regional and global and dynamics of ecological responses across time. This complexity comes with

a high level of sophisticated and advanced policy designs to deal with the ecosystems. Lastly, this research advocates a more profound theoretical insight on ecological services through explanation of categories and association, socio-ecological predictors, and the multi-scaleness of ecological procedures, which are meant to contribute to the academic knowledge and improve sustainable growth and policy making.

Table: Categories of Ecological Services and Their Interrelationships

Category of Ecological Services	Key Components / Examples	Functions	Interrelationships with Other Categories
Provisioning Services	Food (crops, fish, livestock), freshwater, timber, fuelwood, medicinal plants, genetic resources	Provide material goods essential for human survival and economic activities	Depend on Supporting Services (soil formation, nutrient cycling). Influenced by Regulating Services (pollination, water regulation). Linked with Cultural Services through traditional knowledge & agro-cultural practices.
Regulating Services	Climate regulation, carbon sequestration, pollination, flood control, air & water purification, erosion control, disease regulation	Maintain environmental balance and ecological stability	Support Provisioning Services (e.g., pollination increases crop production). Strengthened by Supporting Services (diverse species and healthy ecosystems). Enhance Cultural Services by improving scenic quality and recreation potential.

Cultural Services	Recreation, tourism, aesthetic landscapes, spiritual values, cultural heritage, education & inspiration	Provide non-material benefits, enhance well-being, identity, and community values	Depend on Supporting Services (biodiversity habitats). Enhanced by Regulating Services (clean air, stable climate). Can promote conservation that safeguards Provisioning & Regulating Services.
Supporting Services	Nutrient cycling, soil formation, primary production, habitat provision, biodiversity maintenance	Form the ecological foundation that enables all other services to function	Directly underpin Provisioning Services (soil fertility → crop yield). Enable Regulating Services (biodiversity → pollination, disease control). Shape Cultural Services through habitat diversity, scenic landscapes, and ecological education.

1.2 Studies related Literature Reviews

Ecological services are an underlying concept in environmental science, which supports the multiple benefits that humans have derived out of natural systems. Current studies and literature reviews have underlined the importance of provisioning, regulating, supporting, and cultural services in maintaining the stability and well-being of the ecological systems alongside human beings. The studies also examine how these services relate to each other where they have synergetic and occasionally competing relationships. This introduction places the theoretical

framework in the context of the contemporary academic discourse providing a brief foundation of comprehensive evaluation.

Guerry, A. D., et al. (2015). Delve into the systematic way of understanding how natural capital and ecosystem services can be incorporated in real life choices in order to bring the field out of the theory into the practice. The authors put emphasis on the fact that there is a growing consciousness of the services offered by the natural ecosystems- such as water management and wasting carbon that must be incorporated in the planning and policy along with the economic and social considerations. The paper gives examples of how the assessment of ecosystem services and natural capital accounting has been incorporated with coastal management, city development and national policies. It discusses how ecological benefits can be measured and trade-offs estimated by decision-makers as well as considers the challenge of such procedures as scant availability of data on such issues and governance challenge. The authors suggest that, science, policy and practice are supposed to collaborate more to bring increased scale of application of natural capital information, as the solutions grounded on the insights into the ecosystem services might lead to more sustainable efforts which would require investing in systems and alliances necessary [4].

La Notte, A., D'Amato, D., et. al (2017), revamp the manner in which the ecosystem services are categorized relative to systems ecology, thus suggesting an enhanced insight of the procedure of ecosystem service cascade structure. The analysis has brought to focus the fact that the traditional classifications are more often ecologically unsound, and this prompts confusion in the process of relating the structures, functions as well as utility of the society concerning its ecosystem. The authors appeal to some difference between biophysical processes, ecological processes, service flows and human benefits by implementing the principles of systems ecology. They also highlight the distinction between intermediate ecosystem processes, such as energy flow and nutrient interplay and end service potentially impacting human well being. With this methodology, there is no redundancy of measurements and it offers causal relationships and enhances uniformity of the ecosystem evaluation. Furthermore, an elaborated category improves valuation, inter study comparability, and scientific base of policy design, which promote ecological service cascade, as ecological theory is explicitly implemented on the service identification process to guarantee an improved result of decision-making [5].

Potschin-Young, et al. (2018) describe the importance of conceptual frames in the field of ecosystem service science, and the cascade model is also regarded as one of the interpretative frames. The article argues that conceptual frameworks are a method of analysis and not a diagram that is useful in detecting knowledge gap and synthesizing ecological and social variables. It goes back to the ecosystem service cascade that illustrates how the ecosystem characteristics are transformed into functions that generate services and eventually formulate benefits to the stakeholders. The framework enhances interdisciplinary communications, standardization and policy and governance information. It also addresses the need of the identification of feedbacks and socio-ecological complexities that impact service production, as well. The authors conclude that the frameworks are required in the organization of the ecosystem service studies, analytical clarity and ecosystem service relevancy on decision-making and in the reinforcement of the theoretical underpinning of ecosystem services [6].

Mengist, W., Soromessa, T. & Feyisa, G.L. (2020), critique of the current knowledge, the common themes and gaps in scientific knowledge. The authors methodically review the works, which studied how the ecological environment brings control over climate, water, nutrients and air quality, vectors of diseases and other environmental functions needed to determine the wellbeing of humans. Studies have indicated that climate regulation, carbon sequestration and water purification are of priority in the ecosystem service assessment and other secondary categories such as disease regulation, erosion control and pollination have not been researched in the appropriate manner. Increased application of modeling and remote sensing methodologies in the measurement of regulatory processes is seen and problems in the control of ecological complexity, socio-economic and temporal variability. The authors show that a disparity exists in the degree of knowledge in the developing economies that are vulnerable to the ecological risks. They promote interdisciplinary studies, which acknowledge local knowledge, long term data and resilience methods with the focus of these shortcomings to refine ecosystem services evaluation, environmental regulations and management procedures under the climatic change and land use pressures [7].

Deeksha, & Shukla, A. K. (2022) carry out a systematic literature review to create the existing status of the research on the ecosystem services that are capable of being given by the freshwater

ecosystems as well as identifying the future trends of the same. The review presents the literature available in the world on services that the freshwater ecosystems offer such as provisioning, regulating, cultural and supporting services and their ecological as well as socio-economical significance. Such threats are pollution and climate variability, which are mentioned, although such systems are of paramount importance. The approaches include spatial mapping and hydro-ecological modelling are highly developed and deficiencies in the approach particularly in incorporating the socio-cultural values and ecosystem resilience are achieved. The reason is that the authors suggest the future research to be interdisciplinary and holistic when the connection between ecological processes and governance, and community engagement must be provided to improve sustainable management and policy formulations of freshwater [8].

1.3 Conceptual Foundations of Ecological Services

The functions and benefits of natural ecosystems which sustain the existence of humans and socio-economic development define the conceptual foundations of ecological services. Ecological services refer to natural processes which lead to human benefits and these are divided into provisioning, regulating, supporting and cultural services. The terminology has changed to the ecological functions in the 1980s and subsequently, ecological services in the 1990s, with a focus on the benefits of a human being obtained out of an ecological system. Nature-based systems play a significant role in the well-being of human people in the physical, economic, social, and environmental aspects as they provide fundamental resources, control the climate, facilitate recreation, and create a balance in the ecological system [9]. The conceptual frameworks, including the Ecological Systems Model, Natural Capital Framework, and the Socio-Ecological Systems Model, facilitate awareness and valuation of ecological services, which is useful in implementing it into sustainable policies. These paradigms promote the relationship between the environment and humans, establishing a platform on which environmental and social issues can be tackled with ease.

1.4 Categories of Nature-Based Ecological Services

The division of the ecological services into clear categories contributes to the realization of the dissimilarity of functions of natural systems and their role in the well-being of people. Although the categories tend to overlap, these categories offer an efficient analytical frame that can be used to analyze the role of ecosystems in producing goods, regulating environmental conditions, sustaining the ecological processes, and enhancing cultural life. The subsections below present the key types of nature-based ecological services and examples and concept descriptions. Provisioning services entail the material objects and physical goods offered by the ecosystems, which are vital in regard to the survival of humans, economic growth and even security in terms of livelihood. These comprise food origin including grains, fruits, livestock, fisheries, and edible wild plants which is maintained by healthy ecosystems such as soil fertility, water availability as well as genetic diversity [10]. Forests and wetlands control water availability in the country to the domestic and industrial sectors, allowing ground water to recharge and be purified. The forests provide timber and fiber used in construction and home needs and genetic resources that are used in improving crops and conserving species. Controlling services help in stabilizing the environment by determining the climate, hydrology, and pollution. Carbon sequestration and temperature moderation are some of the important roles of ecosystems in the regulation of climate. The water purification process is performed through natural filtering in wetlands thereby minimizing health hazards and expenditure on treatment. Further, pollinators maintain one-third of food crops in the world, which maintains food security. Supporting services are the processes in the ecosphere which are important in providing a human life indirectly e.g. soil formation, nutrient cycling, and provision of habitat to the biodiversity. Balance in nutrient cycle and healthy soils are important to agriculture and ecological stability [11]. Cultural services also include non-material forms of benefits related to cultural identity and psychological wellbeing such as recreational facilities, aesthetic pleasure and spiritual beliefs associated with natural landscapes. Emerging and hybrid services look into nature-based solutions to the challenges facing the society such as climate change, the reduction of heat islands in the city, and water security, which enhances socio-ecological resilience. This capacity of resilience is based on sustainable management of

ecosystems, diversity of livelihoods, and promotion of biodiversity as a way of adapting to the disturbances.

1.5 Interrelationships among Ecological Service Categories

Ecosystem services do not always operate independently. They are rather entrenched in the complex ecological cycles in which a service in most cases complements, weakens or relies on another. The knowledge of these inter-relationships is vital to environmental planning, policy-making and sustainable management of resources. This part examines synergies, trade-offs, spatial temporal relationships, human nature relationships and the systemic feedback loops that define dynamics of ecological services [12]. Ecosystem services are not isolated phenomena, but they are integrated into unique ecological processes that impact each other in a synergistic, trade-offs, spatial-temporal, human-nature interaction, and feedback loop. Synergies, e.g. forest and wetland ecosystems, contribute to productivity and benefit to society. Trade-offs, on the other hand, are the situation whereby, by improving one service, another is undermined; an example is the agricultural production at the expense of biodiversity and purification, or water extraction. Spatial and temporal connections point to the movement of services through place (e.g., urban dependence on rural resources) and time (e.g., short-term profitability vs. long-term sustainability). The service provision is greatly affected by the land use and human pollution, whilst ecosystem status determines the human health. System thinking exposes the non line interactions and feedback in the ecosystems, the importance of integrated management strategies to respond to such interactions.

1.6 Conclusion

The study aimed at developing a detailed theoretical framework on the understanding of ecological services and their categorical differences as well as complex interrelationships that define their operations. The discussion illustrates that even though ecological services are commonly discussed into the provisioning, regulating, cultural and supporting, these categories are not separate entities but rather interrelated parts of one socio-ecological system. Nature based services are not linear and operate on complex feedback and functional linkages and scale based interaction of the

services in which interpretation is needed in holistic mode and not in isolation. The theoretical integration in this theory enhances the factuality that the ecological processes help to provide a variety of services at the same time, and the disturbance in one area is bound to impact the others. Among the most prominent findings of this research is the fact that trade-offs and synergies can be achieved when managing ecosystems and the acknowledgement of the fact that there is a trade-off between human activities, such as agriculture and urbanization, which can, simultaneously, contribute to the provision of some services and harm others. This demands good decision making within the setting of informed decision making that is informed by knowledge in ecology and science based policies. The other opportunity that has emerged in the forefront of the study is the opportunity of co-benefits that could be attained by conservation and restoration activities that could lead to a number of services that could in turn sustain the ecological health and human wellbeing. Among the contributions, it is possible to mention its concern with multi-scalar dynamics, according to which ecological services are various under multiple spatial and time-independent conditions. This study discusses the importance of the socio-ecological perspective of management practices and the applicability of the governance and the traditional ecological knowledge in the framework of human actions on the services offered by the ecosystem. It fosters active research and policy agenda, to aid to enhance the resilience of the ecosystem, conserve the biodiversity and support human wellbeing. Lastly, it explains how the ecological services have been conserved to be a major contributor to steady growth and survival of the human communities.

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