Journal of Geography, Environment and Earth Science International

Volume 28, Issue 7, Page 52-59, 2024; Article no.JGEESI.119404
ISSN: 2454-7352

Advancing Sustainable Ecosystem Development

Satinder Kaur Khattra [a++*], Ankush Balaut [b#] and Ritu Dogra [c†]

[a] Department of Civil Engineering, Punjab Agricultural University, Ludhiana, India.
[b] Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana, India.
[c] Department of Renewable Energy Engineering, Punjab Agricultural University, Ludhiana, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jgeesi/2024/v28i7789

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:
https://www.sdiarticle5.com/review-history/119404

Review Article

Received: 09/05/2024
Accepted: 11/07/2024
Published: 16/07/2024

ABSTRACT

Ecosystem management integrates natural and human systems, but understanding early stages remains a challenge. Remote sensing aids in monitoring endangered ecosystems. Ecological growth theories and models offer insights, while energy-related tendencies contribute to succession understanding. Collaboration drives sustainable development, alongside social-ecological system understanding. Adaptive management navigates ecosystem transformation, while resource management ensures sustainable use. Engaging communities, leveraging innovative technologies, and effective governance are crucial for long-term sustainability. Conserving biodiversity is essential for ecosystem health, requiring focused actions like habitat restoration and preservation.

[++] Assistant Professor;
[#] M Tech Student;
[†] Professor;
**Corresponding author: E-mail: satinder113@pau.edu;*

Cite as: *Khattra, Satinder Kaur, Ankush Balaut, and Ritu Dogra. 2024. "Advancing Sustainable Ecosystem Development". Journal of Geography, Environment and Earth Science International 28 (7):52-59. https://doi.org/10.9734/jgeesi/2024/v28i7789.*

Addressing climate change impacts strengthens ecosystem resilience and secures sustainable futures. Promoting environmental education and awareness cultivates community involvement and supports conservation efforts. Incorporating economic incentives and valuing ecosystem services encourages sustainable resource management. Effective policy integration across agriculture, forestry and urban planning sectors is crucial for comprehensive and sustainable ecosystem management.

Keywords: Ecosystem management; sustainable; energy.

1. INTRODUCTION

Over time, the demands and actions of humans, along with population growth, have put strain on ecosystems and depleted natural resources. The results of previous ways of managing natural resources have been inadequate and the management strategies have frequently prioritized short-term economic gain and yield over long-term sustainability. This reality, along with the growth of scientific understanding of ecosystems, has prompted the development of novel strategies for managing natural resources.

Based on the idea of the ecosystem, ecologists have recommended a new approach to managing and using public property during the past fifty years. This ecosystem-based strategy had gained the endorsement of numerous scientists, managers and others by the late 1980s. A theoretical foundation for ecosystem management (EM) was outlined in the first book on EM, published in 1988 [1]. EM has emerged as the new strategy concentrating on sustainable development as sustainability has become a clearly stated goal by many governmental, public or commercial resource management agencies [2,3,4,5]. It is a novel approach to regional management that combines aspects of the natural, biological and human worlds with the goal of preserving an ecosystem across time.

Ecosystems are extremely intricate systems made up of numerous distinct biotic and abiotic compartments that could develop over extended periods of time and are intimately connected by interacting process. Water and elemental transport and cycling connect all compartments across scales and link patterns and processes to the general health of an ecosystem. According to [6], "climax" ecosystems have been the focus of the majority of integrating investigations. Even so, theories that contend that conditions at "point zero" and the processes of the early stages determine and control further development [7] and that "small differences early in the process can extend over time" [8] offer limited insight into the early stages of ecosystem development. There are many theories regarding how ecosystems form and develop [9,10,11]. The ultimate energy dissipation hypothesis [12] and Prigogine's restricted production of entropy concept [13,14] are two significantly distinct approaches that were recently published to describe thermodynamic characteristics of ecosystems when they emerge and evolve.

The concepts of exergy and entropy are commonly utilized in thermodynamics research and are being integrated into the lexicon of ecosystems due to their vital perspective on these systems. A system with a lot of energy is switched away to its regard indicate and further from the surroundings since energy is the most prevalent, the amount of labour a framework may achieve in relation to an ecological regard the state. Jørgensen [15] proposed the utilization of energy to consideration for ecological systems advancement by utilizing to be a regard the same system at thermodynamic balance at the same temperature and pressure, the atmosphere is used as a connection indicate for technology energy estimations [16].

A system with more exergy is shifted farther from its reference state and farther from the environment because exergy is the highest amount of labour a system may accomplish in relation to an environmental reference state. Jørgensen [15] introduced the application of exergy to account for ecosystem development by using as a reference the same system at thermodynamic equilibrium at the same temperature and pressure, the environment is used as the reference state for engineering exergy calculations [16]. The requirement for choosing two distinct reference states arises from the fact that, in ecosystems, the focus is on how far the system has moved from its natural balance. In engineering, the focus is on how much work can be done using the environment.

The second type of exercise should be called eco-exergy in order to differentiate it from the other one. Ecosystem dynamics arise from the interactions between living organisms and their diverse abiotic environments across different geographic and temporal scales [17]. Sustainable ecosystem management relies on understanding these dynamics, especially considering global land use and climate change [18,19,20]. With recent advancements in remote sensing technology, it is particularly important to examine ecosystem dynamics at various spatial and temporal scales.

Jabrayilov [21,22] examines and tracks recent alterations to the shahdagh national park area's flora, water supplies and drought conditions. In order to gather pertinent data, the study tracked recent remote sensing data and identified environmental changes. The study's technique proved to be ideal for producing precise results and the environment has been carefully observed to identify endangered ecosystems.

2. ECOSYSTEM GROWTH AND DEVELOPMENT

Growth is the statistical development of a measure, such as biomass or through flow, whereas development is the qualitative change that occurs, such as the structure or understanding currently available quantity. Basic or subsequent succession is the term used to describe the classical theory of ecological growth and development, which holds that rapidly spreading original species first occupy a region before they are replaced by slower-growing organisms that thrive in darkness. Classic biological succession theory describes a bimodal evolution of the diversity of species through species chosen using r to species chosen by K [23]. The logistic model, which emphasizes the ability to carry (K) and density-associated elements throughout the process whereas biological potential (r) and density-independent components become more significant in the early stages, characterizes how it develops and grows. Thompson [24] developed these to three ecological classes based on how a population responded to two further classifications: stress as well as disruption, in his assessment of various species of plants.

One persistent difficulty is that the three-class and bi-modal models downplay the significance of habitats being accessible, biophysical processes. A different strategy would be helpful for defining the manner in which ecosystems grow and develop. Although they did not specifically address ecosystems, [25] defined four different kinds of change for accessible systems that include alterations that occur due to impacted mass as well as input–output relationships; variations in the system's energy content and distribution; changes resulting from adaptations to the internal structure of the system; and at last, changes correlated with the accumulation of mass and resources that cause delays in system functioning [26].

Jørgensen [27] proposed an ecosystem growth model that breaks succession down into three phases: structural in nature, the system and knowledge. For the purpose of comprehensiveness, we include here perimeter development, which is excluded from [27] and represents the final phase of development (really zeroth). Boundary growth enables low-entropy substance input to the system. This is corresponding to the work of [28]. When the physical biomass content of the system rises, typically through an increase in the quantity, variation, and overall dimension of ecosystem components, structural development take place [29].

Network growth is the expansion of the system's connectivity through greater energy-matter exchanges, which leads to the multiplication of pathways and more matter and energy cycling effectively. Information expansion is the qualitative shift in system behaviour from patterns of exploitation to more energy-efficient, conservative patterns. This four-stage model provides a broad conceptual structure for the growth and advancement of ecosystems. Since the four forms can act independently (e.g., border input initiates development, but it continues as long as the system organization continues to exist; network and informational growth might take place simultaneously, etc.), the representation of the different types is not necessarily chronological. Each of these phases closely corresponds to the usual process that occurs during each stage of succession. It's fascinating how the growth model can be used on the processes of ecology. Odum [9] stated a number of energy-related patterns that are probably to become apparent in the development and evolution of ecological systems from initial to later stages. Several of these patterns, that are pertinent to the aforementioned theories describing the direction of ecological succession.

The physical structure of an ecosystem is influenced by several factors, such as an increase in biomass, a decline in the production of enthalpy associated with biomass, a surge in feedback (such the recycling of matter and energy), an upward trend in respiration or an overall decrease in respiration in comparison to biomass and a greater proportion of massive plants and animals, a decrease in total entropy production at early stages of an ecosystem, a decrease in biomass-specific entropy production at mature stages and an increase in information.

3. ECOSYSTEM MANAGEMENT METHODOLOGY

Partnerships and collaboration are essential for promoting ecosystem development. When various stakeholders collaborate, they can pool resources, forge new opportunities and tackle difficult problems more skilfully. Partnerships frequently result from collaborative efforts. Collaboration in the ecology of ecosystems involves cooperation amongst multiple stakeholders, like corporations, government agencies, non-governmental organizations, researchers and local people. They can be informal (like knowledge-sharing networks) or formal (like joint ventures and public-private partnerships). Positive change is driven, sustainable practices are promoted and ecosystem resilience is enhanced through effective collaboration and partnerships [30]. This paper discusses research on social-ecological systems research perspectives and their investigation and application to sustainable development issues, including accompanied human-earth interactions, management of resources, geographical nature trends, system structure and dynamics and the interaction between services provided by ecosystems and the welfare of humans. The goal of this research is to gain an improved awareness of the changes and interactions that occur in complex systems. It provides an overview of relevant approaches and strategies for addressing concerns associated with the social-ecological system.

By understanding social-ecological systems better, we can develop strategies that balance environmental conservation, economic development and societal well-being.

Adaptive Management and Iterative Learning: Environmental policymakers, scientists, engineers, planners and administrators have to make progressively quick decisions on the management of species, natural resources, ecosystems and landscapes based on unreliable, complicated and inadequate scientific, technical and management data. An example involves a development of ecosystem management initiatives which originate from adaptive management, or even completely upon it.

This continuous learning cycle empowers decision-makers—from policymakers to scientists and planners—to adjust their management practices dynamically. Embracing adaptive management enhances the effectiveness of ecosystem management initiatives, ensuring they remain adaptable to evolving environmental conditions and societal demands.

Key Aspects of Iterative Learning include:

- Feedback Loops: Regularly assessing the outcomes of management actions and adjusting accordingly.
- Experimentation: Trying out different approaches, observing results, and learning from successes and failure.
- Risk Tolerance: Being open to taking calculated risks to improve outcomes. Iterative learning ensures that management strategies evolve as our understanding of ecosystems deepens.
- Particularly, adaptive management has been inhibited by the interconnected specifics of the problems, none of which are intractable or lack suggested approaches.

Inadequate or existent biological and ecology concept models provide as a basis for investigation with the goal of restoring ecosystem processes and functioning that more closely align with the model of self-sufficient ecosystems especially in the context of aquatic habitats. When models are available, it takes a lot of time to estimate their parameters; in the absence of models, it takes a lot of research to create them. In both situations, the empirical research is frequently not generalizable outside of the studied region [31].

Large-scale, field-based trial approaches frequently lack replicated systems or control groups in contexts where offering no treatment is usually not achievable. In addition, prior to conducting any experiment, best management practices many of which have not been examined by experimentation must be put into effect [32].

RAD Adaptive Management was investigated by Lynch [33] with the objective to transform ecosystems. In this research, the resist-accept-direct (RAD) Approach is used for implementing adaptive management. It gives managers the ability to navigate the new field of ecosystem transformation by applying tried-and-true adaptive management strategies.

To encourage prudent risk-taking, RAD adaptive management calls for regular evaluation, monitoring, experimentation and bet hedging. The term "resource management" refers to a range of actions pertaining to the prudent use of natural resources. It entails striking a balance between social, economic and ecological demands while maintaining the long-term stability of ecosystems.

3.1 Important Elements of Resource Management

Comprehending the distribution, Caliber and accessibility of resources is the basis for assessment.

Planning: Creating plans for the conservation and use of resources.

Implementation: Putting plans into action to accomplish goals.

Monitoring: Consistently assessing how resources are used and making necessary adjustments to plans.

4. DEVELOPMENT OF ECOSYSTEMS AND RESOURCE MANAGEMENT

The term "ecosystem development" describes how ecosystems naturally evolve over time. Resilience, sustainability and ecosystem health all depend on efficient resource management, instances of resource management in the development of ecosystem. Forestry management involves striking a balance between replanting and timber harvest in order to preserve forest ecosystems.

Ensuring sustainable water use for industry, agriculture and ecosystems is known as water resource management. Fisheries management is the control of fishing methods to avoid overfishing and preserve fish stocks. Conservation of biodiversity refers to the efficient management of species and their habitats. The article by [34] addresses a change in the philosophy of resource management from conventional methods to ecosystem management. It investigates the causes of this shift, highlighting the significance of taking ecological processes, resilience and long-term sustainability into account.

In order to achieve successful ecosystem management, [35] stressed the value of interdisciplinary methods, collaborative efforts and adaptive management. The threshold-based resource management framework provides an institutionally sensitive framework for environmental decision-makers investigating to identify and develop science and engineering-based solutions that more effectively tackle and accommodate ecosystem health and reliability demands. The framework directs four fundamental scientific and engineering strategies with the goal towards creating healthier ecosystems: adaptive management, high reliability resource management, self-sustaining resource management and individual circumstances resource management. This is accomplished by emphasizing which distinct resource management models depend upon natural traits, giving each regime adequate consideration without compromising its significance or effectiveness of the other approaches. According to the research paradigm, the issues with adaptive management have more to do with its application to the wrong ecosystems than its methodology. After describing the concept, the framework was then applied to the San Francisco-Bay Delta (CALFED) Program, a modern ecosystem management system.

4.1 Community Engagement

Engaging local communities in ecosystem conservation efforts fosters a sense of ownership and responsibility. A potent tool for enacting behavioural and environmental changes that will enhance the community's and its residents' health is the community participation process. It usually involves partnerships and alliances that act as catalysts for developing initiatives, regulations and procedures as well as assisting in coordinating resources and affect systems and relationships between partners. [36] investigated the interlink between ecological ethics and ecosystem conservation. Investigated trends in policies related to ecological ethics and ecosystem conservation in Volcanoes National Park in Rawanda. It was suggested that conservation can't find true success without integrating the ecological ethics.

Adom [37] evaluated ecotourism development strategies, specifically those related to the local community. [38] emphasized understanding local ecosystems and involving community members in the process. Innovative technologies and solutions play a crucial role in advancing sustainable ecosystem development. Artificial Intelligence can be utilized by Internet of Things (IoT) devices and intelligent home appliances to turn off the power when they are not in use and to alert users about excessive power consumption. The IoT-based smart irrigation system that was suggested by [39] can save up to 16 gallons of water or 15% compared to regular sprinklers. Carbon capture and storage (CCS), defined by [40], is an innovative technology that distinguishes carbon dioxide, a gas that exists in Earth's atmosphere and is warming our planet, from other gases generated via industrial processes.

Byun [41] suggested that LED lighting reduces greenhouse gas emissions from power plants by using significant quantities less energy per unit light emitted than fluorescent bulbs. A group of scholars at the University of Michigan invented solar-powered glass that enables 50 percent of light though a window and generates an efficiency of a minimum 15%. According to Ogala et al. [42], Networked sensors determine the acidification, detect sources of pollution, monitor the quality of water and air, and acquire precise information on other sustainability problems that threaten the health of the global community.

Policies and effective governance are essential for promoting sustainable ecosystem development. Creating and enforcing regulations that prioritize environmental protection is crucial for long-term sustainability. Jabrayilov's study utilizing remote sensing techniques provides precise insights into environmental changes in Shahadah National Park, aiding in the identification of endangered ecosystems and informing future conservation efforts.

5. CONCLUSIONS

The growth and development of ecosystems, as outlined by various ecological theories, highlight the importance of understanding both qualitative shifts and quantitative increases in biomass and energy flow. Effective collaboration and iterative learning through adaptive management are crucial for promoting sustainable resource management and ecosystem resilience in the face of complex social-ecological challenges. Effective resource management, interdisciplinary collaboration, community engagement and innovative technologies are essential pillars for promoting sustainable ecosystem development, guided by policies and governance frameworks prioritizing environmental protection and long-term sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Agee JK, Johnson DR, editors. Ecosystem management for parks and wilderness. University of Washington Press; 1988.
2. Axelrod M. Climate change and global fisheries management: linking issues to protect ecosystems or to save political interests?. Global Environmental Politics. 2011, Aug 1;11(3):64-84.
3. Brussard PF, Reed JM, Tracy CR. Ecosystem management: what is it really?. Landscape and Urban Planning. 1998, Mar 31;40(1-3):9-20.
4. Neace MB. Sustainable development in the 21st century: Making sustainability operational. WIT Transactions on Ecology and the Environment. 1970, Jan 1;34.
5. Hickel J. The contradiction of the sustainable development goals: Growth versus ecology on a finite planet. Sustainable Development. 2019, Sep; 27(5):873-84.
6. Pennesi ME, Weleber RG. High-resolution optical coherence tomography shows new aspects of Bietti crystalline retinopathy. Retina. 2010, Mar 1;30(3):531-2.
7. Lichter J, Caron H, Pasakarnis TS, Rodgers SL, Squiers TS, Todd CS. The ecological collapse and partial recovery of a freshwater tidal ecosystem. Northeastern Naturalist. 2006, Jun;13(2): 153-78.
8. Walker LR, Del Moral R. Primary succession and ecosystem rehabilitation. Cambridge University Press; 2003, Feb 13.

9. Odum EP. The strategy of ecosystem development: An understanding of ecological succession provides a basis for resolving man's conflict with nature. Science. 1969, Apr 18;164(3877):262-70.
10. Odum HT. Self-organization, transformity, and information. Science. 1988, Nov 25;242(4882):1132-9.
11. Ulanowicz RE. Growth and development: ecosystems phenomenology. Springer Science & Business Media; 2012, Dec 6.
12. Kay JJ, Regier HA. Uncertainty, complexity, and ecological integrity: insights from an ecosystem approach. InImplementing ecological integrity: Restoring regional and global environmental and human health. Dordrecht: Springer Netherlands. 2000, Jun 30;121-156.
13. Fath BD, Jørgensen SE, Patten BC, Straškraba M. Ecosystem growth and development. Biosystems. 2004, Nov 1;77(1-3):213-28.
14. Stengers I, Prigogine I. Order out of Chaos: Man’s new dialogue with nature. Verso Books; 2018, Jan 23.
15. Jørgensen SE, Mejer H. A holistic approach to ecological modelling. Ecological Modelling. 1979, Sep 1;7(3): 169-89.
16. Szargut J, Morris DR, Steward FR. Exergy analysis of thermal, chemical, and metallurgical processes; 1987.
17. Turner MG, Chapin III FS. Causes and consequences of spatial heterogeneity in ecosystem function. In Ecosystem function in heterogeneous landscapes. New York, NY: Springer New York. 2005;9-30.
18. Turner WR, Bradley BA, Estes LD, Hole DG, Oppenheimer M, Wilcove DS. Climate change: Helping nature survive the human response. Conservation Letters. 2010, Sep;3(5):304-12.
19. Trumbore S, Brando P, Hartmann H. Forest health and global change. Science. 2015, Aug 21;349(6250):814-8.
20. Lindenmayer D, Messier C, Sato C. Avoiding ecosystem collapse in managed forest ecosystems. Frontiers in Ecology and the Environment. 2016, Dec; 14(10): 561-8.
21. Ruggerio CA. Sustainability and sustainable development: A review of principles and definitions. Science of the Total Environment. 2021, Sep 10;786: 147481.
22. Jabrayilov EA. A’WOT analysis for sustainability of biodiversity and tourism in Shahdagh National Park, Azerbaijan. Journal of Geology, Geography and Geoecology. 2022, Aug 3;31(2):302-10.
23. MacArthur RH, Wilson EO. The theory of island biogeography. Princeton university press; 2001.
24. Thompson K, Grime JP. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. The Journal of Ecology. 1979, Nov 1;893-921.
25. Chorley RJ. Geography as human ecology. In Directions in geography. Routledge. 2019, Apr 10;155-170.
26. White RE. The accuracy of estimating Q from seismic data. Geophysics. 1992, Nov;57(11):1508-11.
27. Jørgensen SE, Patten BC, Straškraba M. Ecosystems emerging: 4. growth. Ecological Modelling. 2000, Feb 28;126(2-3):249-84.
28. Chorley RJ, Kennedy BA. Physical geography: A systems approach. (No Title); 1971.
29. Sultana N, Turkina E. Collaboration for sustainable innovation ecosystem: The role of intermediaries. Sustainability. 2023, May 9;15(10):7754.
30. Liu F, Dai E, Yin J. A review of social–ecological system research and geographical applications. Sustainability. 2023, Apr 20;15(8):6930.
31. Walters C, Christensen V, Pauly D. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in fish biology and fisheries. 1997, Jun;7:139-72.
32. Carpenter SR. Microcosm experiments have limited relevance for community and ecosystem ecology. Ecology. 1996, Apr 1;77(3):677-80.
33. Lynch AJ, Thompson LM, Beever EA, Cole DN, Engman AC, Hawkins Hoffman C, Jackson ST, Krabbenhoft TJ, Lawrence DJ, Limpinsel D, Magill RT. Managing for RADical ecosystem change: applying the Resist-Accept-Direct (RAD) framework. Frontiers in Ecology and the Environment. 2021, Oct;19(8):461-9.
34. Wallace MG, Cortner HJ, Moote MA, Burke S. Moving toward ecosystem management: Examining a change in philosophy for resource management. Journal of Political Ecology. 1996, Dec 1;3(1):1-36.

35. Roe E, Van Eeten M. Threshold-based resource management: A framework for comprehensive ecosystem management. Environmental Management. 2001, Feb; 27:195-214.
36. Francis W, Robert MC, Dharani N, Nathaniel G. Ecological ethics and community engagement approach to ecosystems conservation: A case study of volcanoes national park in Rwanda. International Journal of Environmental Protection and Policy. 2022, Aug;13(2): 101-8.
37. Adom D. The place and voice of local people, culture, and traditions: A catalyst for ecotourism development in rural communities in Ghana. Scientific African. 2019, Nov 1;6:e00184.
38. Turin TC, Kazi M, Rumana N, Lasker MA, Chowdhury N. Community ecosystem mapping: A foundational step for effective community engagement in research and knowledge mobilization. Journal of Primary Care & Community Health. 2023, Oct;14:21501319231205170.
39. Johar R, Bensenouci A, Bensenouci MA. IoT based smart sprinkling system. In2018 15th Learning and Technology Conference (L&T). IEEE. 2018, Feb 25l147-152.
40. Boot-Handford ME, Abanades JC, Anthony EJ, Blunt MJ, Brandani S, Mac Dowell N, Fernández JR, Ferrari MC, Gross R, Hallett JP, Haszeldine RS. Carbon capture and storage update. Energy & Environmental Science. 2014;7(1):130-89.
41. Byun J, Hong I, Lee B, Park S. Intelligent household LED lighting system considering energy efficiency and user satisfaction. IEEE Transactions on Consumer Electronics. 2013, Feb;59(1):70-6.
42. Ogala JO, Ahmad S, Shakeel I, Ahmad J, Mehfuz S. Strengthening KMS. Security with advanced cryptography, machine learning, deep learning, and IoT technologies. SN Computer Science. 2023, Jul 15;4(5):530.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119404