MAJOR RESEARCH REPORT 2022

Living System Perspective on Ecosystem Services

MICHELLE VAN DER VEGT

Utrecht University

Department of Biology
Division of Bio-inspired innovation
UTRECHT UNIVERSITY
Utrecht, Netherlands 2022

Living system perspective on Ecosystem services
MICHELLE VAN DER VEGT

Daily-Supervisor: Phd. Katharina Hecht, Department of Biology
First examiner: Dr. J.H. Appelman, Department of Biology
Second examiner: Prof. dr. H.A.B. Wosten, Department of Biology

Major Research Report 2022
Department of Biology
Bio-inspired innovation
Utrecht University
Padualaan 8, Z403
0031650737798

Living System Perspective on Ecosystem Services
MICHELLE VAN DER VEGT
Department of Biology
Utrecht University

Abstract

The concept of ecosystem services is gaining popularity in research, policy and industry. However, ecosystem services theory quantifies and commoditizes life without integrating the mechanisms of living systems to sustain, maintain and reorganize themselves. The current concept of ecosystem services pays no attention to the relationships between services as it has been largely developed with a mechanistic and anthropocentric mindset. To redress this caveat we propose to link ecosystem services to a living systems perspective and argue that we can show relationships between ecosystem services when using the concept of exergy. Resulting in the conclusion that when analyzing ecosystem services through exergy the supporting and regulating services both refer to ecosystem processes and can therefore be merged into ecological services. Through the exergy concept we also highlight the gap of energetic relationships within science while arguing that the moment we can identify and quantify energetic relationships between ecosystem services, we think it may becomes possible to analyze trade-offs within ecosystems. We argue that linking the living systems perspective to ecosystem services delivers a better understanding of ecosystem functioning and the long-term survival of ecosystems, which opens up possibilities for an appropriate implementation of ecosystem services in human-designed ecosystems and decision-making in policy and practice.

Keywords: Ecosystem services, Living systems, Exergy, Organisational exergy, Dissipative structures, Autopoiesis, Ecological services.

Layman's summary

Within the last decade, the Earth has become recognized as a coupled social-ecological system, where human activities significantly impact the functioning of the earth system, its ecosystems, and vice versa. Currently, the ecosystem services framework still shows a mechanistic perspective of "*nature for people*". Based on limited social-ecological integration, this view gives the illusion that humans can exploit and control nature to their benefit via a one-way utilitarian relationship whilst perceiving humanity to be outside the system. Therefore, it is time for a paradigm change within the ecosystem services framework by thinking about social-ecological relationships and dynamics rather than treating planetary and ecosystem processes as separate biophysical systems occasionally perturbed by human activity. This thesis attempts to build a bridge between the social and ecological realms by placing the ecosystem services concept into a living system perspective. Showing through exergy how ecosystems can be viewed as living systems whilst adding a foundational layer to the ecosystem services concept. We intend to increase the knowledge of decision-makers within policy and practice on the basic functioning of ecosystems by explaining how ecosystems have evolved to sustain themselves over time. Where we hope that this foundational layer can be used in the future as guidelines when working with the ecosystem service concept.

Acknowledgements

Firstly, I would like to send my gratitude to my Professor of the University of Utrecht, Dr. Jaco Appelman and PhD Katharina Hecht for his guidance, support and feedback during my project. Secondly, I want to credit PhD Katharina Hecht for her encouragement, brainstorms and critical questions and feedback during my entire project. And lastly, I want to thank PhD Madeline Lewis, Bruce Mc Naughton and my study group of the Capra course for their endless discussion of the living system perspective. Without their insight and constructive feedback, this research would not have reached this level of expertise.

Michelle van der Vegt, Utrecht, September 2022

List of Definitions

Below is the list of definitions that have been used throughout this thesis listed in alphabetical order:

Abiotic	Nonliving reffering to the physical and chemical properties of an environment
Biotic	Pertaining to the living factors - the organisms - in an environment
Ecosystem	A dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit
Entropy	A measure of the degree of disorder of the system
Exergy	The total amount of work (= entropy - free energy) that a system can perform.
Pattern of organization	The configuration of the network processes among the components.
Planetary boundary	The levels of human perturbation of the Earth system functioning may be substantially altered.
Structure	The physical properties, activities and roles of the components within the system.
System	A set of interacting, interrelating entities that form an integrated whole.
System boundary	Separates the elements, functions, or activities of a system domain from its environment.
Systemic properties	The system as a whole system contains new measurable variables, qualities and states -and perform new functions, and have new capabilities that are above and beyond those of the parts that comprise them

Abbreviation

Below is the list of abbreviation that have been used throughout this thesis listed in alphabetical order:

ES	Ecosystem services
LS	Living systems.

Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

dS	Total Entropy of the system
dS_i	Entropy production within the system
dS_e	Entropy exchange with the environment
Ex_{eco}	Eco-exergy
c_i	Information captured within species genes
β_i	Weight factor
Ex_{str}	Structural-exergy

Contents

List of Figures

1

Introduction

In the past, we assumed that the earth system was large and resilient enough to continue indefinitely with the provisioning of a pleasant life-support system for humans, no matter the scale of human activity (Young and Steffen, 2009). As a result of this assumption, humans have placed themselves outside the system, giving the illusion of unlimited growth (Capra and Luisi, 2014) while perceiving human activities and components solely as drivers and targets of change. Fortunately, the earth got scientifically recognized as a coupled social-ecological system within the last decade. This more holistic perception includes human societies as an integral part of the whole, not as an outside driver of the natural system (Young and Steffen, 2009). When seeing the earth system as an operationally closed system it maintains and regulates itself by transporting and transforming materials and energy. This new insight challenges our obsession with endless growth without considering the planetary boundaries, resulting in the acknowledgment that human activity significantly impacts the functioning of the Earth System, its ecosystems, and the other way around (Steffen et al., 2015).

1.1 Problem statement

Within scientific studies, social-ecological systems have become the central discourse on human-nature interactions (Ostrom, 2009). Unfortunately, the current Ecosystem Services (ES) framework is based on an outdated mechanistic perspective, which is a view where humans can use and control nature to their benefit via a non-reciprocal utilitarian relationship whilst placing humanity outside of the system (Flint et al., 2013). Therefore, ES theory seeks to describe life in such a way that it can be quantified and commoditized. Which makes it impossible for the ES concept to help science and policy in finding solutions for the global challenges (e.g surpassing planetary boundaries) (Loft et al., 2016). Without including the interrelations between humans and the basic principles of ecosystem functioning within the framework- it is impossible to show the trade-offs and synergies which are essential for decision making within policy and practice (Zari and Hecht, 2020). Due to this reason, it is time for a paradigm change within the ES framework. In this new framework, we need to start to think about social-ecological relations and dynamics rather than treating planetary and ecosystem processes only as separate biophysical systems that are occasionally perturbed by human activity (MA, 2003; Díaz et al., 2015; Potschin-Young et al., 2018). When policy and decision-making focus on the underlying principles of life, it can change human values to enhance positive ecological impact.

The Living Systems (LS) perspective based on the work of Fritjof Capra and Pier Luigi Luisi has the potential to build a bridge between the social and ecological realm, whilst helping us to understand the basic pattern of organization that ecosystems have evolved to sustain themselves over time (Capra and Luisi, 2014). The principles of a LS perspective can be applied as ecological guidelines for maintaining our life-support system.

1.2 Research questions and scope

This research focuses on exploring the integration of the ES concept into the LS perspective to accomplish a revision of the ES framework that can enhance our life-support system and makes it possible in the future to build relationships between ecosystem services and human activities.

To achieve this goal, the scope of this research will only focus on the ecological impact by understanding ecological mechanisms that create life whilst considering the possibility of integrating social and technological dimensions into follow up research. Therefore the main question of this thesis states:

Main research question

Can the ecosystem services concept be integrated into a systemic view that enhances our life-support system?

In order to solve the main research question we answer the following sub-questions:

Sub-questions

1. When within the history of the ecosystem services concept was there an alignment with the systemic view of life?
2. In what ways can a living systems perspective be applied to an ecosystem?
3. Can we integrate the ecosystem services concept into the living systems perspective of Capra and Luigi? (Based on the outcomes of subquestion 1 and 2)

2

Methodology

2.1 Theoretical research

To integrate the ES concept within the LS perspective within this thesis, theoretical research (Chapter 3) is performed, which explores the beliefs, assumptions, and limitations of the ES concept and the concepts of the LS perspective, which hopefully can fill some of the gaps within the ES concept. The ES concept has produced a variety of definitions, paradigms, frameworks and classifications (P. Ehrlich and Ehrlich, 1981; de Groot, 1987; MA, 2003; TEEB, 2008; **CICESwebsite**), making it necessary to examine the evolution of the ecosystem services framework (Figure 3.1). Therefore, this theoretical research starts with a historical overview of the concept, highlighting the beliefs and frameworks (Section 3.1.1 & 3.1.2), which lead to an answer to the sub-question 1.1: "*When within the history of the ecosystem services concept was there an alignment with the systemic view of life?*" (Section 3.1.3). Followed up with an explanation of the core concepts from the LS perspective (Section 3.2.1 & 3.2.2). These core concepts are applied to an ecosystem, answering the sub-question 1.2: "*In what ways can a living systems perspective be applied to an ecosystem?*" (Section 3.2.3). The integration will hopefully leads to an new vision within the ecosystem services concept (Chapter 4) that aligns the ES concept and the LS perspective, which answers the sub-question 1.3: "*How can we integrate the ecosystem service concept into the Living Systems perspective?*".

3

Theoretical research

3.1 The evolution of ecosystem services

> What is there about our way of perceiving that makes us not see the delicate interdependencies in an ecological system? Given its integrity, we don't see them, and therefore we break them.
>
> *Gregory Bateson*

3.1.1 Origins of the framework

The modern history of ES started in the late 1970s when Westman (1977) touches on the unanswerable question "*How Much Are Nature's Services Worth?*", a question increasingly asked by policymakers. To show that ecosystems are beneficial to humans in more ways than a standing stock of resources that can be exploited, Westman introduced the terms *ecosystem goods* and *ecosystem services*. Where *ecosystem goods* refer to the structure of an ecosystem, beneficial for the society in terms of direct harvest of marketable products and the use and appreciation for recreation, study, and aesthetic enjoyment (Westman, 1977). While the term '*ecosystem services*'(ES), referred to the ecosystem functions - the ways in which the components of the system interact and provide a variety of benefits to society. In short, all functions maintaining clean air, pure water, a green Earth, and a balance of creatures: the functions that enable humans to obtain the food, fiber, energy, and other material needed for survival (Westman, 1977). Westman wanted to emphasize the essential functions that ES perform for (human) survival while illustrating the value lost in monetary cost when ecosystems are damaged and can no longer perform these services. He hoped to improve the weighing between benefits that nature supplies when it is allowed to flourish against resource extraction.

Westman emphasized simultaneously that human's quantitative estimates of nature's worth will always be less than the actual value. He believed that when the public becomes educated about the value ES provide, the valuation of nature will grow over time.

In the 1980s, a similar concept of ES appeared when Ehrlich and Ehrlich (1981) discussed how humans are causing the extinction of non-humans species and why this situation should concern us. Within their book they showed nature's values through the lens of *compassion* (ethical values), *beauty* (intrinsic value), *economic interest* (direct values) and our *life support system* (indirect values). Ehrlich and Ehrlich place emphasis on the indirect values of nature, stating that ecological systems provide humanity with indispensable free services, services whose substantial disruption would lead inevitably to a collapse of civilization (P. Ehrlich and Ehrlich, 1981, p.6). As an expansion of this concept Ehrlich and Mooney (1983) discussed how the loss of biodiversity will affect ecosystems services and whether it is possible to find substitutes for these services. To show that not all species are equal in terms of how ecosystems function, they introduced the term ecosystem service *controllers*, called keystone species and ecosystem engineers within ecology (de Visser et al., 2013), which refer to the organisms that determine the ecosystem's structure (e.g., trophic relations) and through which the principal flow of energy and materials pass (P. R. Ehrlich and Mooney, 1983).

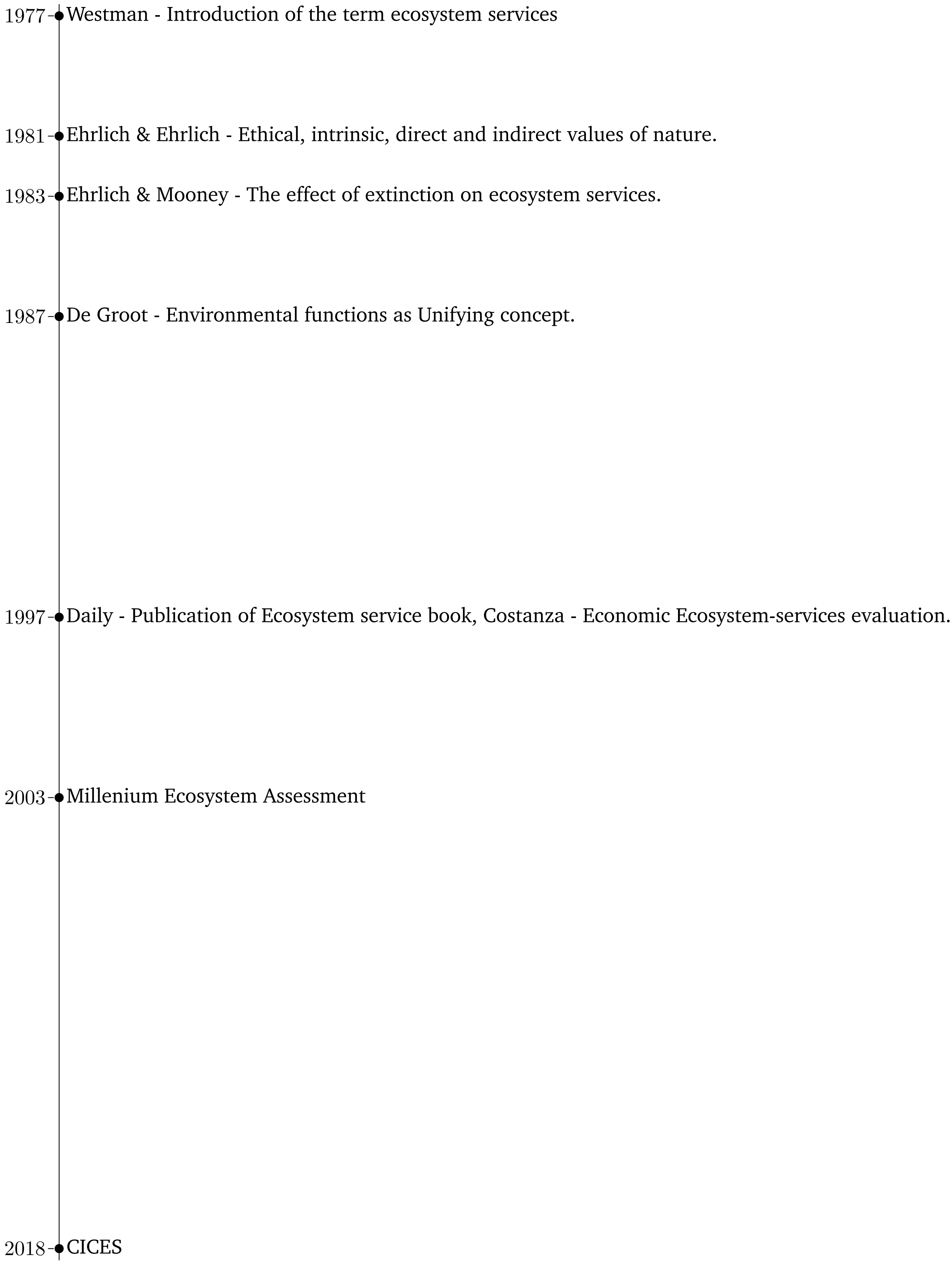

Figure 3.1: Historical timeline on the development of ecosystem services framework, The left side represents the year of publication. The right side states the first publishers and a short sentence on the topic of their publication.

Ehrlich and Mooney argued that the loss of a set of major *controllers* could collapse the entire system. At the same time, they recognize that many *controllers* cannot be identified because the degree of control exercised by a single species always depends on the relational context within an evolutionary time scale, making the substitution of lost species ineffective and expensive. Therefore, the main focus should be to maintain ES by minimizing anthropogenic extinction. These studies, and the development of deep ecology (Naess and Sessions, 1986), increased the attention to biodiversity conservation in the natural sciences. At the same time, ecological theory showed that a considerable variety of species is likely to be more stable, more productive and richer in resources and functions (Kareiva and Marvier, 2000).

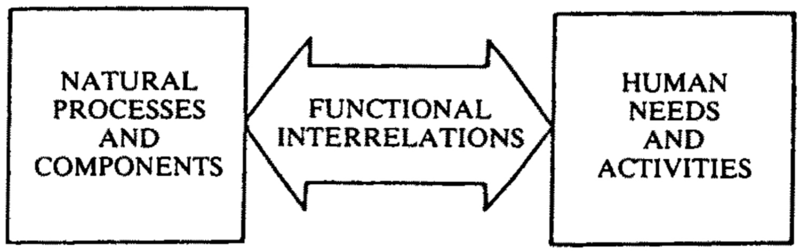

Figure 3.2: New concept for environmental functions The presentation of a new paradigm, which adopts a broader concept of goods and services (functions) provided by the (natural) environment. The functional interrelations in this figure represent the goods and services provided by the natural environment and, in the other direction, the impact of human activities on natural processes and components (de Groot, 1987).

Unfortunately, in 1986 at the "Conference on the Conservation and Development," it became apparent that the need for conservation and sustainable use of nature still lacked appeal among economists, policymakers, and the general public (de Groot, 1987). To bridge the different perceptions of ecologists, conservationists, and economists, De Groot (1987) merged the function-concept with ES, expanding the definition of *environmental functions* to both the natural and economic goods and services (Figure 3.2). By doing so, he showed the misconception within economic theory that environmental resources are free or unlimited, linking *environmental quality* to *quality of life*, where a happy global civilization can only exist when the ecological principles become an integral part of economic, political planning and decision-making. De Groot emphasized that the maintenance of environmental functions (goods and services) may serve as a unifying concept, because both ecologic and economic theory indicate that a healthy planet would offer more chances to develop and maintain a global civilization than a comparatively simple exploited planet (de Groot, 1987).

3.1.2 Mainstreaming of the framework

In the 1990s the development of ES became a serious part of the research agenda of "The Ecology and Economics of Biodiversity loss", and Ecological economics (Perrings et al., 1992; ICSU, 1992; Schulze and Mooney, 1994). Which led to two important meetings, that created the initiative for the first book on ES called "*Nature's Services: Societal Dependence on Natural Ecosystems*" (Daily, 1997) and the article "*The Total Value of the World's Ecosystem Services and Natural Captial*" (Costanza et al., 1997) published in Nature. Together, these publications triggered the policy interest in the concept of ES.

Thereafter the Millenium ecosystem assessment (MA) was carried out between 2001 and 2005 to assess the consequences of ecosystem change linked to human well-being and to establish the scientific basis for actions needed within our global politics to enhance the conservation and sustainable use of the ecosystem (MA, 2005c). The framework intends to help decision-makers balance economic growth and social development. Whilst enhancing trade-off evaluation between alternative ecosystem management regimes and courses of social action that alter the use of ecosystems and the multiple services (Figure 3.3) (MA, 2003, p.21).

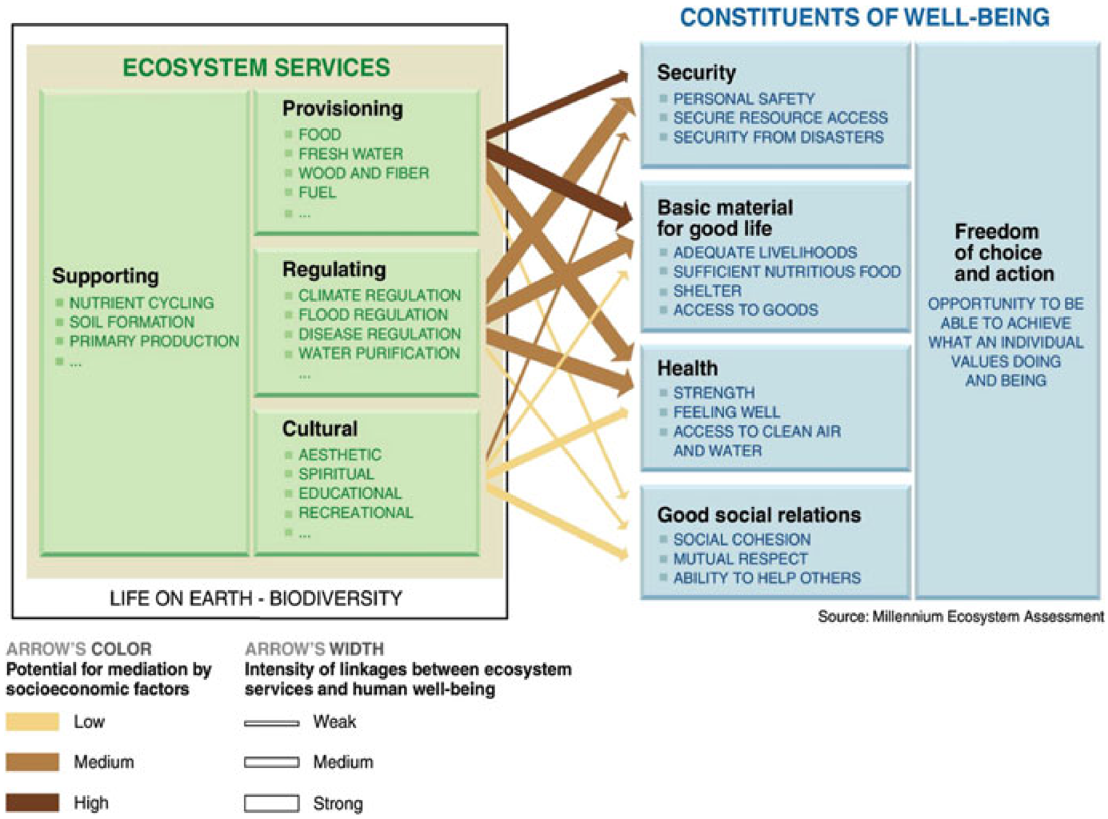

Figure 3.3: Ecosystem Services and Their links to Human Well-being This figure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. The strength of the linkages and the potential for mediation differ in different ecosystems and regions (MA, 2005a).

Within their framework, they have created four ES categories:

1. Provisioning services: the goods obtained from ecosystems.
2. Regulating services: the benefits obtained from the regulation of ecosystem processes.
3. Cultural services: the non-material benefits people obtain from ecosystems.
4. Supporting services: the underlying services necessary for the production of all other ES.

The provisioning, regulating, and cultural services directly affect people, whilst the supporting services only affect people indirectly by maintaining the conditions of life on Earth (MA, 2005b).

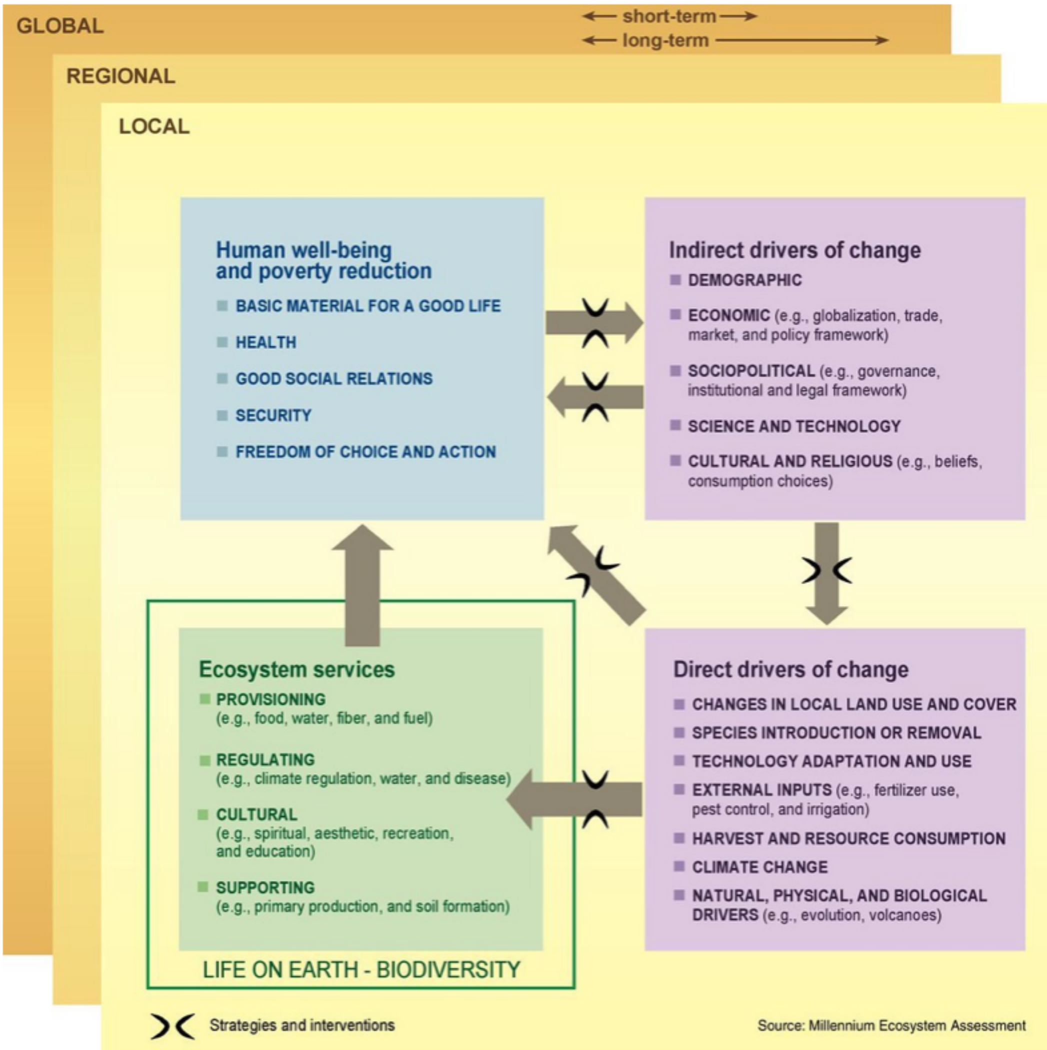

Figure 3.4: Conceptual framework of interactions between biodiversity, ecosystem services, human well-being, and drivers of change. Changes in drivers that indirectly affect biodiversity (upper right corner), can lead to changes in drivers directly affecting biodiversity (lower right corner). These result in changes to ecosystems and the services they provide (lower left corner), thereby affecting Human well-being (MA, 2005a).

The MA (2003) states that ecosystems are living dynamic systems acting as functional units and perceive humans as an integral part of these systems. Where humans can function as direct and indirect drivers, where direct drivers influence ecosystem processes and indirect drivers influence one or multiple direct drivers (Fig 3.4).

The ES framework of the MA was supplemented and thoroughly categorized in 2009 by The Common International Classification of Ecosystem Services (CICES). Based on the cascade model (Figure 3.5) they have created a common clas-

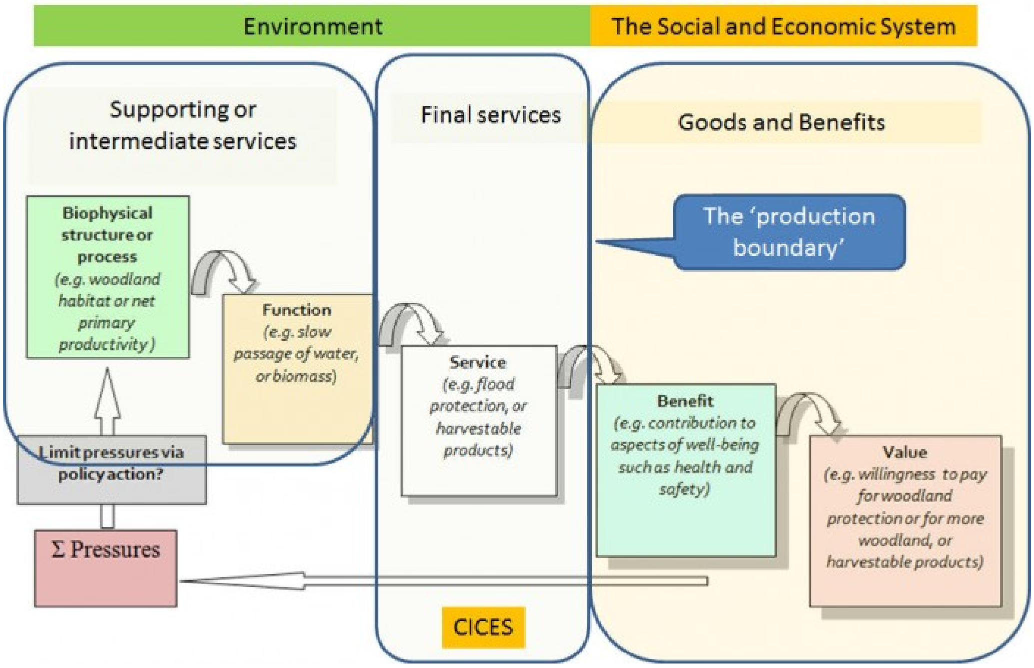

Figure 3.5: The ecosystem services cascade model This figure visualizes a cascade linking two ends of a 'production chain'. Left is the environment showing the natural system which contains the ecological structures and processes created or generated by living organisms, and right the social and economic system showing the benefits that people derive from an ecosystem related to human well-being and are valued within our environmental accounting (Potschin and Haines-Young, 2011; CICES, 2018b)

sification and standardization of the final ES (CICES, 2018a; Potschin and Haines-Young, 2011; Potschin et al., 2016). That link the goods and benefits valued by people and most directly affect the well-being of people: The provision of material and energy needs, the regulation and maintenance of the environment for humans and cultural significants which include the non-material characteristics of ecosystems that affect physical and mental states of people (Haines-Young and Potschin, 2018a). However, the CICES framework does not recognize the underlying supporting services, also described as the intermediate services (Haines-Young and Potschin, 2018b) within the cascade model. Mainly because these underlying supporting services ultimately determine the capacity of the ecosystem to deliver particular services and are seen as ecosystem conditions, and therefore, not part of the economic valuation within environmental accounting (Haines-Young and Potschin, 2018b).

3.1.3 Assessing the integration of the systemic view of life into the current ecosystem services frameworks

Returning to the research question, "When within the history of the ES concept was there an alignment with the systemic view of life?". The history of the ES and the conceptual work surrounding it shows from the beginning an outdated mechanistic world view, with a predominant trend of social-ecological separation. From the origins of the ES concept, it was clear that Westman (1977), Ehrlich (1981, 1983), and de Groot (1987) intended to integrate the natural system into our social-economic value system. They tried this by showing all the essential activities non-human beings perform for a healthy global civilization. That was, within that time, a huge step forward because before the concept of ES, nature was only seen as a stock that could be exploited (Westman, 1977). Nevertheless, placing the ES concept in a "*nature for people*" perspective created an unrealistic split between human and non-human benefits. This separation can give the illusion that ES beneficial to humans are a one-way utilitarian relationship to human health, which can be interpreted as a production chain with intermediary steps (Potschin and Haines-Young, 2011), However, this is not the case, in reality, ecosystems perform many services to sustain and maintain themselves, which are currently not integrated into environmental accounting due to the split between human and non-human benefits. Therefore, these unseen services are still exploited as stocks creating a paradox within the perspective of "nature for people". As long as we only value the ES beneficial to humans and try to maximize these specific ES at the expense of ES beneficial to non-humans, we still disturb the ecosystem's dynamic balance. This forces us to adopt a more systemic view, where we integrate a foundational layer on the mechanisms sustaining and maintaining LS (based on systems theory, dissipative structures, and autopoiesis), which will be the subject of the next paragraph. Because without an ecosystem that is able to sustain, maintain and re-organize its own structure, not enough ES can be delivered to maintain and sustain a healthy global civilization.

3.2 The living systems perspective

> There are solutions to the major problems of our time; some of them even simple. But they require a radical shift in our perceptions, our thinking, and our values.
>
> *Fritjof Capra*

3.2.1 Systems theory

Systems theory describes the concept of interacting processes and the way they influence each other over time to permit the continuity of some larger whole (Elsevier, n.d.). A *system* is a set of interacting, interrelating entities that form an integrated whole (Capra and Luisi, 2014). As a whole, the systems identity is defined through its *pattern of organization*, which refers to the configuration of the network processes among the components. Which are physically embodied by the *structure of the system*, referring to the physical properties, activities and roles of the components within the system (Fleischaker, 1988). Together the pattern of organization and the structure form systemic properties, making it possible for the system to contain new measurable variables, qualities and states -and perform new functions, and have new capabilities that are above and beyond those of the parts that comprise them (McNaughton, 2020).

To study a system a *boundary* is set around the systems domain, separating the elements, functions, or activities of a system from its environment. The boundary of systems is characterized as open or closed. This characterization explains the amount of interaction of the system with its environment. *Closed systems* such as machines are isolated and hermetic, having little interaction with other systems or the outside environment, for example, only thermal energy exchange. The boundaries of such closed systems are rigid and largely impenetrable, making them easy to define.

In contrast, *open systems* such as organisms interact continuously with other systems or the outside environment by accepting matter and energy inputs, acting on the inputs through transformation, and releasing them as outputs, making an open systems boundary flexible and semi- or highly permeable. The higher the permeability of the systems boundary, the harder it can be to define the boundaries of the system itself. Therefore, elements, functions, and activities that have relatively intense and frequent interactions are considered inside the boundary of

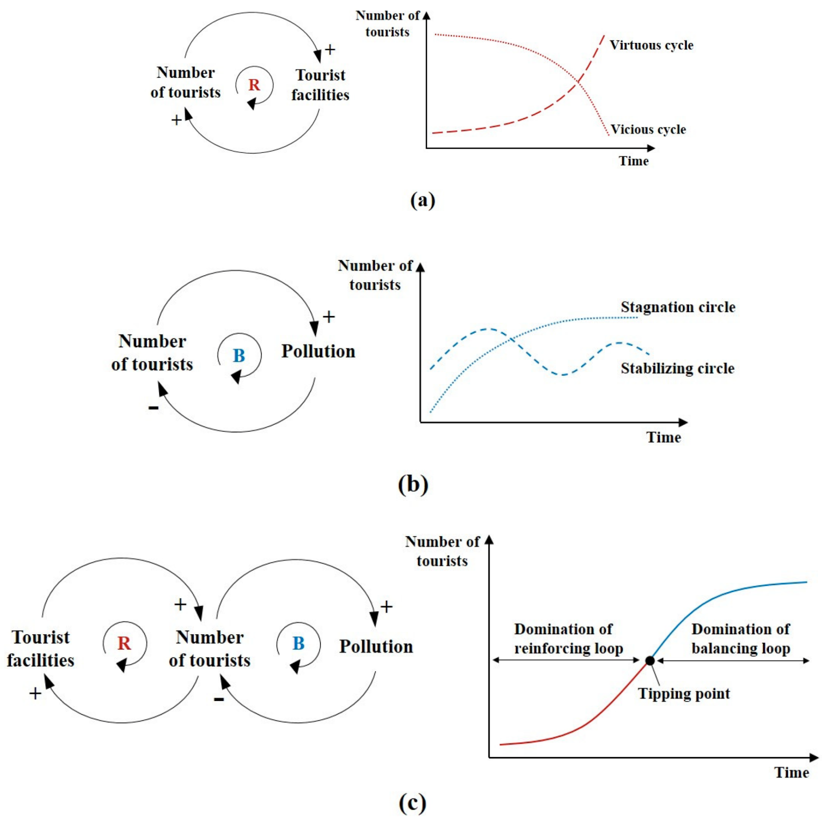

Figure 3.6: Examples of causal loops and their behavior: (a) Structure and behavior of are enforcing loop; (b) Structure and behavior of a balancing loop; (c) Typical example of combinative loops. (Choi et al., 2017).

a system. Conversely, elements with relatively low frequent interactions are considered outside the system. However, in reality, the boundary of a system often depends on the information available and the person's perspective observing the system. Thus to some extent, the boundaries of systems are inevitably artificial and somewhat arbitrary in their placement (Koskinen, 2013).

When the boundary of a system is set, systems theory applies the study of feedback, called cybernetics, to understand the behavior of a system over time. Cybernetics recognizes two types of causal relationships called polarities, a positive link and negative link. *Positive link* (*s* or +) moves one variable in the same direction as the other variable. In comparison, *Negative link* (*o* or -) moves one variable in the opposite direction of the other variable (Roberts et al., 1983). The configuration of these causal relationships between the variables leads to two types of loops, a balancing loop or a reinforcing loop. A *balancing loop* comprises a variable amount of positive feedback and an equal amount of negative feedback, which helps maintain the systems stability (Figure 3.6b and 3.6c). A *reinforcing loop* comprises variable amount of positive feedback and an even or no amount of negative feedback, amplifying the possibilities of divergences and emergences creating conditions for change, evolution, growth, or collapse (Figure 3.6a).

3.2.2 Dissipative structures

Due to the first law and second law of thermodynamics (Campbell et al., 2018, closed and open systems behave differently over time.

Laws of thermodynamics

1. Energy can be transformed from one form to another but can be neither created nor destroyed;
2. Energy transformation or transaction always increases the entropy of the universe.

Closed systems such as machines have structures created by design, prescribing all parts' composition and relations. Therefore, their structure and function are isomorphic, where each structure performs a specific function. They have ideally minimal dissipative or irreversible processes (Kondepudi et al., 2020). Consequently, they must eventually reach an equilibrium state, regardless of their starting conditions (Holt and Schoorl, 1990),.

On the other hand, open systems such as cells, organisms, and ecosystems are dissipative structures. Their structure, relations, and the distinction between parts are intrinsic, influenced by the contexts in which the system develops (Kondepudi et al., 2020). Dissipative structures follow an irreversible process of entropy dissipation, organizing their own structure by reducing their own entropy (Prigogine and Lefever, 1973). Therefore, entropy producing processes maintain and organize the structure and function of open systems, and through the irreversible process of entropy dissipation (3.1) (Kondepudi et al., 2020), they are still able to satisfy the second law of thermodynamics (Prigogine and Lefever, 1973). Due to this, a dissipative structure can only exist in a steady state, a dynamic balance with the environment through a constant flow of energy and matter (Holt and Schoorl, 1990).

$$dS = dS_i + dS_e \tag{3.1}$$

Where dS is the total entropy change within the system, which can be negative or positive. dS_i is the entropy production within a system. The entropy production is always positive or zero. dS_e, entropy exchange with the environment can be both positive or negative. dS_e is positive when disturbances occur from outside of the system, and dS_e is negative when high entropy products are exported to the environment or when the internal order of the system increases (Gunther and Folke, 1993).

When looking at (3.1), dS can be positive or negativedue to this an open systems can have two types of behaviors. They can have a tendency to a state of maximum disorder, destroying their own internal structure while moving to thermodynamic equilibrium, which eventually means the death of the open system (Nielsen, Müller, et al., 2020), shown in formula 3.2. Or they move away from equilibrium by evolving new instabilities and transforming into new steady states of increased complexity when the flow of energy and matter through them increases (Capra and Luisi, 2014), meeting the constraints for life to exist in the long run (Prigogine and Lefever, 1973), shown in formula 3.3.

$$dS_e > -dS_i \tag{3.2}$$

While dS is positive (3.3), it moves to equilibrium, and disorder accumulates within the system.

$$dS_i < -dS_e \tag{3.3}$$

When dS is negative (3.2), the open system is in a thermodynamic balance or homeostasis, moving away from equilibrium over time.

This all, reveals that if the universe's entropy is ever increasing, for a finite-size open system to persist in time (to survive), it must evolve in such a way that it provides easier and easier access to the currents that flow through it, called the constructal law (Bejan, 2005). However, the theory of dissipative structures doesn't explain how LS sustain and maintain themselves. Therefore, we need to combine dissipative structures with another theory called autopoiesis.

3.2.3 Autopoiesis Theory

The concept of *autopoiesis* was developed by Maturana and Varela (1973) in order to explain the essential characteristics of living as opposed to nonliving systems. And till now, the only available simple theory that is capable of providing a unitary view of the living, from the molecular level (Maturana, 1981), the realm of perception (Luisi, 2003) to the level of the Earth system (Margulis, 2000). The abstract principle can even be applied to social systems (like societies and organizations) (Luhnman, 1990), making it a unifying concept in the socio-ecological domain. In this paragraph we will only focus on the biological aspect of the theory.

An autopoietic unit is an open system that is operationally closed, which can sustain its own internal network, by re-generating all the systems components, that again actively determine the relationship with the environment (Maturana, 2002). Within the system the process of flow, links the pattern of organization and the structure together, through continual embodiment of the systems pattern, making the product of an autopoietic systems its own self-organization (Capra and Luisi, 2014).

Autopoiesis theory shows that within an autopoietic unit, the pattern of organization and the structure of a system are complementary (Figure 3.7). The pattern of organization exists only as network relationships among structures, and structure exists only as filling the roles that those network relationships establish (Fleischaker, 1988). The component interactions and system roles are determined by the structural properties of the components themselves, making the organization of the system *structurally determined* (Maturana, 1981). As a structurally determined system, the boundary of the system does not separate but intimately connects the system with its environment (Zeleny, 2005), in the form of *structural coupling* (Maturana, 1981). The system relates to its environment structurally, through recurrent interactions (Capra and Luisi, 2014), by accepting energy, material, and information in the form of physical, functional, behavioral, and communicational perturbations, which may trigger structural changes in the system. Nevertheless, the environment does not actively contribute to the maintenance of the autopoietic unit, only in the form of flow. These flow perturbations are not considered input for the pattern of organization, leaving the system's identity unchanged as long as the organizational roles are filled (Fleischaker, 1988).

Because an autopoietic unit is structurally determined, when structural changes accumulate to the point that organizational roles are breached the pattern of organization may be altered, creating emergence or collapse. Thus the given system will lose its current identity (Fleischaker, 1988). When emergence occurs, the reorganization of the system will be a different class of identity—for example, the transformation caterpillar to a butterfly or the succession of an ecosystem.

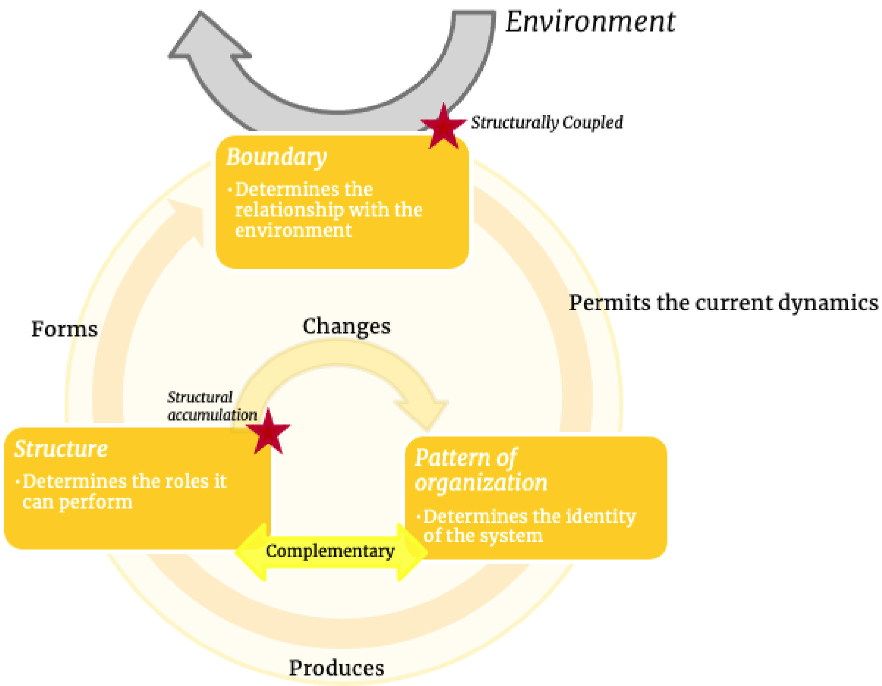

Figure 3.7: Autopoiesis: The cyclic logic of a living systems. Showing that the boundary makes it possible for the network of reactions to persist in its current state, that in turn produces the physical components that form the boundary of the system. Therefore the boundary defines structurally the relationship with the environment. And when structural changes accumulate, a system evolves to a new state. Made by Michelle van der Vegt

3.2.4 Ecosystem as an dissipative autopoietic unit

Within the LS perspective the question of whether, and how exactly, the concept of autopoiesis applies to ecosystems, is still wide open (Capra and Luisi, 2014). This is because mass and energy are not good measures for describing LS since neither energy nor mass can disappear. Günther and Folke (1993) provide a bridging theory of *organisational exergy*, that makes it possible to place the ecosystem in the LS perspective, connecting both autopoietic theory and dissipative structures through *exergy*, the physical quality of energy within a system. Günther and Folke (1993) state that a living system increases its own internal order within their boundary by storing exergy, which they extract from their environment. The amount of energy as extracted will be exported from the system, only this exported energy is always be of a lower quality (Fig. 3.8).

Günther and Folke explain that the exergy is capture through solar energy and used as chemical energy within the system, through a network of heat generating transformations or accumulated by a network of conservative transformation storing exergy via the production of biomass or as instructional information. called organisational exergy, the exergy transformed into the structure of the system (Gunther and Folke, 1993). Günther and Folke argue that instructional information is not solely stored in genetic information, but also in relations between

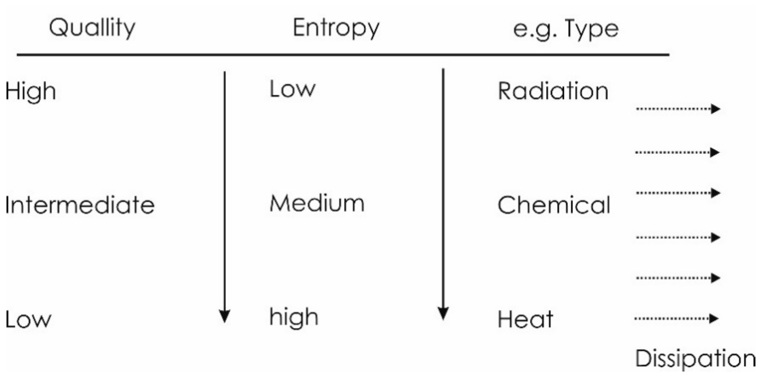

Figure 3.8: Brillouins cascade: A one way conversion of energy quality. Where energy is always transformed in one direction only, from high quality to a sequentially lower quality (Nielsen, Müller, et al., 2020)

(genetically determined) entities. This instructional information has two types with different functions. Where they state that working information (e.g., communication) directly affects the receiver, creating feedback that will change the behavior of both the receiver and the transmitter, making working information important for the organization of the system's current structure. In contrast, they explain that latent information has no current effect because the potential receiver is not present within the system. Therefore, latent information might play an important role in the re-organization of the structure of a system when the system changes from one state to another (Gunther and Folke, 1993).

Returning to the sub-question 1.2: "*In what ways can a living systems perspective be applied to an ecosystem?*". When perceiving an ecosystem as a dissipative autopoietic unit, the structure of an ecosystem is the organisational exergy, including biomass, genetic diversity, and the relationships of genetically determined entities. The structure of the systems determines the boundary and consequently its ability to receive exergy and export entropy products. The structure sustains the pattern of organization of an ecosystem, its metabolic network, including the heat -and conservative transformations within the ecosystem. The metabolic network maintains the structure again by producing the ecosystem's structure. And when eventually exergy accumulates and instabilities occur, an ecosystem can reach a new steady state by reorganizing itself, through dormant information stored within genes, taking different roles (intrinsic functions) depending on the species composition, changing the identity of an ecosystem, like the process of succession. Exergy accumulation can even occur when biomass accumulation is restricted because qualitative improvement can still take place in the form of internal efficiency of organisms or through partnerships, making genetic variation and relationships crucial for the development of an ecosystem.

4

Revision of the ecosystem services framework

> Money is not wealth; it is only a way of measuring human activities or the transactions of goods and services
>
> *Satish Kumar*

The perspective of "*nature for people*" that surround the concept of ES, can only take us so far. When our economy is growing, but our ecosystems are still shrinking. We can conclude that our current way of valuing is not adequate and rather damaging for human health and our life support system in the long run. Therefore within this framework, we change the mechanistic (anthropocentric) view, which eliminates elements that lack direct commercial value, to a LS (symbiotic) view. A perspective in which humanity identifies themselves as part of nature, integrating all ES beneficial to both humans and non-humans within our value system. To achieve this within our framework we will merge the supporting and regulation ES, which together maintain, sustain and (re)-organize our ecosystems and the Earth system. The supporting and regulation ES cannot be viewed in separation, when using the exergy concept, which we reconfirm in the section 4.1 valuation of nature through exergy.

4.1 Valuation of nature through exergy

Links between exergy and ecology can be extended to economics. Jørgensen (2010) proposes that an ecosystems value and ES can be calculated through the annual increase of exergy (total work capacity), called eco-exergy. Which is based on the energy content of a system in a specific reference state coming entirely from the chemical energy, shown in the formula below (4.1):

$$\sum(\mu_c - \mu_{co})N_i \tag{4.1}$$

Where $(\mu_c - \mu_{co})$ contributes to the work capacity of an ecosystem based on the difference in chemical potential between the ecosystem $\mu?$ and the same system at thermodynamic equilibrium $\mu?$ and N_i in number of chemical compounds (Nielsen, Fath, et al., 2020b).

However, to measure the eco-exergy from an ecosystem, using this formula is not possible because of the high complexity of an ecosystem. Therefore a new formula was created, which is a state-based descriptor of a systems structure based on how usable energy is organized in storage, making it possible to measure the distance of the system from thermodynamic equilibrium (4.2)

$$Ex_{eco} = \sum_{i=1}^{N} c_i \beta_i \tag{4.2}$$

Where Ex_{eco} is the work capacity of the sum of the network of *i*th species, based on the biomass and information within the species genes. β_i is the weighing factor that considers the information capture in genes that the *i*th species is carrying in c_i, which stands for the exergy in the biomass for the *i*th species (Nielsen, Fath, et al., 2020a). '

Within the article "*Ecosystem services, sustainability and thermodynamic indicators*" Jørgensen (2010) shows that the value of nature is much higher through eco-exergy calculations, ratio 30-4249 depending on the type of ecosystem, compared to the calculations generated in the old mechanistic paradigm (Costanza et al., 1997) —showing that ecosystems are still undervalued when using the current ES calculations. This comes mainly because eco-exergy analyses include all the possible services nature has to offer to maintain a living system and not only the ES that humanity utilizes (Jørgensen, 2010). However Ex_{eco} have one hug limitation. Ex_{eco} can only estimate the work done within an ecosystem based on genes, assumming that network information is negligible compared to the information in genes, but the weight of modern approaches in systems ecology and advances in modeling continue to indicate the opposite, that network complexity may be equal to, or possibly even more important than genetic information in endowing ecosystems with the capacity to do work (Jørgensen et al., 2000). Therefore, Ex_{eco} still under values natures. Energetic relationships based on exergy are still a huge gab within science, and if we want to value nature to its full potential, this gab needs to be filled.

4.2 New definitions

Within this framework, we propose some new definitions. First, as earlier stated the supporting and regulating ES should be merged into one category, which we will call *ecological services*: all the ES beneficial to humans and non-human that maintain, sustain and re-organize an ecosystem, which can be measured in Ex_{eco}, eco-exergy (4.2). In this way, ecological services can be directly linked to systemic health, the ability to self-generate, self-regulate and self-organize networks. Secondly, the confusion between provisioning ES and goods need to be solved. We propose that when food stays within the boundaries of current system, it is part of the ecological services in de form of detritus. It becomes an *ecological good* when a structure (that cannot perform work anymore) is removed from the current system and transported into another system. The ecological goods can be perceived as structural exergy of a detritus, Ex_{str} (4.3)(Silow et al., 2011), which then acts as an exergy input into the another system.

$$Ex_{str} = (\sum_{i=1}^{N} c_i \beta_i) * (\sum_{i=1}^{N} c_i)^{-1} \tag{4.3}$$

And last, when a structure (organism) is transported from the current system and can still perform work, then that structure is seen as a disturbance to the other system in the form of entropy.

4.3 On the way towards a truly regenerative future

When we go back to subquestion "Can we integrate the ES concept into the living systems perspective of Capra and Luigi?". We showed within section 3.2.4, 4.1, 4.2 that if we use the concept of exergy, it becomes possible to integrate the ES concept into the LS perspective, linking ecosystem services with each other and to human activities. Furthermore, by applying the LS perspective, we understand better the relationships that help sustain, maintain and organize an ecosystem. For example, the theory of dissipative structures explains a system's metabolic or developmental process through the complex relationship between structure, order, dissipation, and change. In comparison, autopoietic theory explains the system's production process through the relationships of structure, the pattern of organization, and the boundary. However, as long as we do not know the energetic relationships, all work performed by the network is unseen and cannot be considered when analyzing trade-offs, potentially leading to incorrect decision-making within policy and practice. Nevertheless, we hope that trade-off analyses between ES become possible in the future when energetic relationships are known. Therefore, our call to the scientific community is to improve exergy calculations in a way that includes energetic relationships.

At the same time, to keep our ecosystems alive. We need to understand exergy flow within our ecosystems and human systems. How our activities and technology affect the current metabolic networks, in biotic and abiotic cycles (that determine a living system's identity), whilst getting insight into the amount of entropy we produce, the exergy we use, the exergy we capture within our structures, and the amount of exergy we transport out of our system. So that we can change our activities so that we do not produce more entropy and at the same time do not consume and transport more exergy than the system can handle, whilst keeping a buffer for disturbances from outside of the system.

5

Conclusion and Discussion

This chapter will conclude this research by summarizing the key research findings in relation to the research aims and questions. And discuss the value and contribution of this thesis's outcomes to the ES research field whilst reviewing the limitations and proposing opportunities for future research.

This study aimed to revise the ES framework in such a way that it can enhance our life-support system and make it possible to build relationships between ES and human activities. We tried to achieve this in three phases.

Phase one explains the current framework's philosophy, highlighting its limitation and answering the following research question "*When within the history of the ES concept was there an alignment with the systemic view of life?*". All together confirmed that the current perspective, "nature for people," makes it impossible to enhance our life-support system in the long run. Because by separating human and non-human benefits and maximizing the specific ES beneficial to humans at the expense of ES beneficial to non-humans, we will disturb the dynamic balance of an ecosystem over time. This shows the need for a paradigm switch within ES theory.

In phase two, we introduced a new perspective with a foundational layer on how living systems maintain, sustain, and organize themselves. Finally, we answered the research question, "*In what ways can a living systems perspective be applied to an ecosystem?*" by applying the theory of dissipative structures and autopoiesis to an ecosystem, resulting in the following conclusions. First, the structure of an ecosystem is the organisational exergy (including biomass, genetic diversity, and the relationships of the genetically determined entities) which sustains the organization's pattern by defining the system's ability to receive and export entropy. Second, the organization pattern is the ecosystem's metabolic network, which includes all heat -and conservative transformations that maintain the system by producing the ecosystem's structure. Furthermore, last, working information makes it possible to organize an ecosystem whilst latent information in genes makes it possible for an ecosystem to re-organize when organisational exergy accumulates, an ineffable process for a system to stay alive, showing the complexity of biodiversity loss.

In the last phase, we answered the research question, "*Can we integrate the ES concept into the living systems perspective of Capra and Luigi?*" which we achieved by revising the ES framework through the lens of exergy. Our revised framework shows that supporting and regulating ES cannot be viewed in separation and should be merged into one category: ecological services. This directly leads to a paradigm that values ES beneficial to humans and non-humans equally.

If we combine all these phases and go back to the main research question, "*Can the ecosystem services concept be integrated into a systemic view that enhances our life-support system?*". ES, in the end, maintain, sustain and organize our ecosystem and urban environments. Understanding the mechanism behind ecosystem function can potentially improve ecosystem implementation and decision-making within policy and practice. However, the integration of ES is not enough to enhance our life-support system. We as a society also need to change our activities and technology, which are currently not included within our framework, and future research is needed to achieve this. Also, current exergy calculations are incomplete because they do not consider energetic relationships. Energetic relationships are still a gap within science, and need further research if we want to analyze trade-offs between ES. However, current exergy calculations do show the potential of the exergy concept and how it can be a bridge between the social and ecological dimensions.

Based on all the above, we can say that the contribution of this thesis within the research field of ES is the proposal of linking ES and human activities through exergy and simultaneously integrating a foundational layer that increases the understanding of how ecosystems function. Because just like Westman said, "*It can be expected that as public education on the value of nature's services increases, the estimate of nature's worth on the part of some will increase.*" - which is exactly what we achieved within this thesis by placing ES in the LS perspective.

Bibliography

Bejan, A. (2005). The constructal law of organization in nature: Tree-shaped flows and body size. *Journal of Experimental Biology*, *208*, 1677–1686. https://doi.org/10.1242/JEB.01487

Campbell, N., Cain, M., Minorsky, P., Reece, J., Urry, L., & Wasserman, S. (2018). *Biology : A global approach* (10th ed.). Pearson Education. https://www.worldcat.org/nl/title/989997353

Capra, F., & Luisi, P. (2014). *The systems view of life; a unifying vision* (1st ed.). Cambridge University Press.

Choi, Y. E., Song, K., Kim, M., & Lee, J. (2017). Transformation planning for resilientwildlife habitats in ecotourism systems. *Sustainability (Switzerland)*, *9*. https://doi.org/10.3390/SU9040487

CICES. (2018a). *Towards a common classification of ecosystems: Structure of cices*. https://cices.eu/cices-structure/

CICES. (2018b). *Towards a common classification of ecosystems: Supporting services and functions*. https://cices.eu/supporting-functions/

Costanza, R., D'Arge, R., Groot, R. D., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Belt, M. V. D. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*, 253–260. https://doi.org/10.1038/387253a0

Daily, G. C. (1997). *Nature's services: Societal dependence on natural ecosystems*. Island Press. http://cmbc.ucsd.edu/content/1/docs/Daily_1.pdf%20https://archive.org/details/naturesservicess0000unse

de Groot, R. S. (1987). Environmental functions as a unifying concept for ecology and economics. *The environmentalist*, *7*, 105–109.

de Visser, S., Thébault, E., & de Ruiter, P. C. (2013). Ecosystem engineers, keystone species. *Ecological Systems*, 59–68. https://doi.org/10.1007/978-1-4614-5755-8_4

Díaz, S., Demissew, S., Joly, C., Lonsdale, W. M., & Larigauderie, A. (2015). A rosetta stone for nature's benefits to people. *PLOS Biology*, *13*, 1–8. https://doi.org/10.1371/JOURNAL.PBIO.1002040

Ehrlich, P., & Ehrlich, A. (1981). Extinction: The causes and consequences of the disappearance of species. *eweb:35542*, 305.

Ehrlich, P. R., & Mooney, H. A. (1983). Extinction, substitution, and ecosystem services. *BioScience*, *33*, 248–254. https://doi.org/10.2307/1309037

Elsevier. (n.d.). https://www.sciencedirect.com/topics/psychology/systems-theory

Fleischaker, G. R. (1988). Autopoiesis: The status of its system logic. *Biosystems*, *22*, 37–49. https://doi.org/10.1016/0303-2647(88)90048-2

Flint, C. G., Kunze, I., Muhar, A., Yoshida, Y., & Penker, M. (2013). Exploring empirical typologies of human–nature relationships and linkages to the ecosystem services concept. *Landscape and Urban Planning*, *120*, 208–217. https://doi.org/10.1016/J.LANDURBPLAN.2013.09.002

Gunther, F., & Folke, C. (1993). Characteristics of nested living systems. *Journal of Biological Systems*, *01*, 257–274. https://doi.org/10.1142/S0218339093000173

Haines-Young, R., & Potschin, M. (2018a). Common international classification of ecosystem services (cices) v5.1 guidance on the application of the revised structure. www.cices.eu

Haines-Young, R., & Potschin, M. (2018b). Common international classification of ecosystem services (cices) v5.1 guidance on the application of the revised structure. www.cices.eu

Holt, J. E., & Schoorl, D. (1990). The application of open and closed systems theory to change in agricultural institutions. *Agricultural Systems*, *34*, 123–132. https://doi.org/10.1016/0308-521X(90)90042-O

ICSU. (1992). Biodiversity and global change: International research initiatives. *Economics of Biodiversity Loss*, *21*, 271–271. https://www.jstor.org/stable/4313938

Jørgensen, S. E., Patten, B. C., & Straškraba, M. (2000). Ecosystems emerging:: 4. growth. *Ecological Modelling*, *126*, 249–284. https://doi.org/10.1016/S0304-3800(00)00268-4

Jørgensen, S. E. (2010). Ecosystem services, sustainability and thermodynamic indicators. *Ecological Complexity*, *7*, 311–313. https://doi.org/10.1016/J.ECOCOM.2009.12.003

Kareiva, P., & Marvier, M. (2000). *Concepts and theories in ecology* (S. A. Levin, Ed.). https://doi.org/10.1016/B0-12-226865-2/00082-1

Kondepudi, D. K., Bari, B. D., & Dixon, J. A. (2020). Dissipative structures, organisms and evolution. *MDPI, entropy*, *22*, 1305. https://doi.org/10.3390/E22111305

Koskinen, K. U. (2013). Knowledge production in organizations: A processual autopoietic view. *Knowledge Production in Organizations: A Processual Autopoietic View*, *9783319001043*, 1–172. https://doi.org/10.1007/978-3-319-00104-3

Loft, L., Lux, A., & Jahn, T. (2016). A social-ecological perspective on ecosystem services. *Routledge Handbook of Ecosystem Services*, 88–98. https://doi.org/10.4324/9781315775302-8

Luisi, P. L. (2003). Autopoiesis: A review and a reappraisal. *Naturwissenschaften*, *90*, 49–59. https://doi.org/10.1007/S00114-002-0389-9/FIGURES/9

MA. (2003). Ecosystem and human well-being: A framework for assesment. *Island Press*, 1–245.

MA. (2005a). *Ecosystem and human well-being: A framework for assesment*. Island Press.

MA. (2005b). Ecosystems and human well-being: A framework for assessment summary. *Island Press*, 1–25.

MA. (2005c). *Ecosystems and human well-being: Current state and trends* (R. Hassan, R. Scholes, & N. Ash, Eds.; Vol. 1). Island Press.

Margulis, L. (2000). *What is life?* (1st ed.). University of California Press.

Maturana, H. (1981). *Autopoiesis: A theory of living organization* (M. Zeleny, Ed.).

Maturana, H. (2002). Autopoiesis, structural coupling and cognition: A history of these and other notions in the biology of cognition. *Cybernetics and Human Knowing*, *9*, 5–34.

McNaughton, B. (2020). https://sysdesc.info/Content/System/CPT_SysProps.htm

Naess, A., & Sessions, G. (1986). The basic principles of deep ecology. *The Trumpeter*, *3*. http://trumpeter.athabascau.ca/index.php/trumpet/article/view/579

Nielsen, S. N., Fath, B. D., Bastianoni, S., Marques, J. C., Müller, F., Patten, B. C., Ulanowicz, R. E., Jørgensen, S. E., & Tiezzi, E. (2020a). Ecosystems have complex dynamics—growth and development. *A New Ecology*, 111–137. https://doi.org/10.1016/B978-0-444-63757-4.00007-3

Nielsen, S. N., Fath, B. D., Bastianoni, S., Marques, J. C., Müller, F., Patten, B. C., Ulanowicz, R. E., Jørgensen, S. E., & Tiezzi, E. (2020b). Ecosystems have thermodynamic openness. *A New Ecology*, 7–25. https://doi.org/10.1016/B978-0-444-63757-4.00002-4

Nielsen, S. N., Müller, F., Marques, J. C., Bastianoni, S., & Jørgensen, S. E. (2020). Thermodynamics in ecology-an introductory review. *Entropy*, *22*, 820. https://doi.org/10.3390/e22080820

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*, 419–422. https://doi.org/10.1126/SCIENCE.1172133/SUPPL_FILE/OSTROM.SOM.PDF

Perrings, C., Folke, C., & Mäler, K.-G. (1992). The ecology and economics of biodiversity loss: The research agenda on jstor. *Economics of Biodiversity Loss*, *21*, 201–211. https://www.jstor.org/stable/4313929?seq=1#metadata_info_tab_contents

Potschin, M., & Haines-Young, R. (2011). Ecosystem services: Exploring a geographical perspective. *http://dx.doi.org/10.1177/0309133311423172*, *35*, 575–594. https://doi.org/10.1177/0309133311423172

Potschin, M., Haines-Young, R., Fish, R., & Turner, R. K. (2016). Ecosystem services in the twenty-first century. *Routledge Handbook of Ecosystem Services*, 1–10. https://doi.org/10.4324/9781315775302-1

Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., & Schleyer, C. (2018). Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. *Ecosystem Services*, *29*, 428–440. https://doi.org/10.1016/J.ECOSER.2017.05.015

Prigogine, I., & Lefever, R. (1973). Theory of dissipative structures. *Synergetics*, 124–135. https://doi.org/10.1007/978-3-663-01511-6_10

Roberts, N., Anderson, D. F., & Deal, R. M. (1983). *Introduction to computer simulation: The system dynamics approach*. Addison-Wesley.

Schulze, E.-D., & Mooney, H. A. (Eds.). (1994). *Biodiversity and ecosystem function*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-58001-7

Silow, E. A., Mokry, A. V., & Jørgensen, S. E. (2011). Eco-exergy use for ecosystem health assessment. *Thermodynamics for ecosystem state assessment*. https:

//www.researchgate.net/publication/301747462_Eco-Exergy_use_for_ecosystem_health_assessment

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*, 1–10. https://doi.org/10.1126/SCIENCE.1259855/SUPPL_FILE/STEFFEN-SM.PDF

TEEB. (2008). *Teeb interim report (2008) european-communities - the economics of ecosystems and biodiversity*. Branson Production. http://teebweb.org/publications/other/teeb-interim-report/

Westman, W. E. (1977). How much are nature's services worth? *Science*, *197*, 960–964. https://www.jstor.org/stable/1744285?seq=1#metadata_info_tab_contents

Young, O. R., & Steffen, W. (2009). The earth system: Sustaining planetary life-support systems. *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World*, 295–315. https://doi.org/10.1007/978-0-387-73033-2_14

Zari, M. P., & Hecht, K. (2020). Biomimicry for regenerative built environments: Mapping design strategies for producing ecosystem services. *Biomimetics 2020, Vol. 5, Page 18*, *5*, 18. https://doi.org/10.3390/BIOMIMETICS5020018

Zeleny, M. (2005). *Human systems management:integrating knowledge, management and systems*. World Scientific Publishing.