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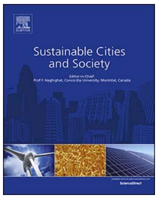

The circularity of the urban ecosystem material productivity: The transformation of biomass into technomass in Southern Patagonia

Luis Inostroza[a,b,*]

[a] *Institute of Geography, Ruhr-Universität Bochum, Germany*
[b] *Universidad Autónoma de Chile, Chile*

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ABSTRACT

Cities are vortex of the anthropogenic accumulated matter: technomass. The urban metabolism captures ecological stocks from other ecosystems to produce technomass in a complex process involving stocks and fluxes, energy and information. As such, the physical development of cities is entangled with the material productivity of other ecosystems, where ecological stocks are appropriated and finally accumulated in the urban tissue after several transformations. The appropriation and accumulation of stocks are essential for the reproduction of the urban material structure. The appropriation of ecological stocks from other ecosystems is an iterative process generating particular urbanisation patterns. This paper analyses the spatial evolution of livestock activity and rising urban development as a metabolic relationship between two ecosystems located in Southern Patagonia, Chile: the steppe ecosystem and the urban ecosystem of Punta Arenas. This relationship leaves behind deep footprints in the urban tissue, in the form of splendid architecture arising from ecosystems' appropriation. The architectural sedimentation found in the urban tissue of Punta Arenas is linked to the depletion of the steppe ecosystem's ecological stocks. The Patagonian pastureland and the bourgeois architecture of Punta Arenas are the initial and terminal phases of a complex process of appropriation; the beginning and the end of a metabolic chain where biomass is transformed into technomass. The stocks are ecological at the origin and become, through socio-economic transformation, material sedimentation.

1. Introduction

Metabolism is a powerful concept with a strong practical analytical value to understanding the co-evolution of socio-ecological assemblages as unitary systems (Foster, 2000). However, metabolism remains trapped by nature-society dichotomies and organic metaphors, not yet providing a wider understanding of specific emerging socio-ecologies (Foster, 2000; Golubiewski, 2012). To date, linear input-output assessments have not considered the fundamental role of other ecosystems in the urban metabolism (UM). Cities are conceived as independent and separate bodies existing in themselves, while other ecosystems are seen as external to human activity, as undefined sources of resources and depositories for waste following autonomous laws (Moore, 2015; Smith & O'Keefe, 1980). Standard UM studies stick to material fluxes in an orthodox approach, looking only to the linear path of particular materials entering the urban ecosystem (UE) (Golubiewski, 2012; Inostroza, 2014b). Such an approach lacks ecological and economic acknowledgement of metabolic fluxes. The necessary, meaningful integration between biophysical and economic fluxes can be achieved by interdisciplinary work from the natural to the social sciences (Braat & de Groot, 2012; Inostroza, König, Pickard, & Zhen, 2017).

Articulating the meanings and communities of metabolism and ecology can enhance the conceptualisation of urbanisation as a central issue for the future of human civilisation. The specific spatiotemporal ecologies of urbanisation are an entangled socio-ecological body (Foster, 2000), a historical, concrete, material reciprocal societal change within nature, mediated by labour through a context-specific metabolism (Glacken, 1973; Marx, 1967; Smith & O'Keefe, 1980). Understanding how urban systems function by entangling ecological processes across spatial scales, including distant teleconnections (Seto et al., 2012), can shed light on several crucial issues, such as ecological deterioration, climate change, resource depletion, and massive extinction, which are at the core articulated within, across and beyond urban systems.

Understanding that the entanglement between the UE and other ecosystems works as a unitary body is highly necessary, not only from a conceptual point of view but also for its high practical value (Foster,

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* Corresponding author at: Institute of Geography, Ruhr-Universität Bochum, Germany.
E-mail address: luis.inostroza@rub.de.

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2000; Moore, 2015; Smith & O'Keefe, 1980). Understanding the metabolic dynamics between ecosystems using the knowledge and background of ecology (Golubiewski, 2012) can be of great help to advance broader interdisciplinary exchanges between currently separated metabolic communities (Newell & Cousins, 2015; Wachsmuth, 2012).

This paper contributes to such conceptual discussion by outlining the entanglement of ecosystems as unitary bodies in which material productivity and fluxes are reciprocally determined. This approach integrates biophysical and economic fluxes within the UM as linked to the metabolism of other ecosystems, while understanding that urban functions are fundamentally determined at the economic level (Bairoch, 1991). The paper develops an analysis of two ecosystems located in Southern Patagonia, Chile – the steppe ecosystem and the UE of Punta Arenas – as an emergent dialectical socio-ecological body, i.e., a unitary body, analytically speaking, and, thus, arising as an indivisible unity (Moore, 2015) that evolves and changes reciprocally over time. The main objective is to conceptualise and analyse the stocks and the metabolic linkages between both ecosystems regarding appropriation and accumulation. This work focuses on understanding how the ecological stock produced in the ecosystem of the Patagonian steppes has been appropriated and accumulated in the form of urban tissue – i.e., bourgeois architecture – in the UE of Punta Arenas. Therefore, the text is structured in four parts. In the first part, the metabolism framework is presented, with an emphasis on its links to land exploitation, articulating such concepts using the socioecological background. This section aims to provide the theoretical basis for analysing the UE metabolism (UEM), with explicit links to spatiotemporal processes of land exploitation. In the second part, both ecosystems are introduced. In the third part, the system of material production and stock appropriation is analysed, including the main environmental and cumulative spatial effects taking place in both ecosystems. The fourth section discusses the main implications and concludes with the central argument.

2. Metabolism and ecosystems

2.1. The metabolism of the urban ecosystem

This paper builds on the concept of the ecosystem as an analytical tool to link existing metabolic studies that largely remain considered in isolation (Newell & Cousins, 2015; Wachsmuth, 2012), allowing transdisciplinary feedback against the background of ecology (Golubiewski, 2012). However, the concept of UE, normally used in Urban Ecology studies, is biased towards green components, biodiversity, green infrastructure and the such as (Francis & Chadwick, 2013). This approach does not explicitly include buildings, roads, and technical infrastructure, which are, indeed, the fundamental components of the urban material structure. Therefore, the concept of UE used throughout the text is broader and encompasses all material components, in the form of biomass and technomass, as fundamental interlinked elements of the built environment (Inostroza, 2014a; Spyra, Inostroza, Hamerla, & Bondaruk, 2018).

The analysis proposes a conceptualisation of the UEM as a process of production and reproduction of technomass. Stocks are a keystone for advancing the understanding of the UM (Inostroza, 2014a). Indeed, all thermodynamic fluxes, in the form of matter, energy and information, will be determined by the size and volume of the ecosystem's material structure (Inostroza, 2014a). At the same time, attention has not been paid to the metabolic path of specific materials, as is normally done in Industrial Ecology (see, for instance (Ayres & Ayres, 2002; Baccini & Brunner, 2012; Kennedy, Cuddihy, & Engel-Yan, 2007; Schiller, Gruhler, & Ortlepp, 2017). The analysis focuses on the metabolic transformations giving rise to particular urban stocks but whose origin can be found in different types of ecological stocks, therefore linking anthropogenic stocks with natural stocks (Chen & Graedel, 2015). Such metabolic transformation begins with the appropriation of ecological stocks localised in distant ecosystems, then transformed into energy and information to be re-materialised in a substantially different material structure. The UEM is a complex spatial-temporal process that extracts, moves and transforms an ecosystem's stocks to reproduce fundamental urban functions. In doing so, concrete material structures are accumulated in the form of urbanisation. To understand such transformations, it is necessary to leave behind 'the linear input-output approach of resource flow through the city' (Golubiewski, 2012) and recognise that metabolic chains alternatively switch between matter, energy, and information. It is through this transformation that urban development, in its physical sense, takes place, producing economic and ecological consequences, like ecological deterioration, economic development, etc., in other ecosystems.

2.2. The human modification of the ecosystem's metabolism

Society and economic activities are dynamic agents that act from within ecosystems as inner components, not exogenous shocks (Moore, 2015). Society manages ecosystems to increase their productivity, producing profound changes and side effects. Relevant ecosystems parameters, such as Net Primary Production (NPP), respiration, nutrient cycles, etc., are affected by different anthropogenic alterations (Pimentel & Pimentel, 1979). Indeed, ecosystem dynamics are driven by anthropogenic drivers (Zewdie, Csaplovics, & Inostroza, 2017). Management of ecosystems increases their social utility, keeping their metabolism in its early stages. For instance, agricultural and livestock ecosystems that replace the existing virgin ecosystems are intended to produce the greatest possible amount of usable biomass (Fischer-Kowalski, 1996, 1998), for which purpose they are not allowed to reach mature states, where the closing of ecological cycles might occur (Odum, 1969). All ecosystems produce a surplus, a part of the stock to be accumulated for further use in the future. In virgin ecosystems, so-called redundancy corresponds to stocks of biomass that are fundamental to the ecosystem's resilience in case of stress (Leopold, 1949). As noted by Leopold (1949), pioneering human settlements in virgin ecosystems profited from the rapid consumption of such ecological stocks.

All ecosystems tend to increase in complexity towards mature stages of ecological succession (Odum, 1969; Pimentel & Pimentel, 1979). The process can be seen as an arising pattern in the ecosystem's spatio-temporal organisation, leading to reciprocal changes between the environment and the communities (Rueda, 2002). This entangled interaction between different types of ecosystems produces particular land use patterns (Inostroza, Zasada, & König, 2016). The human modification and appropriation of ecosystems constitute an assemblage of entangled ecosystems along a spatiotemporal gradient of land transformation.

2.3. The UEM as a spatiotemporal land transformation process

Land is essential for the metabolism of UEs, not merely as the spatial support in which the economic interactions occur. Land in itself is a fundamental input that determines the initial economic base and its further growth. Together with flows of matter and energy, land is the third most important input for economic activities (Giljum, 2004). Land uses and economic activities are allocated along a spatiotemporal gradient that depicts particular metabolic intensities (Inostroza et al., 2016). As a result, a particular land use change pattern arises, determined by the availability of local resources and the feasibility of their extraction, processing, distribution, and consumption. This pattern, in turn, responds to (1) the land attributes, resources and their social value; and (2) the specific economic conditions that make the land attributes and resources more or less viable. The land use change pattern follows a spatiotemporal progression in which the best-located resources are used first. Only when such resources are depleted, or when demand increases, does exploitation advance to use other resources in worse locations (Ricardo, 1959). The growth of economic