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Short Communication

Stocks and flows of natural capital: Implications for Ecological Footprint

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ABSTRACT

Over the past decade, Ecological Footprint has become one of the most popular and widespread indicators for sustainability assessment and resource management. However, its popularity has been coupled, especially in recent years, by the emergence of critical views on the indicator's rationale, methodology and policy usefulness. Most of these criticisms commonly point to the inability of the Ecological Footprint to track the human-induced depletion of natural capital stocks as one of the main shortcomings of the methodology. Fully addressing this issue will require research efforts and, most likely, further methodological refinements. The aim of this paper is therefore to outline the basis of a new area of investigation in Ecological Footprint research, primarily aimed at implementing the distinction between the use of stocks and the use of flows in Ecological Footprint Accounting and debating its implications.

1. Natural capital and the Ecological Footprint: an introduction

There are many meanings to the term 'capital' depending on the subject being discussed and the pertinent adjective matched with it. Capital, in whatever form it is conceived, is generally referred to as a stock able to generate a flow, which in turn serves as an input for the production of something else (Ekins et al., 2003). In particular, the term *natural* capital concerns natural resources and the environment surrounding and supporting human life (De Groot, 1992; Hinterberger et al., 1997). It is usually defined as '*a stock that yields a flow of natural resources and/or ecological services*' (Costanza and Daly, 1992. See also: Hinterberger et al., 1997; Ekins et al., 2003; Farley and Daly, 2006).

Georgescu-Roegen was one of the first authors to introduce the stock-flow model into the bio-economic paradigm (Georgescu-Roegen, 1971), which was then used as the basis for the ecological economics' principles (Daly and Farley, 2004). Since then, the concept of natural capital has increasingly gained importance from an anthropocentric perspective in the field of ecological economics and sustainability (Jansson et al., 1994; Hinterberger et al., 1997; Ekins et al., 2003). It has also been used in assessing the vital role ecosystem services play in supporting societies and human well-being (MEA, 2005; TEEB, 2013; Costanza et al., 1997, 2014).

The paradigm of strong sustainability requires all kinds of capital (natural, human, labor, etc.) to be complementary among each other, and always to remain intact at the optimum level, as each capital's productivity depends on the availability of the others (Daly, 1990; Jansson et al., 1994). Although a certain degree of substitutability might exist at the local level among different kinds of capital – due to new technologies and financial investments (Markandya and Pedroso-Galinato, 2007) – natural resources are globally limited and biophysically constrained. As natural capital degradation takes place, loss of such capital becomes irreversible and resources turn out to be highly non-substitutable (Cleveland et al., 1996). This rationale is supported by the two sustainable development principles (necessary conditions), which according to Daly (1990) are stated as follows:

1. *harvest rates of [renewable resources] should equal [their] regeneration rates*
2. *waste emission rates should equal the natural assimilative capacities of the ecosystem into which the wastes are emitted*

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Natural capital is at the core of the Ecological Footprint accounting (Wackernagel and Rees, 1997; Wackernagel et al., 1999; Wackernagel et al., 2002; Monfreda et al., 2004). Consistent with Daly's two principles of sustainability, the Ecological Footprint methodology accounts for the supply and demand of the basic resource provisioning and regulatory ecosystem services humans require to support their lifestyles (Galli et al., 2016; Goldfinger et al., 2014; Bastianoni et al., 2013). According to Galli et al. (2014), it can be applied at scales from global to local and gives insight on the above by means of two indicators:

- Representing regeneration/assimilation, **biocapacity** tracks the ecological assets[1] actually available in countries, regions or at the global level and their capacity to produce renewable resources and ecological services.
- Representing harvest/emission, the **Ecological Footprint** measures the equivalent biologically productive land and sea area – the ecological assets – that might actually exist or not on the Earth surface and that a population requires to produce the renewable resources and ecological services it uses.

More precisely, the Ecological Footprint deals with ecosystem services to the extent that these services occupy mutually exclusive, biologically productive areas. Accordingly, resource availability, as well as level of consumption, are both converted into the corresponding required area of biological productive ecosystems. Biocapacity and Ecological Footprint are expressed in terms of hectares normalized to represent the world average productivity: global hectares (gha) (Galli et al., 2007; Borucke et al., 2013; Wackernagel, 2014). These ecological services – generated by the photosynthetic activity of plants – include provision of biomass-based resources such as food, fibers and raw materials (e.g., wood-fuels and plant oils), and regulation and maintenance of ecosystems through waste absorption, using prevailing technology and management practices. The current national and global application of Ecological Footprint accounting, the National Footprint Accounts (Global Footprint Network, 2016) limits the direct tracking of waste to CO_2. Thus climate regulation via sequestration and long term storage of carbon is the only regulating service tracked (Galli et al., 2014; Mancini et al., 2016).

According to the 2016 Edition of the National Footprint Accounts, humanity's Ecological Footprint initially surpassed the Earth's biocapacity in the early 70s, and recent results indicate 64% overconsumption in 2012 (Global Footprint Network, 2016). When global demand on natural resources and ecosystem services exceeds the capacity of ecological systems to regenerate, ecological overshoot occurs (Borucke et al., 2013; Galli, 2015; Lin et al., 2015a). In a world with physical boundaries and limited resources, overshoot cannot last indefinitely as it might lead to the break down of natural cycles, liquidation of stocks like forest and fish biomass and depletion of the bioproductive capacity of fertile lands (Niccolucci et al., 2009). In other words, a prolonged use of flows of resources at a rate faster than their regeneration rates is likely to cause the depletion of the stocks of natural capital yielding such resources. This topic represents one of the most challenging research frontiers in Footprint accounting, also referred to as 'fragility of biocapacity' (Wackernagel et al., 2014). Unfortunately, the Ecological Footprint methodology applied to national assessments is not currently able to quantify such depletion and cannot forecast the consequences of overconsumption on the sustainable biological productivity of ecological assets (Galli et al., 2016).

[1] The spatial areas with biotic and abiotic components functioning together, and whose processes and resources are essential for economic and other human activities. See section 2.

Initial attempts to combine a "stock vs. flow" perspective into the Ecological Footprint have been made by Niccolucci et al. (2009, 2011). Along with the annual appropriation of natural flows, representing the classical spatial component, the authors introduced a component of the Footprint, called Footprint depth, related to the depletion of natural stocks (Niccolucci et al., 2009, 2011). While such three-dimensional Footprint approach can provide a more actionable conceptualization of the global overshoot situation, it is still difficult to calculate. Developing the distinction between depletion of stocks and use of flows within the Ecological Footprint is of key importance to clarify the ecological system dynamics and better depict the current overuse of ecosystem services by human societies and the resulting overshoot. Furthermore, it would allow users to track a certain biophysical (rather than monetary) threshold beyond which our societies' use of the planet's ecosystem services is unsustainable. This threshold is represented by the specific point in which humans shift from using flows (as they are completely used up) to using stocks, thus undermining the long term capacity of these stocks to yield a continual flow of ecosystem services. The stock and flow model could thus provide an understanding of what overexploitation of a certain subset of ecosystem services could entail for the future of humanity and how long we can maintain current levels of consumption before bioproductivity will collapse.

As such, the aim of this paper is to first provide a comprehensive definition of natural capital's stocks and flows as well as a framework for understanding the dynamics between these two concepts. Consequently, the Ecological Footprint methodology is then described in light of the "stock vs. flow" perspective to clarify how these two concepts are currently implemented within the methodology and what it would take for their full implementation within the Footprint methodology. Accordingly, new and revised Ecological Footprint and Biocapacity definitions – consistent with the proposed stock vs. flow perspective – are here suggested and a research agenda set up to guide Footprint practitioners' future research efforts in quantifying the human resources consumption within a more tangible ecosystem services framework.

2. The natural capital and the stock vs. flow perspective

Natural capital is directly related to the concepts of stocks and flows of ecosystem services they produce (Costanza et al., 1997). Stocks refer to the elements of an ecosystem describing the state of the ecosystem itself at any particular time; conversely, flows are variables of the ecosystem measured over a period of time (Meadows, 1998). In analogy with the economic assets and balance sheet in financial accounting, as stocks are identified as natural capital, flows can be considered as the income of natural capital (Costanza and Daly, 1992; Wackernagel and Rees, 1997; Meadows, 1998; Wackernagel et al., 2014).

The stock and flow concepts are also at the core of the SEEA (UN et al., 2014), in which stocks are identified as ecosystem assets – the spatial areas with biotic and abiotic components functioning together – on which economic and other human activities take place using the processes and resources generated by those assets. These processes and resources are collectively referred to as flows of ecosystem services, which can be both inputs from the environment to the economy (i.e. forest timber, fishes or crops) and outputs of residues from human activity to the environment (i.e. wastes and emissions) (UN et al., 2014). In this view, stocks and flows have a strong spatial dynamic and a strong connection with the economic sphere. Therefore, the capacity of an ecosystem asset to generate ecosystem services is also function of its extent and condition (Lars et al., 2015).