

Essays and Perspectives

## Ecosystems as infrastructure

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### ABSTRACT

Infrastructure is usually defined as all elements of interrelated systems that provide goods and services essential to enabling, sustaining or enhancing societal living conditions. Although traditionally, infrastructure included only all human-made assets, since the 1980s, both scientists and conservationists have suggested that ecosystems should be also considered as a type of infrastructure. Here we review the evolution of the concepts of 'ecological', 'green', 'natural' and 'blue' infrastructures and evaluate how these concepts have been used in the scientific literature. We found that although the term 'ecological infrastructure' was the most used until 2004, 'green infrastructure' became the dominant one after then. All terms have been applied mostly to urban settings, terrestrial ecosystems and emphasised supporting and regulating ecosystem services, with a strong emphasis on the mediation of water flows in urban centres and the maintenance of species lifecycles, habitat and gene pool protection. We suggest that green infrastructure should be the term adopted to facilitate communication between scientists, conservationists and decision-makers. We also suggest a general concept for green infrastructure aligned with the major global conventions alongside a set of design principles.

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### Introduction

Human prosperity requires infrastructure, which is usually defined as all elements of interrelated systems that provide goods and services essential to enabling, sustaining or enhancing societal living conditions (Fulmer, 2009). Traditionally, infrastructure included only all human-made assets, including human capital, required by the social (e.g., educational, health, cultural and financial) and economic sectors (e.g., energy, water and sewage, transportation). These, as a whole, generate the benefits of welfare and distribute them to society. However, since the 1980s, both scientists and conservationists have suggested that ecosystems should be also considered as a type of infrastructure (Yu, 2012). The rationale for this proposal is that healthy ecosystems, in addition to maintain biodiversity, provide goods and services to humans, some of which are consumed directly, whereas others become valuable to society only after interacting with the human-made infrastructure (Daily, 1997; Collados and Duane, 1999; MA, 2005). Scientists and conservationists assumed that if society in general and policy-makers in particular recognise that protected natural ecosystems

are a type of infrastructure essential to human prosperity and security, just as man-made infrastructures are, then conservation could move up in the political agenda and more public investments would flow to set aside comprehensive and well-managed large-scale conservation systems.

Although the concept of ecosystems as infrastructure is well justified (Frischmann, 2012), there is no consensus on how to name and define this type of infrastructure. Over the last few decades, scientists and conservationists have combined the words "ecological", "natural", "green" and "blue" with the word "infrastructure" to describe the idea. In addition, several concepts have been proposed, most of which are exchangeable. Although the proliferation of different names and concepts to refer to the same idea is expected when the idea comes from people working under different academic traditions, dealing with different contexts and seeking different goals, it can also lead to misunderstandings and the fragmentation of the issue. What fragmentation does not, in turn, is help with mainstreaming the idea into a policy agenda.

### History of the concepts

The first term used to refer to ecosystems as infrastructure was 'ecological infrastructure'. It was proposed in 1984 by 59 scientists from 24 countries participating of one of the technical meetings

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of the Man and Biosphere Programme (MAP) about urban planning. Ecological infrastructure was considered as one of the five principles for guiding the planning of an ecological city, defined as one where “ecologically sustainable growth goes hand in hand with the humanization of the city” (UNESCO, 1984). During the 1990s, the term ecological infrastructure was used interchangeably with other terms, such as greenways, ecological networks, corridors, conservation corridors and multiple use modules, to represent landscape-level conservation planning (Ahern, 1995). More recently, ecological infrastructure has been defined as “the structural landscape network that is composed of the critical landscape elements and spatial patterns that are of strategic significance in preserving the integrity and identify of the natural and cultural landscapes and securing sustainable ecosystem services, protecting cultural heritages and recreational experiences” (Yu, 2012).

The term ‘green infrastructure’ was used for the first time in 2004 by the Florida Greenways Commission in a report to that state’s governor to emphasise that integrating the state’s conservation areas into an interconnected system that forms a green infrastructure is just as important for conservation and management as the built infrastructure (Florida Greenways Commission, 1994). Since then, green infrastructure has usually been broadly defined as “an interconnected network of natural areas and other spaces that conserves natural ecosystems’ values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife (Benedict and McMahon, 2006). Around 2007, the U.S. Environmental Protection Agency (EPA) used the term green infrastructure to refer to an integrated approach for managing wet weather impacts that also provides community benefits at the municipal level. In its description of green infrastructure, the EPA recognised two spatial scales. At the city or county scale, green infrastructure refers to “the patchwork of natural areas that provide habitat, flood protection, cleaner air and cleaner water”, whereas at the neighbourhood or site scale, green infrastructure refers to “stormwater management systems that mimic nature[,] soak up and store water” (US Environmental Protection Agency, 2016). Since then, several authors have used the concept of green infrastructure only in the context of urban planning (e.g. review in Sinnett et al., 2015). More recently, Matthews et al. (2015) restricted the concept of green infrastructure to urban areas, redefining it as “the biological resources in urban areas that are human-modified and primarily serve an overt ecological function’ and which are ‘intentionally designed and deployed primarily for widespread public use and benefit’. Although all attempts to restrict the use of green infrastructure to urban contexts, the European Union embraced the broad concept of green infrastructure, defining it as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, green infrastructure is present in rural and urban settings” (European Commission, 2013).

Natural infrastructure and blue infrastructure are the two most recently coined terms. ‘Natural infrastructure’ was first used to highlight the importance of wetlands in the management of freshwater systems (Sajaloli, 1996). More recently, ecological infrastructure has been defined in an urban context as “any piece of nature that provides important benefits to those in a city” (McDonald, 2015). ‘Blue infrastructure’ was first mentioned while describing the efforts of the city of São Paulo, Brazil, to create a network of “green and blue” infrastructure to reduce risks in floodplains and other flood-prone areas (Frischenbruder and Pellegrino, 2006). The term is used mostly to refer to the conservation and management of freshwater (including wetlands) and coastal-marine systems.

## Use of the concepts by the scientific community

To assess how the scientific community has used the concept of ecosystems as infrastructure, we analysed the contents of all publications listed in two databases (Web of Knowledge and Scopus) that mention at least one of the four terms: ecological infrastructure, green infrastructure, natural infrastructure, and blue infrastructure. After removing duplicates and other references that were not relevant or could not be accessed, we found 852 papers about green infrastructure, 122 referencing ecological infrastructure, 37 referring to natural infrastructure, and only 18 instances of blue infrastructure. These papers encompass the period from 1989 to 2015. Although the term ecological infrastructure was the most used until 2004, green infrastructure became the dominant one after then (Fig. 1). In 2015, for instance, 88.3% of the papers that referred to ecosystems as infrastructure used the term green infrastructure. All terms have been applied mostly to urban settings (Fig. 2). Most of the papers using green and ecological infrastructures were focused on terrestrial ecosystems, but a more integrated vision encompassing different types of ecosystems is the dominant one in regards to both natural and blue infrastructures (Fig. 3). Regardless of the name used, papers proposing ecosystems as infrastructure mostly emphasise supporting and regulating ecosystem services (Fig. 4), with a strong emphasis on the mediation of water flows in urban centres and the maintenance of species lifecycles, habitat and gene pool protection.

## Towards a unified concept

We think the concept of ecosystems as infrastructure is a powerful metaphor to integrate different political agendas (e.g., climate mitigation, climate adaptation, biodiversity conservation, sustainable production and consumption) at all spatial and governance scales and mainstream nature conservation into human development efforts worldwide. However, to foster broad political adoption and facilitate communication among scientists, conservationists and decision-makers, it is time to select one of the several names proposed so far and to define the concept and design principles as inclusively as possible.

We suggest using the term ‘green infrastructure’, rather than the others, because it is the dominant one in the scientific literature and because it has already been adopted in policies in the United States and Europe. In terms of formal concept, we think that the concept advanced by the European Union is the simplest one for use across sectors and disciplines, although it needs to be reframed to show the explicit inclusion of biodiversity conservation, the mitigation of greenhouse gases and adaptation to climate change as its major objectives (Sussams et al., 2015; Liqueste et al., 2015). This is necessary, despite recognising that there will be some redundancies, to avoid misunderstandings among policy-makers and to provide a better match with the goals of the UN Convention on Biological Diversity, the UN Framework Convention on Climate Change and the UN Sustainable Development Goals. Therefore, we suggest that green infrastructure is “a network of natural, semi-natural and restored areas designed and managed at different spatial scales (from local to global), that encompasses all major types of ecosystems (marine, terrestrial and freshwater), and that aims to conserve biodiversity, mitigate emissions of greenhouse gases, enable societal adaptation to climate change, and deliver a wide range of other ecosystem services”.

In terms of design principles, an effective green infrastructure at any spatial scale needs: (a) to be designed holistically with active societal participation (Freeman et al., 2015) and laid out strategically (Yu, 2012); (b) to be connected and managed in an integrated way (Ahern, 1995); (c) to be representative, persistent, efficient and flexible (Watson et al., 2011); (d) to be multi-functional and

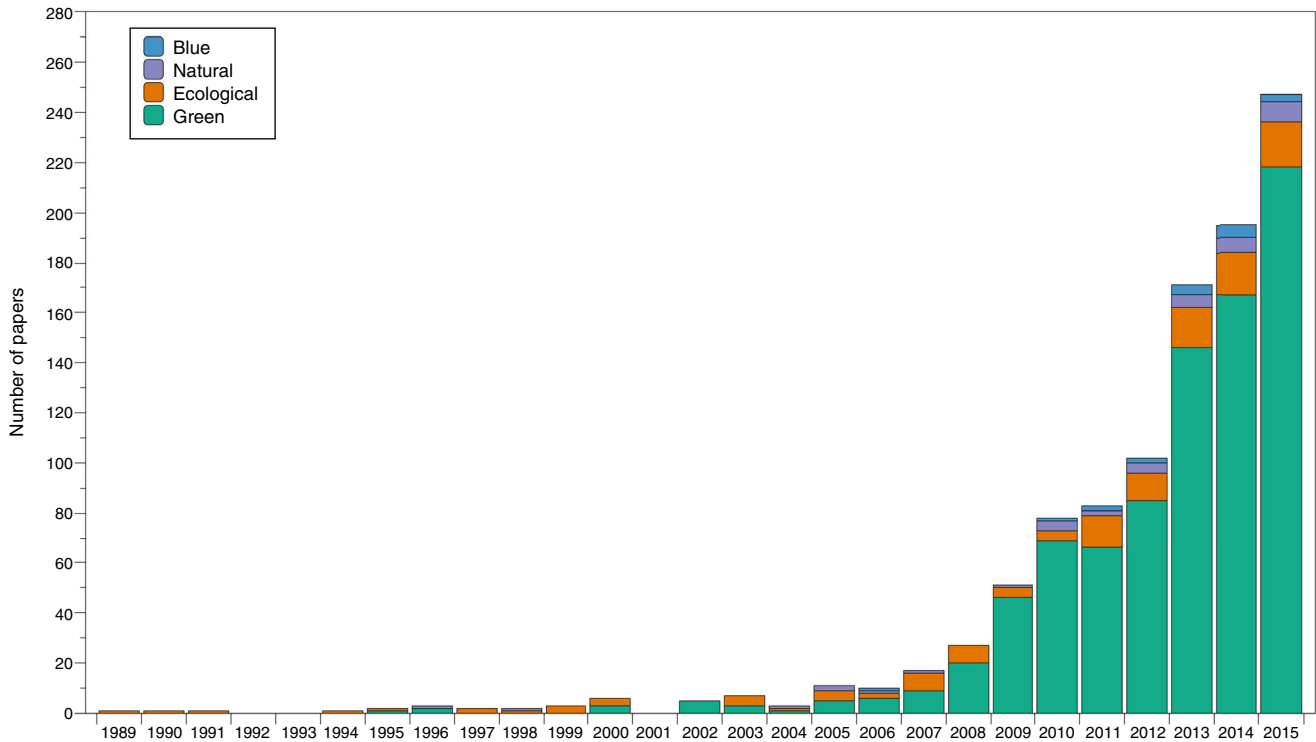


Fig. 1. Number of papers referring blue, natural, ecological and green infrastructures found in Web of Knowledge and Scopus databases.

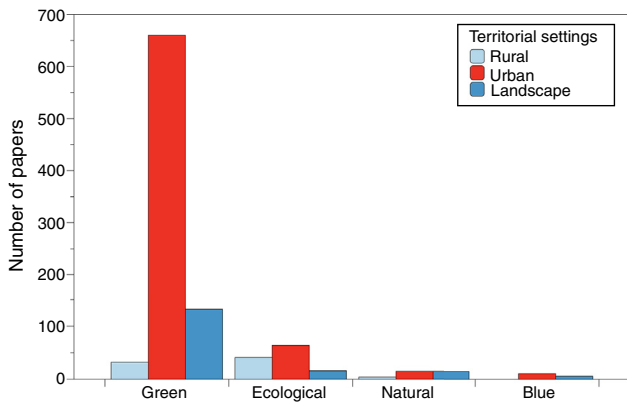


Fig. 2. Number of papers about blue, natural, ecological and green infrastructures classified according to the territorial settings: rural, urban and landscape (including both urban and rural).

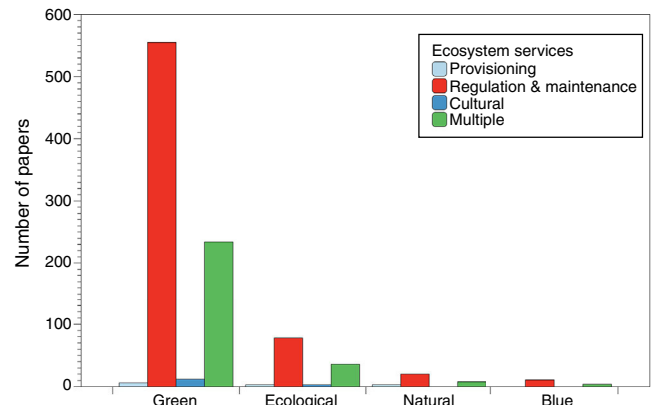


Fig. 4. Number of papers about blue, natural, ecological and green infrastructures classified according to major sections of ecosystem services: provisioning, regulation and maintenance, cultural and multiple (when two or more sections of ecosystem services were mentioned). Classification of ecosystem services according to the Common International Classification of Ecosystem Services ([www.cices.eu](http://www.cices.eu)).

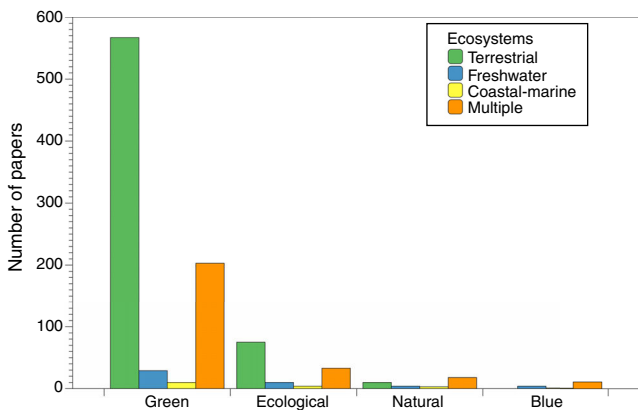


Fig. 3. Number of papers about blue, natural, ecological and green infrastructures classified according to major types of ecosystems: terrestrial, coastal-marine, freshwater (including wetlands), and multiple (when the paper refers to two or more major ecosystems).

resilient (Benedict and McMahon, 2006; Sayer et al., 2013); and (e) to be funded up front as a primary public investment (Yu, 2012; Frischmann, 2012). With the right name, concept and design principles, national societies can find the ways to build together the global green infrastructure that they need so badly to prosper and adapt to a changing climate.

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