



Urban impacts across realms: Making the case for inter-realm monitoring and management



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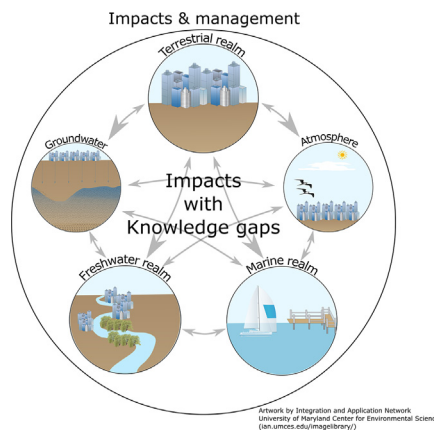
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HIGHLIGHTS

- The impacts of human activities in urbanised areas often transient realms.
- The flow of impacts between realms is multi-directional.
- Management is limited by jurisdictional boundaries and disciplinary traditions.
- A holistic view of urban ecosystems is essential for effective management.

GRAPHICAL ABSTRACT



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ABSTRACT

Burgeoning populations and the increasing concentration of humans in urban areas have resulted in extensive and increasing degradation and destruction of natural ecosystems. The multitude of impacts and their drivers in urban areas across realms are often studied at local scales, but there is regularly a mismatch between the spatial extent of the impacts and that of the pressures driving those impacts. For example, most human activities occur on land and therefore disturb terrestrial habitats (intrinsic impacts), but their impacts can also extend to the atmosphere and aquatic realms (extrinsic impacts). Management of urban impacts is often designed at local scales and aims to control local pressures, mostly overlooking pressures originating outside the 'managed'

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area. This is often due to jurisdictional barriers but can also result from the lack of knowledge and recognition among scientists and managers of larger scale pressures. With the aim to highlight the importance of ameliorating extrinsic impacts for holistic management of urban areas, this paper discusses the range and extent of extrinsic impacts produced by the most common pressures in urban environments. We discuss that the terrestrial realm is a 'net-donor' of impacts, as most human activities occur on land and the resulting impacts are transferred to aquatic and atmospheric realms. However, activities in aquatic realms can result in impacts on land. We conclude that, to achieve effective management strategies, greater collaboration is needed between scientists and managers focussing on different realms and regions and we present suggestions for approaches to achieve this.

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Panel 1. Definitions

The terms 'pressure' and 'impact' are commonly used throughout the ecological literature, but not always consistently, even within a single realm (Oesterwind et al., 2016). For this paper, we will be drawing upon the Driver-Pressure-State-Impact-Response (DPSIR) framework outlined by (Gabrielsen and Bosch, 2003; Oesterwind et al., 2016). Urbanisation is a *driver* or process that results in a series of *pressures* (e.g., waste water discharges, artificial surfaces, human behaviours) which act on and contribute to changes in the environments within and surrounding the modified area. *Impacts* are the ecological consequences of the change in environment resulting from a *pressure*. These impacts can be described ecologically at the level of individuals (e.g., changes in feeding behaviour, changes in longevity), populations (e.g., changes in genotypic or phenotypic frequencies, or breeding success rates) and communities (e.g. decreases in biomass, increases in primary productivity, shifts in functional trait distributions). If the magnitude of an impact is sufficient, it can elicit a *response*, such as a change in policy, or investment in actions that either aim to counter the impact (e.g., ex situ conservation actions) or work towards addressing the *pressure* responsible for the *impact* (e.g., investing in upgrading lighting fixtures and light sources to reduce the impact of artificial light at night). We focus here on the *pressures* and *impacts*, and briefly touch upon the opportunity for more coordinated *responses* at the end of our paper.

1. Introduction

The ecological impacts of urbanisation are extreme and often irreversible, including habitat loss and degradation through pollution, direct modifications (construction) and introductions of non-indigenous species, resulting in ecological change and biotic homogenisation (Walsh et al., 2005; Bulleri, 2006; Lee et al., 2006; Grimm et al., 2008). Even though urban areas at present occupy approximately 1% of the global land area, they are expected to double or triple in size by 2030 (Seto et al., 2011). Most settlements are typically connected to waterbodies by stormwater drainage networks (Walsh et al., 2016b) and many are dependent on groundwater (Morris et al., 2003). Therefore, urbanisation not only affects the terrestrial and atmospheric realms, but also the freshwater, marine and groundwater realms. When examining the impacts of urbanisation, it is useful to distinguish two main categories of pressure-impact interactions: (i) pressures that arise within a realm, where the impact is also largely constrained to that realm (*Intrinsic*); and (ii) pressures that arise in one realm, but which produce impacts in a different realm (*Extrinsic*).

The recognition of the existence of extrinsic impacts in stormwater management has contributed to a rapid expansion of new integrated

approaches that aim to maximize co-benefits for human populations, urban environments and their receiving waters (Fletcher et al., 2015). These approaches include interventions across realms, such as the reduction in impervious areas and protection and enhancement of natural streams and rivers (Fletcher et al., 2015), and provide excellent examples of how to design successful and holistic interventions that consider the connections between realms. Nevertheless, these new approaches have not been applied at scales to achieve their full potential for ecosystem protection (but see Dai et al., 2017), or on other types of extrinsic impacts, such as light and sound pollution and the introduction of pathogens (e.g. Hu et al., 2010; Parris, 2013; Bolton et al., 2017), among others. There are still untapped opportunities for improvement when it comes to recognising the significance and scale of this phenomenon.

In an effort to highlight the relevance and extent of inter-realm impacts, this paper (i) highlights extrinsic impacts derived from pressures originating in the different realms, their direction and type, (ii) considers the issues arising from a failure to consider impacts across realms, and (iii) outlines avenues to achieve a more holistic understanding of urban impacts across realms in urban areas. For the purpose of this discourse, we define 'realm' as a group of ecosystems that share common physical and ecological attributes and therefore tend to be studied or managed together. The 'marine' realm includes all ecosystems present below the high tide mark, including brackish water habitats in estuaries and deltas. The 'freshwater' realm expands from tidal rivers to riparian forests and floodplains, non-riverine wetlands and lakes. Finally, the 'terrestrial' realm includes land-based ecosystems that are only wetted by rain and coastal splash. In making these distinctions we acknowledge that they are conceptual rather than real boundaries, but they provide a simplification to facilitate the general discussion that follows. We also include the realms of atmosphere and groundwater, which may be impacted by extrinsic pressures and also serve as important conduits of pressures between the terrestrial, marine and freshwater realms. While our focus here is on the first three, we have considered the groundwater and atmospheric realms where possible. The extrinsic pressures in the atmosphere and groundwater are extensively documented for some pressures (such as chemical and thermal pollution), but detailed discussion and integration of these realms within this review are limited by the paucity of information on the inherent ecological impacts.

2. Impacts deriving from pressures across realms

This work is the result of discussions held during a workshop attended by a group of 25 experts of each realm in December 2017 in Sydney, Australia. The group identified 11 common pressures (see definition in Panel 1) that connect realms associated with urban areas (Fig. 1). These pressures are not acting independently but are highly interconnected and often the result of the same human activities. They all cause a variety of intrinsic (within-realm) and extrinsic (cross-realm) impacts (see definition in Panel 1), but we have focused our discussion here on the extrinsic impacts produced by each pressure, as the impacts within (intrinsic to) a single realm are generally well recognized and

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