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A Comparative Overview of the Transversal Connectivity of Natural Landscape Mosaics to Freshwaters in the Metropolitan Areas of Berlin, London, & Paris

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Abstract: Connectivity among blue-green infrastructure (BGI) is a vital condition for enhanced ecosystem services provision in metropolitan regions where the social-ecological systems are interwoven. In this study, we conduct a comparative spatial assessment of transversal connectivity of natural surfaces to freshwater sources for the metropolitan areas of Berlin, London, and Paris. We focus on the transversal connectivity, which describes the lateral connection between natural surfaces and water surfaces, as opposed to connections along a water surface geometry. Initially, we compare the distribution ratios of water surfaces, natural lands, and transportation network at both the metropolitan and the urban level, relying on the Urban Atlas (UA) land-use and land-cover data. Our results show that at metropolitan level, Berlin has higher shares of water and natural surfaces (2.6 % and 40.1%) compared to London (1.32 % and 13.4 %) and Paris (0.9 % and 23.1 %). On the contrary, the transportation network covers less surfaces in Berlin (2.00 %) than in London (4.71 %) and Paris (3.62 %). Second, we investigate the connectivity among BGI elements, and most importantly, to the water surfaces. We considered the water surfaces as pivot elements in the landscape, while investigating the connectivity of natural areas to them. As part of the methodology, the transportation network is introduced in the analysis as the main fragmenting geometry. Our results show that in all three cases, more than 80 % of natural surfaces patches had no connection to freshwaters. Among them, the natural surface patches of Berlin record the highest level of transversal connectivity to freshwaters (17 %) On the other hand, London leads the ranking on the water surfaces that are not connected to any natural surface (>60 %). Transversal connectivity can be greatly increased with minor adjustments in spatial planning. For example, in Berlin the percentage of natural surfaces connected to freshwater jumps from 18% to 53%, if we assume that natural areas that are no more than 32 m apart can be connected in a network. This so-called potential transversal connectivity reveals areas where the connectivity among BGI is improvable and can enhance the capacities for nature-based solutions against emerging metropolitan challenges.

Keywords: Nature-based solution, aquatic systems, urban green infrastructure, sustainable development goals, ecosystem services

1 Introduction

Water sources are among the most endangered components within urbanized lands. More and more, the urban agglomerations are becoming dependent on freshwater sources (LUNDQVIST et al. 2005). However, the complexity of the metropolitan zone regarding the water management has not been considered enough by the existing literature (VAN DEN BRANDELER et al. 2019). Blue-green infrastructure (BGI) is advocated to be an efficient conceptual tool for sustainable urban water management (HAMEL & TAN 2022). Apart from storm water management (sustainable urban drainage systems), it includes greenways and ecological networks which are important for biodiversity. For example, small green areas

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such as private gardens, have significant impact on the urban biodiversity especially for specific specialized species such as insects (e. g. butterflies) in Prague (KADLEC et al. 2008) and bats (pipistrelle) as reported in the case of Paris (MIMET et al. 2020). However, a well-connected BGI system is vital for a well-functioning urban ecosystem. Landscape Fragmentation (LF) is an adverse phenomenon happening in continental lands mostly due to land-use alteration. Settlement development, alteration of forested lands to agricultural use (FAHRIG 2001) and transportation infrastructure expansions (GENELETTI 2004) are the major human activities causing fragmented landscapes. Landscape connectivity is targeted as an important part of decision and policymaking practices such as transportation and regional planning in Europe (EEA 2011) or the City Biodiversity Index (CBI) in Asia (CHAN et al. 2014).

Herein, we provide a rapid and simple method to assess the existing transversally connected BGI using the three different European metropolitan areas of Berlin, London, and Paris as study cases. We utilized the Urban Atlas database enabled by the European Commission via the Copernicus program. The workflow of the study was modelled in the open-source software QGIS- Model Designer. We intentionally relied on open-source data and software for both promoting *open science* and making the reproducibility of the method easier. We expect that the selected metropolitan areas contain relatively high amounts of green surface areas. However, we hypothesize that their inter-connectivity and specifically connectivity to freshwater surfaces is relatively low. Since the mere existence of BGI elements is not enough, unless they are well inter-connected, we also push forward this study as a call for future studies to search for ways of improving the interconnection of BGI.

2 Materials and Methods

2.1 Study Area

This study is based on a comparison between the metropolitan areas of Berlin, London, and Paris (see Fig. 1). All three cases are among the largest metropolitan areas in Europe. Furthermore, they are pioneers in developing management plans for improving the green and blue layer of their metropolitan zones. For example, Berlin is shortlisted among the five forerunner cities in implementing green infrastructure for sustainable urban water management (LIU & JENSEN 2018). On the other hand, teams of diverse professionals have collaborated to put forward general guidelines for Paris urban area's evolution by 2030. The enhancement of the surface water systems is highlighted as a core objective (MASSON et al. 2013). Similarly, London makes home for a vast number of parks and gardens which are well known as the 'green lungs of London' providing space for escape from high levels of pollution and recreation. The phrase 'Lungs of London' was used for the first time by William Pitt, during parliamentary debate as early as the beginning of the 19^{th} century while discussing about the urban encroachment on Hyde Park (JONES 2018). We intentionally did this selection to show that high levels of development and abundance of green surfaces are not a guarantee of well-connected and effective metropolitan BGI.

The raw material of this study is the Urban Atlas (UA) land cover data as provided via European Environment Agency (EEA). UA data consist of high-resolution land use and land cover (LULC) data for 36 EEA member and cooperating countries. The LULC classification consists of 17 urban and 10 rural categories having a minimum mapping unit (MMU) of 0.25 ha and 1 ha, respectively. First, the water surfaces including the wetlands are highlighted as the focal surfaces. A second set consists of the natural surfaces, including green urban areas, forests, and herbaceous vegetation. The artificial surfaces are disregarded and have been filtered out during the processing workflow. Indirectly, they silently remain as landscape fragmentation geometries within the metropolitan urban fabric. While the transportation geometries are considered as core fragmentation agents.

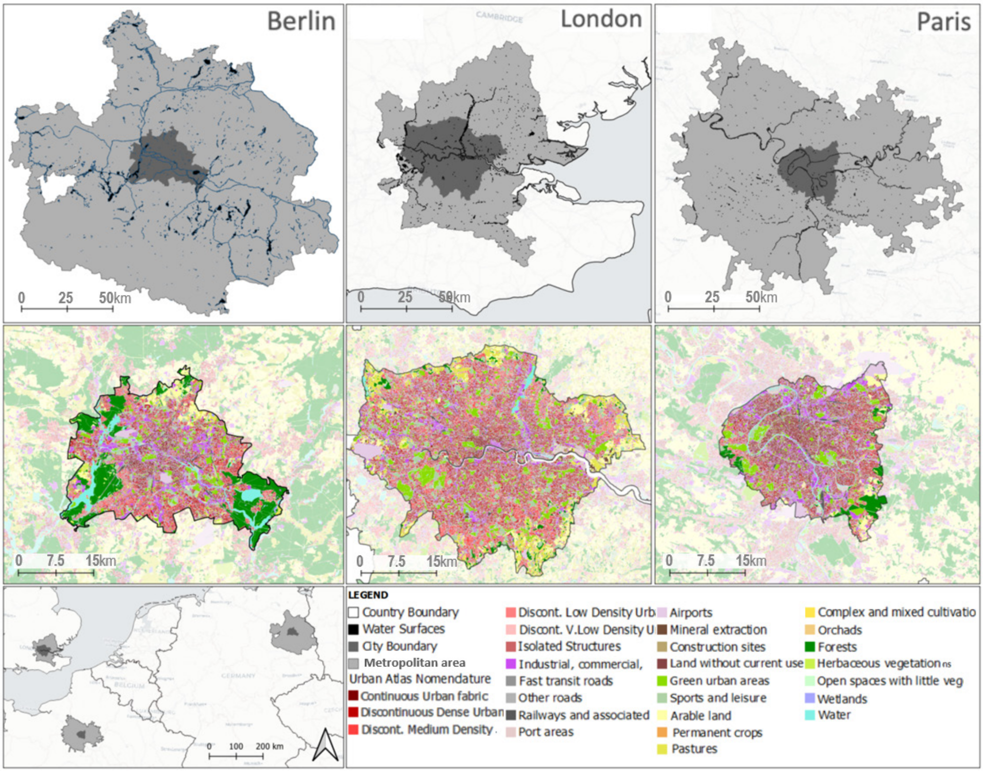

Fig. 1: Study areas of Berlin, London and Paris and their respective UA (2018)

2.2 Water-oriented Transversally Connected Natural Landscape Mosaics

This study follows the conceptual approach developed by HYSA & BAŞKAYA (2018a), which generates consecutive *bands* (patch order) of landscape patches within the coastal zone, based on their spatial relationship with the coastline. Initially, the concept has been developed into an automated model in ModelBuilder (ArcGIS) for the coastal zone (HYSA & BAŞKAYA 2018b). Further on, the model is adjusted for the metropolitan level connectivity analysis to identify the transversally connected natural landscape mosaics (TCNLM) (HYSA 2021). This study considers the freshwater surfaces as focal elements, to which the transversal connectivity of natural surfaces is investigated. Here the workflow is modelled in the open-source software QGIS, contributing to *open science* and to enable reproducibility for other metropolitan study areas where the land cover data are available. Another important parameter is the *patch order* (PO). It refers to the connectivity order of a landscape patch to water geometry. Patches that are located at the waterfront are assigned a PO value of 1. Patches that are connected to PO 1 patches are assigned a PO value of 2, and so on. PO values can continue infinitely by indicating the connectivity order a patch has with the water surface (Fig. 2b).

Figure 2 shows how the potential TCNLM are derived. Transportation network is accepted the main fragmenting agent in metropolitan areas (Fig. 2a). First, if we assume that patches less than 4m (approximately a single lane road) apart are connected, connectivity greatly increases, and we obtain a network of natural landscape patches of different PO values (Fig. 2b) and the potential TCNLM for this fragmentation distance (Fig. 2c). Technically, this process is implemented by buffering the original patches with half the fragmentation distance and identifying overlapping polygons. Further details about the procedure are provided in the study introducing the *Transversal Connectivity Index* (HYSA 2021).

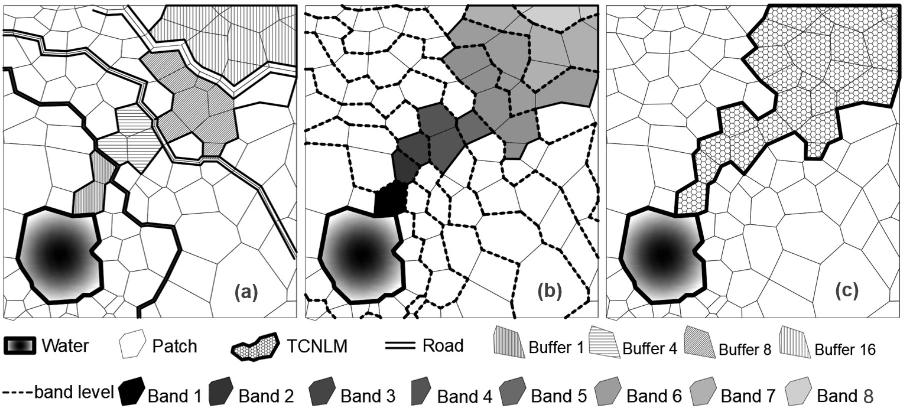

Fig. 2: Fragmented natural landscape patches (a) of different PO value (b) and the potential TCNLM (c) (after HYSA 2021)

3 Results

3.1 Comparative Highlights about LULC Inventory Based on UA Data

The comparison of three cases based on UA data (2018) shows that the metropolitan and urban surface area of Berlin and Paris are similar. While the metropolitan area of London is about half of them, its urban core is double the size of the two other cases (see Fig. 1). According to Figure 3, Berlin is leading the ranking of water surface areas both in metropolitan and urban level, being 3 to 5 times higher than in the other two cities. A similar trend appears when considering the natural surfaces at metropolitan level. Regarding the surface area of roads and associated lands, Paris is leading with a small difference. Furthermore, Figure 3c and 3d deliver interesting ratios of natural lands surfaces per inhabitant. Berlin scores almost ten times higher than London and Paris at metropolitan level (see Fig. 3d). While at urban level, Berlin marks twice higher than London, and four times higher than Paris (see Fig. 3c).

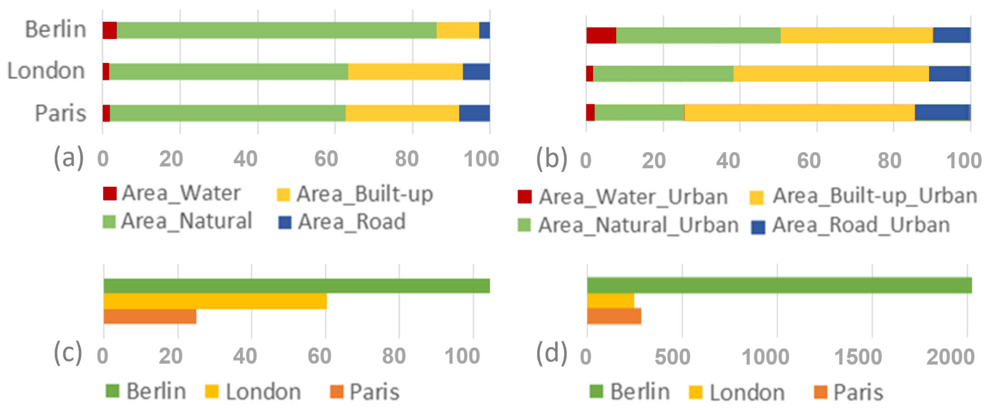

Fig. 3: Comparison of Berlin, London and Paris in terms of percentage distribution of water, built-up, natural, and transportation surfaces in (a) metropolitan & (b) urban scale, and the green surfaces per capita at both (c) metropolitan & (d) urban scale

3.2 Revealing the Water-oriented TCNLM within the Metropolitan Regions

According to the results of the TCNLM analysis at metropolitan level, only 37.9 % of water surfaces in London are connected to natural lands (Fig. 4a). While the water surfaces within metropolitan areas of Berlin and Paris are at least two times more connected then the case of London. Furthermore, only 38 % of natural surfaces of Berlin, 21 % of Paris, and 14 % of London, are connected to freshwater surfaces (Fig. 4b). On the other hand, when calculating by counts of natural surface patches, the connectivity percentages drop to as low as 15.5 %, 7.9 % and 6.0 % for Berlin, Paris, and London respectively. Nevertheless, the potential improvement is recognizable after the applied buffers. Figure 4b shows that after applying the buffer of 32m, the transversal connectivity of natural landscapes to freshwaters increase to 88 % in Berlin, 63 % in Paris, and 35 % in London. This fact implies that the natural land surfaces at metropolitan level have the capacity to be better connected to available freshwater surfaces.

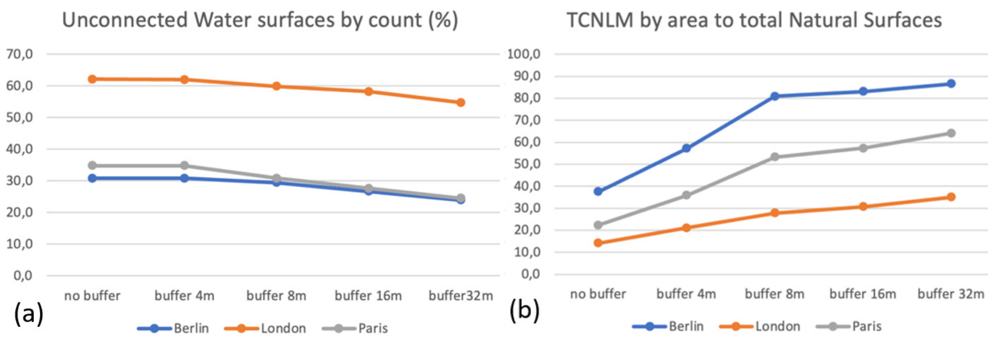

Fig. 4: (a) % of freshwater landscape patches that are not connected to natural areas, and (b) % of natural area patches that are connected to freshwater surfaces

Figure 5a presents the distribution of natural landscape patches within the identified TCNLM at five buffer levels (buffer of 0 m, 4 m, 8 m, 16 m, and 32 m). At the first level of no buffer, in Berlin there are 2551(12.7 %) natural patches that currently have direct connection with freshwaters (PO 1), followed by Paris with 1265 (7.5 %) and London with 721 (5.7 %) patches. The higher connectivity of Berlin's BGI compared to London and Paris is shown by spatial distribution patterns as well (Fig. 6). In all three cases, there is an abrupt drop in the number of connected patches of second band (PO 2).

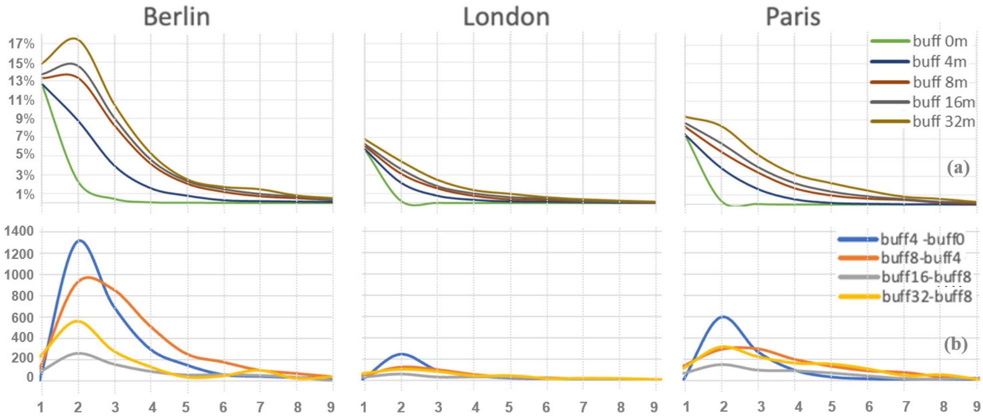

Fig. 5: Distribution of patches (count percentages) within the TCNLM by applied *buffer* distances for the metropolitan area of Berlin, London, and Paris (a) and the difference of patch count between consecutive *buffer* distances (b)

Nevertheless, after applying the buffering procedure of potential connectivity, there is a significant increase in the number of connected patches of second band (PO 2). Furthermore, in all three cases, the patches of second band (PO 2) show the highest increase after each buffer distance application, compared to the other bands (Fig. 5b). Thus, we conclude that further efforts must be put on analysing further in detail the potential patches of second band (PO 2), and especially those that are fragmented by narrow roads of up to 8m width.

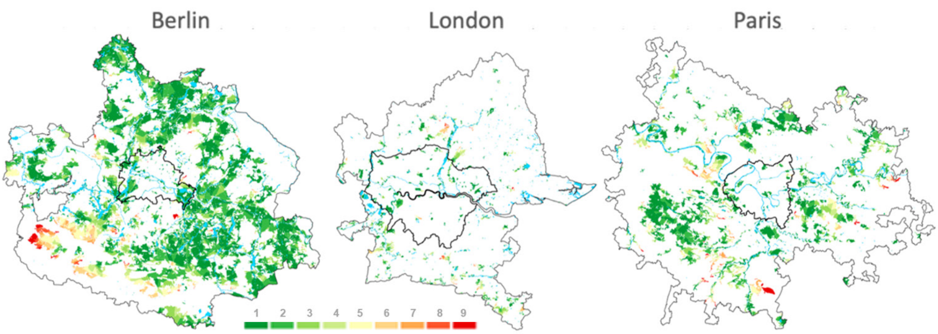

Fig. 6: The spatial distribution of TCNLM by *band* level at *buffer* distance of 32 m, for metropolitan area of Berlin, London, and Paris

4 Discussion on Implications and Limitations

An important implication of the method presented in this paper relates to the concept of "sponge cities", which is accepted as a revolutionary concept to simultaneously deal with diverse metropolitan challenges such as water cycle management, social-ecological benefits, and addressing climate change consequences. Recent literature proposes the need for further research in comprehensive computer-based models to support the implementation of the sponge city concept (NGUYEN et al. 2019). In particular, this relates to quantitative availability of measures supporting sponge cities, while the qualitative aspects are underestimated. This research work contributes to the discussion of sponge cities by providing an explicit method for long-term monitoring of connectivity among BGI at the metropolitan scale.

Our method is not aiming a new landscape metric, but instead targets at providing a novel approach to BGI analysis by focusing on the water surfaces. While it results useful for identification of the freshwater-oriented TCNLM, the structural and functional diversity of TCNLM requires further analyses. Consequently, next studies should expand the integration of various landscape metrics that targets not only the structural but also the functional properties of diverse habitats. Also, future research can focus specifically on roads that significantly fragment water-oriented BGI, e. g. to inform feasibility studies about road alterations to reduce landscape fragmentation and enhance connectivity among metropolitan BGI. A challenging discussion will be on how much of this connectivity is needed (ratio thresholds), to effectively orient the stakeholders in decision making processes. As we are not yet sure if all natural surfaces within metropolitan areas should necessarily be connected to freshwater surfaces and vice versa.

5 Conclusions

This study reveals pronounced differences in the TCNLM to freshwater surfaces among the three metropolitan areas of Berlin, London, and Paris. Based on the UA data from 2018, it highlights that only 15.5 % of natural landscape patches within the metropolitan area of Berlin are connected to freshwaters, with even lower levels of only 7.9 % and 6.0 % for Paris and London, respectively. Similarly, a significant portion of water surfaces remain unconnected to any metropolitan natural surfaces. Yet, our potential connectivity analysis shows that if proper interventions are made, the transversal connectivity of natural landscapes to freshwaters can be improved. For example, through scenarios of altering the fragmenting sections of the road network, the percentages of TCNLM to freshwaters rise to 86.5 %, 64.1 %, and 35.0 % for Berlin, Paris, and London. The current transversal connectivity of natural landscapes to freshwaters in the selected three metropolitan areas is not satisfactory, particularly in light of climate change and emerging challenges for large urban areas. Yet, we revealed that if proper spatial planning and management measures are taken by the responsive metropolitan administrative units, the situation could be improved significantly.

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