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A Global Inventory of Urban Corridors Based on Perceptions and Night-Time Light Imagery

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Abstract: The massive growth of some urban areas has led to new constellations of urban forms. New concepts describing large urban areas have been introduced but are not always defined and mapped sufficiently and consistently. This article describes *urban corridors* as an example of such a concept with an ambiguous spatial definition. Based on the existing usage of the concept in scientific literature and the results of a questionnaire, we attempt to spatially parameterize and identify the main characteristics of urban corridors on a global scale. The parameters we use are physically measurable and therefore serve as a basis for a harmonized and scientifically sound mapping of urban corridors using remote sensing data and methods. Our results are presented in a global urban corridor map.

Keywords: urban corridors; large urban areas; urban mapping; global urban mapping; remote sensing; night-time lights; urban area mapping; OpenStreetMap

1. Introduction

Cities imply changes. Such changes occur on different scales and levels, mostly based on an increasing urban population and bringing about changes in urban areas worldwide—not just in numbers, but also in size, shape and type. Consequently, the land surface area taken up by urban space is also increasing. Many cities have morphed into large urban areas with an unknown population size and unclear boundaries. These new constellations, with their massive extents and complex patterns, can sometimes not be adequately described with classic terms and methods. Thus, new concepts are needed (and have been introduced) to distinguish and conceptualize them—for example, metacity, mega-region or urban corridor (e.g., [1–3]). Some of these terms, however, have not yet been properly defined and furthermore show considerable overlap across concepts [4]. Global comparisons regarding the evolving spatial patterns between them are almost impossible due to different data sources, methods and interpretations [5]—the task of mapping urban areas globally with a consistent classification in certain types such as mega-region or urban corridor (among others) proves to be a challenge, especially due to inconsistent, imprecise or ambiguous definitions.

While we acknowledge that there are complex interrelations on a functional level within and between cities, these connections cannot easily be described. Data to interpret these interrelations include population, social, statistical, cultural or economic data—information that is generally not available reliably on a worldwide scale, hampering global comparisons. Remote sensing data, however, are now available globally and consistently in an adequate resolution: these data, thus, lend themselves to a physical identification and description of large urban areas. Most of today's global land cover and urban extent maps are based on satellite images with a resolution of 100 to 1000 m [6–11], which is sufficient for our analysis in this paper. While recent initiatives such as the German Aerospace Institute (DLR)'s Global Urban Footprint [12] or the European Commission/Joint Research Centre (JRC)'s Global Human Settlement Layer [13] contain significantly higher resolutions (up to 12 m), they are not yet available on global scale. Studies have shown their potential for analyzing development of settlements [13–16] or spatially characterize new urban concepts such as mega-regions (e.g., [17,18]).

The focus of this paper is on global-scale *urban corridors*, generally described as a number of large, linear urban areas linked through a well-developed transport network (e.g., [19–21]). The term has been applied to quite some extent in scientific literature but we believe a proper definition is still missing. Although smaller axes, such as intra-urban major roads, can also be regarded as corridors, our focus is on the global scale, with dimensions frequently exceeding 1000 km in length. There is an abundance of concepts describing larger urban areas which often show considerable—spatial—overlap [4], such as mega-region [17,22–24], urban agglomeration [23] or megapolitan [3,25]. None of these, however, sufficiently describe the specific spatial pattern of urban corridors.

Urban corridors are of interest for a variety of disciplines including politics, economy, social science, urban geography, urban planning and administration since they are cohesive regions extending beyond administrative boundaries. In contrast to phenomena such as megacities and mega-regions which have been well researched (e.g., [4,15,18,22,23]), not many studies on urban corridors exist. The concept and understanding of the term is complex and a universal acceptance of indicators for a classification and delimitation is not given. This serves as an example to underline the different perceptions and insufficient definition of a relatively unexplored conceptual approach. A number of qualitative case studies exist but there are no systematic, transferable approaches to capture, quantify, characterize and delineate urban corridors on a global scale. The United Nations Human Settlements Programme (UN-Habitat) [26] provide the first comprehensive map of urban corridors, mega-regions and city-regions but do not specify their methodology. This map is furthermore not based on a clear definition of the term and shows inconsistencies in the interpretation of different types of large urban areas. We seek to update this map using a classification method that is applied globally to a consistent dataset.

The question is whether the concept warrants a term of its own or whether existing terms fully encompass its properties: are corridors just another type of mega-region? Are they the mega-regions of the future? In this study, we aim to provide a common understanding of urban corridors through a globally consistent method for their delineation.

2. Conceptual Framework

To answer our questions, we use a three-stage approach consisting of a literature review, a questionnaire and an analysis using geographic information science (GIS) methods (Figure 1). In our literature review, we explore existing definitions and give an overview of presumed urban corridors worldwide. The questionnaire examines their perception on a global scale and complements the initial list. We then examine the identified corridors spatially using night-time light imagery and road network data. Our main focus is on the question: Which spatial pattern characteristics define an urban corridor? Our aim, therefore, is to analyze the evolving spatial patterns of possible urban corridors. We understand these spatial patterns to be the result of a complex interweaving of economic, political and socio-demographic developments. The result is a global map of all potential urban corridors identified through our approach and our own basic definition of the concept. This will contribute towards overcoming the lack of robust comparisons of urban areas worldwide observed by the Organisation for Economic Co-operation and Development (OECD) [24]. We further describe some limitations of our method but we strongly believe that this method serves as a first step towards a globally consistent delimitation of a less-researched concept describing large urban areas. The following figure illustrates this framework:

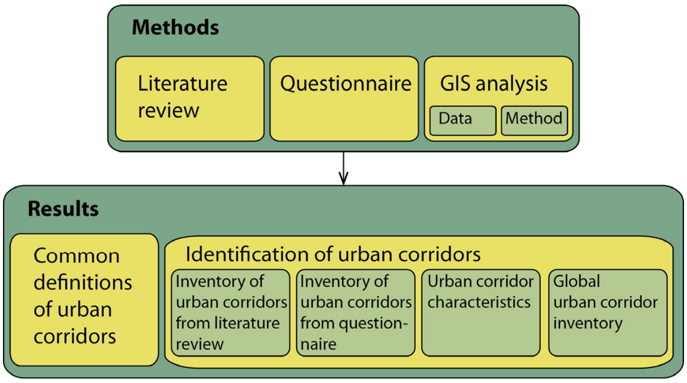

Figure 1. Methodological steps of the paper.

3. Data and Methods

3.1. Literature Review

In our literature review, we searched scientific journals, book chapters and conference proceedings for spatial units labeled "urban corridors". Close to a hundred journal papers—mainly from the fields of urban planning as well as social, economic and transport geography—research and project reports plus book chapters were taken into account. We carried out this review as meticulously as possible but we do not claim it to be exhaustive.

The (presumed) urban corridors ranged in size from an intra-urban scale (down to a single road) to massive urbanized areas. With a focus on a global dimension, we only took the largest corridors into consideration but we purposely did not set any thresholds for the extent in order to get an unbiased list. From this review, we gathered definitions and compiled a list of areas categorized as urban corridors.

3.2. Questionnaire

To investigate the perception of *urban corridors* on a global scale in the geo-scientific community, a questionnaire was handed out to 40 scientists. The questionnaires were completed during international conferences/workshops in applied geospatial science in Austria, at a remote sensing research institute and an alumni meeting (both in Germany) by mainly German-speaking participants but also by an international audience. The questionnaire was handed out to individuals directly. All participants have a scientific background in various geo-related disciplines including but not limited to urban geography, urban planning and GIScience—however, background knowledge in these areas was not required for our purpose of exploring whether some main spatial characteristics can be identified.

3.3. GIS-based Analysis

3.3.1. Data

The potential urban corridors identified in the literature review and questionnaires are measured using remote sensing imagery, road data and image analysis software. The imagery we use is the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS), which acquires night-time images in the visible near infrared (VNIR; 0.4–1.1 μm) range in a 30 arc second grid (around 1 km^2 at the equator) between −65 and 75 degrees latitude. The images are freely available as cloud-free composites (with glare, aurora, sun- and moonlight removed) from [27] for calendar years starting 1992; we use 2013 data. This type of imagery has been used for global mapping of human settlements, energy utilization and socioeconomic parameters (e.g., [8,28–31]. Although this resolution is very coarse, it serves our purposes of a first rough outline of urban corridors. For our questionnaire, a printed night-light poster was used for drawing corridor outlines. One of the disadvantages of night-time light imagery is the blooming effect of rural areas brightened by urban lights, which leads to an overestimation of economically strong urban areas. However, we believe that for our global inventory this is acceptable; any further analysis may have to re-consider this.

We further use an OpenStreetMap (OSM)-based routing service [32]. Over recent years, volunteered geographic information (VGI) and especially OSM data have been increasingly used for urban and land use studies (e.g., [33–35]). Major roads are mapped to a satisfactory degree in OSM. From the routing service, we use the geodata of the major road network to find a route connecting the main centers of each corridor.

3.3.2. Methods

To measure and compare urban corridors, we need a globally consistent method. Our analysis aims at finding common denominators of large urban areas identified as urban corridors in our literature review and questionnaire. Since the understanding of an urban corridor is extremely varied, our method is based on a "master" corridor which serves as a template for the analysis of our identified corridor candidates. This "master" is the Boswash region in the USA (Figure 2). We chose this region for two reasons:

1. It represents a well-studied area which fulfils a first rough definition of an urban corridor (a number of (large) cities, connected by transport infrastructure, linear in shape).
2. It is the area most frequently recognized as an urban corridor in our survey and widely accepted in literature.

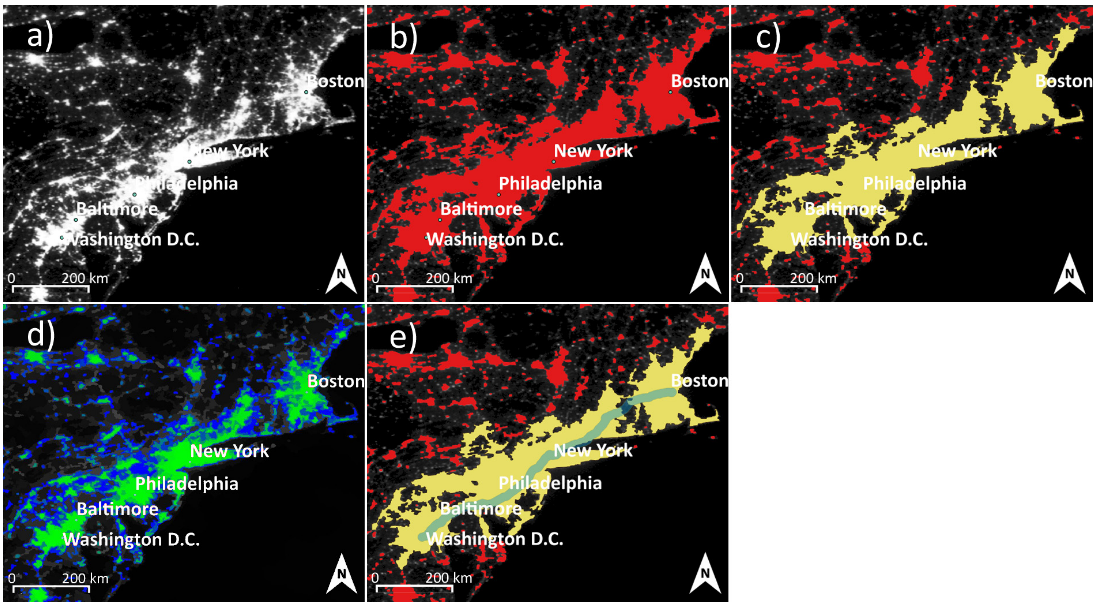

Figure 2. The Boswash urban corridor: (**a**) raw night-time imagery; (**b**) classified urban areas; (**c**) corridor patch (merged); (**d**) threshold derived for Boswash; (**e**) road connection Boston to Washington.

We base the use of a master corridor on Florida, Gulden and Mellander [22] who use a straightforward method to define mega-regions using night-time imagery: they set a threshold (which is not defined in their paper) which best describes mega-regions in the US, apply this threshold globally, close gaps smaller than 2 km and then split patches which include several mega-regions at their narrowest point. Figure 2 illustrates our method: On the night-time light imagery (Figure 2a), we first perform a segmentation (a multiresolution segmentation in eCognition using a low shape factor of 0.1, compactness 0.5 and scale parameter of 25) to identify lighted patches with similar properties, which we understand as populated locations (Figure 2b). In order to identify our "master" as an urban corridor, we set a threshold so the segmented patches form an area which is internally connected but separate from large neighboring urban areas; in other words, the individual patches or segments can be merged into a massive single object (Figure 2c). This allows us to calibrate our model for a sound comparison of urban corridor extents on a global scale. Our specific threshold derived for Boswash is 15 (Figure 2d), i.e., segments with a value of 15 or above form a cohesive region from Boston to Washington. We apply this threshold globally to form large patches of "light" (urban) and "dark" (non-urban) areas. Being aware that night-light intensities reflect a country's population and gross domestic product (GDP) (e.g., [11,36]), we tested this threshold in different areas and found it suitable globally.

In general, the urban patches roughly represent a single city or several connected cities but do not form fully joined corridors, i.e., most presumed urban corridors consist of a number of smaller patches which can not be merged into one single, large patch like the Boswash master corridor; rather, they have a more or less fragmented pattern. Thus, we link the patches of our potential corridors identified through literature and survey through their main road connection (using the OpenStreetMap data), taking into account the fact that cities within urban corridors are aligned along high-speed transportation routes: a road network is one of the defining features of an urban corridor. This road connection is defined through the start and end nodes of an urban corridor derived from the literature review. Usually, the literature provided information of the main cities with urban corridors, often located at either end. In the Boswash example, this means the fastest road trip from Boston to Washington (Figure 2e).

We apply a 10 km buffer around the routes obtained through map.project-osrm.org [32] to include patches close to routes but not directly intersected, i.e., where a route bypasses the urban areas. This buffer is based on the—subjective—assumption that settlements in (functionally) connected areas are never too far from main traffic arteries. We then analyze the resulting connected patches—i.e., our global inventory of potential urban corridors—to obtain the following properties:

- Total urban area (calculated from the total area of all night-lit patches of a corridor classified as "urban").
- Length and width (manual measurement).
- Length-to-width ratio (calculated from measurements).
- Number of gaps along the route (manual count of how many times the route passes through non-urban areas).

This method allows us to apply the same dataset globally, independent of administrative units. However, we are aware that our threshold may be a somewhat artificial delimitation and thus, it is at risk to be subjective. However, we argue this is not the point here; we think being consistent allows us to find spatial characteristics for a global comparison and typification of urban corridors. We purposely limit our analysis to night-time lights and OSM street network since other data (such as functional connectivity) is not available free of charge, globally and consistently.

To obtain typical measures of the potential urban corridors, we subdivide each of the properties (length, width, ratio, area, gaps) into quartiles based on all measurements of the suggested urban corridors. The interquartile range for each property serves as the basis of our suggested definition, while the highest and lowest 25% of values are outside of the typical range.

In a last step, we assign a property class to every potential urban corridor: interquartile range (IQR), quartile 1 (Q1) and quartile 3 (Q3). According to membership within the property classes, the corridors are grouped into different categories (Table 1). Category A includes all corridors that are within the IQR for all properties (length, width, length-to-width ratio, area, number of gaps), i.e., the most "typical" corridors in our analysis. For all other categories, only coherence (number of gaps) and length are taken into account, which are expressions of the most defining features of urban corridors, linearity and connectedness (see Section 4.1.1) [19,21]. Length can be clearly identified in the examples through a start and end point, and connectedness is expressed through the number of gaps.

Table 1. Urban corridor categories.

Category	Description				
	Number of Gaps	**Length**	**Width**	**Length-to-Width Ratio**	**Area**
A	within IQR	within IQR	within IQR	within IQR	within IQR
B1	within Q1	within IQR	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
B2	within Q1	within Q1	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
B3	within Q1	within Q3	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
C1	within IQR	within IQR	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
C2	within IQR	within Q1	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
C3	within IQR	within Q3	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
D1	within Q3	within IQR	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
D2	within Q3	within Q1	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3
D3	within Q3	within Q3	Q1, IQR or Q3	Q1, IQR or Q3	Q1, IQR or Q3

Category B (B1, B2, B3) consists of the most coherent corridors (i.e., within Q1 for the number of gaps), while category D corridors show a large degree of fragmentation. Category C1 differs from category A insofar as width, area and ratio are not all within the IQR. Although a low number of gaps implies a better coherence, our categories are not intended to represent a ranking of urban corridors; rather, our aim is to find some common denominators in the great variations within each property.

4. Results

To show that there is no common understanding of or agreement on the concept, we summarize existing definitions of urban corridors: these are either vague or qualitatively describe a single corridor (or several corridors in physical, political or cultural proximity), and the only rough global map [22] is without a consistent definition, delimitation or completeness. We then investigate corridors that have been identified in various papers. Through our questionnaire, further potential corridors are included in our preliminary inventory. We present the results of our remote sensing analysis and quantify the urban corridors identified in our literature review and survey. Based on this, we approach the problem of ambiguous definitions with a pragmatic own definition for global urban corridors based on the requirements for available, consistent and global data sets for a traceable delimitation.

4.1. Results of Literature Review

4.1.1. Common Definitions of Urban Corridors

Whebell (1969) first introduced the concept describing the development of '*corridors*' with Southern Ontario (Canada) as a phenotype region [37]. In Whebell's view, a corridor is a "linear pattern of major towns joined by highly developed 'bundles' of transport routes". Corridor development happens in continuous, cumulative stages from initial occupancy to metropolitanism through transport improvements (rail, early automobile, rapid transit). Surface characteristics, settlement behavior, time, direction and distance are important elements of the corridor model [37]. Whebell's definition is very basic, the main factors being linearity and transportation infrastructure. The scale is implied by the dimensions of the Southern Ontario corridor: from Windsor via London to Toronto and then on to North Bay and Ottawa respectively, i.e., about 700–800 km. However, Whebell's corridor stops at national and even regional borders: Detroit, only across the Detroit River from Windsor, is no explicit end point, and Montreal, around 75 km from the Québec–Ontario border, is also not part of the corridor despite its supra-regional importance.

In Dutch urban planning, a corridor takes on the form of one or more of three types of axes: an infrastructure axis, an economic development axis and an urbanization axis [38,39]. These axes build upon each other: an urbanization axis includes an infrastructure and an economic development axis. This leads to a minimum definition of corridors as "bundles of infrastructure that link two or more urban areas" [39] where infrastructure can be roads (highways) or rail but also waterways or air connections and generally consist of more than one type. Also possible are other infrastructure lines such as power cables, water pipes, gas or oil pipes.

For Albrechts and Tasan-Kok [40], corridors and axis development exist on different scales and from a variety of views (economists, ecologists, policy planners, transport engineers, etc.). They are not limited to urbanization corridors but, in line with Priemus' interpretation [38], include other functions (ecological, transportation or economic development corridors). The focus of interest is thus not so much on urban areas but rather on connecting links. This of course is justified from a variety of perspectives (traffic planning, etc.), but this study is concerned with the physical settlements themselves, with infrastructure lines as a necessary by-product.

The most distinguishing element of a corridor, in Trip's view [19], is its linear structure. Historically, linearity dates back to the 19th century when the Spanish urban planner Soria y Mata (1844–1920) developed his idea of the Ciudad Lineal, a linear garden city [21,40]. Trip [19] outlines the structure in three basic network concepts: begin-end (point-to-point), line and trunk-feeder network (Figure 3). All three have a linear shape with "poles" at either end. Line networks have nodes in between the poles, while trunk-feeder networks are further branched and the intermediate nodes serve as hubs. The size and characteristics of the nodes and hubs vary depending on the modality (airport, major intersection, railway station) and the distance between them [41]. Batten [42] illustrates corridor cities in a less abstract form and allows for more branches and nodes of different size and connectedness (Figure 3).

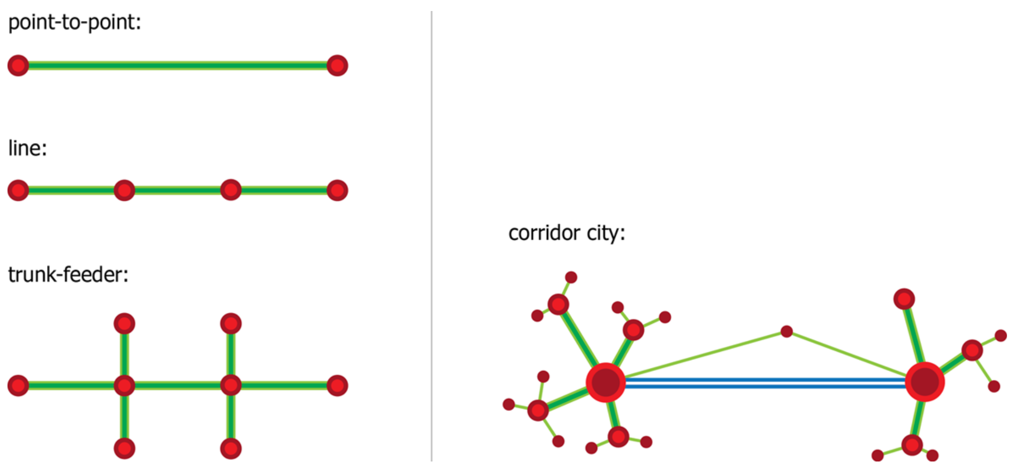

Figure 3. Left: corridor morphologies in terms of network types (after [19]; **Right**: corridor city with connecting surface infrastructure (after [42]).

Li and Cao [20] identify some basic aspects of corridors such as a high population density, existence of large cities or city clusters, high land use heterogeneity and a well-developed transport infrastructure. Their role in the development of the regional economy is both one of convergence (in terms of spatial accumulation and economic hubs) and of divergence. Kunzmann [43] observes that one of the main reasons for urbanization along transport corridors is the low rent (for both residential and commercial estate) due to outdated infrastructure and poor environmental conditions.

A critical feature of any corridor, according to Chapman et al., who studied the London to West Midlands corridor in the United Kingdom (UK), is that of "connection", i.e., the "free and easy flow or transmission of people, goods or information" [21].

One of the more precise definitions of corridor regions is given by Neuman [44] who separates regional settlement patterns into metropolitan, corridor, and rural, with several in-between types plus a more recent form, the mega-city region. Again, linear transportation routes are a key element in this corridor characterization. Located at either end of a corridor is—depending on the scale—a town or a city. The size can range from two medium-sized cities to the Boston-Washington *Megalopolis*. In between urban areas, the corridor crosses suburbs and rural lands in haphazard development patterns. Often, regional centers are located along transport corridors: compact towns with defined boundaries, termed "corridor centers" by Neuman. The form of a corridor can also be an arc or a loop. Furthermore, it can be a ring road around a large metropolis, or several rings like in London or Madrid.

In several reports, two United Nations (UN) institutions use the terms *urban corridors*, *mega-regions* and *city-regions* as three principal "novel configurations" [45]. UN-Habitat first use the term *urban corridors* in 2008, describing them as "a number of city centers of various sizes" which are "connected along transportation routes in linear development axes that are often linked to a number of mega-cities, encompassing their hinterlands" [26]. The UN Department of Economic and Social Affairs (UN-DESA) emphasizes the linking infrastructure and services and compares urban corridors to Gottmann's Bos-Wash megalopolis [23]. Two UN-Habitat reports on African Cities [46,47] interpret urban corridors as integral part of mega-urban regions, consisting of urban and semi-urban areas with a linear or ribbon shape and spanning large distances along road, rail or water connections. Continuous settlement is not necessarily essential along corridors; rather it is a possible result of their growth. Rural lands can be part of a corridor if they are within the influence area of a dominant center. The reports stress the dynamic nature of corridors due to industrial and residential developments away from the core but within reach of its infrastructure and services. A more recent UN-Habitat report [45] already takes into account the growing dimension of urban corridors by stating that "often [. . .] a number of megacities, encompassing hinterlands" are part of urban corridors.

In South-East Asia, urban corridors follow a specific settlement pattern. This pattern is due to the mix of rural and urban spaces (agriculture, retail, industry, residential), which has elsewhere been described as extended metropolitan region [48,49]. With respect to the Pacific Asia region, Choe [50] notes that "the concepts of urban corridor, growth triangle, and/or natural economic territory began to appear in the literature from the late 1980s". He observes that urban corridor, megalopolis, extended metropolitan region and ecumenopolis—a term coined by Greek urban planner Doxiadis in 1961 to describe a projected fusion of all urban areas worldwide to a universal settlement, the "city of the whole inhabited earth" [51]—are used interchangeably. Several authors emphasize the functional aspect of the Asia Pacific urban corridors (e.g., [52,53]) and refer to them as transnational, functional city systems with strong finance, commerce, transportation, services and manufacturing industries. Urban corridors along the Western Pacific Rim spread over large areas, contain a number of megacities and show a very high degree of interconnectedness [53].

4.1.2. Global Map of Examples from Literature

Figure 4 shows all urban corridors identified in our literature review. A detailed description of the corridors is available in the Supplementary Materials. We use this map as basis for our further analysis based on measurable criteria but are aware that it is debatable whether the term urban corridor can be applied to all these regions: some areas are very thinly populated, others are economically or spatially disconnected.

The examples are areas termed urban corridors in scientific papers. Overall, it seems that the term "urban corridor" is taken for granted: no reasons are given why the term is used, what it implies and which spatial extent a corridor has. Generally, only the start and end points—usually a large city—are given but no path or intermediate areas. A number of areas, particularly in Asia, are characterized as "economic growth zones" and are therefore excluded from this summary unless they are also explicitly classified as urban corridors. Similarly, "development corridors" which are common in Africa (Figure 4) are also disregarded. Corridors vary greatly in size but generally—with a few exceptions—their shape shows a large degree of linearity. In a later step, we attempt to find a spatial characterization of urban corridors we assume is most appropriate.

Figure 4. Urban corridors identified in the literature review. 1. Northern California, 2. Texas Triangle, 3. Dublin–Belfast, 4. M4 Corridor, 5. London–Cambridge, 6. Lille–Aachen, 7. Cologne–Berlin, 8. Frankfurt–Prague, 9. Dresden–Prague, 10. Karlsruhe–Vienna, 11. Rhône Valley, 12. Ebro Valley, 13. Delhi National Capital Region (NCR), 14. Mumbai-Ahmedabad, 15. Mumbai–Pune Infrastructure Corridor, 16. Chennai–Bangalore–Mumbai Industrial Corridor (CBMIC), 17. Bangalore–Mysore Infrastructure Corridor (BMIC), 18. Mumbai–Jalgaon, 19. Hyderabad–Vijayawada, 20. Beijing–Qinhuangdao, 21. Shanghai–Nanjing, 22. Shanghai–Hangzhou, 23. Hangzhou–Ningbo, 24. Taiwan–Fujian, 25. Pearl River Delta, 26. Taiwan, 27. Hanoi–Haiphong, 28. Danang-Hue, 29. Ho Chi Minh City, 30. Jakarta–Bandung.

4.2. Results of Questionnaire

As part of our questionnaire (see Supplementary Materials), the participants were asked to mark areas which they regarded as Urban Corridors. For this, a global "Night Lights" image was provided in which the participants highlighted the areas for a spatial approach. Although this type of image has its limitations (for example, it does not properly show the global population distribution since the per capita energy consumption is not the same; see also [36,54]) but seemed the most suitable map for our purposes. Since the participants used different methods to mark their corridors (circles, lines; coarse/fine), only a rough comparison can be made. Figure 5 shows a map of the highlighted corridors. Overall, certain areas clearly stand out in the participants' opinions. The two most striking areas on the global map are the Northeast of the US ("Boswash"), and California (often subdivided into northern and southern part), each marked by about two thirds of the participants. The Mediterranean coastline is identified with a great variety (ranging from individual cities such as Marseille, Nice or Genoa via larger areas such as Greater Barcelona to almost the complete coastline) and no unique area could be made out. A strong agreement can be observed for the London–Midlands area in the UK, the Benelux countries, Japan (sometimes extending into South Korea and Northeast China), Taiwan, Florida, Chicago–Milwaukee, Rio de Janeiro–São Paulo and the Nile delta. To a lesser extent, Northern India (around Delhi and along the Ganga River), Germany's Ruhr area (as well as the whole of Central Europe), various extents around Moscow, Bangkok (to Singapore), Malaysia's west coast, Texas (Houston, Dallas), Caracas–Bogota, Abu Dhabi–Dubai, the east coast of the Mediterranean and others (see map) were also highlighted. Furthermore, a number of smaller, point-shaped rather than linear, urban regions were marked, such as Vancouver, Seattle, Indianapolis, Denver, Copenhagen/Malmö, Naples, Rome, Istanbul or Saint Petersburg. Areas that were only identified once or twice in the questionnaire were not included in Figure 5. Clearly, this map represents a subjective perception of the participants. Again we emphasize that this map is intended as a basis for an urban corridor inventory which needs to be objectively tested.

Figure 5. Urban corridors identified by participants of the questionnaire (areas marked by two or more participants). The map shows areas with strong agreement but the actual extents vary.

4.3. Results of the Spatial Characterization of Settlement Patterns for Urban Corridors

Neither the literature nor the perception of scientists on urban corridors provide an unambiguous definition, localization or delimitation of these. In order to overcome the absence of a systematic description of urban corridors, our approach uses remote sensing imagery and GIS methods, allowing us to delineate the corridors identified above.

We examined a total of 80 possible urban corridors: 63 from the literature review (from the original 66 areas, Hangzhou–Ningbo, Shanghai–Hangzhou, Shanghai–Suzhou–Nanjing were combined under "Shanghai" and the Flemish Diamond extends from Lille to Aachen), plus a further 17 from the survey that have not previously been identified in the literature.

These 80 areas are, as we emphasize again, subjective and not independently proven but serve as a first guideline for further investigation. They range from 115 to 4200 km in length and from 20 to 400 km in width, totaling in urban area between under 1000 and almost 270,000 km^2. The length-to-width ratio varies from almost 1 (very compact shape) to over 20.

We doubt whether all the areas identified actually qualify as urban corridors if they are measured against a more precise definition. In particular, one of the defining aspects of an urban corridor is its lengthy shape. Since no definition of this lengthiness exists, we use a preliminary threshold and exclude all compact areas with a length-to-width ratio of less than two (see Figure 6). These are: London-Cambridge, RhineRuhr, Randstad, Bangalore–Mysore, SIJORI (*Si*ngapore, *Jo*hor and *Ri*au), Taiwan–Fujian, the Pearl River Delta, Ho Chi Minh City, Hanoi–Haiphong, Seoul–Busan, Shanghai, Johannesburg and the Texas Triangle. In our study we are concerned with urban corridors of a *global* dimension—a factor which, spatially, has no proper delimitation; however, we abstained from setting a threshold for length, width or area this at this stage since in order to get an objective result. Our categorization in Section 4.4.2 groups the corridors into more meaningful clusters.

The remaining 67 urban corridors with a length-to-width ratio of over two show a great heterogeneity. Removing the 13 most compact areas clearly changed the range of the ratio (2–20) but also the width (with two of the widest corridors among 13 removed areas). These ranges, pictured in Figure 6 (bottom), serve as a basis for our suggested spatial delimitation of urban corridors below.

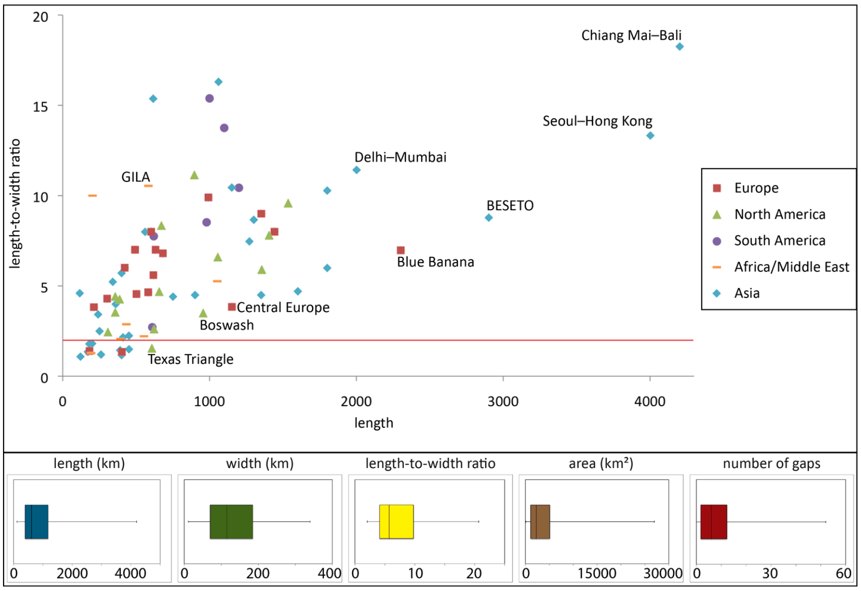

Figure 6. **Top**: Length (x-axis) and length-to-width ratio (y-axis) of urban corridors. All corridors with a ratio of less than two (red line) were removed from further analysis; **Bottom**: Range of properties of urban corridors.

4.4. Overall Result: Quantification of Urban Corridors

In this section, we attempt to consolidate the main characteristics of urban corridors on a global scale based on the above definitions, examples and perceptions. Our aim is to provide a consistent, quantitative description of what constitutes an urban corridor on a global scale, based on the qualitative results of our literature review and questionnaire. This can serve as a reference on which to base future studies that aim to compare and analyze urban corridors in more detail.

Although some of the areas can be described using other concepts such as mega-region or megapolitan, the term *urban corridor* should in general be applied for *linear*, *massive urban constructs*. Based on our findings above, we conclude that among the constituent features of a global urban corridor are *several major cities*, a more or less *linear structure* (i.e., generally linear but with curves and branches to the side), and a *connecting transport infrastructure*. To be more precise, urban corridors consist of a number of cities of significant size, expand over several hundred km and have a well-developed *surface transport infrastructure* (rail, road). Urban corridors have a high length-to-width ratio and are more or less continuously populated if the physical land surface allows. Administrative and international boundaries can be crossed.

The questionnaire results revealed a high ambiguity of whether or not a big water body can be part of an urban corridor. In the case of BESETO (*Be*ijing, *Se*oul, *To*kyo)—a region commonly agreed to be an urban corridor—the Korea Strait covers a quite significant section of about 8% of the total length. Flow of traffic, goods and people is hindered to a great degree. However, it can also be argued that some international boundaries, especially those with rigorous border controls, are just as hard to cross. Therefore, we support the idea that an urban corridor can also reach across a big water body, which, strictly speaking, separates a corridor into different parts (as is the case with BESETO, see Figure 4).

4.4.1. Typical Measures of Urban Corridors

Assuming that the areas we identified above are initial urban corridor candidates, we take the results from Figure 6 for a spatial delimitation. The interquartile range represents the "typical" characteristics of our urban corridors (with some rounding applied to the values): Urban corridors are typically between 400 and 1200 km long, 70 to 200 km wide and with a length-to-width ratio between four and ten. The urbanized area is between 10,000 and 50,000 km^2. Although less fragmentation means better coherence, we refrain from qualifying these values.

4.4.2. Categories of Urban Corridors

In Table 2, we list the urban corridors including their categories (cf. Table 1), length, width, length-to-width ratio, urbanized area, number of gaps between urban patches and their source (literature review and/or questionnaire). Category A includes the most "typical" (but not necessarily "best") corridors from our analysis. Category B contains the least fragmented corridors, category C those with a typical number of gaps and category D the most fragmented ones. No corridors fit into categories B3 and D2: coherent corridors are generally shorter in length, while longer corridors are more fragmented. For two of the most fragmented corridors (Blue Banana, Bohai Rim), we did not specify the number of gaps because of the complexity of the road network. Category D3 corridors generally surpass the maximum measures of the "typical" interquartile range. While a large physical size of a corridor may imply a global significance, the high number of gaps counterbalances this.

Table 2. Categorization of urban corridors.

No.	Cat.	Corridor Name	Length (km)	Width (km)	Length-to-Width Ratio	Area (km^2)	Number of Gaps	Lit. Review	Ques-Tionnaire
1	A	Venezuela Coastal Corridor	980	115	8.52	18,405	10	x	
2	A	Karlsruhe–Vienna	680	100	6.8	23,895	10	x	
3	A	Cascadia	665	80	8.31	26,665	8	x	x
4	A	Northern California	650	140	4.64	23,854	6	x	x
5	A	Buenos Aires–Montevideo	620	80	7.75	15,860	9	x	x
6	A	Frankfurt–Prague	615	110	5.59	15,533	8	x	
7	A	Ebro Corridor	600	75	8	20,270	9	x	
8	A	Cologne–Berlin	580	125	4.64	27,200	8	x	
9	A	Mumbai–Ahmedabad	560	70	8	16,706	6	x	
10	A	Stockholm–Gothenburg	490	70	7	15,311	9	x	
11	B1	Nile Valley	1050	200	5.25	66,294	0	x	x
12	**B1**	**Boswash ***	**950**	**275**	**3.45**	**142,452**	**0**	**x**	**x**
13	B1	Tokyo–Kobe	750	170	4.41	60,263	0	x	
14	B1	Rhône	630	90	7	33,152	1	x	x
15	B1	Abu Dhabi–Dubai	550	250	2.2	35,789	0		x
16	B1	Porto–Lisbon	500	110	4.55	30,180	0		x
17	B1	Beijing–Qinhuangdao	450	200	2.25	41,785	1	x	
18	B1	Beirut–Gaza	430	150	2.87	36,505	0		x
19	B1	London–Midlands	400	300	1.33	88,121	0	x	x
20	B2	South California	350	100	3.5	23,481	0		x
21	B2	Taipei–Kaoshiung	340	65	5.23	18,881	0	x	x
22	B2	Chicago	300	125	2.4	34,125	0		x
23	B2	Flemish Diamond	300	120	2.5	29,051	0	x	x
24	B2	Jakarta–Bandung	250	100	2.5	10,698	1	x	
25	B2	Mumbai–Pune	240	70	3.43	8611	0	x	
26	B2	Dublin–Belfast	210	55	3.82	8509	1	x	
27	B2	Danang–Hue	115	25	4.6	891	1	x	
28	C1	Java	1150	110	10.45	24,352	10	x	x
29	C1	He-Xi	1060	65	16.31	4408	12	x	
30	C1	Mediterranean	990	100	9.9	52,228	5		x
31	C1	Delhi	900	200	4.5	50,673	5	x	
32	C1	Colorado Front Range	890	80	11.13	16,271	9	x	
33	C1	Xining–Lanzhou–Yinchuan	615	40	15.38	6761	9	x	
34	C1	São Paulo–Rio de Janeiro	610	225	2.71	32,152	4	x	x
35	C1	GILA	580	55	10.55	6324	4	x	
36	C1	Thessaloniki–Volos–Athens	420	70	6	10,535	11	x	
37	C1	Shinuiju–Kaesong	410	190	2.16	44,049	2	x	
38	C1	Mumbai–Jalgaon	400	70	5.71	9811	4	x	
39	C1	M4 (London–Bristol)	400	300	1.33	88,914	2	x	x
40	C2	Bahrain–Qatar	390	190	2.05	22,474	4		x
41	C2	Calgary–Edmonton	380	90	4.22	22,760	4	x	
42	C2	Hyderabad–Vijayawada	360	90	4	8185	3	x	
43	C2	Arizona Sun Corridor	350	80	4.38	12,418	4	x	
44	C2	Athens–Patras	300	70	4.29	7132	2	x	
45	C2	Dakar–Touba	200	20	10	772	2	x	
46	C2	Dresden–Prague	180	130	1.38	10,344	3	x	
47	C3	Delhi–Ganga (Kolkata)	1800	175	10.29	61,913	12		x

Table 2. *Cont.*

No.	Cat.	Corridor Name	Length (km)	Width (km)	Length-to-Width Ratio	Area (km^2)	Number of Gaps	Lit. Review	Ques-Tionnaire
48	C3	East China (Beijing–Shanghai)	1350	300	4.5	137,795	10		x
49	C3	Taiheiyō Belt (Tokyo–Fukuoka)	1270	170	7.47	81,822	3	x	x
50	D1	Buenos Aires–Mendoza	1100	80	13.75	14,987	13	x	x
51	D1	Piedmont Atlantic	1050	160	6.56	73,394	16	x	x
52	D1	Natal–Recife–Salvador	1000	65	15.38	14,510	21		x
53	D1	Florida	615	240	2.56	48,973	17	x	x
54	D3	Chiang Mai–Bali	4200	230	18.26	90,258	52	x	
55	D3	Seoul–Hong Kong	4000	300	13.33	269,731	32	x	
56	D3	BESETO	2900	330	8.79	196,244	14	x	x
57	D3	Blue Banana	2300	330	6.97	444,883	n/a	x	x
58	D3	Delhi–Mumbai	2000	175	11.43	67,899	14	x	
59	D3	Bangkok–Singapore	1800	300	6	61,431	19	x	x
60	D3	Bohai Rim	1600	340	4.71	109,754	n/a	x	
61	D3	Gulf Coast	1530	160	9.56	51,995	22	x	
62	D3	Moscow–Ufa	1440	180	8	78,885	19		x
63	D3	I-35	1400	180	7.78	51,031	25	x	
64	D3	Paris–Madrid	1350	150	9	47,364	20	x	
65	D3	Québec–Windsor (Southern Ontario)	1350	230	5.87	108,071	20	x	
66	D3	Chennai–Bangalore–Mumbai	1300	150	8.67	24,713	20	x	
67	D3	Caracas–Bogota	1200	115	10.43	16,793	15		x

* "Master" corridor.

4.4.3. Global Map of Urban Corridors

All urban corridors suggested above are mapped in Figure 7 and numbered as in Table 2. This result is our approach to locate and categorize urban corridors across the globe. Using the same consistent method based on objectively measurable criteria, we generate a comprehensive global inventory of urban corridors. This inventory shows the (rough) spatial extent of all corridors plus a categorization according to spatial criteria (length, width, length-to-width ratio, area and number of gaps).

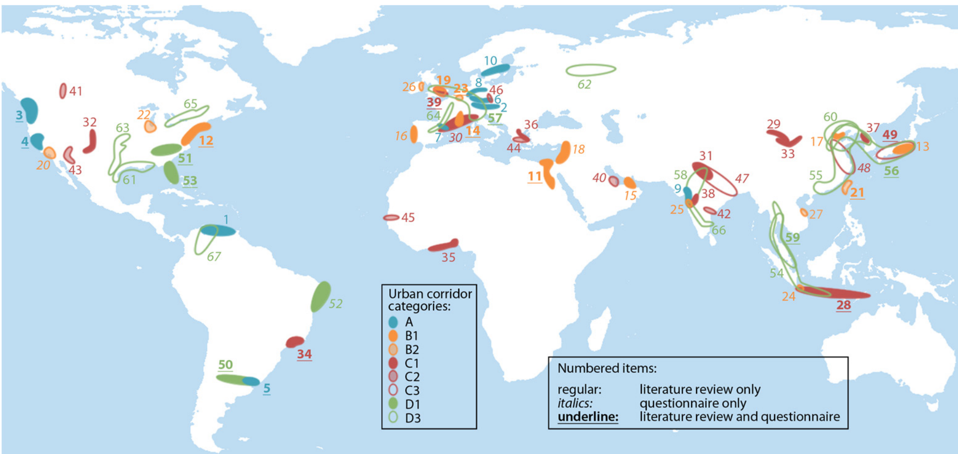

Figure 7. Global inventory of urban corridors. Corridors numbered according to Table 2.

However, our results can only be a rough approximation of the extent of urban corridors since no proper outlines were provided in the literature. List and map are thus intended as an empirical typification of possible urban corridors. It will have to be further tested and amended to include further corridors not yet identified while at the same time removing non-corridor areas in more thorough analysis. Our criteria can only be suggestions to differentiate urban corridors from other large urban areas. The spatial patterns we chose for our definition can be measured and delineated globally and consistently using current earth observation data sets and methods (e.g., classification methods, feature extraction, landscape metrics). Other characteristics, e.g., population, economic characteristics, information and communications technology (ICT) infrastructure, or air/sea links, are not taken into consideration at this stage. However, increased availability of data such as mobile phone usage, airline connections or global population estimations may provide the possibility of a further refinement of our definition in future analyses.

5. Discussion

Our analysis describes urban corridors from a spatial point of view, based on examples from a literature review and questionnaire and illustrated in a global map (Figure 7). While we believe that our method provides some valuable insights into a concept which has not been specified in detail, we are aware of some shortcomings of our research. Some of the issues we had to deal with include the fact that some corridors in the literature are only defined through start and end points but no indication is given on cities/towns in between, making it difficult to establish the total dimension. This, for example, makes it impossible to outline the long corridor from Japan to Java [53] (see Figure 4), which subsequently has been omitted from our analysis due to the lack of further information in the literature. Furthermore, corridors labeled "development corridors" (Figure 4) are also not part of our study, neither are corridors identified above with a length-to-width ratio below two.

As could be expected, the distribution of urban corridors reflects the global population distribution. The largest number by region is in Asia where also the most massive constellations can be found. The urban corridors in Europe are comparatively small and compact. A reason for this is the relatively small area of individual countries and the fact that frequently, start and end of an urban corridor within the same country are given, neglecting the fact that international boundaries can easily be crossed. Since our method analyzes coherent lighted areas, we could include the large patch running through Central Europe that has not been labeled urban corridor before.

OSM data proved to be problematic for large urban corridors such as the Blue Banana or BESETO, which are difficult to delineate with our method. These areas, therefore, are underestimated because not all urban patches could be captured. Also, some manual editing of the linking street network was required for cases where OSM data fail to provide a road connection (such as border crossings or across water bodies). We further acknowledge that our method fails to include some urban patches which visually seem to belong to an urban corridor, especially for smaller, more fragmented corridors (Figure 8f). Using a 10 km buffer along the roads includes some urban patches close to the main connecting road but omits patches further away. We are aware that choosing this particular threshold of 10 km is subjective. However, we argue the main point is to apply our threshold consistently across the globe and thus allow for a comparable classification. We therefore think that the buffer is valuable since at least some areas close to the main roads could be captured. We tested other buffers (25 km, 50 km) on sample regions but concluded that for a first global analysis, a smaller buffer is preferable. Wider or even multiple buffers will need to be tested on all corridors in future research to establish the best distance without compromising the overall connectedness.

Night-time imagery serves as an adequate basis for our purposes, allowing a globally consistent spatial delimitation. However, we are aware that this type of imagery shows inconsistencies due to the economic situation in different areas. Thus, the spatial characterization may be biased to a certain degree by this issue. In addition, night-time lights do not provide additional (particularly functional) information. Occasionally, the connected night-lit area forms a larger patch, as in London–Cambridge (absorbed by the London–Midlands region) and especially Abu Dhabi–Dubai (Figure 8e). Here, the well-lit road network, classified as urban area in the image, extends well over 500 km beyond Muscat (while Abu Dhabi and Dubai are only about 150 km apart). This is a problem any global analysis using the same parameters is likely to encounter and, as far as we are aware, can only be overcome by manual editing of each corridor—an approach we feel would compromise its global relevance. Especially for some of the longer corridors, our results can only yield an underestimation of the actual extents of the urban corridors, omitting some areas which are functionally connected (e.g., through commuter flows, governance or economically) but not linked to the main traffic artery determined through our method (Figure 8f).

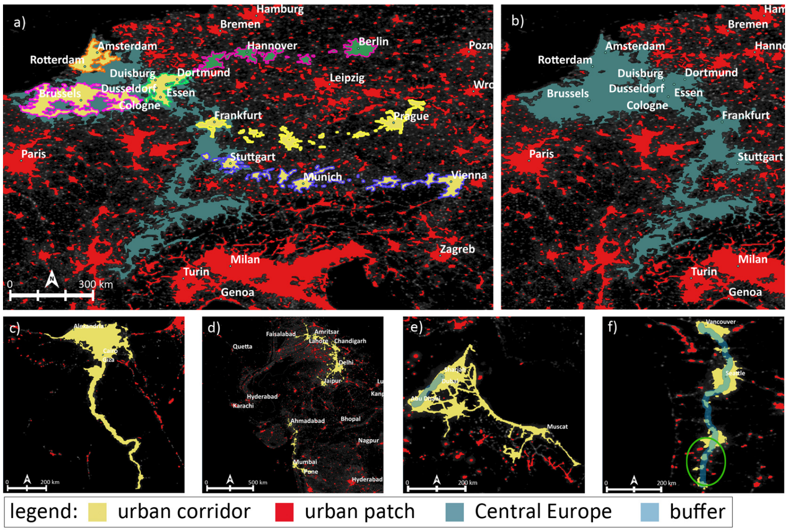

Figure 8. (**a**) Central Europe (blue) with subcorridors RhineRuhr, Randstad, Flemish Diamond, Stuttgart–Vienna and Frankfurt–Prague (right); (**b**) Central European corridor; (**c**) Nile Valley; (**d**) India: Delhi Region and Mumbai–Ahmadabad; (**e**) large night-lit patch from Abu Dhabi and Dubai extending south-east; (**f**) patches omitted from the Cascadia urban corridor (green circle).

Higher-resolution global night-time imagery is available through the Visible Infrared Imager Radiometer Suite (VIIRS) from the Earth Observation Group (EOG), National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) [27]. The imagery can be obtained for each calendar month and the method employed in this paper should also be tested with these data (see also [55,56]). However, for the purposes of our initial mapping of urban corridors on a global scale, we regarded the coarser resolution of the DMSP-OLS imagery, which uses all available data for a calendar year, to be sufficient.

At the same time, some resulting patches reveal contiguous areas that have not been considered urban corridors before. For example, the large Central European patch absorbs the smaller "corridors" Randstad, RhineRuhr, and Flemish Diamond (Figure 8a). Spatially, with a length of 1150 km, an area of almost 20,000 km^2 and a length-to-width ratio of close to four, this constellation is closer to the typical measures of an urban corridor than the smaller sections alone, forming a category B1 corridor (Figure 8b). For a preliminary delimitation of the three subregions, i.e., in order to separate them off Central Europe, we raised the threshold for the lighted areas to obtain smaller patches. The higher threshold is also used for the delimitation of smaller corridors intersecting this large patch (Cologne–Berlin containing RhineRuhr, Frankfurt–Prague, Karlsruhe–Vienna), allowing us to cut out parts of the Central Europe corridor for a more meaningful result. While those intersecting corridors are dwarfed by Central Europe, they may provide insights into the future growth direction of this massive constellation. Also, since they are spatially connected to the main European corridor, they might be considered part of it instead of separate, intersecting corridors. Overlapping or intersecting corridors cannot be separated spatially and therefore will most likely not withstand a more detailed spatial analysis.

For our categorization (Tables 1 and 2, Figure 7), we believe that length and coherence are two of the most important factors to describe urban corridors, in particular after removing the most compact ones with a length-to-width ratio of under two. While category A corridors are within the "typical" range for all properties, they are not necessarily "better" corridors—category B corridors (with no more than one gap) show a much higher spatial connection.

Finally, our analysis is based on examples (or, in other words, subjective perceptions) from a literature review and questionnaire since there is no global index of urban corridors. Due to the lack of a proper definition, we have no information whether these areas can actually be regarded urban corridors. Almost certainly, some examples have been missed—our list, therefore, can only be an incomplete inventory of potential urban corridors at this stage. At the same time, our list includes some areas that are most likely not regarded as "urban" corridors by most people (such as the thinly populated He-Xi corridor). Despite this, our analysis complements and extends the UN-Habitat map [24], providing what we believe is the most complete compilation of urban corridors to date.

6. Conclusions

In this paper, we analyzed a less well-known construct describing a specific type of large urban areas: urban corridors. We summarized their common definitions as found in scientific papers and book chapters, detailed their occurrence in different parts of the world, and presented results of a questionnaire. Based on all this, we provided a description of urban corridors on a global scale which we believe covers their main characteristics in order to answer our main research question: Which spatial patterns define an urban corridor?

An urban corridor is a massive urbanized area with a linear shape and high-speed surface transport infrastructure (such as road or rail). Our results show that a typical urban corridor is 400–1200 km long, 70–200 km wide and covers 10,000–50,000 km^2. There are up to twelve gaps in the otherwise continuously populated (identified by night-time light imagery) area, with a low number of gaps implying more coherence of the area. The typical length-to-width ratio is between four and ten; areas with a ratio of less than two have been omitted from our analysis because of their compact (as opposed to linear) shape.

The result of our research is a list of potential urban corridors, identified through a literature review and survey and checked against our suggested definition. Each corridor is assigned a category depending on length, number of gaps and other spatial criteria. Yet whether this list actually withstands a more thorough investigation using more distinct criteria is uncertain. For example, the settlement density varies significantly between the He-Xi and the BESETO corridors. Even more noteworthy is a comparison between Mumbai–Ahmedabad and Stockholm–Gothenburg, both of which are category A corridors: spatially, they are similar in overall size, but vary greatly in population (both Swedish cities are well below 1 million each, while Mumbai belongs to the largest cities in the world). Our results in Figure 7 are based on a top-down approach based on existing perceptions. They serve as the basis for future research on urban corridors including their detection and delineation using remote sensing and GIS methods for which we recommend using additional data such as population and economic data. To identify the *global* dimension of urban corridors, a Global City inventory may prove useful, such as [57,58].

A large share of urban corridors is located in Asia, including the three longest ones (Chiang Mai–Bali, Seoul–Hong Kong and BESETO; Figure 6). With the exception of the Blue Banana, no corridor outside of Asia exceeds much above 1500 km. These massive corridors, however, are also very fragmented (category D). Shorter subsections, though, form fully connected corridors, as has been pointed out for BESETO. Therefore, we recommend re-investigating the category D corridors for more coherent sections which may then fall into a different category. We further suggest that overlapping and intersecting urban corridors need to be combined in order to obtain a more meaningful delimitation.

In the beginning of this paper, we asked whether urban corridors are merely another type of mega-region. With the characterization we provided above, we believe that they complement the mega-region concept: not all urban corridors are mega-regions, while others exceed their dimensions. Their specific spatial pattern also sets them apart. If the current urbanization trend—growing urban population, changing physical shape of large urban areas—continues, we expect the number of urban corridors, particularly around Asian megacities, to increase.

Supplementary Materials: The following are available online at www.mdpi.com/2220-9964/5/12/233/s1.

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