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Impacts of Zagreb's Urban Development on Dynamic Changes in Stream Landscapes from Mid-Twentieth Century

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Abstract: Urban streams constitute a valuable form of multi-functional blue and green infrastructure (BGI) and can support urban development to generate ecosystem, social, and economic benefits. In global cities, planning for BGI enhancement contributes to climate change adaptation, ecosystem restoration, community health and wellbeing, improved quality of life, etc. This research aims to assess the dynamics of stream landscape change in Zagreb as well as the influence of urban development on the blue and green landscape and related urban values. The analysis of landscape features and their planning is conducted at the level of the stream system of the whole city of Zagreb and at the level of two stream sequences by superimposing spatial data from cartographic sources. By developing an urban planning-social-ecological approach to evaluation, monitoring, and management, a quantitative and qualitative trend in stream landscape changes is identified and indicators for detecting areas of critical urbanization pressure are established. This research confirms the trend of negative changes in the urban BGI, evident in the present state (interruption of open streams, and the reduction, fragmentation, and disconnection of blue and green landscape), as well as in the planned neglect (plans for further stream closures and reduction in public green areas). Stream landscape potential is emphasized as one of the greatest urban assets for improving the system of BGI, and areas needed for their prioritization in urban planning measures, directed towards an increase in multiple landscape values, are determined.

Keywords: blue-green infrastructure; urban planning; city resilience; quantitative and qualitative landscape analyses; graphic analyses; spatio-temporal landscape analyses

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1. Introduction

Complex urbanization processes in the city of Zagreb, as well as provisions pertaining to urban planning documents for Zagreb, have had an impact on the dynamic changes in its stream landscapes. This research is involved in examining stream landscape changes in Zagreb from the urban planning point of view from the mid-20th century onwards. The role of Zagreb's urban streams in the formation of the urban landscape system is explored through the global blue and green infrastructure approach, as well as in the context of the contribution of the urban watercourse to ecological and social values of the city and the quality of life.

1.1. Theoretical Background

Urbanization processes and urban growth generate landscape changes that cause a loss and fragmentation of the 'natural' landscape, putting great pressure on urban blue and green spaces, and altering the distribution and characteristics of urban water bodies. Urbanization is characterized as the most dramatic form of irreversible land transformation, affecting both landscapes and urban inhabitants [1]. It is a worldwide and complex process that causes diverse and profound changes by creating new and highly heterogeneous landscapes [2].

At the global level, cities have been rethinking the starting points of traditional technical approaches to urban streams, considering their shortcomings in the context of climate change [3–5], limited natural resources [6,7] and the neglected ecological, social, and cultural value of watercourses [8–10]. Water landscapes are less often perceived as static and hydrotechnical, and more as socio-ecological systems undergoing numerous dynamic changes [11–13]. The increased variability and uncertainty of urban development has shown that a technical focus on watercourse planning is no longer adequate for providing solutions for coping with complex dynamic contexts. The objective of watercourse transformation is to improve their livability, sustainability, resilience, and productivity.

1.1.1. Water-Sensitive Approach in Promoting Ecosystem Services

Many ecological corridors have been established globally in the flood plains of streams and rivers and occur in riparian areas associated with surface waters [14], forming a blue and green infrastructure (BGI) basis for urban landscapes. BGI is a global approach to promoting the sustainability and resilience of dynamic city–landscape relationships. It is a nature-based solution that encompasses all actions that rely on ecosystems and their services in responding to various societal challenges, such as climate change, food security or disaster risk [15,16]. Urban ecosystems are becoming increasingly important as contributors to environmental issues by providing important ecological, production, and cultural functions [17]. Ecosystem services (processes and functions) are essential for human well-being and include supporting (biodiversity, habitat, soil formation), cultural (recreation, property value, community cohesion), provisioning (food, water, fuel), and regulating (noise reduction, modulation of temperature, protection of water quality) services [18]. The blue and green infrastructure has a critical role in conserving biodiversity [9,14], climate change adaptation, urban heat mitigation, and air quality improvement [5,19], as well as in managing urban water challenges and risks [20,21]. At the same time, urban watercourses and associated green areas meet the cultural needs of residents [8,9], embody the aesthetic preferences of the community [10,22], contribute to place making [23] and the preservation of historical landscape features. Multiple co-benefits of blue and green infrastructure enhance the blue landscape through urban water management and improve society through having a positive impact on residents' quality of life [24].

Urban growth is altering the distribution and characteristics of water bodies [3], transforming urban watercourses into gray infrastructure [21,25], obliterating functions and aquatic habitats [26], generating imbalances and flood risks [27], and degrading stream ecosystems through urban stormwater runoff [28]. Globally, cities have been rethinking their approaches to altered urban hydrology by promoting retrofitted green stormwater infrastructure [29], sustainable urban stormwater management [30,31], and urban flood risk management [21]. The comprehensive approach of a water-sensitive city ensures the quality of urban spaces, improves environmental health, and gives priority to creating adaptable and multifunctional solutions in water infrastructure planning [4,25,32,33]. The recovery of urban rivers [5], the restoration of urban streams [34,35], and stream daylighting and de-culverting [36,37] promote the renaturation approach to degraded riverine systems [26] and provide foundations for the blue-green city [38]. Urban streams are considered a valuable form of blue-green infrastructure with positive environmental, economic, and social benefits [39]. The restoration of urban streams and their interaction with urban systems of public and green areas and safe pedestrian and bicycle paths enhance the blue and green infrastructure in densely built urban areas [34,40].

1.1.2. Holistic Approach to Planning Blue and Green Infrastructure

Understanding the role of water, as well as recognizing types and patterns of blue areas in a city, provides a planning basis for maximizing the potential for human–water interactions, delivering urban water management solutions and strategically structuring future urban development [20,27]. The identification of key sites for BGI and their differentiation for management strategies should ensure that limited land resources and public funds be directed to where interventions are really needed [6].

Holistic and integrated approaches to all planning processes and urban development foster a new language and awareness regarding blue-green issues [23]. The eight planning principles—connectivity, multi-functionality, applicability, integration, diversity, multi-scale, governance, and continuity [41]—promote a transformative change in spatial planning principles, needed to optimize the delivery of multiple BGI benefits in order to address each city's priorities and strategic objectives [24]. Integrating ecosystem services within spatial planning policies and practices, as well as implementing a flexible BGI into the existing urban landscape fabric and management systems, supports sustainable and livable cities [16,42]. Various ecosystem services need to be balanced, optimized, and considered simultaneously in the process of sustainable BGI planning [43,44]. To be successful, BGI planning requires key stakeholders' active involvement and participation and a careful analysis of value pluralism [8,45], ensuring citizens' access to important ecosystem services since their provision depends on the configuration and distribution of ecosystems within the city space.

Planning urban blue and green landscapes for a sustainable future requires understanding their different change patterns and seeing them as highly dynamic, complex, and multifunctional spaces. Therefore, detailed inventories of landscape conditions, together with monitoring continuity and change, are needed to obtain reliable data for good decision-making [46]. The state of urban watercourses, as well as the management of urban blue and green landscape change, is established according to metrics of factors, indicators, and indices [27,32,33]. By identifying the past urbanization patterns, policy makers and planners can gain better insights into the contributing factors that have resulted in the most problematic development patterns now and into the future [47].

1.1.3. Exposing Research Gap within the Literature Review

Despite the broad range of research approaches to fundamental metrics, limited attention has been paid to the multi-faceted character of landscape change. Environmental practitioners and academics tend to view blue and green areas as either a visual/physical phenomenon (land cover) or as a functional element (land use) [48]. These single-dimensional perspectives do not accurately capture the character and complexity of landscape heterogeneity, function, and use in urban areas [49]. Although spatio-temporal, social, and ecological characters of landscape change have been explored from various points of view, research into landscape changes anticipated by urban planning projections has been neglected.

From the urban planning point of view, the effective mapping of complex stream landscape attributes necessitates the simultaneous characterization of land cover (form) and land use (function) observed through the existing condition and expected planning changes. By developing an urban planning-social-ecological approach to the evaluation, management, and monitoring of urban stream landscapes, the benefits ensured by blue and green spaces could help to establish a balance with the needs of urban inhabitants and raise the quality of life in cities. This comprehensive approach could contribute to a better integration of urban stream ecosystem services within urban planning policies, as well as support urban streams as a structural part of the city and an active contribution in achieving urban sustainability, resilience, and livability.

1.2. Previous Research of Zagreb's Stream Landscape

Historical research pointed out the roles and importance of watercourses in the urban development of Zagreb and considers the impact of regulations on the change and development of the modern city [50]. Biological research focused on the increasing degradation of the environment and the ecological role of streams in connecting the city with nature [51]. Sociological research emphasized the growing awareness of citizens about the endangerment of streams and the need for their inclusion in the fabric of public urban areas [52]. Hydrological research indicated the problems of torrential water regimes, erosion, and flood protection in the city [53]. The analyses of previous findings show that most studies had a common emphasis on the need to reaffirm the natural and social landscape value of Zagreb's urban streams and develop a critical attitude towards the concepts of their channeling and/or transformation into traffic corridors.

Although watercourse landscapes have played a significant role in the historical development of Zagreb, spatial plans and the urban development of the city have not been systematically researched from the perspective of urban stream landscape changes.

1.3. Importance of Urban Streams in Historical Development of Zagreb

In the context of the historical development of the city of Zagreb, streams have always played an important role. Descending from the mountain massif of Medvednica in the north of the city, into the river Sava in the south, they irrigated the lowlands and ensured soil fertility for centuries, continuing the existence of the medieval city and surrounding settlements.

The Medveščak stream, which ran between two formative cores on the neighboring hills—Gradec and Kaptol—played a prominent defensive role in the development of the town [54]. It was also fundamental in the founding and operation of numerous mills in the 13th and 14th centuries, and also contained baths. In the 18th century, the first manufactories were built in its valley, and early industrial plants grew into the first industrial zone of the city at the beginning of the 19th century [55]. Due to increasing industrial pollution and the disturbed ecological balance of the stream valley, the Medveščak stream became the greatest obstacle to the development of the city, and at the end of the 19th century, it was transformed into a closed city sewage system. It was the first covered and regulated stream in the city of Zagreb. The part of the city where it once flowed was protected in 1953 as an urban ensemble of distinct environmental value, and in the 1980s it was revitalized and converted into a pedestrian zone—today one of the most vibrant areas of the city center [56].

Zagreb's urban streams are related to the formation of 19th century historical parks as the most valuable monuments of landscape architecture of the city. Historical Park Ribnjak was formed near the city cathedral on the site of an artificial former bishop's pond, which received water from the Medveščak stream. Maksimir Park, surrounded by a rich water system of seven streams and lakes, and it is considered the first public park in Southeast Europe and one of the first public parks in the world [57–59].

The regulation of most streams, the diversion, and the partial covering of regulated streams and planned canals began parallel to the industrialization expansion. The period from the second half of the 20th century to the present day has been marked by stream interventions, primarily in the function of protecting the city from floods. Many of them have been channeled, closed, and turned into road infrastructure. The arrangement of the remaining open streams through the city fabric is uniform, rectilinear with embankments built along both banks, whereby pedestrian interaction is enabled only in small parts.

Zagreb's urban streams lead the landscape wedges (green corridors) that were recognized as an element of spatial composition in the historical Zagreb Master Plans (1971), forming a landscape network, and shaping urban identity [60]. The integral planning vision of the city and the blue and green landscape has weakened with the rise in pressure from urban expansion, resulting in the fragmentation of landscape corridors. In the 21st century, Zagreb's urban streams are mostly not recognized as an integral part of the urban system of open public spaces, although they still represent a significant landscape resource.

1.4. Research Framework

This research aims to identify and map the changes in Zagreb's stream landscape from the middle of the 20th century in order to assess the influence of Zagreb's urban development and urban planning provisions on blue and green infrastructure and their services in contributing to the quality of life. The main research questions are as follows:

- What trends can be detected in the dynamic changes in Zagreb's stream landscape from the second half of the 20th century onwards?
- What urban planning criteria should be used for evaluating quantitative and qualitative changes in Zagreb's blue and green landscape?
- What are the indicators for detecting areas of critical urbanization pressure requiring the prioritization of urban planning measures for the social ecosystem service improvement?

An urban planning-social-ecological approach to the evaluation, monitoring, and management of urban stream landscapes that fosters the implementation of blue and green infrastructure into strategies and plans for Zagreb and other cities is provided by this research. Negative changes in the existing and planned state of Zagreb's urban streams are determined on the basis of the established criteria for evaluating changes in stream landscape, as well as on the basis of indicators for detecting areas of critical urbanization pressure. The roles and potential of Zagreb's stream landscape as an active asset of urban development provide implications for other cities in terms of establishing a balance between social needs, raising the quality of life as well as ecological and landscape quality.

2. Materials and Methods

The research on the dynamic changes in Zagreb's stream landscape is based on the urbanistic approach, which considers urban blue-green spaces (UBGS) an integral part of the urban area. It is based on urban planning research methods that interpret the structure and features of natural and urban landscapes using functional, historical-genetic, morphological, and visual analysis [61]. The quantitative and qualitative assessment of UBGS, as one of the most important concerns for sustainable urban planning, relate simultaneously to both social provisions (i.e., function) and environmental quality (i.e., form). In that way, the developed research approach supports urban green infrastructure planning that promotes both social and ecological resilience [49].

The research was conducted in three parts:

I. Research on the role of watercourse landscapes in planning in European green capitals (compared to Zagreb) was based on the analysis of relevant scientific sources and spatial planning documents for four selected European cities. The comparative analysis investigated models of blue and green infrastructure planning, as well as the goals and benefits that are realized through its implementation in the city.

II. Research on the stream landscape changes at the level of the City of Zagreb was conducted by superimposing spatial data from available cartographic sources (historical and contemporary) for the period from 1850 until 2020 (Table 1). The classification of watercourse flow types (open flow, closed flow, flow planned for closure) was established and the stream system was divided into five (5) spatial and functional groups. The dynamic changes in the stream flow types were compared to Zagreb's urban development and urban planning documents through quantitative research. The lengths of different stream flow types were measured, their shares/ratios were expressed, compared to each other, and correlated with the city area, total city population, and urban planning principles with regard to urban streams for the periods 1850–1968–1991–2020.

III. The most detailed part of the research referred to two distinctive sequences of Zagreb's stream landscape that have undergone a dynamic rural–urban transformation characterized by significant morphological, land use and landscape changes analyzed for periods 1968–1986–2018.

Table 1. Overview of research materials used in the analysis of dynamic changes in Zagreb's stream landscape.

Research Materials	Source	Aim and Usage of Research Materials
Maps, Geoportals and GIS Viewers		
Second Military Survey (1806–1869) 1:25,000 Third Military Survey (1869–1887) 1:25,000	Arcanum https://maps.arcanum.com/en (accessed on 29 March 2022)	Natural state and historical condition of the stream landscape and Zagreb's urbanization process
Digital Orthophoto Map 1968 (DOF 1968) 1:2000 Croatian Basic Map (1991) Hrvatska osnovna karta (HOK 1991) 1:5000 Digital Orthophoto Map (DOF 2011–2020) 1:500	MGIPU ISPU https://ispu.mgipu.hr/# (accessed on 29 March 2022)	Historical and present conditions of the urban stream system and Zagreb's urbanization process (DOF 1968 as an existing urban state for the Zagreb Master Plan 1971) (HOK 1991 as an existing urban state for the Zagreb Master Plan 1986) (DOF 2016 as an existing urban state for the Zagreb Master Plan 2016) Determination of green area percentage Character of urban morphology (built structure)
Spatial Plans		
Zagreb Master Plan 1971 Land Use Map 1971 Zagreb Master Plan 1986 Land Use Map 1986 Zagreb Master Plan 2016 Land Use Map	Zg GeoPortal Zagreb infrastructure of spatial information https://geoportal.zagreb.hr/Karta (accessed on 29 March 2022)	Ratio and character of the planned landscape of Zagreb's urban streams Realized usage of space (current state of use) Planned green space classification (planned land use)
Statistical data		
Number of inhabitants	Census 1850, 1971, 1991, 2021	Measure of the urbanization process and urban development of Zagreb
Field research		
Photographic documentation	Authors collection	Present condition and characteristics of the urban stream landscape in 21st century Zagreb

The research was conducted based on the visual image classification of maps made by using the holistic ability of human perception to recognize patterns [2,62]. Analyses, mapping, and metrics of UBGS were derived from available cartographic data sources—maps (Table 1).

i. Digital Orthophoto maps and Croatian Basic Maps were used for determining the green area percentage as well as the characteristics of urban morphology (building structure);
ii. Existing land use maps from the city GIS portal were used for determining the realized usage of space (current state of use);
iii. Land use maps from Zagreb's masterplans were used for determining the planned green space classification (planned land use);
iv. Housing density maps—derived by combining official population density, land use data and built structure characteristics (morphological analysis of building type and height).

Digital overlap of cartographic sources allowed for a graphic visualization and classification of four analytical spatial data layers:

i. Structural/morphological features indicating zones of transition from individual construction (family houses) towards multi-apartment settlements;
ii. Population density features show a gradual concentration of the population in certain zones—indicating areas of urbanization pressure;

iii. Existing green space areas classified into three distinctive (land use) types: public green areas (PUG), sports and recreation areas (SR), and unarranged green areas (UG);
iv. Planned green space areas classified into four distinct (land use) types: public green areas (PUG), protective green areas (PG), sports and recreation areas (SR), and unarranged green areas (UG).

Quantitative changes in the urban landscape were determined by objectively measuring greenness and expressed in the percentage area of green [63]. A total share of all existing (realized) and planned green spaces is graphically and numerically represented for each analyzed period.

A qualitative analysis seeks to determine the impact of landscape changes on the quality of life, which in urban planning largely depends on green space distribution, its (multi)functionality and spatial arrangement in accordance with population density. Therefore, to make a quality evaluation of stream landscape change more sensitive to urban context features, an additional four parameters were observed:

i. depth/with and continuity of green along the stream;
ii. built up density degree (morphology pattern);
iii. population density degree;
iv. multi functionality/public availability of green spaces.

Digital graphic superposition of three layers—existing green space areas, morphological characteristics, and housing density—enabled the visual identification of areas of critical urbanization pressure where local population density is above average, and the share and width of green areas along the stream is narrowest and most fragmented or even non-existent.

Additionally, special attention is paid to multifunctional public use and perceptual/identity value, as important urban planning parameters that aim to create high-quality urban green spaces [64]. Information on green space types (differentiating formal parks from informal or incidental green spaces) is a necessary step in describing and evaluating landscapes from an urban planning perspective [65]. Public green areas (PUG) are estimated as those of the greatest value as the most publicly available and the most flexible in terms of use. Sports and recreation areas (SR) have lower public use and perceptual value then public parks. What follows are protective green areas (PG), which most often do not have any public use. The least public use and social values are found in inaccessible unarranged green areas (UG).

Changes in the distribution of green space types (function) were identified visually/graphically (Figures 4 and 6), and the percentage area of each type was expressed numerically for both the existing state and planned use for all three research periods.

3. Results

3.1. The Role of Watercourse Landscapes in the Contemporary Development Strategies of European Cities

The European Green Capital Award (EGCA) has been awarded by the European Commission since 2010 as an incentive for cities to improve the environment and promote sustainable development. The Award promotes green actions in European cities and joins most objectives from the European Green Deal, the New European Bauhaus, and the Zero Pollution Action [66]. Out of a total of 13 winners of the EGCA so far, this research includes four (Essen—EGCA 2007; Nantes—EGCA 2013; Ljubljana—EGCA 2016; Oslo EGCA 2019), which stand out for their development of strategies and measures aimed at the better integration of green and blue surfaces [67].

The city of Essen planned a network of green and public open spaces based on the watercourses of the wider urban context as a part of the comprehensive ecological and economic renewal of the Ruhr region. The water system connecting the Emscher and Ruhr rivers with smaller watercourses, streams, and other types of water landscapes became a part of the network of cultural monuments, parks, forests, and other green areas joined into an integral and recognizable network for urban and regional renewal [68,69].

The metropolis of Nantes invested great effort in the restoration and rehabilitation of its extensive watercourses network, with a total length of over 250 km. As part of the so-called green and blue framework, 210 km of hiking trails along watercourses were established, with the aim of connecting the public with nature [70,71]. Biodiversity preservation is achieved by forming new green corridors as well as protecting and improving existing corridors that intersect with a rich blue network and the fabric of the city all the way to its center.

Due to the shortcomings of the drainage system, pollution, and limitations of urban development, many watercourses in Oslo were underground. Realizing that culverted watercourses have limited capacity to manage water, which can cause urban flooding problems in extreme weather events, the city implemented a new strategy of deculverting/daylighting urban watercourses. Closed rivers and streams are reopened wherever possible as an integral part of the climate change adaptation plan to make the city resilient to flood risk [72,73]. Oslo plans its future development in accordance with the carrying capacity of nature, making watercourses more accessible to residents, managing rainwater more efficiently, and restoring aquatic habitats. By deculverting as many streams as possible, blue-green corridors are formed through the city, making an urban network of living watercourses that connect the urban landscape into an organic, logical, functional, and attractive whole. In this way, a significant contribution is made to maintaining and strengthening the recognizable character of Oslo as a blue-green city [74].

Ljubljana demonstrates the preservation and strengthening of natural and cultural values as one of the strategic goals of a city's spatial development. Numerous urban green measures have already been implemented as part of Ljubljana's sustainable transformation. The basis of landscape planning is the preservation and restoration of five green wedges connected by green links into a network of parks that penetrate the city center and connect to the landscape hinterland. Water areas, watercourses, and coasts are particularly important elements as a link between green areas. The established blue-green infrastructure thus has a functional-design, ecological and climate role [75].

The analyzed cities have successfully implemented the concept of blue and green infrastructure on different levels of planning documents—strategies, action plans, and spatial plans (masterplans)—thus ensuring its systematic implementation. The landscape has been given multiple and important roles in sustainable development planning. Corridors of blue and green infrastructure are part of the image/physiognomy of the city that interconnect (through pedestrian routes) individual parts, the city as a whole and the wider region, that protect and enhance biodiversity and enrich the system of public spaces. In the highly urbanized areas, and especially in the areas of transformation, watercourses are reaffirmed as carriers of green corridors or as their links. Watercourses are protected in the peripheral parts of the city due to the preservation of natural structures within the green environment (Table 2).

Table 2. Contemporary urban blue-green infrastructure (BGI) planning comparison.

General Information	Essen	Nantes	Ljubljana	Oslo	Zagreb
EGCA	2007	2013	2016	2019	–
Population	584.41	318.808	292.988	698.66	779.000
City area	210.34 km^2	537.7 km^2	275 km^2	480 km^2	641.32 km^2
BGI planning levels					
BGI strategy	+	+	+	+	–
implementation in planning documents	+	+	+	+	–
BGI roles and benefits					
Blue-Green corridors, wedges	+	+	+	+	–
Ecological, biodiversity enhancement	+	+	+	+	–
Social and cultural	+	+	+	+	–
Identity, city branding	+	+	+	+	+/–

3.2. The Research on the Stream Lanscape Changes at the Level of the City of Zagreb

Zagreb's stream system is divided into five (5) spatial and functional groups, the West, Central-West, Central, Central-East, and East group (Figure 1), to enable a quantitative tracking of stream landscape change. A graphic interpretation of the genesis of Zagreb's stream system is created by superimposing spatial data from the available cartographic sources for the period from 1850 to 2020 (Figure 2). It demonstrates the most significant changes evident in stream closing, channeling and diverting interventions which are measured (length) and compared in ratio for each spatial group and for each genesis phase (Figure 3).

Established genesis phases of the Zagreb stream system (Figure 2) in correlation with historical planning documents (Table 3) can be described as follows:

i. The natural stage (1850 figure) was characterized by mostly free and meandering flows of streams descending from the slopes of Medvenica into the Sava River, forming the plain. In the 1850s, only one stream (Medveščak) flowing through Zagreb's historical core was partially closed. This phase was simultaneous with the initial urban planning documents for Zagreb, the Building Regulations from 1857 and the Regulation Plan from 1865, which do not mention the streams.
ii. The defense system (1968 figure) from torrent streams was developed after the great flood in 1964, by retentions, accumulations, stream bed regulation, diversion, channeling, and integration into the sewerage system as interventions that threatened the streams' character as valuable to the urban landscape. The Zagreb Master Plan of 1971 recognized streams as leading continuous landscape wedges (green corridors) through the city and as elements shaping urban identity.
iii. The landscape fragmentation (1991 figure) of green corridors led by urban streams and their additional closing characterized the transition of Zagreb from a socialist to a capitalist city in the 1990s. The provisions of the Zagreb Master Plan from 1986 referred to the streams with regard to defense from torrents, retentions and stream bed regulations, therefore enabling the fragmentation of Zagreb's green corridors.
iv. The additional closing of urban streams (2020 figure) and lost continuity of Zagreb's green corridors characterize 21st century Zagreb. The further closing of open streams within the urban area by the Zagreb Master Plan of 2016 demonstrates the trend of negative changes and planning neglect of the urban stream system.

All genesis phases of Zagreb's stream system indicate that the central urban area hosts the sites of the most intense urban pressure where urban streams are transmuted into grey infrastructure and where the continuity of Zagreb's blue infrastructure is interrupted (Figure 3).

Table 3. The comparison of the genesis of Zagreb's stream landscape, the population growth, and the development of Zagreb's urban planning documents. Source: Authors.

Phases of Zagreb's Urban Development	Features of Urban Stream Landscape	Population Number	Urban Planning Documents	Planning Attitude Toward Urban Streams
Mid-19th century Pre-Industrial City	Natural phase Regulation of Medveščak stream	16.036 (1850)	Building Regulations 1857 Regulation Plan 1865	Not mentioned in plans Water source Defense, manufacture, and industry role
The 60s and 70s Socialist City	Channeled Sava River Closings of central and central-east streams	629.896 (1971)	Zagreb Master Plan 1971	Defense from torrent streams Streams as leads for continuous green corridors

Table 3. *Cont.*

Phases of Zagreb's Urban Development	Features of Urban Stream Landscape	Population Number	Urban Planning Documents	Planning Attitude Toward Urban Streams
The 80s and 90s The transition from Socialist to Capitalist City	Closings of central-west, central and central-east streams in central Zagreb	777.826 (1991)	Zagreb Master Plan 1986	Defense from torrent streams in retentions and stream bed regulation Fragmentation of green corridors lead by urban streams
21st century city	Urban flows open only in west and east Zagreb streams	769.944 ** (2021)	Zagreb Master Plan 2016	Open streams planned for closing Loss of green corridors lead by urban streams

** Preliminary data.

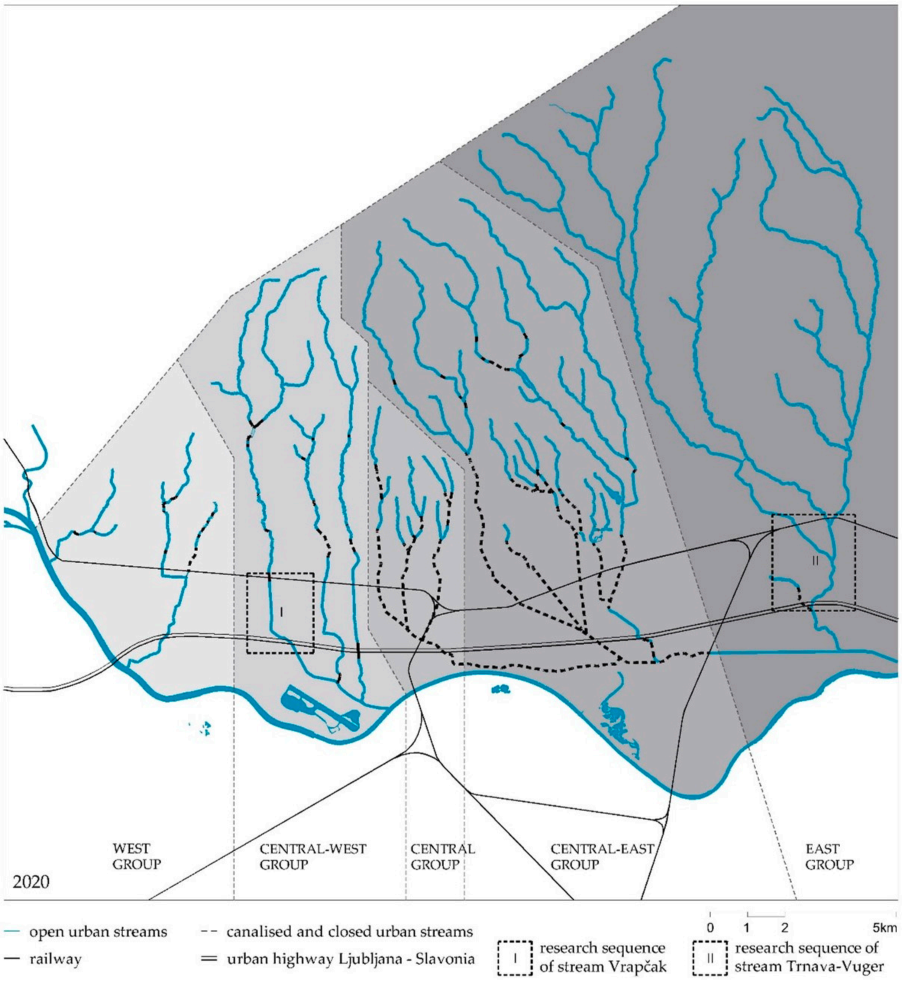

Figure 1. The current state (2020) of spatial and functional groups of Zagreb's urban streams. Source: Authors.

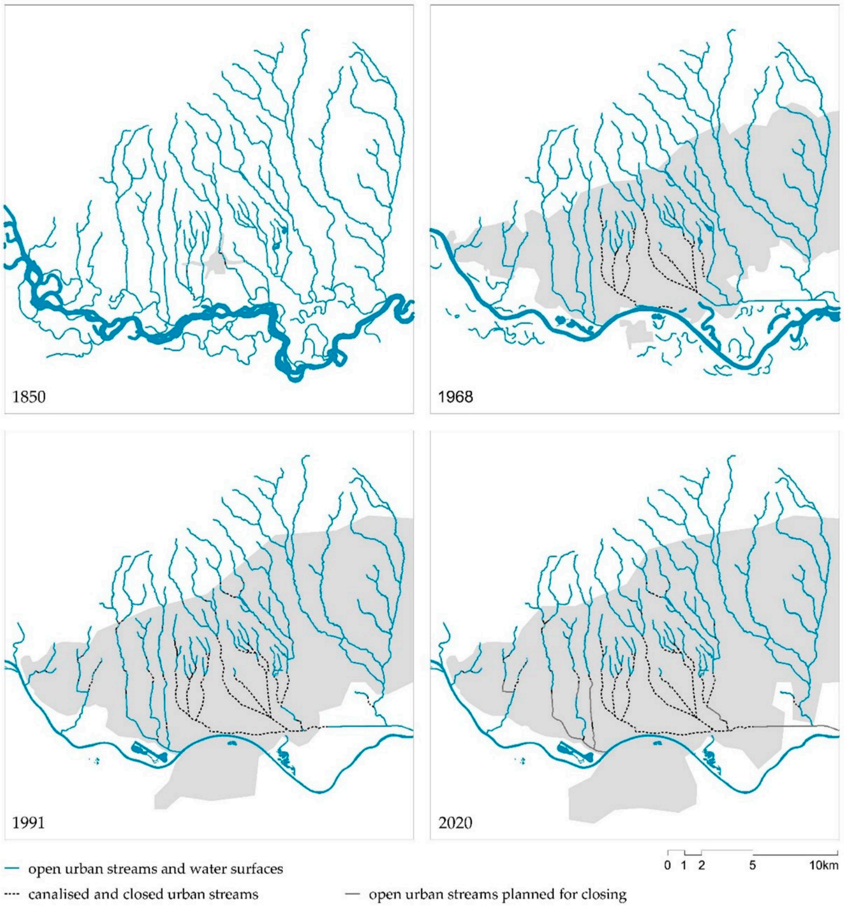

Figure 2. The genesis of the Zagreb stream system. Source: Authors.

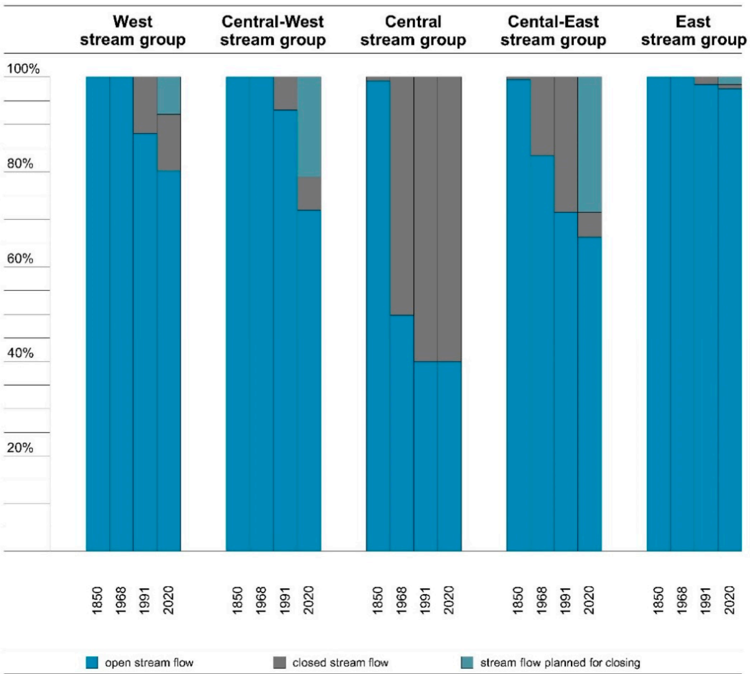

Figure 3. The ratio of open, closed, and stream flows planned for the closing of five spatial areas, in 1850, 1968, 1991, and 2020. Source: Authors.

3.3. The Research on Landscape Changes in Sequences of Selected Zagreb Streams

Two characteristic areas are selected for a more detailed examination of the dynamic changes in stream landscapes—the stream Vrapčak in the western part of the city, and the Trnava-Vuger streams in the eastern part of the city. The criteria for selecting research areas are as follows:

– areas included in the spatial planning documentation of the city (Zagreb Master Plan) in all analyzed periods—1971, 1986, and 2016,
– areas located on the largest landscape wedges (green corridors) planned in the Zagreb Master Plan of 1971,
– areas located in the part of the city, between the railway and Zagrebačka Avenue/Slavonska Avenue (city highway), which has experienced dynamic urbanization in the period from the second half of the 20th century onwards,
– areas of significant urban transformation in recent decades—new residential settlements built, transformed brownfield areas, emergence of uncontrolled illegal construction,
– areas covering min. 500 m on both sides of the stream bed as one of the most frequently used spatial indicator of green infrastructure.

3.3.1. Changes in the Landscape of the Vrapčak Stream

The research area along the Vrapčak stream is located in the western lowland part of Zagreb, where four open streams flow, in the Stenjevec district with a four times higher population density compared to the city [76]. The first settlements of an agricultural character were formed in that part of the city in the 19th century [77]. Significant structural changes began in the 1960s, when a largely undeveloped area of individual construction (family houses) began to gradually transform under the influence of metropolitan urbanization. Significant changes were initiated in 1976 by the urban plan of the first multi-apartment settlement (Sjeverno Špansko) and continued in the 1980s and 1990s with the intensive construction of a recognizable multi-apartment semi-block morphology [78]. The physiognomic transformation culminated at the beginning of the 21st century with the construction of housing estates of extremely high density (Špansko Oranice—250 inhabitants/ha; Pavlenski put—315 inhabitants/ha), partly realized in brownfield areas along the Vrapčak stream [79].

The impact of urbanization on the stream landscape, from 1960 onwards, is measured and compared based on urban criteria which are decisive/crucial for change monitoring. Quantitative changes in the landscape were analyzed and graphically presented (Figure 4). The results show an evident continuous reduction in the share of green (unbuilt) areas as well as their fragmentation. The changes can be followed from the 1960s, when almost half of the analyzed area was used for agriculture, until the last recorded state (2018), when only a third of the original landscape space remained undeveloped (Table 4).

Qualitative changes in the urban landscape were determined by comparing changes in the morphology of built areas, housing density and the use of green areas, and are shown graphically (Figure 5).

The results of the influx of a new population, whose number in recent decades has grown dramatically in some parts of the analyzed area, within the range from 19% to as much as 74%, include:

i. gradual structural (morphological) changes evident in the single-family to multi-story housing typology transformation;
ii. increase in housing density in the areas of intensified high-rise construction evident along Zagrebačka Avenue in the south and in the areas of the brownfield transformation concentrated along the Vrapčak stream itself (indicated with darker grey in the population density scheme—Figure 5);
iii. changes in the character (function) of existing green areas focused on the share of public multipurpose green spaces (parks). It was established that parks were formed only in the last period (2018), that their share in the total area of greenery is only 12% and that they are mainly not positioned along the watercourse (Figure 4).

iv. changes in the character of planned green areas (master plan land use) represent the intention of the planners to establish a significantly sized homogenous, compact, and continuous green wedge along the stream, which gradually decreased and fragmented from 79.6 ha in 1971 to 13.4 ha in 2018, making up a share of only 7% of the total area.

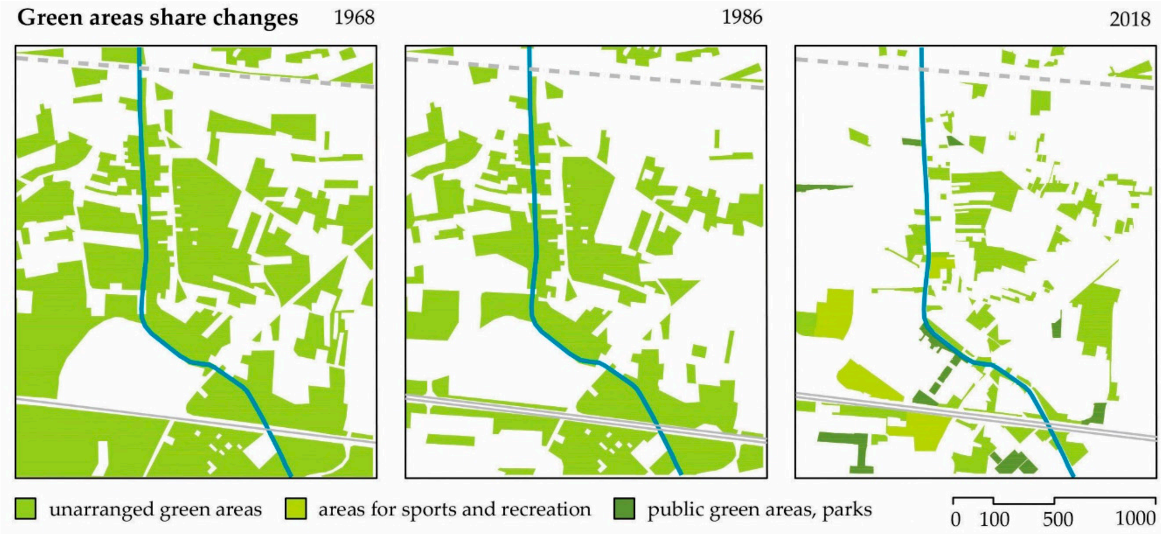

Figure 4. Changes to the existing state of green areas along the Vrapčak stream. Source: Authors.

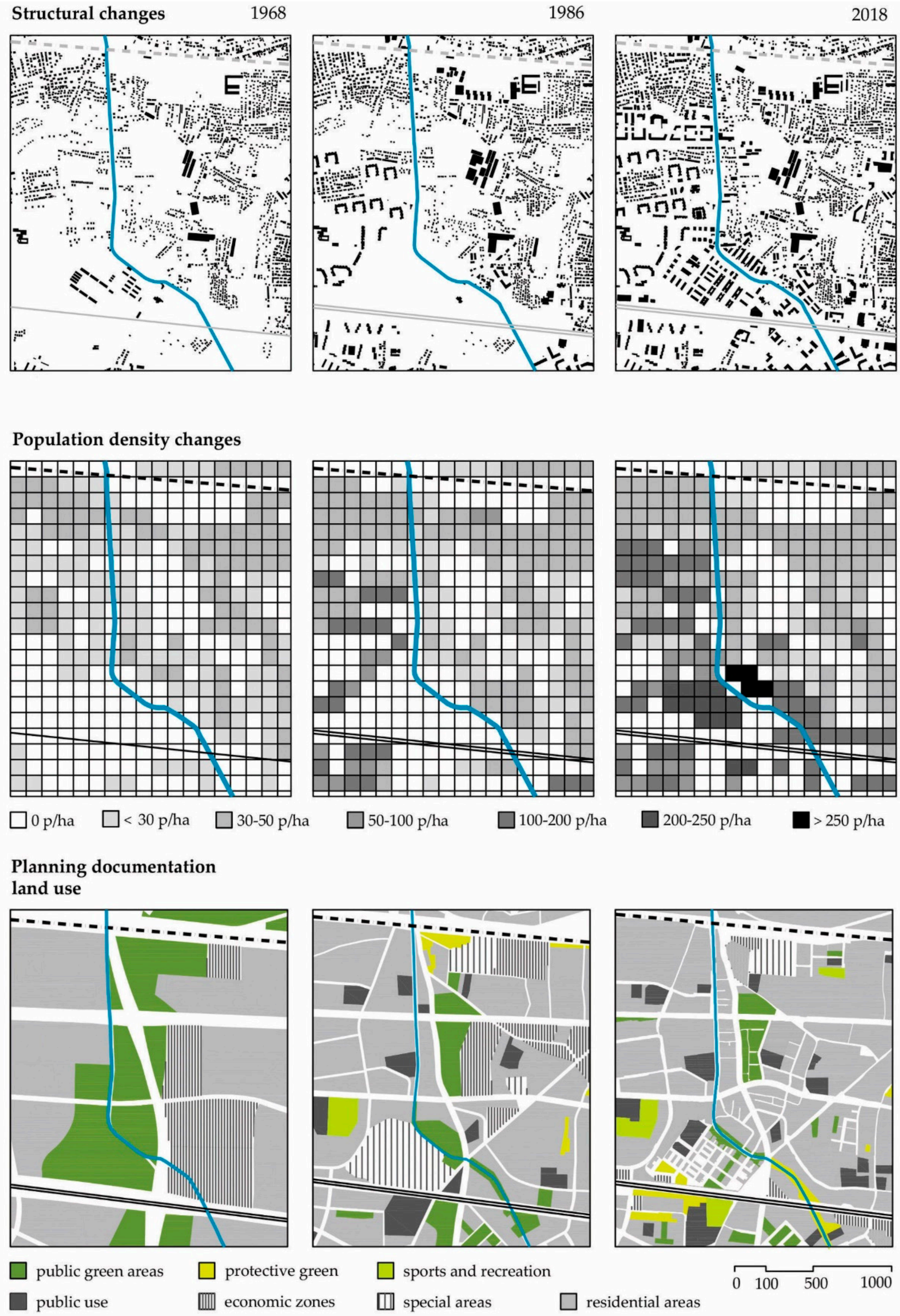

Figure 5. Urban landscape features along the Vrapčak stream. Source: Authors.

Table 4. The share of green areas along the Vrapčak stream. Source: Authors.

Year	Total Green Areas	Share of Green Areas in Total 380 ha
1968	181.7 ha	47%
1986	123.3 ha	32%
2018	62.5 ha	16.4%

The results indicate that planning decisions, in this example, did not anticipate the need for the qualitative and quantitative enhancement of blue-green infrastructure, which would have been an adequate response to the pressures related to the increase in construction and population density. On the contrary, the drastic urban development pressure, in the master plans, was accompanied by a decrease in public green spaces.

3.3.2. Landscape Changes in the Trnava-Vuger Streams

The research area along the Trnava and Vuger streams is located in the eastern part of the city (Sesvete and Donja Dubrava districts) in the area of a fertile plain that stretches towards the Sava River in the south. Until the middle of the 20th century, the Trnava and Vuger streams flowed freely, meandering through predominantly undeveloped green space of a distinctly rural character. In the mid-1960s, industrialization and the associated immigration of thousands of new inhabitants encouraged urbanization, first by developing and expanding the industrial zone, and then by expanding residential areas [80]. The morphological features of the area and the number of inhabitants in the recent period have been particularly influenced by two processes:

- spontaneous (illegal) construction of a dense settlement of individual constructions (Vrinice VII) along the Trnava stream in the 1990s, during and after the Homeland War when many refugees from war-torn areas came to Zagreb [81],
- realization of the residential settlement Novi Jelkovec along the Vuger stream with the transformation of a former pig farm in 2007 within the national program POS (subsidized housing) with an actual housing density of 245 inhabitants/ha [82].

Although the area is still largely undeveloped (50%), the first decades of the 21st century were characterized by a drastic change visible in the rapid expansion and densification of multiple housing estates, with the population growing by 21% to as much as 88%.

Quantitative landscape changes between 1968 and 1986 were minor. About 70% of the area consisted of landscape—agricultural and forest areas, and the part of the Vuger stream was regulated due to the realization of the traffic corridor. More significant changes in green areas are evident in the last stage (2018), when they were reduced to 49% (Table 5, Figure 6).

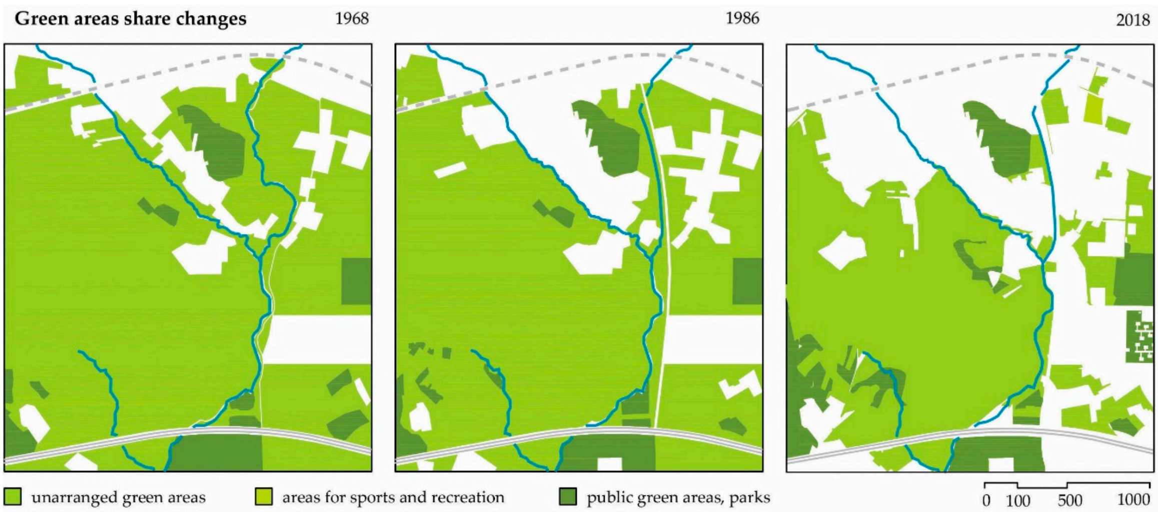

Figure 6. Changes in the existing state of green areas along the Trnava-Vuger streams. Source: Authors.

Table 5. The share of green areas along the Trnava-Vuger streams. Source: Authors.

Year	Total Green Areas	Share of Green Areas in Total 574 ha
1968	414.7 ha	72%
1986	398.6 ha	69%
2018	282.1 ha	49%

Qualitative changes in the urban landscape mark the 21st century and are visible in (Figure 7):

i. the expansion of built-up areas by almost 50% and morphological transformations particularly noticeable after the construction of a new multi-apartment settlement;
ii. an increase in housing density in the areas of intensified construction (spontaneous single-family settlements and planned high-density multi-story settlements);
iii. changes in the character (function) of existing green areas characterized by the abandonment of much of the former agricultural fields, transforming into unarranged neglected greens or forest parks;
iv. changes in the character of planned green areas (master plan land use) are evident in the planner's intention, from 1971, to divert several streams into a planned rectilinear canal running through one of the richly dimensioned planned public green wedges. In this way, the remaining areas were 'free' for the formation of the then-expected development of the city. In the next planning stages (Masterplans—1986, 2016), the diversion of watercourses was abandoned and landscape corridors along the watercourses gradually reduced.

3.3.3. Change Comparison of the Vrapčak vs. Trnava-Vuger Stream Landscapes

Urbanization has unquestionably affected the drastic reduction in stream landscapes of both analyzed areas, and consequently negatively influenced the multiple benefits that it could have provided to the city and its inhabitants (Figure 8).

The western part of the city along the Vrapčak stream has undergone a transformation from a sparsely populated agricultural area of dispersed individual housing to a very densely populated area with a strong urban character with high density residential settlements. The share of original landscape areas was thus reduced by 35%, their character was fragmented and today remains mostly unarranged. The Vrapčak stream did not become part of the public spaces of the surrounding settlements, as there are only a few small and fragmented parks along it. From all of the above, it can be concluded that the 'reserves' of free landscape areas have been reduced to a minimum (only 16.7% of the total area), and their ecological and multifunctional role in establishing the goals of sustainable planning is questionable today.

The eastern part of the city along the Vuger-Trnava streams is accompanied by a seemingly less drastic transformation, since almost half of its coverage is still undeveloped space. The most intensive changes in the residential part of the area are visible in two isolated spatial 'islands' caused by specific development circumstances—the settling of war refugees in illegal settlements and the city's policy of concentrating subsidized housing in the brownfield transformation zone. Both transformation zones occur alongside the watercourses, thus fragmenting and neglecting the stream landscape. The opportunity and potential for creating new public green spaces and improving the quality of life in critical areas exposed to the sudden pressure of urbanization have not been seized upon.

The established urban planning-social-ecological approach to stream landscape analyses enables a comprehensive evaluation and monitoring of its changes. By combining and interrelating quantitative parameters of (i) the percentage of green with qualitative parameters of (ii) social value (green space type and multi-function), (iii) perceptual value (depth and continuity of the blue and green corridor), and (iv) urbanization pressure (built-up and population) (Figure 9), it is possible to indicate critical areas. These are the stream landscape parts characterized by low landscape quality and exposed to the highest urbanization pressure that should be prioritized in urban planning action as the spots where the extreme decrease in blue and green should be stopped or reversed, and planning measures directed towards an increase in social and perceptual landscape value.

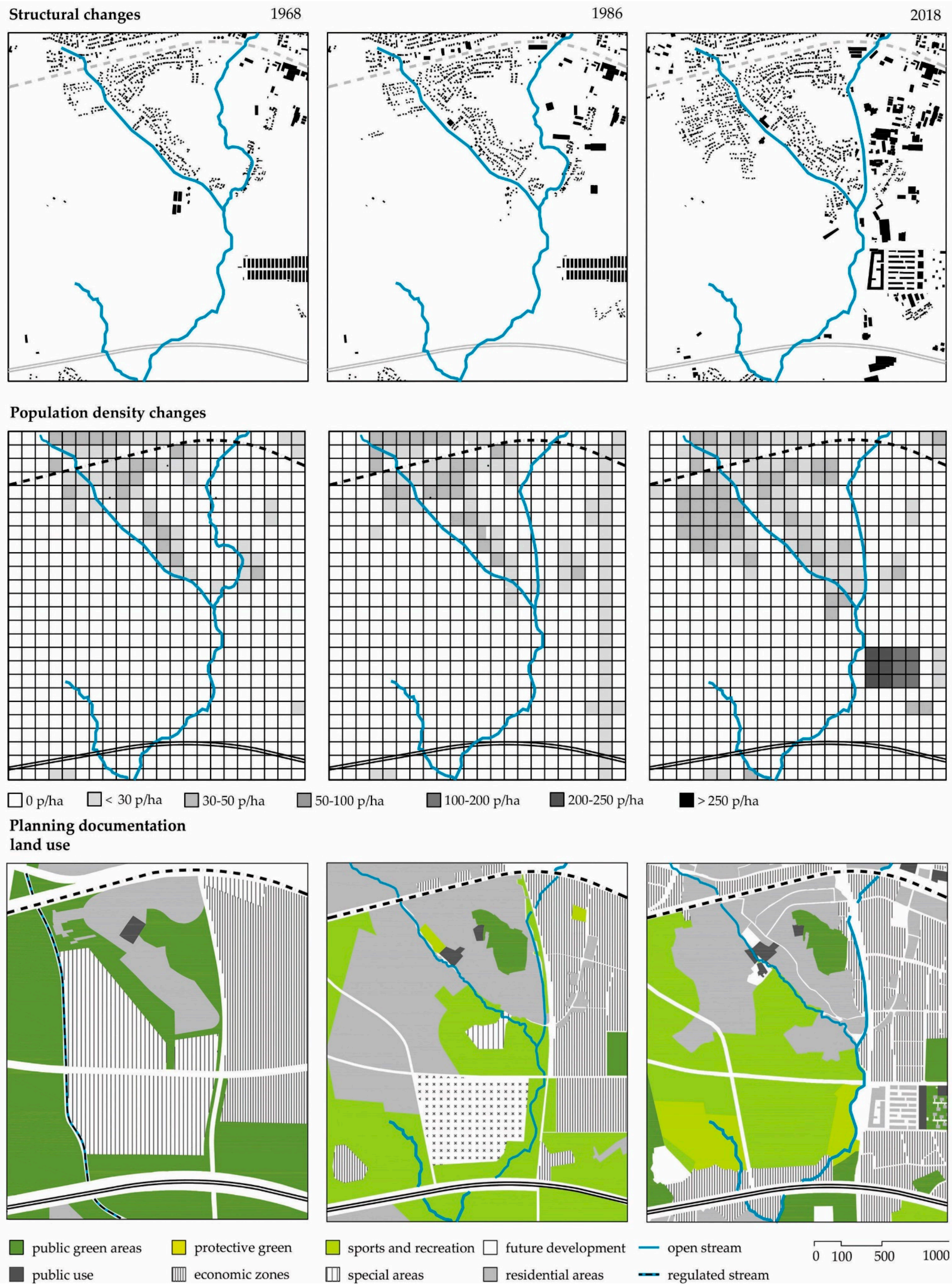

Figure 7. Urban landscape features along the Trnava-Vuger streams. Source: Authors.

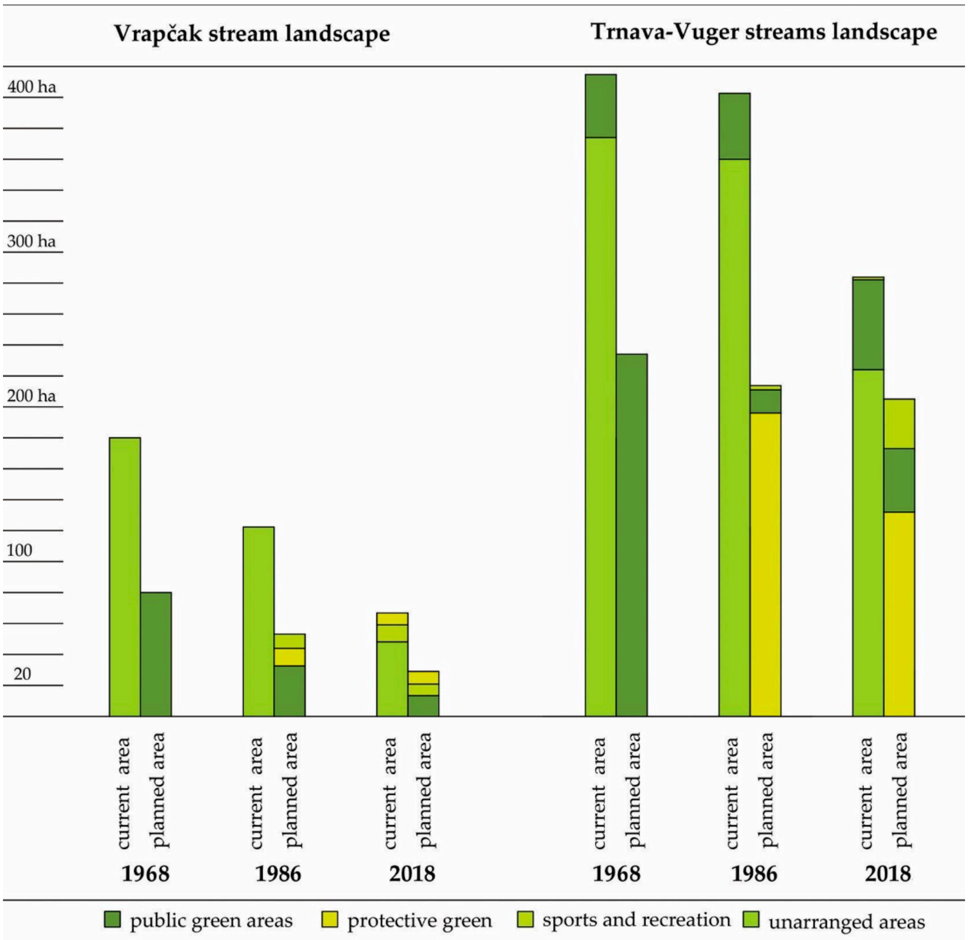

Figure 8. Stream landscape change comparison. Source: Authors.

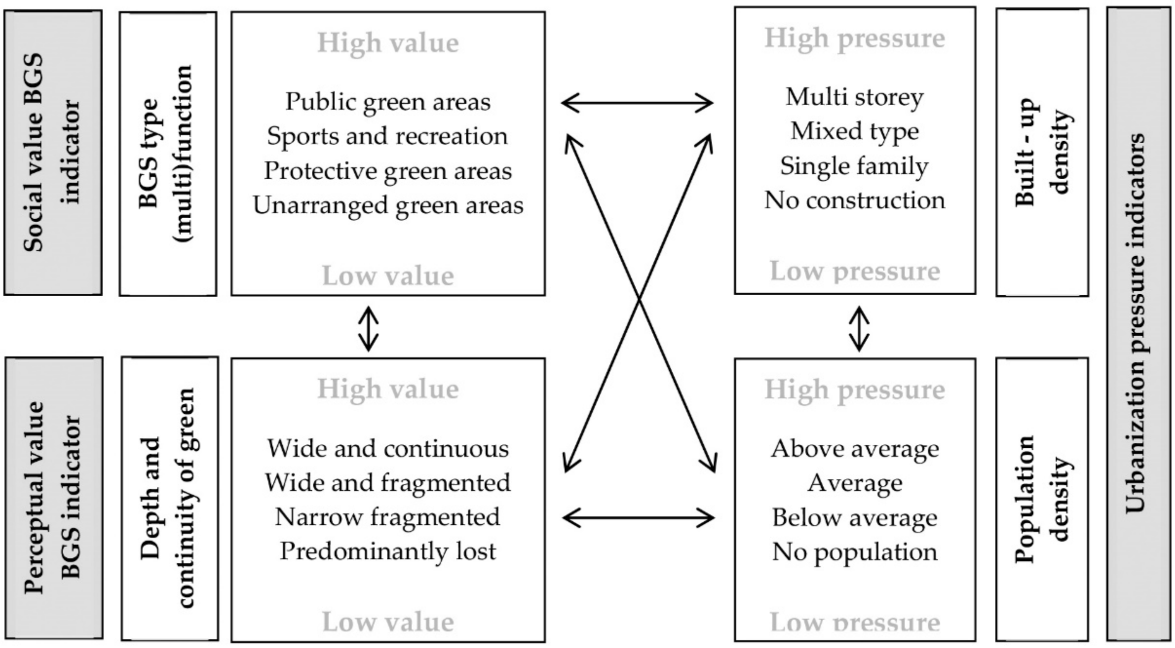

Figure 9. Interrelation and evaluation of urban blue and green space (BGS) criteria defining qualitative change indicators relevant to urban planning.

The conducted analyses of quantitative and qualitative criteria determined the places along the Vrapčak and Trnava-Vuger streams where the local population density is above average and where the share and width of green areas along the stream is narrowest, most fragmented or even non-existent. Additionally, from the comparison of current and planned strategies, it is concluded that the current Zagreb Master Plan (2016) does not provide prerequisites for sustainable planning that establish high social and perceptual values of BGS (high level of multifunctionality, continuity, and corridor width) in areas of high urban pressure (high built-up and population density).

The obtained results can be used in the development and implementation of the BGI strategies and plans of Zagreb and other cities, providing guidance for the detection of places for the necessary improvement of the stream ecosystem services, which should consequently raise the quality of life in the cities.

4. Discussion

4.1. Theoretical Evidence of Research Results

The broad context of the conducted research is set on the urban planning approach that examines the contemporary role of landscape in urban development [47,83–86], as well as means to control/balance urbanization pressures on the landscape [87,88]. A systematic review of the relevant literature (Section 1.1. Theoretical background) and good practice examples of development strategies of European green capitals (Section 3.1) indicate a constantly growing landscape approach in contemporary urban planning. This approach intends to improve the quality of the urban environment and the comfort of the urban population established on understanding that the best option for the organization of urban areas should be founded on landscape features [61]. Unlike the landscape approach taken in European cities, previous research by the authors shows that the modern planning approach in Zagreb is exactly the opposite. The role of landscape in Zagreb's urban planning has been gradually neglected, and an active approach to landscape planning at the city level has been drastically weakened [60]. The conducted research elaborated and confirmed the previous thesis focusing on a specific form of landscape—the stream landscape.

The theoretical review has confirmed that urban streams constitute a valuable form of multi-functional blue and green infrastructure [34] and can support urban development [27] to generate ecosystem, social, and economic benefits. In global cities undergoing expansion and densification, planning for BGI enhancement contributes to climate change adaptation [89–91], restoring ecosystem [92,93], water management [94,95], community health and wellbeing [96,97], improving the quality of life [98], and economic development [99,100]. The protection of natural capital to provide multiple benefits is a priority in implementing European green and urban policies—The European Green Deal, Urban Agenda for the EU, and European Strategy on Green Infrastructure. The benefits of BGI are also aligned with the European Spatial Development Perspective and the European 2020 Strategy as documents that promote the sustainability, resilience, and livability of urban landscapes.

The European Strategy on Green Infrastructure advocates for the full integration of blue and green infrastructure into EU policies and requires their implementation in master plans as binding planning documents that ensure the preservation of existing and enhancement of degraded landscape networks. The comparison of development strategies of European Green Capitals (Section 3.1) highlights the watercourse network as the key element in planning and establishing urban blue and green infrastructure on both the strategic level of city strategies and master plans and the implementation level of urban plans and design [101].

The literature review highlighted the lack of research focus on blue and green landscape changes anticipated by urban planning projections that relate to the neglect of scientific evaluation of spatial planning results [102,103]. Additionally, limited attention has been paid to the multi-faceted character of landscape change, evaluating the blue and green landscapes as either a physical phenomenon (form) or a functional element (use). These represent a knowledge gap that is complemented by conducted research. The spatial characteristics of the urban landscape system affect the specific processes and functions of urban areas, and therefore have to be considered when planning urban blue green areas for landscape services [104].

4.2. Empirical Evidence of Research Results

This research investigates quantitative and qualitative features of landscape and its planning at the level of the stream system of the whole city of Zagreb and at the level of individual stream sequences in the western (Vrapčak stream) and eastern parts of the city (Trnava-Vuger streams). The levels of stream systems and sequences relate to the planning of urban blue and green infrastructure on the strategic level and the implementation level. The research on the urban stream system provides the detection of key sites for restoring the urban watercourse landscape and for planning implementation. These are the sites of the most intense urban pressure, where the continuity of landscape corridors is interrupted, where blue is transmuted to grey infrastructure, and where the connection of the watercourse to the ecological network and to the society has been lost.

The research at the Zagreb city level is conducted on the genesis (1850–2020) of watercourse flow types (open flow, closed flow, flow planned for closure) according to the five-part spatial and functional streams system division. The research shows the transformation of 12.5% of natural flows into the closed streams flow, as well as an additional 11.8% streams planned for closing. The results confirm that the central urban area hosts the sites with the most intense urban pressure, where 60.1% of the total length of the stream has been transmuted into gray infrastructure and where the original continuity of blue infrastructure is interrupted. The increase in stream regulation was also confirmed by the analysis of planning documents for each genesis phase: from the 1850s' natural stage of mostly free meandering flows not mentioned in urban plans, to the 1971 Master Plan for the constitution of wide green wedges along the streams and the 1986 Plan for partial flow closing and green corridors fragmentation, to the last phase of the 2016 Plan, indicating additional flow closing, followed by the neglect and loss of green corridors.

The more detailed part of the research conducted at the level of two selected stream sequences (Vrapčak in the west and Trnava-Vuger in the east) indicated landscape transformation for the period 1968–1986–2018. The quantitative changes, determined by the objective measuring of greenness, confirmed that the share of original landscape areas was fragmented and reduced for Vrapčak by 35% and for Trnava-Vuger by 23%.

The quality evaluation of changes, observed by the interrelation of landscape and urbanization parameters, indicated areas in the state of critical negative change along the streams. These are areas of the greatest morphological density and landscape function changes, standing out as places with the most endangered landscape services. These are associated with the newly realized high-density settlements created by the brownfield transformation and spontaneous settlements of individual houses, whose drastic increase in population was mostly not accompanied by the realization of sufficient multifunctional and publicly accessible blue and green areas.

Although the former intention of the planners (1971) was to establish significant areas of homogenous, compact, and continuous public green wedges along the streams, the idea gradually decreased and fragmented for the Vrapčak stream from 20% in 1971 to only 7% of public green of the total area in 2018, and for Trnava-Vuger streams from 41% to 7% in the same period.

4.3. Responses to Research Questions

(i) What trends can be detected in the dynamic changes in Zagreb's stream landscape from the second half of the 20th century onwards?

The research on the stream landscape changes at the level of the City of Zagreb, as well as the research on the Vrapčak and Trnava-Vuger streams, indicates the trend of negative changes to the urban stream system. The continuity of Zagreb's blue and green infrastructure has already been interrupted by transmuted urban streams into gray infrastructure, as well as by the constant reduction, fragmentation and disconnection of the green spaces accompanying streams from the past. The planned neglect of streams is obvious in plans (Master Plan 2016) in the additional closures of open streams and the reduction in planned public green areas compared to previous periods. The negative trends result in the reduction in the ecological, environmental, and social value of the city and the decrease in the quality of life for urban dwellers

(ii) What urban planning criteria should be used for evaluating quantitative and qualitative changes in Zagreb's blue and green landscape?

The implementation of urban blue and green infrastructure calls for a simultaneous quantitative and qualitative assessment needed to direct cities towards the enhancement of human well-being and urban sustainability. Urban planning criteria for evaluating landscape change have been derived from an urban planning-social-ecological approach to the evaluation, management, and monitoring of urban stream landscapes, including:

- the existing state of the blue and green landscape;
- the planned state of urban planning projections for blue and green landscape;
- environmental quality of land cover (landscape form);
- social provisions for land use (landscape function).

Urban planning criteria lead to quantitative and qualitative parameters that need to be observed over the course of time (historically) by monitoring changes in the existing and planned state, land cover and use in order to determine a trend in landscape change.

(iii) What are the indicators for detecting areas of critical urbanization pressure which require a prioritization of urban planning measures for social ecosystem service improvement?

The combination and interrelation of quantitative and qualitative parameters of landscape change provide indicators for identifying areas of critical urbanization pressure. The quantitative parameters of the blue and green landscape change are determined by (i) objective measuring and share a comparison of stream flow types (open–closed) and by (ii) measuring greenness expressed in the percentage area of green. The quality evaluation of blue and green landscape change is determined according to (i) landscape parameters: depth (continuity of green along the stream) and multi-functionality (public availability of green spaces); and according to (ii) urbanization parameters: built-up density degree (morphology pattern) and population density degree.

The stream landscape areas characterized by a low percentage of green areas, by low landscape quantity of social and perceptual value, and exposed to high built-up levels and population density, indicate areas of critical urbanization pressure on the blue and green landscape. The indicated areas should be prioritized in urban planning action as the spots where the extreme decrease in blue and green should be stopped or reversed, and planning measures directed towards an increase in social and perceptual landscape value.

5. Conclusions

This study analyzes the quantitative and qualitative changes to Zagreb's stream landscape from the urban planning point of view. The provided method identifies a negative trend in the change in Zagreb's stream landscape and critical areas of urban pressure that require prioritization in urban planning measures for improving social and ecosystem landscape services. By developing an urban planning-social-ecological approach to the evaluation, management and monitoring of urban stream landscapes, the benefits achieved by the blue and green infrastructure could establish a balance between urban dwellers' needs and ecological needs by assuring the expected quality of life and quality of landscape in cities.

Although watercourse landscapes have played a significant role in the historical development of Zagreb, spatial plans and the urban development of the city have not been systematically researched from the perspective of stream landscape changes. This research contributes to promoting the contemporary roles and significance of Zagreb's urban streams, fostering urban stream system as an active asset of Zagreb's urban development and planning, and affirming the potential of the stream landscape in achieving urban resilience and sustainability.

The research results establish urban planning criteria for evaluating quantitative and qualitative changes in Zagreb's blue and green landscape, as well as indicators for detecting areas of critical urbanization pressure. The obtained results can be used in the development and implementation of BGI strategies and plans for Zagreb and other cities, consequently raising the quality of life in them.

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