▲ **Palabras clave/** Infraestructura verde, planificación territorial, cambio climático.
▲ **Keywords/** Green infrastructure, territorial planning, climate change.
▲ **Recepción/** 22 enero 2019
▲ **Aceptación/** 10 septiembre 2019

From ecological networks to green infrastructure as mitigation actions: Florence's Metropolitan Area, Italy

De redes ecológicas a infraestructura verde como medidas de mitigación: el área metropolitana de Florencia, Italia

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ABSTRACT/ This article proposes ecological networks and green infrastructure as mitigation actions to avoid natural disasters produced by climate change and their possible application in the territorial planning of the metropolitan area of Florence, Italy. This city has declared the need to plan the Area Vasta proposing new infrastructure networks. However, how to solve territorial fragmentation, uncontrolled urban sprawling, and protected area disconnection is still unclear. The question is how the territorial planning of the Florence Metropolitan Area can incorporate new tools for the integration of natural and urban systems while avoiding the risk of climate change. In conclusion, integrated territorial planning is necessary to achieve connectivity between natural and urban systems so as to mitigate climate change risks and achieve more resilient metropolitan areas. **RESUMEN/** En este artículo se propone a las redes ecológicas y la infraestructura verde como medidas de mitigación para evitar los desastres naturales provocados por el cambio climático. Específicamente, se apunta a su potencial aplicación en la planificación territorial del Área Metropolitana de Florencia, Italia, ciudad que ha establecido la necesidad de planificar su Area Vasta proponiendo nuevas redes de infraestructura. Sin embargo, algunos problemas son de difícil solución, por ejemplo, la fragmentación territorial, la urbanización descontrolada y la desconexión de las áreas protegidas. La pregunta a responder es cómo incorporar nuevas herramientas para integrar los sistemas naturales y urbanos en la planificación territorial del Area Vasta de Florencia, evitando al mismo tiempo los riesgos del cambio climático. En suma, la planificación territorial integral es necesaria para conseguir conectividad entre los sistemas naturales y urbanos, permitir mitigar los riesgos que implica el cambio climático y mejorar la resiliencia de las áreas metropolitanas.

INTRODUCTION

Urbanization processes are related to global environmental change in an important way, although urban areas represent only 2% of the Earth's surface. They produce 78% of greenhouse gases and contribute to global climate change. Anthropogenic activities, like urban sprawling, are the most irreversible and human-dominated forms of land use. Urban sprawling is indeed changing landcover, hydrological systems, biogeochemistry, climate, and biodiversity (Seto et al. 2011).

In fact, cities are responsible for the alteration of global biogeochemical cycles and biodiversity changes due to habitat fragmentation, introduction of exotic species, and changes in land use and coverage that go well beyond cities' boundaries (Brunetta and Voghera 2014).

In the past decades, ecological networks have been defined in multiple ways. Environmental sciences understand ecological networks as coherent natural or semi-natural systems the purpose of which is to maintain or restore ecological functions for the conservation of biodiversity and habitats (Fariña-Tojo 2001). More recently, ecological connectivity is not only meant in a physical sense but also functionally. The distribution of green infrastructure elements can help in the mitigation of the urban heat-island effect, ventilation, and access to green spaces for recreational use (Hansen and Pauleit 2014).

During landscape planning, these networks

enhance the quality aspects of perception, identity, and use, and focus on the connection between "natural environment" and "urban environment" (Battisti 2004). In the case of environmental policies, focusing on the networks' structure is functional to maintain biological continuity and to implement conservation operations for natural systems (Todaro 2010).
Furthermore, within territorial planning, an ecological network may varyingly become an interconnected system of habitats whose biodiversity needs to be safeguarded; and a system of parks and reserves embedded in a coordinated system of infrastructures and services. We can also outline a polyvalent ecosystem scenario that supports sustainable development (Malcevschi 2010).
In 2015, the Florence Metropolitan Area was arranged following the reorganization of the Province and the promulgation of Act 56/2014, (Gazzetta Ufficiale 2014,1) which defines its functions as follows: "[...] care of the metropolitan area's strategic development; integrated promotion and management of services, infrastructures and communication networks of interest for the metropolitan city; care of same-level institutional relations [...]" (author's own translation from Italian).
Although this new law indeed introduces the concept of infrastructure networks, what is not clear is the incorporation of ecological networks in the metropolitan planning of Florence Metropolitan Area. To draw inspiration from network semantics is required in order to be able to identify the "connection" between the two situations described above (the eco-networks and the metropolitan city in the vast area planning).
Thus, this paper highlights the features of the development of ecological networks and green infrastructures as mitigation climate change actions and the possible application of these tools in the context of the metropolitan territorial planning of Florence. This research addresses the question of how the territorial planning of the Florence Metropolitan Area can introduce new tools for the integration of natural and urban systems while avoiding climate change risks.
The structure of the article is as follows: First, it starts with a literature review; then the general background of the metropolitan area of Florence is introduced, to continue with the method. In the fourth section, the findings of the analysis of the case study are conducted, followed by discussion and conclusions.

1. LITERATURE REVIEW

1.1. Multifunctional networks

Green and blue infrastructure concepts initially promoted by the European Community and later by the Ministry for the Environment can be used like a bridge between natural territory and anthropic semi-natural and artificial aspects. In this context, a polyvalent ecological network may be defined as the design of a vast area in which the needs of the various levels of an ecosystem combine efficiently with the needs of the population who lives in that territory (Malcevschi 2010).
Connectivity in urban ecosystems is achieved through multifunctional networks known as greenways, ecological networks, blue or green networks, waterways, and parks. All these networks are related to hydrology, transport, and urban mobility. Greenways are important to achieve urban biodiversity and should be conceived, planned, and designed early on each territorial planning process (Bryant 2006, Ahern 2013). The connectivity in urban ecosystems is threatened by fragmentation. There are four types of effects caused by fragmentation (Fariña-Tojo 2001): The extension of certain habitats is reduced, the margins increase, the whole area shrinks, and the single pieces become more isolated. While we studied these effects, we highlighted both the "critical environmental issues" and the similarly well-known "anthropic barriers". Additionally, we developed models to analyze the environmental fragmentation and defragmentation widely used for various applications and which resulted in the development of GIS-dedicated algorithms.
We can understand green infrastructure as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services, such as water purification, air quality, space for recreation, and climate mitigation and adaptation" (European Comission 2017).
Green infrastructure can also be defined as an element that enables the development of ecological relations between the city and its environment, whilst catering for social needs that are fundamental for the attainment of a high standard urban life (Tulisi 2017).
Specifically, green infrastructure refers to the development of urban green spaces, such as parks, rain gardens, and greenways that provide a variety of social and ecological benefits, from improved public health to stormwater abatement (Meerow and Newell 2017).
Green infrastructure can also be viewed as simultaneously providing natural resource sinks to assist urban climate control and water management, and provide important green networks in an increasingly urbanized territory. Green infrastructure planning is more a synthesis of different planning approaches than a completely new approach (Mell 2009).
Finally, green infrastructure is a concept for systems that provide multiple ecosystem services in urban areas. Green infrastructure is often a hybrid of built infrastructure and human-made ecosystems as is the case with stormwater wetlands that process highway drainage, or bicycle corridors that provide wildlife habitat and connectivity (Ahern 2013).

1.2. Mitigation, ecosystem and resilience

In 2015, the European Union's Energy Commission increased the relevance of environmental policies for the reduction of greenhouse gases (GHG) emissions through a political incentive fund –an electoral dividend for mayors– who commit to reducing emissions at a local level for climate change mitigation (made within the Covenant of Mayors of the EU) (Martelli et

al. 2018). In fact, urban sprawling interacts with global environmental change in important ways. Although urban areas account for only 2% of the Earth's land surface, they produce 78% of greenhouse gases, thus contributing to global climate change (Brunetta and Voghera 2014).
Global warming is unequivocal. Nonetheless, the effects of global warming and the related changes in climate and geo-hydrological hazards (e.g., floods, landslides, droughts) remain difficult to determine and to predict (Gariano and Guzzetti 2016).
In the past years, flooding is a major social and economic issue across Europe. The increasing risks of flooding are not solely due to changing climate patterns but also to river catchment management from uplands, through floodplains to rivers (LIFE Platform Meeting 2014).
An important climate change-mitigation city planning procedure is the introduction of geography and ecosystems, including wetland coastal areas, lakes, and rivers (UN-HABITAT 2011).
Over the past few years, green spaces have been recognized as effective tools to fight climate change impacts, particularly in terms of mitigation and adaptation policies (Tulisi 2017). Two very important ecosystem properties linked to this objective are resilience and resistance. Resilience is the capacity of an ecosystem to return to the condition prior to a disturbance once this is suppressed, and it is related to the self-regulation ability. (López et al. 2013).
Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters (Holling 1973). Since the last decade, the concept of resilience has been used in different scientific fields to refer to the capacity of ecosystems, people, societies, the economy, and even urban systems to deal with disturbances (Chelleri 2012).
Other authors suggest that: [...] resilience also has a social dimension, both formal via welfare state institutions and informal in terms of volunteerism and mutual trust. The notion of recovery also includes the capacity to learn, meaning that recovery should not imply just restoration. Instead, regulations and also habitats may change, and economic structures may adapt [...] (Van Well et al. 2018, 2).

1.3. Waterway requalification and river restoration

Waterway requalification is intended as "[...] *an integrated and synergic combination of actions and techniques of various kinds (from legal-administrative-financial, to structural) designed to bring a waterway and its connected surroundings ("river system") up to the most natural conditions possible, and able to fulfil its characteristic ecosystem functions (geomorphologic, physical-chemical, and biological), and maintaining a higher environmental value whilst trying to satisfy socio-economic objectives*" (CIRF 2006).
The "requalification" concept adequately expresses the idea of moving from degraded to better situations. Furthermore, the idea of requalification actions is not to return to the original state before human intervention, although it could always consider potential conditions like geographic location of waterways, climate, topographic, geological and geomorphological features, and previous history (CIRF 2006).
Another strategy being used today is river rehabilitation, a concept based on a multidisciplinary approach. It aims at the restoration and operation of the river or fluvial system, supporting biodiversity, recreation, flood management, and landscape development (European Centre for River Restoration 2018).
Some authors suggest that cities with waterfront conditions have the opportunity to design water-facing areas to improve landscape sustainability, enhance the safety and quality of living, and help people rebuild their sense of identity by introducing landscape adaptation and regeneration strategies (Sessarego 2017).
We suggest a framework that integrates the concepts of territorial planning and mitigation and adaptation policies that are disconnected in the literature. Territorial planning includes geographical and ecosystem aspects that, in turn, are reflecting hydrological features –such as wetlands, coasts, lakes, and rivers– that possess special resilience and resistance properties. On the other hand, mitigation and adaptation policies are built upon multifunctional networks that include green infrastructure which, in turn, includes greenways, blue and green networks, and requalification waterways. Once implemented, multifunctional networks can result in several social and health benefits for inhabitants, as well as in biodiversity and climate change adaptation and mitigation (figure 1).

2. BACKGROUND OF FLORENCE METROPOLITAN AREA

The Florence Metropolitan Area covers a surface area of 3,500 km2, with a population of 1.7 million inhabitants. This Metropolitan Area has many cultural institutions and high- level international education centers, as well as world-class manufacturing, crafts, winemaking and gastronomy industries all within a high-value landscape.
"Contrary to other metropolitan cities, and in line with the Law 142/1990, the Regional Council of Tuscany (DL 130 of 01/03/2000) had already determined the metropolitan area of Florence through the merging of the Provinces of Florence, Prato and Pistoia, mainly focusing on the coordination of programming and spatial planning activities" (Rubbo 2018, 39).
The Metropolitan Area is crossed by one of Tuscany's most important waterway corridors: The Arno river. River areas and their immediate surroundings need to be managed with an integrated network of the smaller hydrographic network and a more naturalistic planning as far as the main contained waterways (first and second order) are concerned, so as to

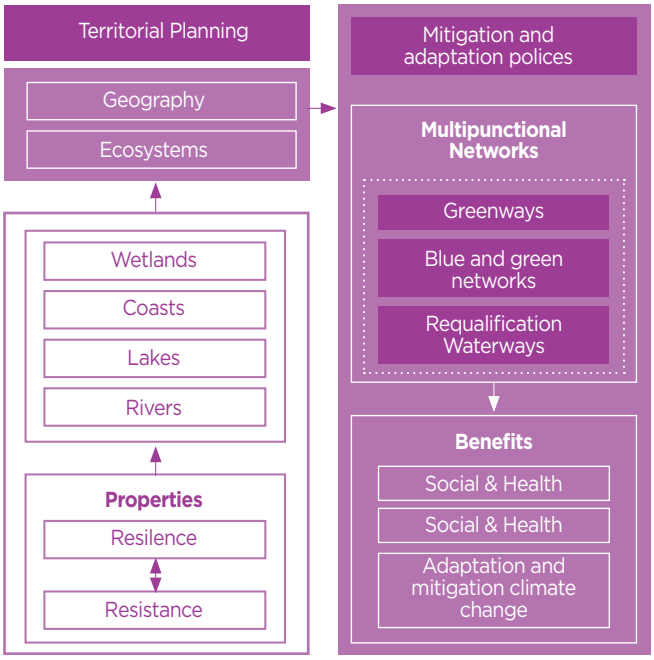

Figure 1. *Territorial planning and multifunctional networks' framework (source: Own elaboration).*

Figure 2. *From above: Arno river and its surroundings areas, Mugnone river and Terzolle river during some riverbed arrangement work of 2017 (source: Own archive).*

achieve a proper or excellent water quality and ecological state of overall waterways (European Union Law, EU Water Framework Directive (WFD) 2000/60/EC).
The role of the Arno River as a multifunctional blue-green infrastructure has become topical as a consequence of the legal institutionalization of the Metropolitan City of Florence (2014), which coincided with the 50th anniversary of the Florence Flood (Alberti and Paloscia 2018). Although several initiatives have already been conducted in the Arno River area, many restorations are still missing (see examples in figure 2).
This decision would also reinforce natural protection factors against hydraulic risks and hydro-geological instability. We suggest that waterway requalification and rehabilitation promote the implementation of various ecosystem services. It provides and restores habitats, contributes to climate change mitigation by absorbing carbon, offers recreational opportunities, helps prevent disasters by consolidating riverbanks, filters pollutants and shades crops in farming, and improves the urban fabric by improving overall well-being.
In the context of the metropolitan city, substituting endless sequences of impromptu buffer interventions with integrated, multi-disciplinary, flexible, and cyclical management of blue and green infrastructures could be an additional opportunity to retrieve ancient lifestyles and territory uses.
The role of the Area Vasta has been outlined in Act 56/2014 about an inherent administrative level for provinces and municipalities and is aimed at the planning and management of the territory, the resources, and the relationships among local authorities working with municipalities and regions.
The document, drawn up by the Italian Ministry of Environment, Territory, and Sea Protection titled "Towards a National Strategy for Biodiversity 2009" (own translation from Italian) refers to the "vast area planning" as a tool to apply an ecosystem approach (Giupponi, Galassi, and Pettenella 2009).
The administrative boundaries of the Florence Metropolitan Area embrace an extremely non-homogeneous territory. Although the area (which matches that of the former Province of Florence) is strongly subjected to urban sprawling dynamics which mainly concern the plains and hills, it also includes a large forest area (44% of the entire surface) and another significant portion devoted to agroforestry (Città Metropolitana di Firenze 2017).

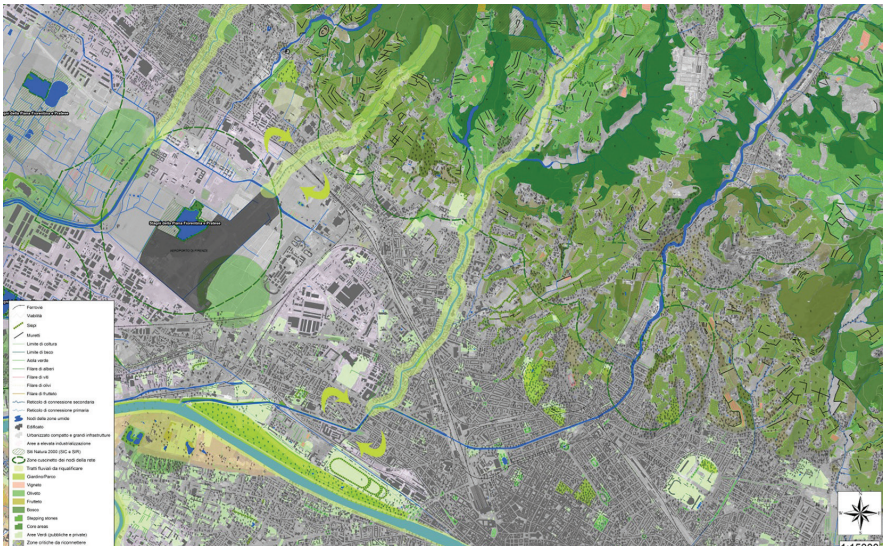

Figure 3. *Proposal for ecological interconnection in urban areas of Florence. The double green arrow on the point of confluence between the main river and the secondary streams (Mugnone and Terzolle) highlights some points on which to carry out an ecological reconnection (scale 1:15.000) (source: Own elaboration).*

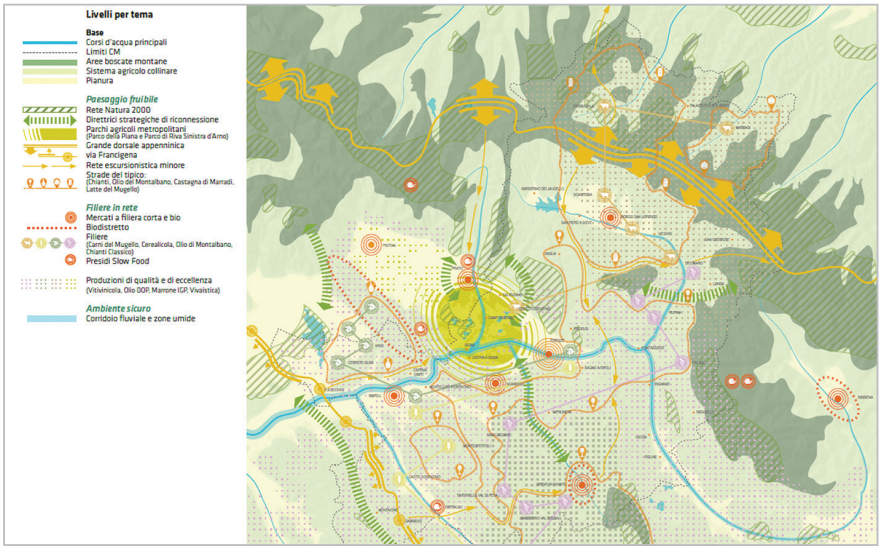

Figure 4. *Strategic territorial plan integrating ecological network and green infrastructure (source: re-elaboration vision 3 of Metropolitan Florence Strategic Plan – PSM, 2017 at the scale 1:400.000).*

The 42 municipalities within the Florence Metropolitan Area, and particularly those which have endured widespread urban sprawling (e.g. Florence, Empoli, Scandicci, Pontassieve), as well as the municipalities within the heavily anthropized Piana Fiorentina (Florence – Prato – Pistoia), have found it useful to refer to an eco-territorial network and green infrastructure, precisely to underline the presence of minor, but not irrelevant, natural elements (Magnaghi, Fanfani, and Bernetti 2010).
These zones are distributed mainly in the metropolitan area of Florence and also where in places with intensive urban sprawling and industrialization. They may be "added to the system" due to the existing ecological interconnection elements (figure 3) and often inaccessible remote and isolated natural areas.

3. METHOD

Considering the Florence Metropolitan Area as representative of the impacts of unplanned urban development and its devastating consequences, it was chosen as a single case study. In fact, the last devastating impact was registered in 1966, when the Arno River damaged historical Renaissance buildings and art-related heritage through unprecedented floods (Salvestrini 2016). The case is relevant because the region holds the world's largest Renaissance art heritage that is exposed to urban intervention and climate change threats.
Secondary data were collected, including legal frameworks and projects or actions designed by the authorities but still not implemented. The laws that affect the case in terms of urban planning and climate change actions are:
• Act 56/2014 (April 7th), titled "Provisions on Metropolitan Cities, on Provinces, on Unions and Mergers of Municipalities"
• Act 2000/60/CE about water ecology from the European Union Law.
Additionally, information disclosed by the Metropolitan Area of Florence in the "Metropolitan Renaissance Strategic Plan 2030" report was reviewed.

4. FINDINGS AND DISCUSSION

One possible solution for the environmental "disconnection" identified so far could be to upgrade intercluded areas. In the case of the Florence Metropolitan Area, for instance, recovering these areas by means of self-managed collective activities like farming (e.g. urban allotments) could ease re-territorialization and reconnect, defragment, and requalify the agro-landscape fabric. Hence, the concept of ecological networks and green infrastructure needs to be introduced in the Area Vasta planning, especially when the network is integrated and polyvalent. The Metropolitan Florence Strategic Plan is an example of this integrated approach (see figure 4).

Also included in this typology are those urban stretches of watercourses characterized by at least one supporting vegetation strip, preserving or enhancing the natural state of the river. Many projects are good examples and point in the direction of 'daylighting' in urban areas (reopening of 'buried' streams) conducted in important European metropolis such as Zurich or Madrid, or non-European cities like Seoul (Nardella et al. 2017).

One of the first problems that emerge when adopting an eco-system approach within a metropolitan area is fragmentation. Environmental fragmentation means an active process of anthropic origin during which a natural area is segmented into small fragments which are increasingly isolated from each other and less connected among themselves. This fragmentation causes a territory to break down into multiple pieces which undermine its coherence. An increase in the number of pieces, or tiles, shows the progressive anthropization of the so-called "eco-mosaic" (Malcevschi 2010). This happened, for example, in the Florence-Prato-Pistoia plain, a strongly fragmented area (figure 5).

Another problem that needs attention when planning a systemic Area Vasta is uncontrolled urban sprawling . We can briefly introduce this phenomenon by referring to a synthesis of PLoS ONE journal from 2011, (Seto et al. 2011), summarizing various monographic studies, and taking information from different case studies (see figure 6).

The third point is particularly interesting when investigating the case of the Florence Metropolitan Area, where there is approximately a dozen protected areas (Figure 7). These areas are safeguarded by Rete Natura 2000 (SIC, SIR, ZPS), and ANPIL and RAMSAR, with administratively defined boundaries that only partially cover the local ecological network that needs protection. In addition, they present a global (European) coherence under a conservational and functional profile (Regione Toscana 2000).

Moreover, the Florence Metropolitan Area is disseminated throughout hilly wood areas and wetland plains, which could be an interesting opportunity, in terms of ecosystems, for countryside and agroforest development in general. Good examples

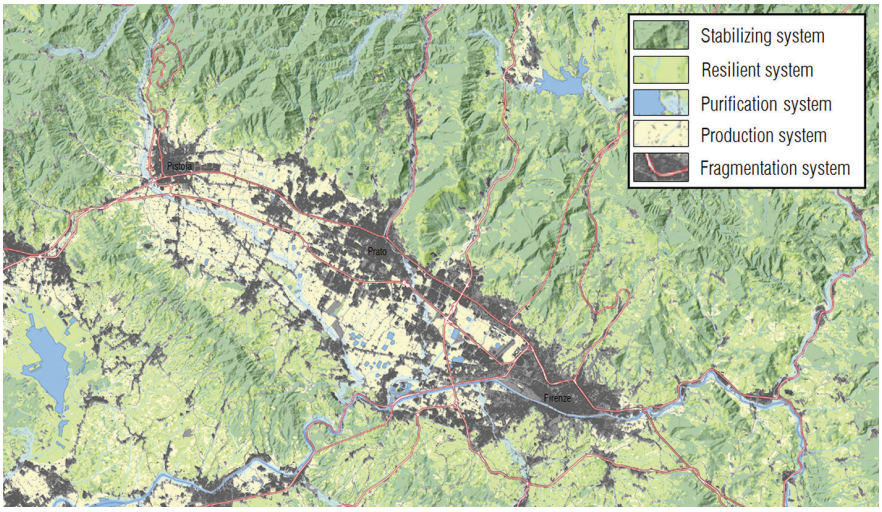

Figure 5. *The natural and anthropic system of the Florence area. In the middle of the map is the Florence-Prato-Pistoia plain: the fragmentation system of Florence metropolitan area (scale 1:250.000) (source: Own elaboration).*

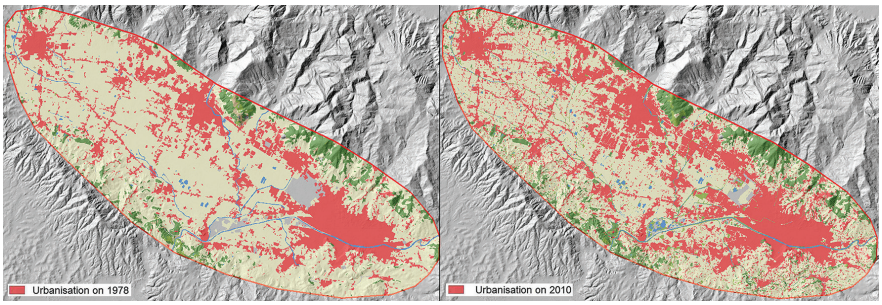

Figure 6. *Uncontrolled urbanisation in the Florence Area between 1978 and 2010 (scale 1:150.000). The map uses the Land Use Data of Regione Toscana in the two periods taken in exam (source: Own elaboration).*

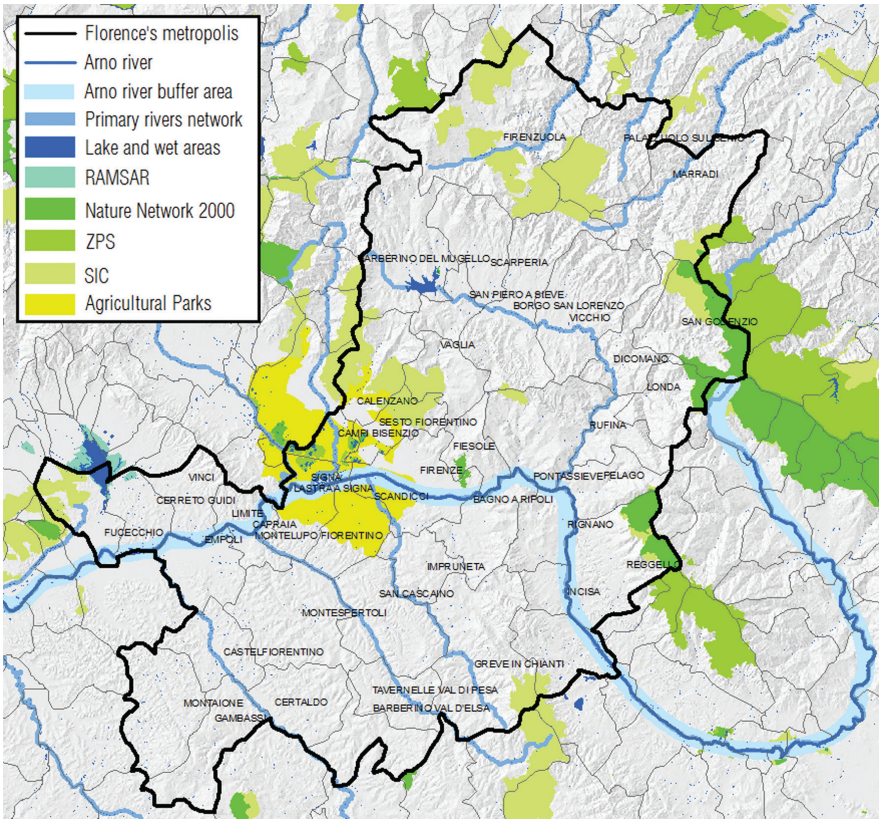

Figure 7. *Natura 2000 Network and protected natural area system around Florence's metropolis. The map uses the last update of boundaries of Public Administration of the year 2014 (scale 1:400.000) (source: Own elaboration).*

of agricultural requalification are the local plans of some Italian wine cities, where the landscape plays an important role in the culture and history of its inhabitants (Camaioni et al. 2016). However, we are still faced with the problem of how to recover the excluded landlocked areas.
Through integrated planning of green and blue infrastructures as a key strategic component, the said planning would have the opportunity to protect and integrate those elements within the territory and would thus result in a more resilient metropolis. This entails several benefits for inhabitants, including the raising of awareness among the local population with initiatives, programs, and projects aimed at environmental sustainability, all within a comprehensive territorial planning that connects natural and artificial ecosystem networks.
An ecological network for the Piano di Area Vasta (vast area plan) will not only mean an integration of species-specific networks existing in an area, but will also be the result of a complex territory evaluation based on the knowledge of the composition and environmental function of each element of the agro-environmental matrix (DPN 2018). This includes the protection from hydraulic and hydrogeological hazards, as well as climate change mitigation or adaptation; the upgrading or the creation of public spaces and facilities; urban embellishment; and the provision of ecosystem services aimed at increasing urban sustainability (Alberti and Paloscia 2018).
In terms of its implementation, the territorial planning linked with ecological networks required for local authorities and planners to translate the current strategic plan into actual projects. Several political decisions are needed to fund and prioritize projects and to build the networks. These new tools must operate at a metropolitan level and are expected to focus on the local level in currently disconnected areas. In this scenario, knowledge is multidisciplinary, and the public administration has the challenge of pursuing a relationship with the original scientific committee of Florence University. This committee could provide support to articulate and train teams of different functional units and background. Leadership from the mayors, teams, and the urban institute is essential in the implementation stage. Florence Metropolitan Area could benefit from benchmarking of other national or European regions that are ahead and keep its current collaboration with the Metropolitan Area of Bologna, which has taken a lead in the management of climate change resilience.

CONCLUSIONS

In order to answer the question of how the territorial planning of the Florence Metropolitan Area can introduce new tools for the integration of natural and urban systems to simultaneously address climate change risks, the following actions are required:
First, the concepts of ecological network (protected areas, agro-ecosystem fabric) and green infrastructures need to be introduced, both of which are related to hydrology, transport, and urban mobility, like greenways, ecological networks, blue networks, waterways, and parks. There is a need to rejoin the pieces of a territory wounded by severe anthropization and to achieve the reconnection of rural agricultural

and forestry territories with urban areas. Second, an integrated planning approach inspired by an ecosystem concept seems to be the best solution to reconnect both natural and urban systems and repair a spatial dimension dramatically fragmented and therefore potentially destined to "empty" itself both from an agroforest land and hydraulic point of view.
Third, waterway requalification and river restoration or rehabilitation are useful approaches for the development of green and blue infrastructures in urban and rural areas. However, more projects are necessary to integrate metropolitan planning for climate change mitigation and adaptation, avoiding geo-hydrological hazards and promoting territorial resilience.
Finally, even if the strategy of integrating ecological networks and green infrastructure is not new, the proposal has the merit of linking real-life data and reflecting on experiences in other Italian and European cities.
This research contributes to expanding the knowledge of ecological networks as tools to fight climate change in the context of territories and urban areas by creating a theoretical framework that reveals the linkages of territorial planning and multifunctional networks. It also contributes to the operationalization of territorial planning needed by practitioners to impact positively on the effects of climate change through mitigation and adaptation policies. This becomes more important in the region of Tuscany, where the world's largest Renaissance heritage is threatened by the effects of climate change. ▲US

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