On the Coastline: The Genesis of Green Infrastructure Towards a Future Sustainable Landscape for the City of Maputo, Mozambique

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Abstract

Cities in Africa, where the most remarkable forthcoming developments in the overall pattern of urbanization are expected, and quite notably in Sub-Saharan cities such as Maputo, experience accelerating population increases that stress urban infrastructures beyond capacity, and increase pressure on existent valuable ecosystems. In the city's coastal plains, the recently constructed Maputo ring road and Katembe bridge are drawing urban development towards the last stretch of vacant land of the Municipality, compromising the flood plains and mangrove ecosystems.

This paper aims to refine the planning discourse by systematizing urban strategies associated to green infrastructure functions, having mangrove wetlands as central element. This is achieved by mapping urban tissue and current land uses in relation to mangrove ecological land suitability classes, in order to give concrete spatial solutions for each urban condition. The definition of different types of green infrastructures based on mangrove ecology are outlined, to be implemented within the current land occupation context and that can support future scenarios of SLR.

The research explores green infrastructure planning applied to Maputo as a strategy to accommodate current and future urban development challenges, not only as urban biophysical networks that can create socio-ecological networks that improve urban resilience through a stewardship of urban ecosystems, but also as an ecosystem-based approach for adaptation to climate change.

Introduction

Coastal cities worldwide are experiencing a fast urban growth, with 40% of the world's urban population currently living in coastal areas (IOC/UNESCO et al. 2011). This reinforces the increase of coastal megacities trend, defined by the United Nations as metropolitan areas with population over 10 million inhabitants (UN 2006), which is also ongoing in the African context (Lagos and Cairo), in what promises to be one of the more remarkable forthcoming developments in the overall pattern of urbanization (UN-Habitat 2012, UN 2015). Such trends add pressure on mangrove ecosystems, on the one hand due to the significant amount of goods and services obtained through these ecosystems (Barragán and de Andrés 2015) and on the other hand, due to the environmental degradation through land consumption for urbanization and infrastructure, coastal erosion, salinization (Meyer and Nijhuis 2014) and disruption to which these same ecosystems are subjected to.

Maputo city, the capital of Mozambique, is situated in a plateau overlooking Maputo Bay, which is formed by the confluence of six rivers (Incomati, Infulene, Matola Umbeluzi, Tembe and the Maputo rivers), comprising a sequence of coastal ecosystems, including mangrove wetlands, which are among the most productive systems in the world. Maputo's coast currently suffers from direct drivers of degradation due to population growth and increasing economic development, which include infrastructure development, land conversion, water withdrawal, pollution, overharvesting and overexploitation, and the introduction of invasive alien species (Millenium Ecosystem Assessment 2005), as Maputo's Metropolitan area fits in the Sub-Saharan Africa (SSA) main metropolitan regions where urban growth is increasing dramatically (Jenkins 2012).

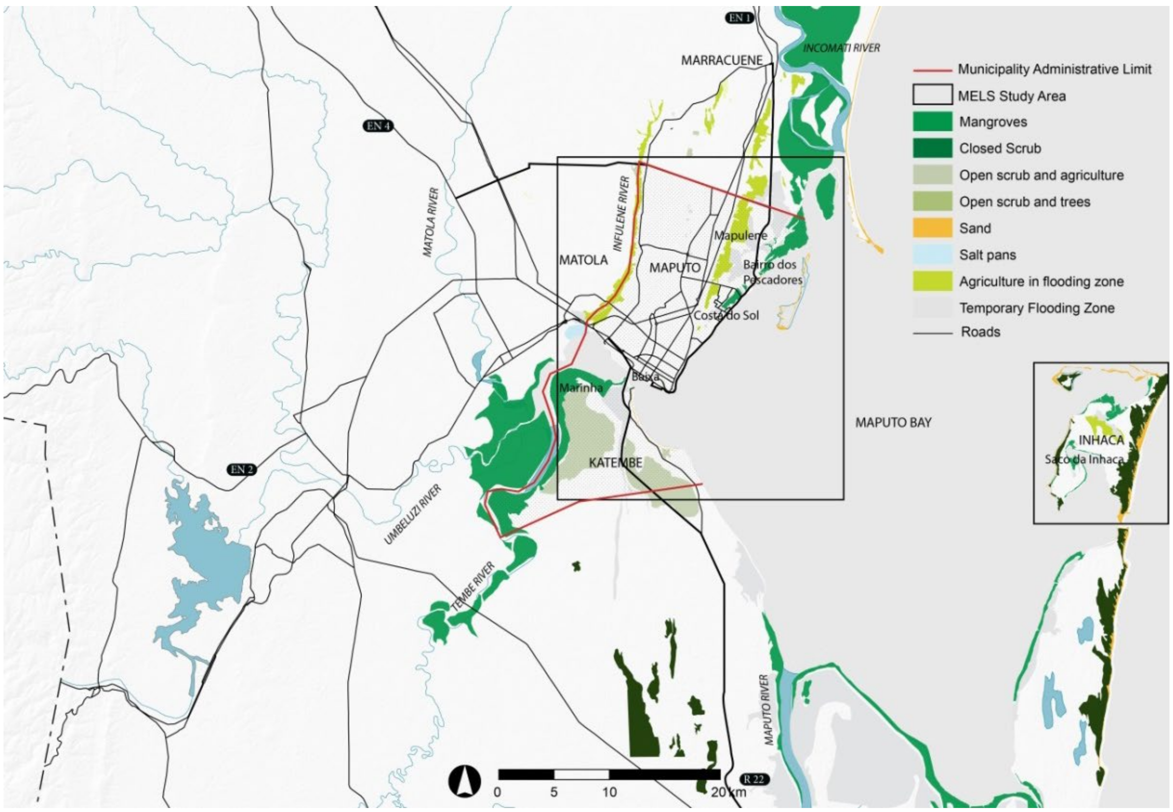

Fig.1. Maputo Bay map with Maputo's Municipality location

Maputo province and Maputo city's population respectively had a 4% and 1.2% growth rate between 1997 and 2007 (INE 2018), motivating a series of mega infrastructure developments in the past decade, as the Katembe bridge and the *Circular de Maputo* ring road. This was expected to decongest the city centre by increasing mobility between Maputo and the neighbouring cities of Matola (in the east) and Marracuene (in the north), and by opening up new areas for urban development, which often coincide with Maputo's coastal plains, at Katembe and Costa do Sol. Here, urbanization led by a neo-liberal market logic (Raposo et al. 2012) is advancing towards the peripheries which become the place for new industries, housing, services and shopping malls (Mazzolini 2016). As stated by Simon (2008), "coastal cities and towns from Dakar via Lagos, Cape Town, Maputo and Mombasa to Djibouti contain many low-lying areas, often accommodating concentrations of poor residents, strategic infrastructure and economic production." The ongoing urbanization dynamics on the coastal plains are on the one hand degrading and consuming mangrove wetlands and thus compromising local communities livelihoods; and on the other hand, are putting at risk people settling in the new coastal developments and self-produced neighbourhoods, due to exposure to increased flood risk, coastal erosion, extreme storm events and, in the near future, to climate change related sea level rise (SLR).

This research is based on the hypothesis that mangrove wetlands have the potential to become a structuring element of an urban green infrastructure for Maputo, providing ecosystem services and acting as an ecosystem-based climate change mitigation and adaptation element at its coastline. This hypothesis is sustained by the possibility of integrating mangrove wetlands within the urbanization processes and dynamics, by providing spaces for recreation, tourism, contemplation, job security (agriculture and fisheries) and biodiversity, while increasing urban resilience to coastal erosion, extreme storm events and SLR. Testing this hypothesis is supported by deepening the mapping concerning mangrove ecological land suitability (developed *at priori)* at the scale of the Municipality, by combining it with urban tissue mapping. This aims at informing a possible green infrastructure layout with concrete urban functions related to different mangrove land suitability classes.

Given that Maputo is following the general development trends of coastal cities, facing also specific challenges of SSA cities where environmental concerns are “largely absent from academic, policy and civil society activist discourses” (Schaffler and Swilling 2013) and where landscape planning is residual, it is relevant to address the potential of Maputo’s still functioning mangrove wetlands, to become the starting point of an urban green infrastructure.

Background and literature review

Maputo is a coastal city developed through successive urban plans during the colonial period (1825-1975), that shaped the city with marking features that are present up to today, as “the quality of its architecture, the openness of its avenues and the constant presence of street trees which gave Maputo its green city image” (Beja da Costa and Ribeiro 2017). After independence (1975) and throughout the civil war (1975-1992), Maputo’s population influx grew exponentially (Raposo et al. 2012) due to rural-urban migration patterns (Mazzolini 2016) and to the impact of natural calamities (Jorge and Melo 2014). Throughout the city’s history, and more accentuated since the independence, the expansion of the peri-urban areas happened beyond the city’s formal development through the increase of self-produced neighbourhoods, where a semi-rural space production and lifestyle (Raposo and Salvador 2008, Vanin 2013) took place, in what Jenkins (2003) describes as a rural–urban continuum, derived from “the need for rural residents to combine non-agricultural activities, mainly in the urban informal sector, with subsistence farming for their survival, rather than the product of demand for labour in urban-based industry and services”. This has contributed to the preservation of landscape features essential to an urban spontaneous green matrix (Fig. 2 & 3).


Fig.2. Maputo's bird eye circa 1970;
Fig.3. Polana Caniço self-produced neighbourhood in 2018

Since the independence, Mozambique moved from socialist ideals and guidelines towards a neo-liberal economic and political context (Raposo et al. 2012, Mazzolini 2016), favouring foreign investments on large-scale urban infrastructure along Maputo's coastline (Circular of Maputo ring road and KaTembe bridge).The layout of these mega infrastructures, brought major urban transformations to its surroundings, with more low income families settling in self-produced neighbourhoods (as Bairro dos Pescadores), but also on a linear built up urban corridor for middle and high income class throughout Costa do Sol coastal plains, all of which are pressing on mangrove ecosystems, fundamental for the above mentioned ecosystem services, acting as drivers for urban resilience and sustainability.

Given the context and considering the specific dynamics of Southern African cities, where research and planning around environmental issues are in early stages, it is relevant to contemplate the following concepts: of greenway / green infrastructure and of resilience, which set the basis for this planning exercise.

The greenway concept, which stems from the ecology concept of 'patch and corridor' (Forman 1990), taking in account the need to link landscape features that "connect isolated natural areas that remain in an increasingly fragmented megapolitan landscape" (Ahern 1995). Magalhães (2001) expands this by recovering the 'natural continuum' concept which establishes the connection between urban and rural (or natural) landscape. Furthermore, the 'system – landscape' concept, which includes the notions of 'natural continuum' and of 'ecological aptitude' of a certain territory to specific uses and functions, assumes that the landscape's ecological auto-regulation capacity depends on the maintenance of energy flows throughout continuous structures (Magalhães et al. 2007), complementing the greenway definition through the notions of complexity and systemic thought. It is relevant to note that the ecological aptitude is also the base concept for the Mangrove Ecological Land Suitability method referred to for producing the base maps for the green infrastructure mapping aimed at in this paper.

Greenways have many definitions worldwide, among which green infrastructure (GI) is commonly used throughout this research and is defined (in European context) by being a "strategically planned network of natural and semi-natural environmental features designed and managed to deliver a wide range of ecosystem services" (EC 2013). Nowadays, and appropriately so due to increasing numbers of population coming into the urban realm, GI can be considered as a multipurpose "new urban hardware" (Balestrieri and Ganciu 2017), bringing in numerous possibilities for the improvement of urban resilience (Ahern 2011) and quality of life. GI serve multiple functions, as green open spaces for recreational activities, soft mobility improvement and provide a framework for urban activities planning (Groome 1990); Improve people's life quality, creating conditions for healthier lifestyles and promote economic well-being by attracting new investments (Balestrieri and Ganciu 2017); Balance heritage and cultural landscapes (Ribeiro and Barão 2006); Provide ecosystem goods and services (du Toit et al. 2018, Cilliers et al. 2013) and ecosystem based adaptation measures for climate change mitigation and adaptation (Gaffin, Rosenzweig, and Kong 2012), particularly relevant in cities along coasts and near waterlines, that find themselves at a particular cross road of vulnerability (Simon 2010).

The resilience concept, defined by Holling (1973) as "the amount of disturbance that a system can absorb without changing state" (Gunderson 2000), contributing to the "paradox of sustainability" by adopting a non-equilibrium perspective in scenarios of permanent "disturbance and change" so intrinsic to the processes of urbanization in SSA cities, rather than the traditional sustainable "fail-safe" (Ahern 2011) static conceptualization. In particular, Maputo's mangrove wetlands embrace the resilience categories when considering its scale, regenerative and adaptive capacity, thus they should be regarded as a trigger to putting "broader socio-economic opportunities of resilient ecosystems" in the planning agendas and social dialogues (Schaffler and Swilling 2013) in the context of SSA coastal cities, of which there is a lack of in-depth studies in ecosystems services and green infrastructures (du Toit et al. 2018, Schaffler and Swilling 2013). It represents an opportunity for testing plans and designs that "spatially associate urban form with multiple social and biophysical functions" (Ahern 2011). Maputo's urban context adds to that, given its specific landscape potential, and the ways of cultural appropriation and replication which are intrinsically expressed in the urban form, with a strong relation to the rural context (Bénard da Costa and Biza 2012, Jenkins 2003).

Goals and Objectives

The aim of this paper is to reflect upon the potential of engaging Maputo's mangrove wetlands within its planning strategies, as means to establish a green infrastructure throughout the city. The main goal is to outline areas for a potential GI based on areas of existing mangroves and areas of mangrove ecological land suitability and its possible functions, taking also in account existing urban morphology in self-produced neighbourhoods through GIS mapping analysis. This analysis will systematize scenarios for urban expansion at Maputo's coastline that considers land use in relation to different mangrove ecological land suitability classes in current times, and that will also be valid in a scenario of climate change induced SLR.

By linking ecological land suitability and urban morphology, the goal is to give concrete spatial answers towards the outline of an urban GI that can inform urban planning tools, as the current Partial Plans for Urbanization (PPU). For this research the Maputo Municipality area is analysed, with an in-depth focus on the Bairro dos Pescadores neighbourhood.

Methods

The above mentioned goal is achieved through the continuation of conducted research on mangrove ecological land suitability at the scale of the Municipality of Maputo, which was developed by:
a) Mapping Maputo's Municipality biophysical conditions and land use changes within a 50 years interval (1967- 2017) having as base cartography the 1967 Military Map and the 2017 ESRI satellite image (Beja da Costa and Ribeiro 2017);

b) Constructing scenarios of Mangrove Ecological Land Suitability for Maputo's Municipality in the (i) current land use situation (2017) (see Figure 4 a and b) and in a (ii) projected 5m SLR scenario (2100) (see Figure 4 c and d);

The mangrove suitability analysis (i) was carried out taking in account physical components (geology, soils, hypsometry, slopes) and biological component (1967 mangrove vegetation areas) to which GIS codes were attributed according to the weight considered for optimal mangrove development conditions, achieving the MELS1 map (Fig.4a). The components variable weight and combinations for each suitability class are described in Table 1; The MELS1 is then recombined with the current land use map originating the map 'Current land use (2017) in relation with MELS1' (Fig.4b), which shows land use conversion trends in the coastal areas in relation to mangrove suitability;

Table 1. Mangrove Ecological Land Suitability components combination per class

				Mangrove Ecological Land Suitability					
System	**Sub-system**	**GIS code**	**Components**	**Max**	**Very high**	**High**	**Medium**	**Low**	**Very Low**
Physical	Geology	1000	Alluvial deposits	x	x	x x	x	x	x x
	(or)		Paleo-tidal plains	x	x	x x	x	x	x x
	(or)		Tidal plains w/ mangroves	x	x	x x	x	x	x x
	Soils	100	Salic fluvissols	x	x	x x	x	x	x x
	Hypsometry	10	0-14m	x	x	x x x			
		20	14-22m				x	x	x x x
	Slopes	1	0-8%	x	x	x x	x	x	x x
	Hydrology		Water lines						
		20000	Temporary flood areas				x	x	
			Tidal influence (in hipsometry) Saline intrusion						
		20	Flood levels in extreme events (in hipsometry)						
	Climate		Sub-tropical climate						
Biological	Vegetation (1967)	10000	Mangroves	x	x				

c) The mangrove ecological land suitability scenario in case of SLR (MELS2) (ii) is an incremental projection of MELS1, considering the INGC's 5m High SLR scenario as basis predicted for 2100 (INGC 2009) (Fig. 4c and d), assuming increased tidal influence in temporary flood areas and areas with ideal biophysical conditions.

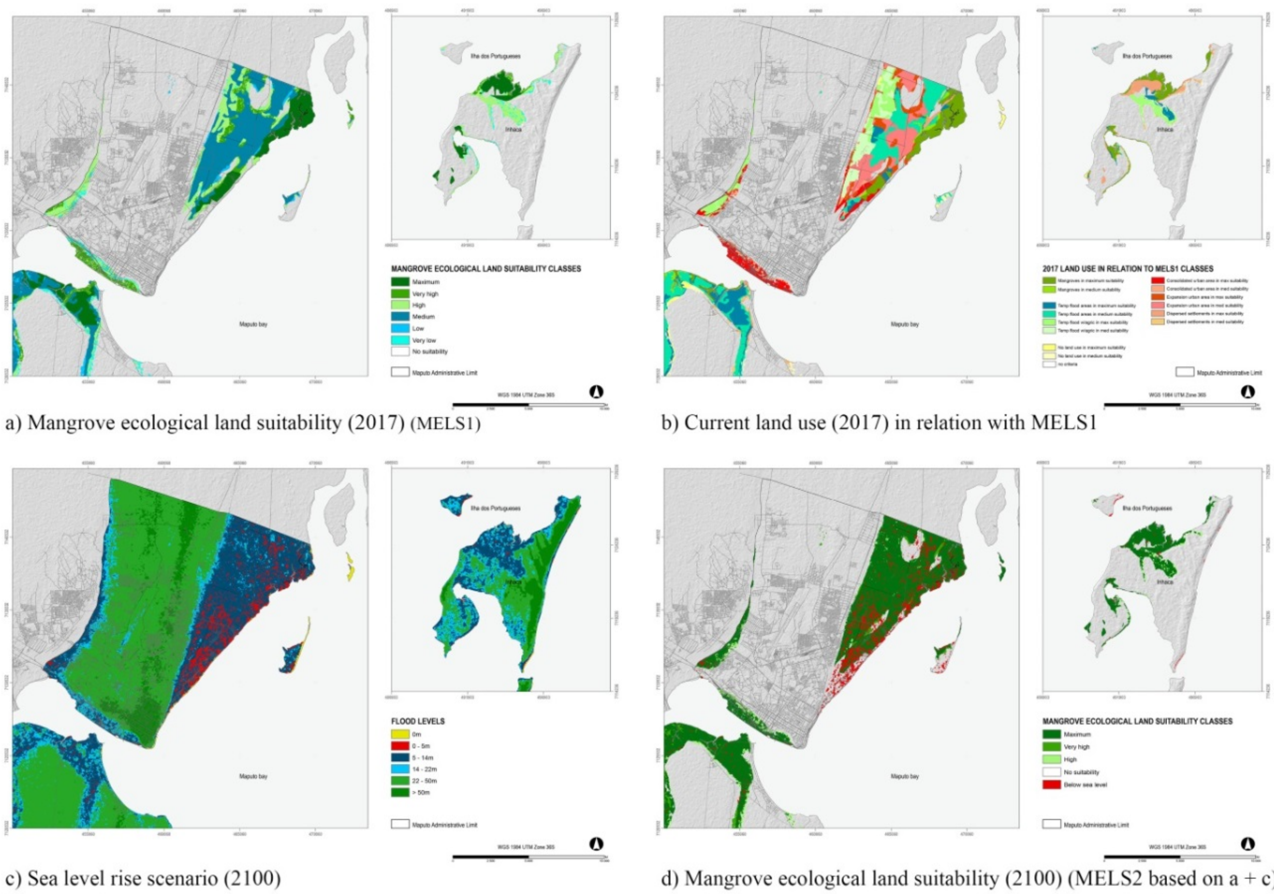

Fig. 4. Mangrove ecological land suitability base maps for green infrastructure outline

d) A zoom is made to the Bairro dos Pescadores area (Fig. 5), where urban morphology is mapped and overlapped with 'Current land use (2017) in relation with mangrove ecological land suitability 1'; Here, it is relevant to stress that maximum suitability are areas with current mangroves or with ideal physical conditions for its development (in current climate), whereas medium suitability areas are related to current temporary flood areas.

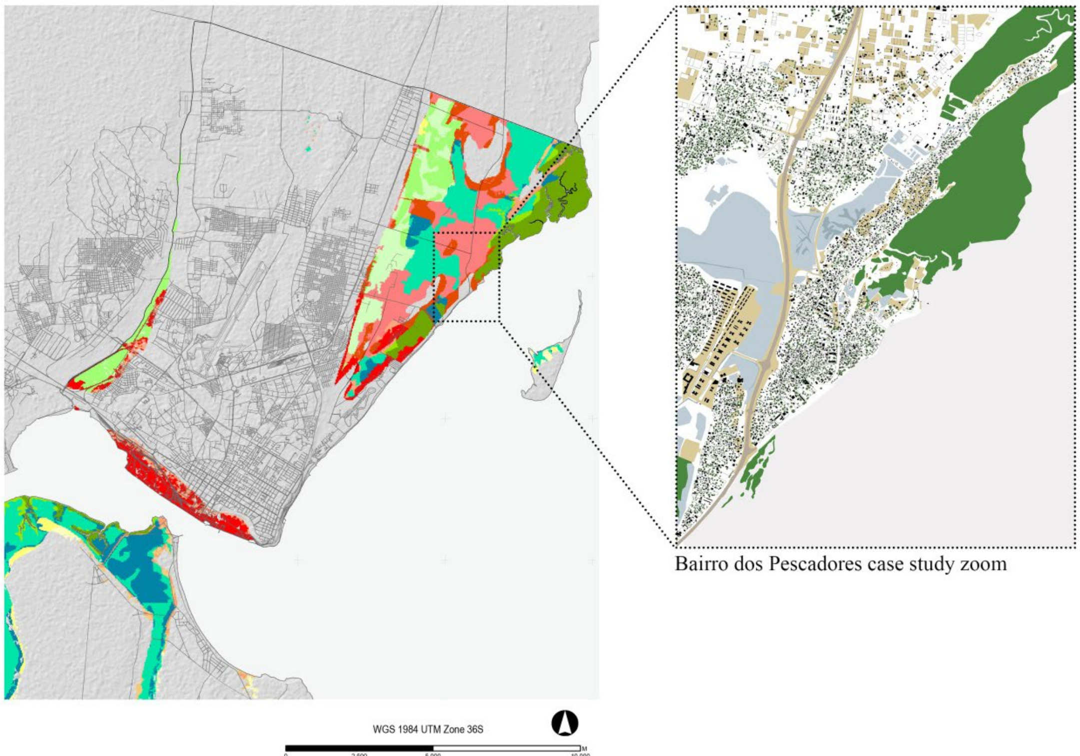

Fig. 5. Current land use in relation to mangrove ecological land suitaility and Bairro dos Pescadores case study zoom location

Results

Previous spatial analysis process demonstrates that though major transformations towards consolidated urban areas occurred, implying an overall mangrove area loss of 24.3% of its original area within a 50 year period (1967-2017) (Beja da Costa and Ribeiro 2017). Through MELS1 one can infer that 21.7% of Maputo’s coastal plains have high suitability and that 20.9% have maximum suitability for mangrove establishment (Fig.4a). When analysing the ´Current land use in relation to MELS1’ (Fig.4b) we can locate 5% of urban expansion in maximum mangrove suitability areas and 12% of urban expansion in medium suitability areas, which correspond to temporary flood areas. Finally, when considering a 5m SLR scenario for 2100 in MELS2 (Fig.4c), areas with maximum suitability for mangrove development increase from 21.7% to 89.7% (Fig.4d). All of the previous results confirm the pressure that mangrove wetlands are subjected to at the coast of Maputo, as consequence of urban expansion.

Mangrove ecological land suitability scenarios become useful when combined with concrete urban tissue conditions, in order to give a step further in proposing a GI that can redefine mangrove wetlands as part of the urban realm. Therefore, the ‘Current land use in relation with MELS1’ map becomes relevant as:
(i) its interpretation of current land uses in relation to the different mangrove suitability classes allows to ouline urban strategies for each urban condition in relation to mangrove suitability.
(ii) These urban strategies become concrete GI functions, related with specific ecosystem services and uses, systematized in Table 2.

(iii) By overlapping Bairro dos Pescadores detailed urban tissue with the 'Current land use in relation with MELS1' we can locate with precision areas for distinct interventions, as the spatial reading of the urban conditions becomes concrete at a plot scale.

Table 2. Urban strategies and functions for a coastal GI outline according to 2017 Land use in relation to MELS1 classes

	2017 Land use in relation to MELS1 classes	Urban strategies for mitigation and adaption	Green infrastructure	Ecosystem services	Ecosystem uses
(a)	Mangroves in maximum suitability	.Reserved areas for mangrove conservation .Sustainable forest & fisheries management plan	Mangrove wetland park	Storm buffer	Forestry
(b)	Mangroves in medium suitability			Grouwater recharge Flood control Nutrients removal Toxic retention Biodiversity	Food provision (commerce & self-consumption) Materials provision (commerce & self-consumption) Cultural & religious significance
(c)	Temporary flood areas in maximum suitability	.Mangrove expansion in SLR scenario	Urban 'water' parks	Flood control	Flood retention basins & drainage
(d)	Temporary flood areas in medium suitability	.Reserved areas for flood and SLR mitigation		Groundwater recharge Biodiversity	Recreation & Tourism Cultural & religious significance
(e)	Temporary flood w/ agriculture in max suitability	.To maintain	Urban agriculture	Storm buffer	Crops provision (commerce & self-consumption)
(f)	Temporary flood w/ agriculture in med suitability	.Reserved areas for flood and SLR mitigation .Sustainable community management plan		Flood control Groundwater recharge	
(g)	No land use in maximum suitability	.Reserved areas for mangrove expansion	Mangrove nursery / plantation for wetland park	same as (a)/(b)	same as (a)/(b)
(h)	No land use in medium suitability	.Reserved areas for flood and SLR mitigation	Urban parks	same as (c)/(d)	same as (c)/(d)
(i)	Consolidated urban area in max suitability	.Flood and SLR adaptation measures .Retrofitting the urban tissue	Mangrove 'edge' linear parks	Storm buffer Biodiversity	Flood retention basins & drainage Proximity park / public space
(j)	Consolidated urban area in med suitability		Mangrove 'pocket' parks	Flood control	Recreation & Tourism Cultural & religious significance
(l)	Expansion urban area in max suitability	.Contention of urban areas	Mangrove 'edge' linear parks	same as (i) / (j)	Proximity park / public space Recreation & Tourism
(m)	Expansion urban area in med suitability	.Retrofitting the urban tissue .Flood and SLR adaptation measures	Mangrove 'pocket' parks Urban 'sponge'		Cultural & religious significance Flood retention & drainage
(n)	Dispersed settlements in max suitability	.Flood and SLR adaptation measures .Mangrove expansion in SLR scenario	same as (f) / (g)	same as (a)	same as (a)
(o)	Dispersed settlements in med suitability	.Flood and SLR adaptation measures	same as (f)	same as (f)	same as (f)

The 'Current land use in relation with MELS1' classes picture which type of urban development is happening in each mangrove suitability class. As such, it allows to think of which type of GI can be incorporated in order to address the needs of each urban area. The Bairro dos Pescadores sample area does not include consolidated urban tissue, but the urban strategies adopted in urban expansion areas are similar.

For each land use in relevant mangrove suitability area (maximum and medium), urban strategies for mitigation and adaptation to common events in coastal areas (floods, storms, tides, erosion…) are foreseen. In the case of consolidated urban areas and expansion urban in suitability areas it is proposed urban growth contention, by allocating GI functions to its surroundings, as well as within the urban tissue. Relocation of entire neighbourhoods is not considered, as self-produced neighbourhoods grow in a spontaneous way that is difficult to control. As alternative, strategies for retrofitting the urban tissue and public space should be contemplated (building in *pilotis*, rainwater drainage network...).

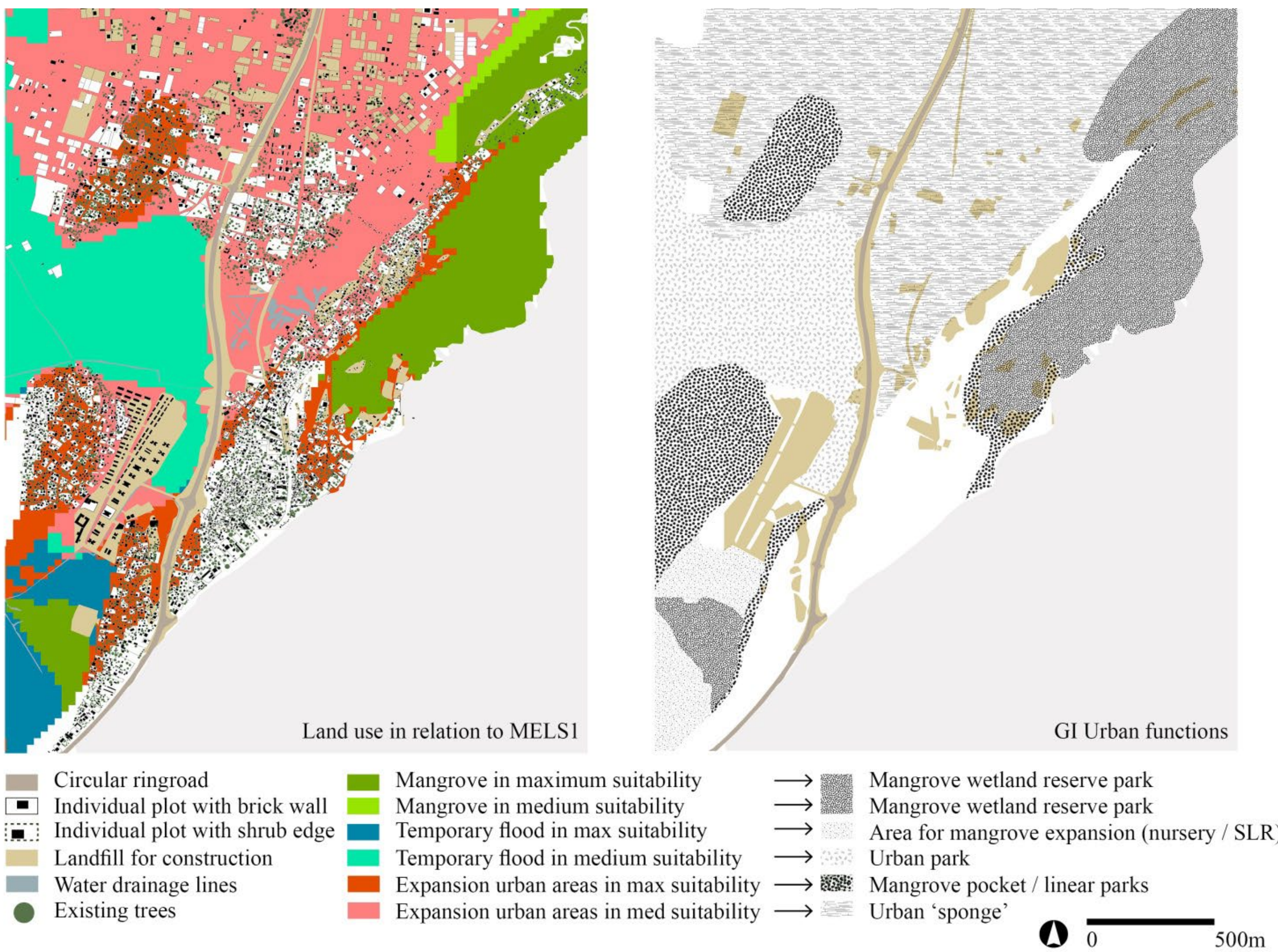

Fig. 6a and b. Urban urban tissue on 'Current land use in relation to mangrove ecological land suitability' translated into GI functions

Each GI typology (Table 2, column 3) relates to concrete urban strategies and will provide various ecosystem services and uses that will redefine functions and value of mangrove wetlands and flood plains.

This will allow to build urban resilience, achieving a compromise between urbanization and sustainability. The GI urban functions map presented in Fig. 6b will also provide strategies for future adaptation to climate change and SLR. In this scenario, relocations are assumed to occur, hence SLR will flood some of the areas included within the "urban sponge" and along the coastline (Fig. 7b). The maximum mangrove suitability area is assumed to increase in a SLR scenario, which will facilitate the inclusion of new mangrove wetlands as an adaptation soft infrastructure, in the 'Mangrove wetland' park, 'edge' park and 'pocket' parks typologies.

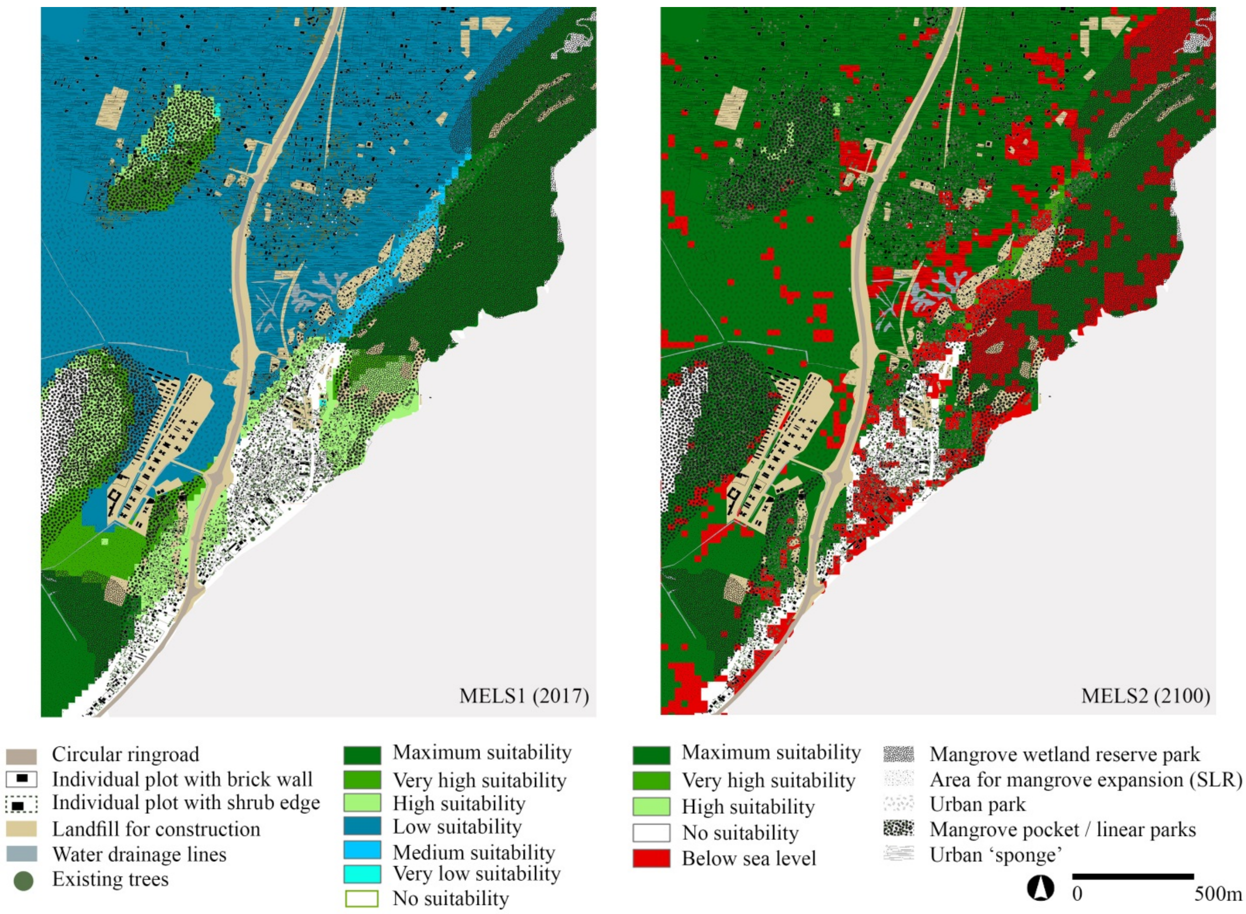

Fig. 7a and b. MELS1 and MELS2 with proposed GI functions overlapped

Discussion and conclusions: Green infrastructure planning applied to Maputo as a strategy to accommodate current and future urban development challenges

Maputo is a coastal city where urban sprawl is expanding towards the low-lying areas at the coastline, jeopardizing mangrove wetlands that play an essential role as ecosystem services and ecosystem based adaptation measures providers. If integrated in an urban GI, mangrove wetlands represent an opportunity to promote resilience and to trigger the implementation of sustainable planning strategies.

Through the presented steps was possible to allocate existing mangroves, but also mangrove maximum to medium suitability areas to different land uses included in a GI, as wetland parks, agricultural areas, retention basins, etc., in order to preserve biodiversity, accommodate flood an extreme storm events, as well as to reserve areas for future mangrove establishment in a climate change scenario, as MELS2 shows a positive evolution for suitability to mangroves facing SLR.

Putting a GI into practise represents challenges due to weak legislation, to the lack of operational and fiscal staff, as well as the probable lack of political will. The ongoing neo-liberal agenda brings profit as it is set up, and urbanization is gaining terrain throughout Bairro dos Pescadores, putting at risk not only mangrove wetlands that face systemic interruptions, but also the population settling in these areas. Facing this problem, it is relevant to identify distinct GI functions that can become the intermediate (and negotiating) factor between local communities and planning. As such, including resilient, multifunctional ecosystems in the urban realm through a GI can be achieved working in a two folded strategy, both by reviewing planning and environmental policies (top-down approach) and by working closely with local communities for its implementation (bottom-up approach).

On the one hand, by applying MELS as tool for adaptive planning and design, that informs land use zoning at the PPUs scale, and serves as a communication support tool. Also, designing the edge between mangroves and urban areas is an economic and efficient way to contain urban expansion, providing multifunctional public spaces that improve landscape's perception and that maintain mangrove wetlands connected and functioning. Degraded and neglected 'left over' areas can become thriving urban parks to which the mangrove – urban interface design, having MELS as a support tool holds (part of) the solution. On the other hand, by working closely with local communities in order to redefine mangrove wetlands as part of the urban context and to promote strategies for ecosystem management. Campaigns for environmental awareness and risk mitigation are an essential part of the process, as the inhabitants are the main doers that can fulfil the Municipality's lack of staff. Promoting risk adaptation and mitigation strategies through cultural replication could represent an effective manner to retrofit existing urban tissue in flood prone areas, by setting up strategic built examples that could be appropriated and reproduced by the communities.

The 'hardware' for an urban GI is already present in Maputo, especially in what concerns the opportunity for mangrove wetlands to contribute for the city's resilience and to SLR adaptation. Its implementation would represent an opportunity to join synergies in answering to recurrent urban problematics common in overall context of other SSA coastal cities, of expanding urbanization in coastal plains and in deep need of adopting mitigation and adaptation measures towards risk and climate change, and improving its inhabitants life-quality.

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