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The Green Infrastructure Transect: An Organizational Framework for Mainstreaming Adaptation Planning Policies

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Abstract When considering the range of spatial planning actions that cities can take to adapt to climate change, many of them fall under the conceptual umbrella of green infrastructure (GI). GI has been defined as the spatial planning of landscape systems at multiple scales and within varying contexts to provide open space, safeguard natural systems, protect agricultural lands, and ensure ecological integrity for cultural, social, and ecosystem benefits (Benedict and McMahon, Renew Resour J 20:12–17, 2002, Green infrastructure: linking landscape and communities. Island Press, Washington, DC, 2006; Ahern, Cities of the future. IWA Publishing, London, 2008). While the traditional definition of GI refers to areas of land that are least intervened by human action, in this expanded definition, we are deliberately including areas that are engineered to mimic natural processes and which provide cost-effective ecosystem services.

Although climate adaptation is a fairly new policy goal for GI (Gill et al., Built Environ 33(1):115–133, 2007; CCAP, http://www.ccap.org/docs/resources/989/Green_Infrastructure_FINAL.pdf, 2011), three key characteristics qualify GI as a suitable tool for adaptation planning including multifunctionality (to match ecosystem benefits with adaptation needs), multi-scalar nature of the spatial elements, and a 'no-regrets approach'. However, GI needs to be matched to the character of the urban environment and coordinated across jurisdictions and planning scales to become an effective adaptation policy. In this chapter, we present a policy framework, the green infrastructure transect, that can help planners and

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policymakers identify appropriate GI policies for different urban environments and describe how these policies can create a regional adaptation planning framework.

Keywords Adaptation planning • Green infrastructure • Resilience • Urban regions • Urban and regional planning

1 Introduction

One of the primary principles of green infrastructure (GI) planning is to reconnect communities in urban regions to natural environments (Lewis 1964; McHarg 1969; Noss and Harris 1986; Benedict and McMahon 2002, 2006; Jongman 1995; Jongman et al. 2004; Fábos 2004). This is achieved through practices within and around cities that identify, protect, and create spatial elements that provide ecosystem services that communities depend on (Benedict and McMahon 2006; Forman 2008). Development of community parks and recreation trails, greenways, ecological networks, restored streams, natural reserves, gardens, engineered natural systems, green roofs and facades, and conserved agricultural land are all within the scope of GI. Furthermore, the same spatial areas also provide urban cooling, storm water management, flood water storage, flora and fauna habitat, and biking and walking routes. All of these urban functions must be increased to build resilience to climate change. By connecting ecosystem benefits to community well-being (Nassauer 2006) and adaptation needs, GI planning may be mainstreamed to become an integral part of adaptation planning policies.

A key advantage of the GI approach to adaptation is that it is already becoming an accepted practice (Benedict and McMahon 2002; Ahern 2008). GI has become part of current sustainable planning and design practices in many cities (EPA 2011; Newman and Jennings 2008; Farr 2008). These initiatives function at multiple scales to improve urban living conditions. These may include retention ponds and swales (at the parcel scale), green streets and parks (at the neighbourhood scale), increased tree canopies (at the urban scale), and greenways (at the regional scale). As an accepted practice, GI is also a 'no-regrets approach' (Bedsworth and Hanak 2010) when considered as an adaptation measure. As we move into the future, investment in GI policies will prove to be beneficial regardless of whether climate change scenarios materialize. For example, urban greening results in cleaner air and cooler temperatures that would address current problems (pollution and urban island heat effect) as well as ameliorate future increasing temperatures. As a result, fairly minor changes to the technical specifications for GI could, quite effectively, bring adaptation into mainstream practice. As GI is implemented to accommodate increased flooding, ameliorate rising temperatures, or address the rise in sea levels, communities can take advantage of the cultural, social, and health benefits of cleaner and greener environments, regardless of the future magnitude of climate change impacts.

Furthermore, the same characteristics that qualify GI as a spatial adaptation tool within urban regions (notably GI's multifunctional and multi-scalar properties) make it difficult to mainstream GI into adaptation planning. These characteristics create problems in organizing intervention areas, jurisdictional coordination and implementation, and trade-offs in economic benefits and urban quality.

2 The Green Infrastructure Transect

To address these problems, we propose the green infrastructure transect (GI transect) as a framework to utilize GI as an adaptation policy and to mainstream adaptation into current planning practices. The GI transect is a conceptual tool that integrates GI measures across varying urban contexts and across planning scales. It builds on transect concepts from ecology, landscape planning, and urban planning.[1] We specifically use the urban transect as a stepping stone to develop this framework.

The urban transect (Duany and Talen 2002) was devised as an urban planning tool to plan and design physical environments according to peoples' preferences of where to live and work. The urban transect identifies six zones (urban core, urban centre, general urban, suburban, rural, and natural) with distinct physical boundaries as units of study. These zones form a planning model applicable within many urban contexts. The zones provide the basis for a neighbourhood structure based on walkable streets, mix of uses, transportation options, and traditional architectural styles and housing diversity. The strength of the urban transect is in describing the appropriate built forms and identifying interventions within each urban zone in a simple and comprehensible manner. The concept falls short of specifying the respective open spaces and natural functions that respond to the specific urban contexts and needs within each transect zone.

In contrast, the natural transect used by ecologists and biologists is a scientific method of assessment of habitat. It is based on the fundamental principles of relationships and interdependencies between ecozones and used to assess the physical, biological, and natural processes within and across ecozones. Contrary to the urban transect, it does not specify distinct spatial zones. Rather, the characteristics of different local ecosystems define different habitat zones and the relationship between them. This same principle is later adopted within landscape and regional

[1] In the early twentieth century, the natural transect became one of the foundational tools of ecological research. The evidence that certain flora and fauna flourished symbiotically together, and within a specific mineral and climactic environment, became the ethical basis for the protection of species. Patrick Geddes (1854–1932) adopted the ecological transect as a model to devise the 'valley section' (Geddes 1915). Taken from ridgeline to shoreline, the 'valley section' shows natural conditions with their associated human presence and occupation to show a gradation of human preference for location and work. Based on Geddes, Lewis Mumford's (1895–1990) concept of human ecology was used to develop a decentralized regional vision of metropolitan areas (Mumford 1937). Ian McHarg (1920–2001) applied the natural transect for land conservation in landscape planning showing transitions and relationships within and across natural ecozones (McHarg 1969).

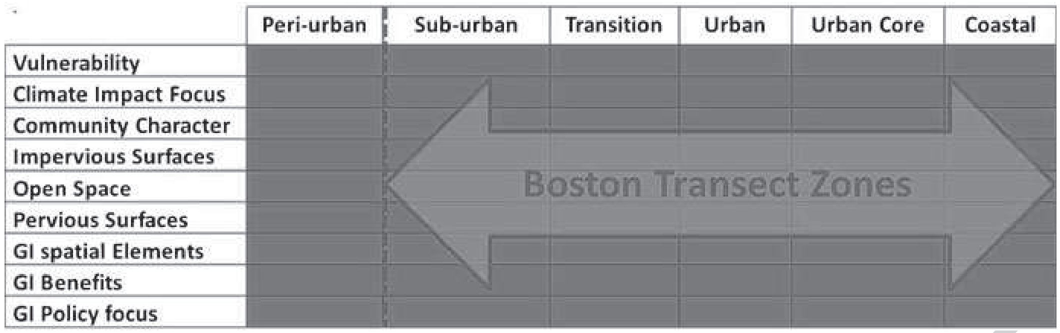

Fig. 1 The green infrastructure transect: concept and organization

planning to assess and understand relationships between land, and natural and human systems in order to plan and manage natural resources within urban regions (McHarg 1969; Picket 2004; Berger 2006).

Overall, the GI transect combines the general principles of urban and natural transects into a single assessment model. The primary characteristics are three: (1) the simultaneous consideration of human and natural systems as a mutual cause-and-effect relationship effecting the functional capability of GI (pervious and impervious surfaces as indicators), (2) the designation of urban zones as unique spatial contexts that may impact the adaptive capacity of communities within, and (3) the explicit consideration that GI is an interconnected system that transcends administrative and political boundaries.

This interconnectedness of GI serves as an impetus and analogy to integrate adaptation policies across the GI zones increasing the local capacity for adaption. We qualify this level of policy integration as 'horizontal integration'. The term is meant to generate targeted GI recommendations specific to each GI zone and coordinate them across boundaries[2] (within scales). This is achieved by mapping and assessing each GI zone against a set of criteria to be able to recommend targeted GI measures. Six GI zones are identified and are intended to represent an alternative model (to the urban transect) of contemporary urban regions. These include coastal (if present), urban core, urban, transition (the middle ground), suburban, and peri-urban zones. In addition, we use the following criteria to assess each GI zone: vulnerability assessment using spatial data (physical and social), identifying the primary climate change impact based on spatial configuration and character, identifying the spatial character of each GI zone, determining the spatial configuration of pervious and impervious surfaces (existing and potential GI), determining GI typology relevant to each zone, and recommending appropriate GI measures within each GI zone (Fig. 1). The sequential process of assessment begins with vulnerability assessment

[2]Cross-jurisdictional coordination was identified as a primary concern when assessing the 4,000 GI networks across the conterminous USA for their ecological connectivity where 10% of the hubs and links cross administrative and political boundaries. When downscaling the same observation to regional and local scales, forest stands, water bodies, and wetlands are not restricted to regional, city, town, or property boundaries (Fig. 4).

and concludes with recommendations providing a specific policy focus to local communities for adaptation and the possible responses through GI.

Furthermore, several existing GI recommendations relevant to adaptation policies call for the protection of forest stands and wetlands or increasing tree canopy or engineering swales and rain garden systems. These GI spatial elements are not restricted to regional, city, town, or property boundaries as they are subject to conditions (i.e. topography, geology, and hydrology) beyond the control of governing bodies. Therefore, analysis and assessment should consider recommendations within each zone and the outward extensions of GI. By mapping adjacent spatial configurations, horizontal integration is attained. This enhances the adaptation capacity of local communities through coordination of policies. Yet, it does not account for coordination across jurisdictional boundaries and planning scales necessary for regional resiliency.

Developing a network of GI increases the resiliency of a region. It provides alternative evacuation routes, species migration routes, CO_2 sinks, flood water storage, buffer zones against rising sea water and reduction in regional temperatures. To achieve a coordinated regional network requires the integration of planning scales (neighbourhood, urban, regional) into a single regional planning framework providing a platform for communication and coordination across jurisdictions. We term this integration across scales as 'vertical integration'.

Vertical integration provides the mean to respond to the multi-scalar and hierarchal nature of GI by considering current planning processes. GI networks are hierarchal especially when planned within urban contexts. When considering GI for storm water management, connectivity of GI elements should be considered across the hierarchy of urban planning scales (street or parcel neighbourhood, city, and urban region) (Kato 2010). For example (Fig. 2), several streets with bioswales and retention ponds in residential yards at the neighbourhood scale can constitute a green corridor at the city scale which, in turn, with city parks can be part of a regional park system (Jim and Chen 2003; Girling and Kellett 2005). But each individual GI element (parcel to regional scales) is planned and implemented differently, depending on the context, size, and planning process. Vertical integration provides a way to unify these processes under a hierarchal single framework that leads to a regional vision.

Integration across scales is necessary to increase the adaptive capacity at both the regional and local levels. The adaptive planning meta-model developed by Kato (2010), for a planning framework to manage GI, is an example of such a process. It is an iterative process designed for the US context. Similar to the GI hierarchy, neighbourhood plans that are participatory in nature form the basis of an urban plan. The sum of the several urban plans could define a vision for a region. In the US context, a bottom-up approach (participatory) could lead to a regional vision. The reverse (top-down planning) may also hold true when considered within other planning and administrative contexts. Regardless of whether the vision (top-down) or local planning (bottom-up) comes first, the intention here is to advocate for a two-way and iterative approach that includes both and provides the flexibility and adaptability to respond as circumstances arise and change.

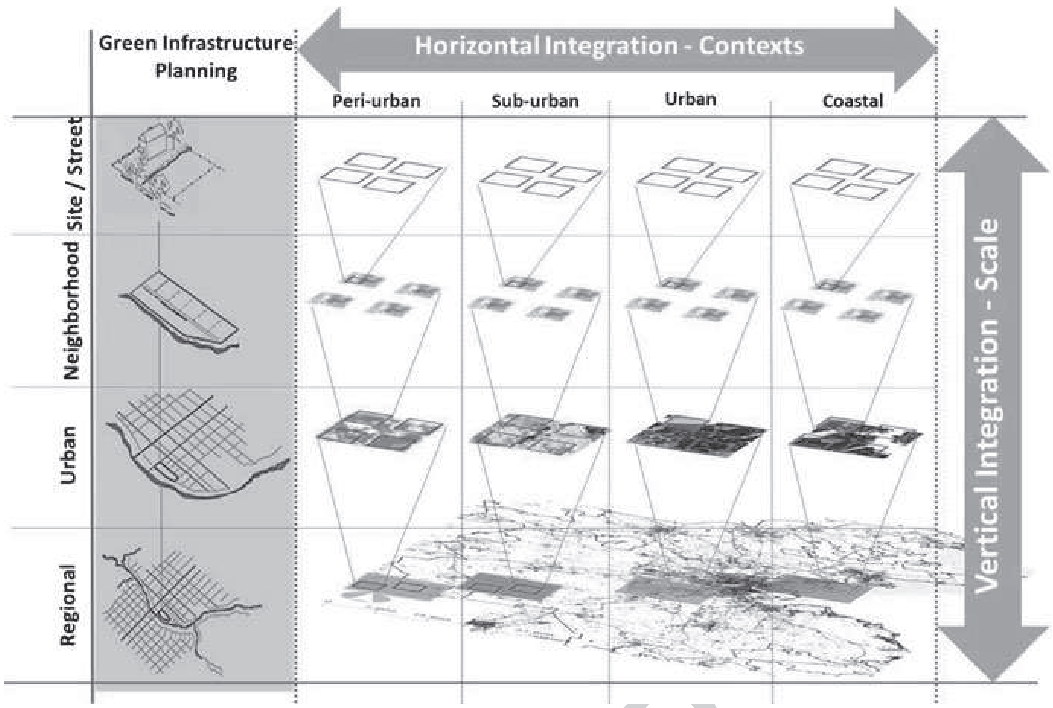

Fig. 2 Multi-tiered GI adaptation planning framework: horizontal and vertical integration

The underlying concepts behind the GI transect point to the spatial, contextual, and administrative interdependencies governing mainstreaming adaptation planning. Vertical and horizontal integration are the primary elements of the GI transect that integrate local and regional plans into a single and flexible adaptation planning framework. To make these ideas concrete, we apply the three-step approach of vulnerability assessment, characterization of existing GI, and GI policies recommendations to the Boston metropolitan region.

3 Boston Metropolitan Region

The metropolitan region of Boston occupies the eastern shoreline of the state of Massachusetts in the USA. It covers a land area of approximately 12,000 km^2, housing 4.5 million people with an average density of 366 persons per square kilometre (Census Bureau 2010). The metropolitan region incorporates 120 towns and 8 regional jurisdictions within its boundary (Census Bureau 2010). It is characterized by an urban core (Boston) as the centre of governance, business, and transportation. From the urban core to the periphery, residential sprawl of varying densities along transportation corridors and around commercial centres is interspersed by forest, wetlands, river basins, and, to lesser extent, agricultural land (Figs. 3 and 4). At the planning level, the state of Massachusetts (MA) has adopted and is implementing smart growth principles to control development and preserve

Fig. 3 Metropolitan region of Boston: spatial distribution of pervious and impervious surfaces

natural and cultural assets.[3] Part of the smart growth initiative is the Climate Action Plan (CAP 2007, 2010). The plan is focused on mitigation measures to reduce emissions from buildings, transportation, waste management, and land use. In the 2010 update of the plan, recommendations for adaptation were included as part of addressing causes and effects of climate change.

The NECIA (2007) report on climate change impacts within the New England region shows that Massachusetts climate will resemble the southern states of the Eastern Coast of the USA.[4] Taking the year 2000 as the baseline, the report demonstrates that the metropolitan region of Boston will experience increase in temperatures by 4–7°C in the winter and 3–8°C in the summer, rising sea level of 25–60 cm, and increased precipitation by 20–30%. To address these impacts, the City of Boston identified guidelines for adaptation planning (CAP 2010) that include, in addition to economic and social measures, spatial measures that focus on GI.

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[3]Since planning is locally based and participatory, the state of Massachusetts may only advance these planning principles through financial incentive means. Towns and cities may develop their comprehensive zoning, recreation and open space, and economic development plans based on smart growth principles in return for financial incentives.

[4]Under the high emissions scenario, the Massachusetts climate will likely resemble that of the current Florida climate and under a lower emissions scenario will resemble the current weather of Northern Carolina.

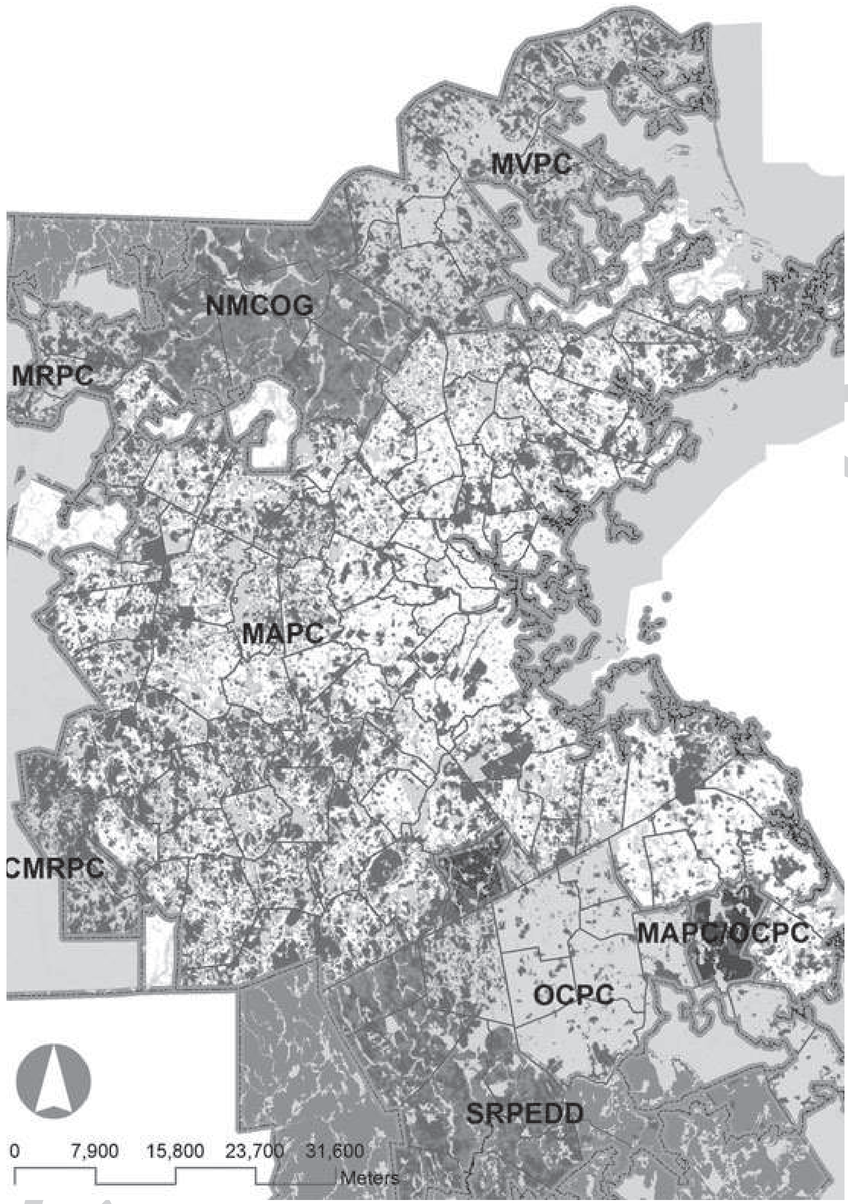

Fig. 4 Metropolitan region of Boston: green infrastructure across town boundaries

The adaptation recommendations for Boston (CAP 2010) set priorities and define the required information and planning priorities and approaches. Out of the 13 recommendations, many focus on GI principles such as greening the city, green roofs, sustainable water management, and protection and increase of large tracts of vegetated surfaces. In addition, planning cross-jurisdictions and scales is identified as a priority to increase the adaptive capacity of the urban region.

In the process of transforming these adaptation recommendations into actions, we apply the GI transect to assess the applicability of the multi-tiered organizational framework to Boston. In the assessment stage, we map vulnerability, climate change impacts, and the physical environment across the GI zones (Fig. 5). Vulnerability

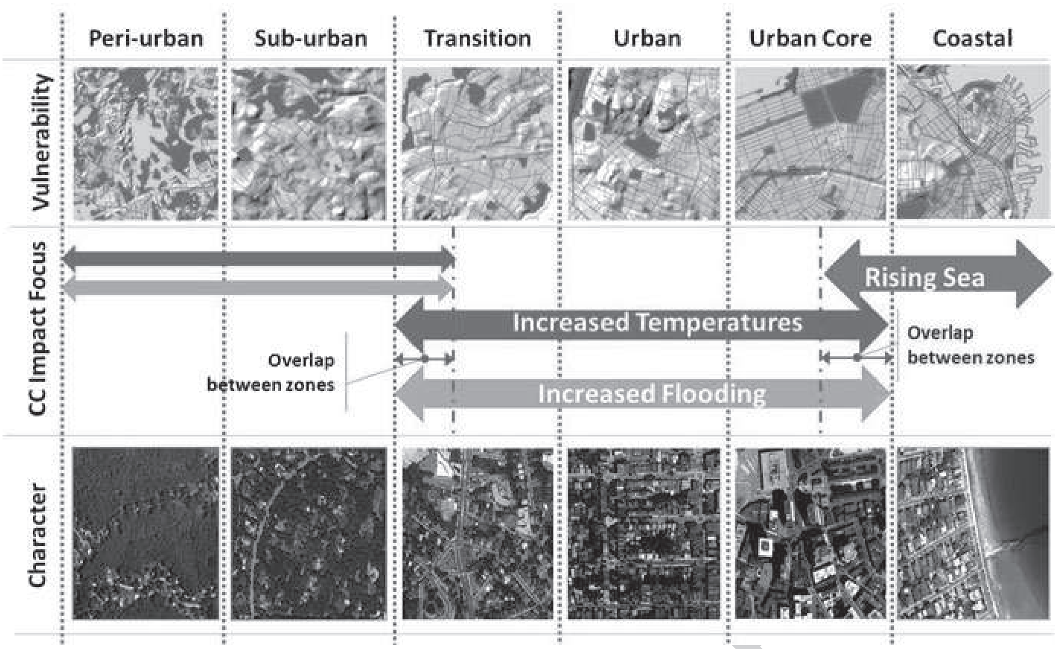

Fig. 5 Green infrastructure transect application to Boston region, step one: vulnerability assessment

is mapped using the following spatial data layers from Mass GIS[5]: topography, open space, roads, location within the watershed, and socio-economic data for each location. Climate impact is mapped according to the NECIA (2007) report showing the magnitude and focus within each zone. Aerial images are used to map the urban character identifying the physical environment of work and housing.

We found that the coastal zone is predominantly impacted by rising sea level, the urban to transition zones are affected by a high magnitude of increased temperatures and flooding, and the peripheral zones are impacted, at a lower magnitude, by temperature rise and flooding. The exposure to physical risks is further exasperated by the effect of the urban heat island effect (UHI) and the gradation of impervious and pervious surfaces across the GI transect. The compounded impacts of climate change and the physical characteristics of the urban region of Boston are grounds to consider different adaptation planning focuses for communities across the GI transect. To be able to devise and recommend GI policies within existing pervious surfaces, which address the variation of vulnerability, we map the existing distribution of GI across the zones.

To map the spatial distribution of GI across the zones, we also use Mass GIS data. We overlay the following layers: impervious surfaces, digital terrain, open space layers (public domain), waterways, forests, roads, and administrative boundaries.

[5]Mass GIS is a spatial data portal managed by the state of Massachusetts that provides a free download service of available data layers across the state. See http://www.mass.gov/mgis/.

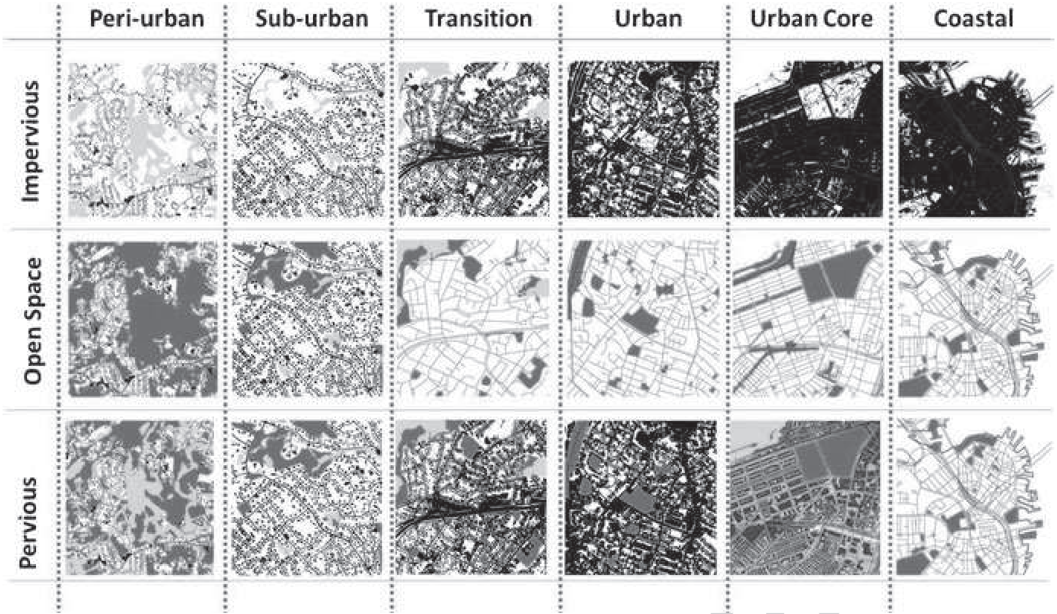

Fig. 6 Green infrastructure transect application to Boston region, step two: existing green infrastructure patterns

We find that open space and unbuilt[6] land increases in area as we move towards the periphery (Figs. 3 and 6). What significantly increases, and not usually included in the inventory of GI, are unbuilt spaces within the private domain (yards, gardens, and school grounds). Since ecosystem benefits are not bounded by administrative limits (Fábos 2004) and increase proportionally with GI area,[7] it is critical to ensure that GI policies simultaneously address land within the private and public domains.

The final step is to identify and recommend appropriate GI policies across the GI transect zones. We distinguish clear complementarities between GI benefits, community needs, and vulnerability requirements (Fig. 7). We list the typologies of GI elements that already exist within each zone or those that could potentially be introduced or enhanced. Ecosystem benefits that are complementary to community needs and climate impacts are also listed in accordance with the spatial typology. By overlaying information from steps one and two, we begin to identify the potential GI policies. For example, the coastal area will benefit from planned retreat – where vulnerable built areas across the coast may gradually be transformed into landscapes for recreation. The resulting coastal landscapes become non-structural[8] defences incorporated as recreational and ecological landscape features. Therefore, the policy

[6]Unbuilt land is considered as potential to increase green infrastructure area within an urban region.

[7]Ecosystem benefits are directly proportional to the amount of land available for GI: the more forested land, the more the potential for temperature control, and the more the golf courses and open land, the more water storage may be achieved.

[8]Non-structural defences are based on naturally occurring or engineered defences such as wetlands, marshes, sand coasts, and eastern dams.

	Peri-urban	Sub-urban	Transition	Urban	Urban Core	Coastal
GI Spatial Elements	• Wetlands • Agriculture • Forest · • water ways • Nature Parks • Greenways • Ecological networks • Agricultural land	• Gardens • Domestic yards • School grounds • Cemeteries • Subdivisions • Wetlands • Forest Stands • Green ways • Street trees • Unused lots • Derelict land • Parks • Swales	• Gardens • Domestic yards • School grounds • Cemeteries • Subdivisions • Wetlands • Forest Stands • Green ways • Street trees • Unused lots • Derelict land • Parks	• Parks • Gardens • Interstitial Spaces • Private sites • Unused lots · • Street trees • Green facades • Green roofs • Parking lots ·	• Parks • Piazzas • Garden • Interstitial spaces· • Street trees • Green facades • Green roofs	• Coastal zones • Wetlands • Coastal parks • beaches· • Rivers ·
GI Benefits	• Water regeneration • Recreation • Ecological connectivity • Biodiversity • Heat reduction • Food production & Clean Air		• (+)Rain water retention · (-)roof heat exchange · Flood storage · Provide opportunities for urban agriculture · (-) Urban island heat · Provide shade & cooling· recreation Increased · (+)real estate value			• Natural defenses • Surge reduction • Recreation
GI Strategy	• Conserve • Protect • Private property • Aggressively increase land under GI • Ecological connectivity	• Conserve • Protect • Reclaim land • Private Property • Reclaim land • Ecological connectivity	• Conserve • Protect • Large land • Private Property • Incentives for private owners • Reclaim land	• Densify GI • Hybrid Systems • City Green	• Densify GI • Green Roofs • Green Facades • Transform pervious to impervious • City Green	• Planned Retreat • Densify coastal GI • Protect Coast

Fig. 7 Green infrastructure transect application to Boston region, step three: identification of GI policies

here would focus on preserving and intensifying all existing GI elements and to define a long-term plan to allow time for legal procedures and financial compensation to take place for the coastal zone transformation. Within the urban zone of the GI transect, policies should address increased temperatures (compounded by UHI) and retention of water run-off. Existing parks and open space, green roofs, green facades, and street planting are spatial elements that should be increased through revisions to building regulations, open space plans, and environmental policies. Through the Biotope Area factor,[9] the city of Berlin is an example where zoning and financial incentives result in an increase in tree canopy and 'at the source' water management. Towards the periphery, policies that enhance connectivity and preserve, conserve, and increase forests, large parks, natural reserves, and biospheres are integral for run-off storage, species migration, temperature control, and water infiltration to ensure ecosystem services at the regional scale.

To ensure consistency across local GI policies with the Boston region, vertical and horizontal integration of policies (Fig. 2) is utilized to coordinate and implement planning projects across town jurisdictions. Planning in Massachusetts

[9]See the City of Berlin, Senate Department for Urban Development: http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/bff/index_en.shtml.

is predominantly participatory and happens at the local (town) scale. This means that parcel and neighbourhood scale plans should build up to form an overall town plan that explicitly considers GI measures for adaptation. The open space plans that are mandatory to US towns could be extended beyond recreation to incorporate ecological and adaptation plans. Town plans then need to build the overall regional vision. This may be achieved by expanding the mandate of regional planning bodies beyond transportation and economic development towards a more active role to coordinate and integrate local plans. Even more, regional bodies should be responsible to monitor and develop regional climate projections that help in providing the vision for regional and local adaptation plans. A hierarchal organizational structure that works in both directions (from local to regional or from regional to local) ensures that all constituents and measures serve an intended local role within a larger regional approach. The proposed structure that we have presented may be a first step in integrating local adaptation planning across scales and jurisdictions using current and accepted knowledge.

4 Conclusion

Adaptation policies run the risk of a piecemeal, systematized approach. It is easy to prescribe a green roof here and a rain garden there and hope that they will add up to a proper systematic approach. However, the challenges of adaptation are too significant for this to be effective. Framing GI planning through the transect approach provides a way to conceptualize a whole system of GI spatial elements, identify coming climate challenges, and plan to integrate local policies at site scale with adaptation needs at the neighbourhood, city, and regional scales. In this chapter, we briefly used Boston as a case study to demonstrate how the GI transect may be applied and how it can assist in interpreting and framing overall GI for adaptation. We conclude that GI will be an effective adaptation policy when it is matched to the physical character of urban environments (urban, suburban, and rural) and the needs of communities they are intended to serve. This approach is a first step in mainstreaming adaptation planning using current GI practices.

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