RESILIENCE THINKING IN LANDSCAPE PLANNING: A TRANSDISCIPLINARY FRAMEWORK AND A CASE FOR CLIMATE CHANGE ADAPTATION

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1 ABSTRACT
Climate change and urbanization have exacerbated environmental hazards and affect health, safety, and welfare of society. Resilience thinking provides a foundation for landscape planning framework to investigate social-ecological drivers and outcomes in the linked social-ecological systems. Transdisciplinary approach includes organizational, institutional, and interdisciplinary hierarchies and collaborations and plays an important role in redefining issues and building consensus for achieving common goals. The proposed transdisciplinary planning framework aims to build adaptive capacity through a revolving feedback loop. A case study from the Boston Metro Area Urban Long-Term Research Area-Exploratory project demonstrated the use of the proposed planning framework. Growth scenarios were developed through transdisciplinary planning process. The study evaluated planning innovations in growth strategy (e.g., infill redevelopment) and green infrastructure (e.g., stormwater detention) for climate change adaptation. Climate change-induced flooding risks, served as social-ecological outcomes, were measured through integration of flooding hazard index and social vulnerability index under multiple climate change and land use scenarios in the Charles River watershed. The results from empirical study support the role of integrating anticipated climate change-induced social and ecological impacts into spatial planning decisions to mitigate impacts, minimize exposure of hazards, and increase adaptive capacity. In addition, innovations in green infrastructure planning and design serve as climate change adaptation strategies. Applying the transdisciplinary planning framework, the findings can be used to inform decision-making and prioritize climate change adaptation strategies to serve the needs of the socially vulnerable groups. The study provides an insight of integrating transdisciplinary approach in landscape planning for building social-ecological resilience.

1.1 Keywords
social-ecological systems, resilience, transdisciplinary planning framework, climate change adaptation

2 INTRODUCTION
Climate change has exacerbated climate related disasters (IPCC, 2007) and associated casualties and property damages, particularly in already risk-prone areas, not only in low- and middle-income countries but also in developed countries (Leary, 2008). The interaction and reciprocal feedback between social and ecological systems has augmented complexity in landscape planning aiming toward resilience and sustainability. The scale of complexity in the interlinked social-ecological systems involves cross-institutional and organizational consensus-building as well as interdisciplinary collaboration. Coping with the dynamics of change therefore requires integration of resilience thinking and transdisciplinary approach in landscape planning framework. I propose a landscape planning framework integrating transdisciplinary participatory planning process in the interlinked social-ecological systems for research and practices to untangle complex issues such as climate change. Applying the framework to the Boston Metro Area Urban Long Term Research Project-Exploratory (BMA ULTRA-ex) project, the social-ecological outcomes are presented through the evaluation of stakeholder-input growth scenarios and climate change-induced flooding risks assessment in the Charles River watershed. The study provides insights in applying the transdisciplinary landscape planning framework for climate change adaptation planning strategies in building social-ecological resilience.

3 BACKGROUND
3.1 Resilience Thinking in Planning
Resilience theory is rooted in ecology. Ecological resilience refers to non-equilibrium and inter-connected open systems that possess
adaptive capacity to absorb disturbances, reorganize within a threshold level, and re-generate in order to cope with change (Holling, 1973; Folke, 2006; Walker and Salt, 2006). Resilience thinking opened a window for a more comprehensive theory in connecting ecological, social, and physical dimensions in the linked social-ecological systems. Social-ecological systems emphasize the integrated concept of humans-in-nature and interplay between human and natural systems (Berkes and Folke, 1998). Human activities, socio-economic drivers, and institutional structures across temporal and spatial scales have impacts on ecosystems, which then have reciprocal feedback and impacts on human systems (Grimm et al., 2000; Folke, 2006). Social resilience associated with livelihood of human systems is therefore linked with ecological resilience (Adger, 2000). In addition, resilience thinking has been applied to planning in building adaptive capacities in governance, institutions, communities, and cities to cope with shocks (e.g., natural disasters, economic depressions, wars), uncertainty and change (e.g., climate change) (Adger, 2006; Pendall et al., 2010; Bealley, 2009; Wilkinson, 2012).

Resilience thinking provides a powerful metaphor and inspiration in landscape planning research and practices. Resilience research has provided an insight of linking structure and function in the non-equilibrium and interlinked social-ecological systems, which offers an effective framework to study integrated ecological and social heterogeneity of patterns and processes in landscape and urban systems (Pickett et al., 2004). In addition, the concept of adaptive cycle across multiple temporal and spatial scales in resilience theory has spurred resilience thinking in the development of adaptive planning and design. For example, Ahern (2011) suggested learning-by-doing planning strategy with multifunctional, diverse, redundant modules, multi-scale connectivity, and safe-to-fail design to provide opportunities for building resilience capacity. Moreover, social-ecological resilience thinking can serve as a common framework in transdisciplinary research on complex and multifaceted issues such as climate change adaptation (Deppisch and Hasibovic, 2013). Built upon previous research, this paper aims to apply resilience thinking through the lens of building adaptive capacity of the social-ecological systems to cope with climate change in a transdisciplinary landscape planning framework.

3.2 Transdisciplinary Landscape Planning

Landscape planners are facing challenges of planning issues that involve multiple dimensions in the interlinked social-ecological systems across multiple disciplines (e.g., ecology, economy, sociology, archeology, engineering, art, architecture, public policy, public health) and multiple institutional hierarchies (e.g., global, national, regional, local, individual) simultaneously. The concept of transdisciplinarity, which can be traced back to the education system proposed by Jantsch (1970), promotes an innovation system through a multi-level, multi-goal, hierarchical system interlinked with interdisciplinary coordination. Fry (2001) used transdisciplinary approach to address multi-functionality and interdisciplinarity challenges in landscape research. Tress and Tress (2001) applied transdisciplinary approach for landscape research in an interactive people-landscape model with multiple disciplines from biological, geographical, social, cultural, and spiritual elements and multiple levels of spatial, temporal, and mental dimensions. Stokols (2006) proposed transdisciplinary action research (TDAR) that involves interactions of organizational scope (inter-sectoral, inter-organizational, intra-organizational), analytical scope (biological, psychological, social/environmental, community/policy), and geographical scale (local group, community, regional, national/global).

The TDAR model in particular has gained prevalent attention in the field of landscape and urban planning involving participatory planning as an effective approach to address issues in complex social-ecological systems. Schroth et al. (2011) employed TDAR framework and landscape visualization tools in multiple case studies involving researchers and community stakeholders in the landscape planning processes as well as landscape design and policy implementation. In addition, Antrop and Rogge (2006) evaluated the process of employing TDAR approach involving interdisciplinary researchers, program team, and stakeholders for preserving cultural landscapes. Moreover, Thering and Chanse (2011) argued for plural design using TDAR framework by addressing challenges of using transdisciplinary approach in landscape planning processes. Furthermore, Deppisch and Hasibovic (2013) included interdisciplinary researchers and practitioners to work with stakeholders in the scenario planning process for developing climate change adaptation strategies in the urban region. Combined with resilience thinking in social-ecological systems, transdisciplinary approach provides an effective
common planning framework to include multiple actors, stakeholders, and communities, as well as interdisciplinary researchers and practitioners at multiple organizational hierarchies to work in tandem to address complex landscape planning issues such as climate change adaptation (Deppisch and Hasibovic, 2013).

4 TRANSDISCIPLINARY PLANNING FRAMEWORK IN SOCIAL-ECOLOGICAL

In order to have a comprehensive understanding of linked systems, it is necessary for a synthesis and integration of several different conceptual frames (Costanza et al., 1993). First, social-ecological resilience concept is embedded in the planning framework (Deppisch and Hasibovic, 2013) to include both social and ecological drivers and their interactions and outcomes, which then inform planning decisions. Second, a revolving learning-by-doing feedback loop in the planning framework serves as windows of opportunity to evolve and adapt. Adaptive planning processes includes identifying goals and objectives, plan formulation, plan implementation, plan evaluation, and plan monitoring (Kato and Ahern, 2008). Third, adopting the TDAR framework, transdisciplinary participatory planning process includes three dimensions: vertical (i.e., institutional hierarchy), horizontal (i.e., interdisciplinary collaboration), and organizational hierarchy. Finally, transdisciplinary approach in the planning framework provides opportunities for learning, integration, synthesis, and innovation for sustainable and resilient development (Meppem and Gill, 1998). Integrating resilience thinking in the interlinked social-ecological systems and transdisciplinary approach, I propose a landscape planning framework in a feedback loop as following (Figure 1):

(1) Initiate a transdisciplinary participatory planning process that involves interdisciplinary researchers and practitioners, local authorities, stakeholders, and the general public through a combination of various forms of participatory methods (e.g., preference surveys, small group discussion, memory mapping) that allow consensus-building toward common goals (Innes, 1996)

(2) Integrate transdisciplinary participatory planning process that drives plan-making development to incorporate planning interventions and decide social-ecological drivers based on the goals and objectives in the planning agenda.

(3) Conduct empirical research in the social-ecological systems for the evaluation of plans that are formulated through planning intervention and indicators identified in the planning process.

(4) Document and monitor social-ecological outcomes from the plan evaluation and share findings and lessons learned with the transdisciplinary participants.

(5) Continue the transdisciplinary participatory planning process with the new insights from social-ecological outcomes and improve plans and/or modify social-ecological drivers as adaptive planning processes toward resilience and sustainability.

5 CASE STUDY

5.1 Study Context and Area

Climate change is projected to increase the intensity and frequency of storm events that would increase flooding hazards in the Northeast region (IPCC, 2007; Rock, et al., 2001). Urbanization associated with land use and land cover change has altered hydrological cycles by increasing stormwater runoff, reducing baseflow and increasing flooding hazards. Combined urbanization and climate change impacts on long-term riparian flooding during future growth are likely to affect more socially vulnerable populations. The Boston Metropolitan Area, consisting of 101 communities with a population of 3.16 million, is expected to grow 10% by 2030 (MAPC, 2009). Currently, the population is aging, becoming more diverse in its younger cohort, increasing in inequality in socio-economic status, and increasing in needs for support for minority groups and immigrants. The current demographics and socio-economic structure exemplify with some of the key concepts of social vulnerability. The increased frequency of extreme storm events in recent decades—Superstorm Sandy in 2012, Hurricane Irene in 2011, and serious floods in 2011, 2010, and 2005—has coincided with climate change projections in the Northeast. The socially vulnerable groups are likely to be impacted most.

The Charles River watershed encompasses 778 km² and is predominately within the Boston Metropolitan Area with minimal coastal lines. The watershed consists of 35 municipalities, includes large portions of the City of Boston, is the most densely populated, and covers the most environmental justice (EJ) populations among nine watersheds in the metropolitan area. The EJ populations defined by the Massachusetts Office of Geographic Information (MassGIS) include non-white, low-income, and English-isolated groups, which are corresponding to characteristics of socially vulnerable groups (Cutter et al., 2003).
Figure 1. Transdisciplinary Landscape Planning Framework in Social-Ecological Systems.
Diagram by the Author

Therefore, Charles River watershed is susceptible to increased social impacts and climate change-induced flooding hazards in the Boston Metropolitan Area under anticipated urbanization and climate change. The term “climate change-induced flooding” refers to floods that are exacerbated by climate change in this study.

5.2 BMA ULTRA-ex Project and Study Goals
The BMA ULTRA-ex project aimed to understand the socio-economic (e.g., land use policy, population change, investment, social capital) and bio-physical (e.g., climate change) drivers that influence social-ecological processes (e.g., land use and land cover change, urban greening development, environmental stewardship) that interact within ecosystems and their impacts on social-ecological outcomes (e.g., biodiversity, water quality, stormwater management, natural hazards, public health, social equity) (BMA-ULTRA, 2011). The project team engaged with stakeholders in two workshops and developed four growth scenarios in a transdisciplinary scenario planning process (Ryan et al., 2013).

Growth strategies and green infrastructure were two planning interventions identified during the workshops for plan evaluation. Infill redevelopment as a growth strategy focused on compact form and redevelopment of existing built areas in contrast to suburban sprawl that often results in the clearance of agriculture, forest, wetlands and large open space during the urbanization process. The four growth scenarios varied in allocating the same amount of projected population through various levels of infill redevelopment between the inner cities and the suburbs. Current Trends scenario followed a suburban sprawl pattern with the lowest level of infill redevelopment. MetroFuture scenario aligned with policies set forth by the Metropolitan Planning Area Council (MAPC) for the region and focused on developing lands along transportation corridors and public transit cores with moderate level of infill redevelopment. Green Equity scenario emphasized allocating urban green infrastructure (e.g., trees, stormwater best management practices) for underserved neighborhoods (e.g., low-income, minority) with slightly less infill redevelopment than MetroFuture in order to provide more space for urban greening in the inner cities. A separate study has demonstrated Green Equity scenario encompassed the most equitable distribution of urban tree canopy comparing to other scenarios in relation to low-income neighborhoods in the City of
Boston (Danford et al., 2014). Finally, Compact Core scenario explored the highest level of possible infill redevelopment in the inner cities.

Applying the transdisciplinary landscape planning framework, the study goals were (1) to understand the social-ecological dynamic interaction through an integrated flooding risk assessment that combines climate change-induced flooding hazards and their exposure to socially vulnerable groups, and (2) to evaluate the effects of planning interventions (infill redevelopment and stormwater detention) in mitigating climate change-induced flooding and associated social impacts.

5.3 Study Design in the Planning Framework

Applying the proposed transdisciplinary landscape planning framework, climate change and population change were considered as social-ecological drivers and growth strategies and green infrastructures were the planning interventions identified in the BMA ULTRA-ex project (Figure 2). Flooding risks served as a medium for studying the interactions between social and ecological systems. Population change shaped land cover through land use change derived from growth scenarios. A flooding hazard index (HI) was defined as the probability of number of days in a period of 45 years when the stream outflow would exceed the baseline bankfull discharge volume under current climate. HI was constructed through a hydrological model—Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998). A Social Vulnerability Index (SoVI) (Cutter et al., 2003) was constructed based on 30 demographic and socio-economic characteristic variables from the U.S. Census 2010 through statistical methods. Subsequently, a climate change-induced flooding risk index (RI) (Cheng, 2013) was constructed through multiplying the flooding hazard index and SoVI.

Planning intervention evaluations were conducted through inputs of land use and climate variables and pot hole function in SWAT modeling. Four growth scenarios were converted into land use change (Cheng et al., 2013). A total of 3% of the Charles River watershed land areas associated with public open space were modeled for stormwater detention function (Cheng et al., 2013). A climate sensitivity study testing firstly was conducted to include 150 climate conditions (combinations of mean temperature change of 0, +1, +2, +3, +4, +5°C, mean precipitation change 0, ±10, ±20%, precipitation variation change 0, ±10, ±20%) (Cheng, 2013). Among positive impacts on the increased flooding hazards, a total of 36 climate combinations—mean temperature 0, 1, 2 or 3°C increase, mean precipitation at 0%, 10% or 20% increase, and precipitation variation at 0%, 10% or 20% increase—were tested further for the evaluation of stormwater detention (Cheng, Brabec, Yang, & Ryan, 2013). Finally, three climate change scenarios that closely matched the general circulation models (GCMs) projection for the Northeast were selected. Low Impact, Medium Impact, and High Impact climate change scenarios were composed of 3°C, 2°C, and 1°C increase in mean temperature, 10%, 10%, and 20% increase in mean precipitation, and 0%, 10%, and 20% increase in precipitation variation respectively (Cheng, 2013).

The social-ecological outcomes play an important role in closing the feedback loop of the planning framework and informing planning decisions through continued revolving transdisciplinary participatory planning processes. Additionally, the planning interventions serve as both climate change mitigation (e.g., reducing carbon emissions, minimizing impervious surfaces, reducing urban heat island effects) and climate change adaptation strategies (e.g., enhancing resilience to climate change-induced flooding risks).

5.4 Social-ecological Outcomes

The climate change-induced flooding risk index (RI) derived from the integration of climate change-induced flooding hazard index and Social Vulnerability Index represented social-ecological outcomes of this study. Figure 3 illustrated the flooding risk index in Current Trends scenario among the climate change impact scenarios. Across scenarios, higher flooding risks were located at the lower basin of the watershed. In High Impact scenario, a significant increase of flooding risk index presented throughout the entire watershed. Among the growth scenarios, flooding risk held similar patterns across scenarios with the higher flooding risks located at the lower basin of the watershed. However, little variance was shown for the effects of growth strategy and associated land use and land cover change on the increased flooding risks (RI between 0 and 1.2%) (Figure 4) in contrast to the significant effects of climate change impacts on flooding risks (RI increased up to 3%) shown in Figure 3.
Social impacts corresponding to climate change impacts varied greatly among growth scenarios by the variance of the amount of projected population who were likely to be exposed to areas with high flooding risks (hot spots) (Figure 5). The flooding risk hot spots were generated through spatial statistics in geographic information systems (GIS) of RI value with the standard deviation of z score greater than 1.65. Current Trends scenario distributed the largest percentage of projected population growth (4.5%) with 2877 more people allocated to flooding risk hot spots than that of the Compact Core scenario (3%).

The effects of using stormwater detention on mitigating climate change-induced flooding hazards were significant within flooding risk hot spots in all climate change scenarios. Figure 6 illustrated the difference in flooding risk index (RI) values between stormwater detention treatment and no treatment. The negative values (shown in green and blue areas) represented positive effects in mitigating climate change-induced floods. In general, stormwater detention was effective throughout the entire basin except in some upper stream areas (shown in positive values and in yellow, orange and red areas) in all climate change scenarios. Even in High Impact scenario, the small amount of the detention area (3% of land area applied in this study) remained having positive effects in mitigating climate change-induced floods.
Figure 3. Maps of the Long-Term Climate Change-Induced Risk Index (RI) in Current Trends Scenario among Climate Change Impact Scenarios. Diagram by the Author.

Figure 4. Maps of Climate Change-induced Flooding Risk Index (RI) under Current Climate Conditions among Growth Scenarios. Diagram by the Author.
Total projected population increase in 2030 distributed in areas of flooding risk hot spots (Z score >1.65 Std. Dev. in all redish census tracts)

**Current Trends:** 13,188  
**MetroFuture:** 11,060

**Legend**
- Population Increase
- 1 Dot = 10 people
- **RI HotSpot**
- GiZScore
  - < -2.58 Std. Dev.
  - -2.58 - -1.96 Std. Dev.
  - -1.96 - -1.65 Std. Dev.
  - -1.65 - 1.65 Std. Dev.
  - 1.65 - 1.96 Std. Dev.
  - 1.96 - 2.58 Std. Dev.
  - > 2.58 Std. Dev.

**Figure 5.** Maps of Allocation of Projected Increased Population in Growth Scenarios Overlaid with Current Climate Conditions of Long-Term Flooding Risk Index (RI) Hot Spots. Diagram by the Author.
6 DISCUSSION

6.1 Resilience Thinking and Planning Implications

This study has demonstrated the effects of planning interventions in mitigating social-ecological impacts from climate change and serving as adaptation strategies. The root cause of social vulnerability resides in social systems created by society and is inherent in the process of urbanization under social, political, economic, and cultural context (Beck, 1992). In addition, social vulnerability is place-specific (Cutter, Boruff, and Shirley, 2003), particularly associated with natural disasters and environmental justice (Colten, 2006; Walker and Burningham, 2011). Therefore, spatial planning for the allocation of projected population should take anticipated environmental hazards and associated health and safety impacts into considerations. In this case, planning agencies (e.g., MAPC) and local municipalities could use the social-ecological outcomes shown in Figure 5 to refine the growth management and land use plans by accounting for projected climate change-induced flooding hazards and socially vulnerable groups. To enhance social-ecological resilience, communities could consider (1) mitigate climate change impacts, (2) minimize exposures to hazards, and (3) increase adaptive capacity. In light of uncertainty in planning exacerbated by climate change, place-based assessment plays a critical role in providing parameters of climate change impacts and assisting in setting policy frames for building social-ecological resilience. Furthermore, this study demonstrated the positive effects of using stormwater detentions in mitigating climate change-induced floods, which in turn enhancing safety and livelihood of the communities. Therefore, green infrastructure also serves as climate change adaptation strategy. Growth strategy and green infrastructure are planning interventions connected through land use/landscape planning and site
design. Innovations in adaptive land use in the interconnected green infrastructure system network across rural to urban transect (Cheng, 2013) can help to restore and enhance ecosystem functions (e.g., stormwater detention, biodiversity, carbon sequestration, micro climate moderation) and eventually strengthen social-ecological resilience.

6.2 Closing the Loop

The social-ecological outcomes from this study were presented to the interdisciplinary research teams that consist of multiple institutions and disciplines (e.g., landscape architecture, regional planning, conservation biology, ecology, public policy, geography, hydrologic engineering, and environmental psychology). The other research teams have used growth scenarios developed from the transdisciplinary participatory planning process to explore other social-ecological drivers and outcomes. For example, one team is investigating water conservation policies and people’s perceptions on green infrastructure in relation to water quality and accessibility. Another team is exploring carbon sequestration in the Charles River watershed based on land cover change associated with various growth scenarios. Furthermore, our team has evaluated the effects of using landscape preference and scenarios as visualization tools in the transdisciplinary process during the stakeholder workshop for deliberating common goals in sustainability. Currently, the BMA ULTRA-ex research teams are working on assembling interdisciplinary social-ecological outcomes for sharing with stakeholders and closing the loop of the planning framework. This study serves as a seed project in the exploratory efforts for the social-ecological long-term research in Boston Metro Area. The ultimate goal is to apply the transdisciplinary planning framework in a continuous feedback loop that allow plans to be adopted and evolved overtime with new insights from the empirical social-ecological outcomes. Subsequently, plans can be adaptive in coping with climate change and uncertainties in planning, which eventually build social-ecological resilience at multiple scales. Therefore, it is critical to close the loop gap and secure resources for long-term transdisciplinary participatory process in the proposed landscape planning framework.

7 CONCLUSIONS

Climate change and urbanization impacts on associated disasters have increasingly become an eminent threat to cities. This paper has contributed to theoretical framing of landscape planning research issues, empirical case studies, and knowledge gained for building innovations in landscape planning and design practices. The planning framework can be applied in landscape and urban planning processes involving dynamics of social and ecological factors and processes in the interlinked social-ecological systems and to address complex issues such as climate change. Plan evaluations through empirical studies on landscape performance and social-ecological outcomes could inform policy-makers and practitioners for setting climate change parameters and seeking innovations in landscape planning policies and practices. This knowledge is critical for the integration of ecological design, environmental justice, and climate change mitigation and adaptation in landscape planning. The proposed transdisciplinary planning framework allows continuous feedback loop at multiple scales across organizational hierarchies, interdisciplinary coordination, and institutional hierarchies. The transdisciplinary approach is particularly important for building mutual understanding and consensus towards common goals and for setting priorities in allocating resources and planning strategies to enhance people’s livelihoods and ecosystem services for building resilient and sustainable communities.

8 REFERENCES


