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Incorporating the effect of urbanization in measuring climate adaptive capacity

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ABSTRACT

Measuring the ability of a community to face climatic changes, or its adaptive capacity, is necessary in order to plan and guide development as the global climate continues to warm. One factor that has not been thoroughly addressed by previous attempts at measuring adaptive capacity is urbanization. This study looks to measure adaptive capacity in relation to urbanization, as many areas of the world are undergoing this rapid transition. An indicator system was created with land-use sensitive measures and applied to three different land use projection scenarios (A, BAU, and B − high, medium, and low growth, respectively) to 2030 and 2050 for two case study areas, Tamsui, Taiwan and West Palm Beach, USA. In Tamsui, the adaptive capacity decreased in all scenarios, but most dramatically for the high growth scenario. The low growth scenario decreased more slowly through each time slice. For West Palm Beach, the high growth scenario had the highest score in 2030, but declined in 2050. The medium growth Scenario BAU, also had a higher adaptive capacity score in 2030 than in 2050. The low growth Scenario B had a score that improved less dramatically but continued to rise through 2050. Scenario A would be ideal for short term gains, but its benefits would plateau in the long term. Scenario B, with conservation measures and more restricted growth would be the most ideal alternative. This study shows that urbanization has short term socioeconomic gains, but long term environmental consequences. The results also successfully incorporates the effect of land use change into an adaptive capacity indicator system, and can be applied in other localities expecting significant increases in urbanization.

1. Introduction

In 2016, 54.5% of the world's population lived in urban areas was estimated (UN-DESA, 2016a), and that figure has surely risen since. Urbanization is expected to continue well into the future all over the world. By 2030, the projected urban population in Africa and Asia will occupy about 85% of the global level (UN-DESA, 2016b). Asia, in particular, will continue to hold about half of the world's urban population. However, urbanization has many positive as well as negative aspects and consequences (Sánchez-Rodríguez et al., 2005). Driven by a number of social and economic transformations like industrialization, urbanization catalyzes a number of its own changes, affecting the state of poverty, of land use and land cover, and more. This has, and will continue to have, a great effect on demographic and environmental developments (UN-DESA, 2015).

Urban development and climate change both have resounding effects on land use and transformation that are further complicated by their complex relationship with each other. Due to the perceived irreversibility, urban land change is considered one of the most problematic trajectories of land change (Verburg et al., 2015). Urbanization can affect the socioeconomic and biophysical functions influencing adaptation efforts and has severe consequences on climate, biodiversity, ecosystem quality and ecosystem services (Elmqvist et al., 2013). Considering that environmental, economic, political, and social factors all play critical roles in the capacity of communities to adapt to climate change, it has become increasingly relevant to consider how urbanization and land development affects adaptive capacity at a local level, where adaptation is most relevant.

In recent years, there has been an upswing of adaptation, vulnerability, and resilience literature with regards to anthropogenic climate change and global environmental change (Janssen, 2007). With this influx, the concept of adaptive capacity is the recipient of increased interest as a way of combing resilience and vulnerability literatures (Engle, 2011; Gallopin, 2006) and has resulted in a variety of studies (Posey, 2009; Acosta et al., 2013; Panda et al., 2013; Goldman and Riosmena, 2013; Quiroga et al., 2015; Hogarth and Wójcik, 2016; Nhuan et al., 2016). Yohe and Tol (2002) and Smit and Wandel (2006) outline the concept of adaptive capacity in relation to vulnerability, and

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one still prominent definition in use is "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014). Systems can refer to both socioeconomic and biophysical systems, and thus adaptive capacity is influenced by a wide variety of factors. In which, urbanization and land use change has been recognized as the important one (Verburg et al., 2015).

World urbanization has a profound impact on the extent and spatial character of urban land cover and land use (Foley et al., 2005). With geographic movement of demography comes geographic change of resources, capital, and demand, all of which have corresponding physical manifestations. With more people living and working in cities, metropolises expand and agricultural and natural vegetated land cover is developed, increasing the concentration and total area urban land. When urbanization causes a decrease in natural land surface, it affects carbon, energy, and water budgets, and a number of other factors, such as temperature patterns and biodiversity, with far reaching consequences (Dale, 1997; Pyke and Andelman, 2007; Haines-Young, 2009; Pielke et al., 2011; Zhou et al., 2014; Fu and Weng, 2016).

Changes in land use and land cover (LULC) as a result of urbanization are also major drivers and results of global climate change (Sánchez-Rodr & guez et al., 2005; Verburg et al., 2015). LULC have complex interactions with atmospheric conditions, which contributes to climate change while simultaneously compounding or mitigating climate impacts at a range of scales. Conversely, climate impacts can also spur urbanization, changes in vegetation, or reallocation of agriculture land or pasture land (Ostwald et al., 2007; Lee, 2009). LULC and climate change are intimately linked; both climate mitigation and adaptation are influenced by, and in turn influence back, LULC and urbanization.

Changes in land use have clear, observable effects on greenhouse gas emissions and vice versa (Liao et al., 2013; Jones et al., 2013), but climate adaptation is also mediated by LULC. Many determinants of adaptive capacity are affected by levels of urbanization as LULC have effects on both socioeconomic and biophysical systems. Socioeconomic determinants, like access to resources or income level, are highly related to urbanization (IPCC, 2012). The rural-urban disparity is the key in considering factors that influence adaptive capacity. Many economic resources are concentrated in urban areas, as they are linked to international markets and finance. Also, urban areas tend to be better serviced by infrastructure from roads to electricity, compared to rural areas that may not have as easy access to things like running water or cellular service.

However, cities are complex places, and have both positive and negative impacts on adaptive capacity. Cities may be associated with more resources, but they also bring many consequences like increased inequality or weaker social ties that provide support in times of stress (IPCC, 2012). Biophysical factors are also often dependent on land cover, as previously mentioned; for example, flooding impacts and temperature variance are often exacerbated by loss of coastal wetlands and wetlands have historically been filled in for the sake of agriculture or other kinds of development (Marshall et al., 2003). Forest cover has also been shown to have cooling effects, or other positive impacts on soil retention or precipitation patterns (Bonan, 2008).

Studies have shown clear links between LULC and climate change and the feedback between them, but a literature gap remains in drawing connections between LULC change and measuring adaptive capacity, although IPCC (2012) addressed urbanization specifically as a potential driver of vulnerability. Metzger et al. (2006), Huang et al. (2012), and Acosta et al. (2013) addressed this in previous studies, but the intersection remains understudied.

To contribute to this topic of study, this research aims to measure adaptive capacity of two case study areas, Tamsui in northern Taiwan and West Palm Beach in Southern Florida in the USA. Both are areas that have experienced significant growth, and are slated for still more urban development and land use change in the next decade, making them interesting cases for an international comparison of how these changes affect adaptive capacity. This research aims to contribute to existing adaptation science by creating a new indicator system, targeted specifically at areas in transition, the Urbanizing Adaptive Capacity Index (UACI). The UACI can measure current and future adaptive capacities under various scenarios based on both biophysical and socioeconomic factors to assist decision makers and policy builders in climate adaptation planning.

2. Methods

Indicators influenced by land use change and urbanization were chosen for the Urbanizing Adaptive Capacity Index (UACI), and both biophysical and socioeconomic aspects are considered. This study uses the data for indicators from years 2000 and 2010 as a baseline, and creates three alternative future land use scenarios based on land use and socioeconomic inputs via *ESRI ArcGIS 10* and *What if?* (Klosterman, 2016). Total area of built up land was used as a proxy for levels of urbanization. Indicator scores were pushed to future time slices along each scenario and corresponding levels of urbanization, as calculated by *What if?,* in order to predict the adaptive capacity for both Tamsui and West Palm Beach.

2.1. Indicators and scoring

This research aims to compile a set of indicators to measure this change with regards to urbanization and its effect on adaptive capacity on a local scale. Indicators chosen are based on IPCC frameworks and previous literature on vulnerability and adaptive capacity (Smit and Pilifosova, 2001; Brooks et al., 2005; Sietchiping, 2006; Acosta et al., 2013). This research scores climate adaptation capacity indicators for years 2000 and 2010 using land use percentages to act a baseline and uses this data to predict indicator values to future time slices along land use change scenarios. Data for indicators were sourced from government census data and reports, land use surveys, and historical documents of each case study site.

Adaptive capacity indicators in this study were chosen based on the major priorities of data availability, previous literature, relationship with urbanization, and scalar suitability. All the selected indicators are correlated with urbanization in one way or another. Extreme climate events, such as tropical cyclones, heat waves, cold waves, and droughts, should be considered when planning for climate adaptation on a local or regional level. However, rather than being a hazard-specific indicator system, the UACI is used for comparison to allow for a wider

Table 1
Biophysical indicators.

i	Determinant	Indicator	Measure	Literature
B1	Storm water and Runoff	Urban	Percent Impervious surface	Cutter et al. (2008), Jubeh and Mimi (2012), Monterroso et al. (2014)
B2	Temperature Variance	Diurnal Temperature Range (DTR)	DTR (Celsius)	Xu et al. (2013), Cheng et al. (2014), Maimaitiyiming et al. (2014), Monterroso et al. (2014), Zhou et al. (2014), Fu and Weng (2016), Li et al. (2016)
B3	Surface Water Stability	Forest/wetland	Percentage of forest/wetland area coverage	Brooks et al. (2005), Monterroso et al. (2014), Remondi et al. (2016)

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