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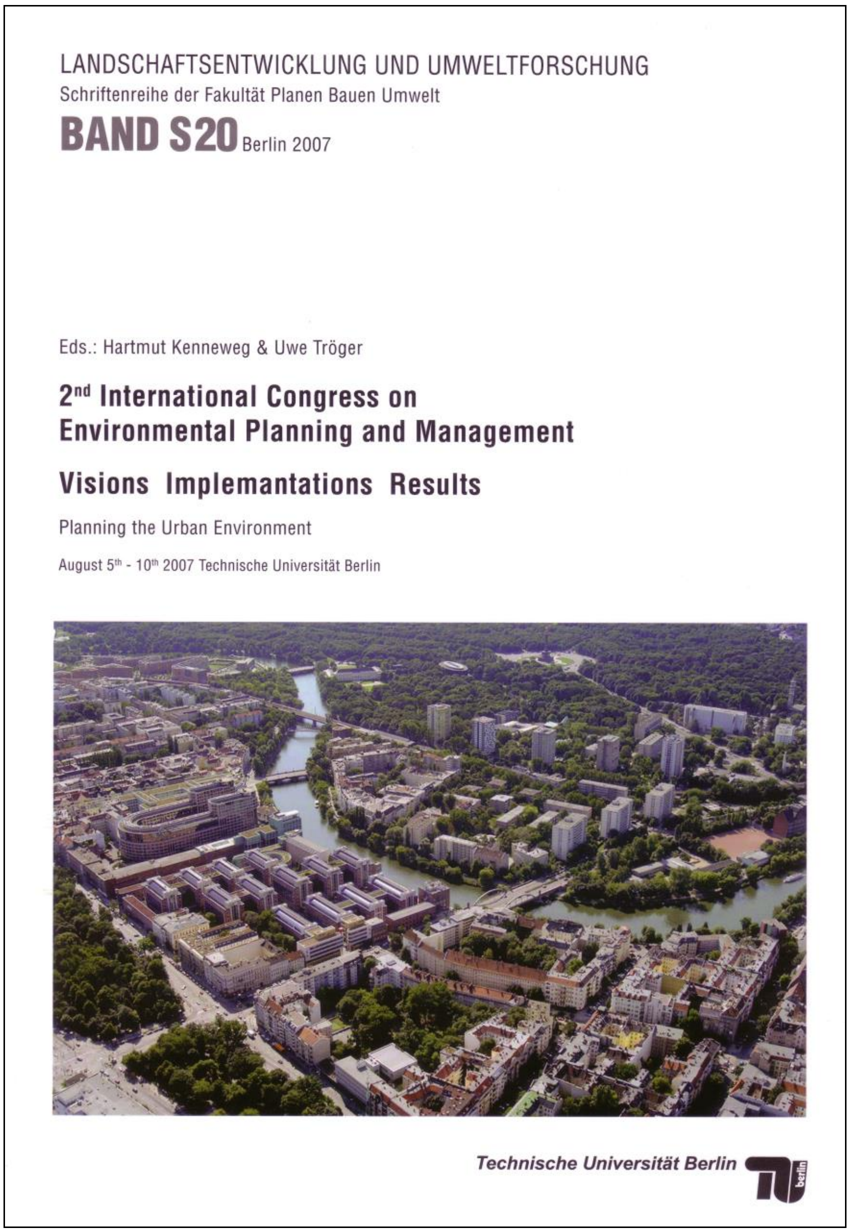

GIS Assessment of Environmental Impacts on Urban Forests

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Abstract
For many species of vegetation, climatic changes resulting in a temperature difference of a few degrees or a slight variation in rainfall pattern may determine whether a particular species survives or becomes extinct. Unlike earlier climatic events, such as that following the last Ice Age, which slowly took place over long periods of time, forecast climate changes are expected to occur suddenly. Because climate and vegetation are so strongly associated, it is assumed that such rapid changes in climate will affect plant distributions and result in altering the makeup of natural communities. An intensive study was recently completed to determine the effect of climatic change on 15,000 known native vascular plant species found in North America. The analysis assumed that a doubling of carbon dioxide would lead to a 3 Celsius degree increase in global temperatures and based the study on the climatic envelope or maximum and minimum mean annual temperature that each species experiences in its current distribution. The results suggest that with a 3 Celsius degree increase in temperatures, approximately 7 to 11 percent or 1,060 to 1,670 of the species under investigation would be beyond their climatic envelope and at risk for extinction. Rare species, which make up approximately 27 percent of North America's flora, were especially at risk with 10 to 18 percent threatened with extinction. Because climate plays such an important role in the distribution of plant species, the predicted global and regional climatic changes will likely affect a variety of existing vegetation patterns. Some species will migrate forming new associations while others will be lost completely. While environmental impacts are difficult to quantify, this research demonstrates how Geographic Information Systems (GIS) can be used to examine proposed scenarios including rising seas, severe droughts, rainstorms, heat waves, and floods and the associated negative effects on urban forest sustainability.

Introduction
The Intergovernmental Panel on Climate Change (IPCC) recently revealed that the warmest years of the past century have taken place since 1990 as the atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 parts per million (ppm) to current levels of nearly 380 ppm, against the backdrop of the natural range of carbon dioxide concentration during the past 650,000 years, which is between 180 to 300 ppm according to ice core data [1]. Based on a global warming scenario consisting of 1 to 3 Celsius degrees by the year 2100, the IPCC concludes that such change will put the most stress on those systems, such as forests and woodlands, already affected by pollution, thus increasing resource demands, and non-sustainable management practices. Urban forests supply numerous benefits for society, such as carbon sequestration, conservation, and biodiversity as well as research, recreation, and relaxation. Because forests are major components of the biosphere, negative impacts on these ecosystems could have damaging effects on other associated goods and services [2], and research indicates that climate change will be accompanied by significant socioeconomic repercussions [3]. In light of these findings, a GIS assessment of the environmental impacts on urban forests seems essential.

Climate Change Scenarios
If global warming continues as the IPCC and others have suggested, locations from the equator toward the poles will begin to experience higher temperature profiles which ultimately could lead to rising seas and more severe droughts, rainstorms, heat waves and floods [4]. Locations in the arctic and temperate latitudes are likely to experience warmer and stormier winters. Summers might be hotter with less precipitation, and summer rains will be the result of thunderstorms rather than showers. Of course, there a number of regional factors such as variations in hills, lakes, coastlines, and soils that will affect local climate, so that some areas could experience higher or lower temperatures than the mean global changes [5]. Factors such as ground-level air temperatures, relative humidity, dew concentrations, exposure to winds, persistence of snow, length of frost-free growing season, and duration and intensity of sunlight vary considerably. However, an increase in temperature of 1 to 3 Celsius degrees over the next century would be equivalent to shifting isotherms pole ward 150 to 550 km [6]. Thus, higher latitude locations can expect to be exposed to higher increases in temperature.

Among the most publicized impacts of global warming are rising sea levels. It has been reported that during the past century, sea levels rose by 5 to 10 inches [7]. Although estimates are highly variable, a recently published paper in Nature suggests that by 2100 sea levels will be about 500 mm higher than today as result of global warming, with thermal expansion of seawater accounting for over half of this rise [8]. Global warming is most likely to contribute to a 6-inch increase in sea levels by 2050 and an increase of about 14 inches by 2100 [9]. Besides rising seas, there is also the threat that wetlands could dry up in an expansive mid-continent warming [10]. Such potential changes in wetland hydrology and vegetation could result in a dramatic decline in the quality of habitat for breeding birds [11]. A rise in global temperatures would also increase the number and intensity of tropical storms along the coasts. The result might be severe outbreaks of violent weather, which could potentially damage coastal forests through heavy winds and flooding, possibly resetting ecosystems to early successional phases. With 40 percent of the population in the U.S. living within 50 miles of a coastline, such impacts could have a negative effect on the economy as well as coastal ecosystems.

Climate change could cause regional wind patterns to shift, which would be accompanied by an increase in wind speed intensity. Such shifts could impact existing rain shadow effects in some regions causing more precipitation on the windward side of mountain ranges while creating even drier conditions on the leeward sides. Fire patterns are likely to be altered as well, which could affect a variety of plant species, even those that are fire resistant or require the presence of fire to regenerate. A study based on a doubling of carbon dioxide levels reveals that wildfires in Canada would undergo a 46 percent increase in seasonal severity [12]. There are unique species such as the bristlecone pine (Pinus longaeva) and the giant sequoia (Sequoiadendron giganteum), which have maintained their present locations for thousands of years despite substantial climatic change, indicating that some species have a high degree of physiological tolerance to climatic fluctuations. In fact, some stress-tolerant species could benefit from extreme climates if competitors are locally depleted or eliminated. However, for many species of vegetation, climatic changes resulting in a temperature difference of a few degrees or a slight variation in rainfall pattern may determine whether a particular species survives or becomes extinct.

Forests Impacts

Unlike earlier climatic events, such as that following the last Ice Age, which slowly took place over long periods of time, these forecast variations are expected to occur suddenly with the average rate of warming probably greater than any seen in the last 10,000 years. Because climate and vegetation are so strongly associated, it is assumed that such rapid changes in climate will affect plant distributions and result in altering the makeup of forest communities [13]. History has shown that most species respond individually to climatic change and not as communities. Those individuals that have the ability to migrate likely will do so, resulting in a number of new associations. In addition to differences in migration rates, community types will be altered and new associations will be created due to changes in disturbance regimes and competition.

Many species attempting to adapt to this rapidly changing climate will be forced to migrate at rates of speed beyond their abilities, which may be the greatest of all potential threats to biodiversity. Evidence from the fossil pollen record reveals the migration rates of various species since the end of the last glacial period. According to a benchmark study by the Environmental Protection Agency, beech and maples migrate at a rate of 10 to 20 km per century, hemlock migrate at 20 to 25 km per century, and pine and oak species migrate at 30 to 40 km per century [14]. Other research suggests that within the next century plant species may be forced to shift as much as 500 km, which is well beyond the migration rates of many species [15]. Due to temperature increases, the limited availability of water, and other environmental factors, entire forests may disappear, and new ecosystems may take their places. Also, a global average of one-third of the existing forested area could undergo major changes in broad vegetation types with the greatest changes occurring in high latitudes. Both plant and animal communities at high elevations and in high latitudes may have no place to migrate and could be lost completely. Alpine ecosystems are thought to be particularly sensitive to climate change largely due to their low productivity, tight nutrient cycling, and their position at a limit for many plant processes [16]. Research that spanned a 125,000-year record of the forest/steppe border along the eastern Cascade Range of the northwest United States, reports climatic variations are the primary cause of regional vegetation change [17]. Additionally, a study analyzing 19 isolated mountain peaks in the U.S. Great Basin, predicts a loss of 9 to 62 percent of the species currently found at these locations based on a temperature increase of 3 degrees Celsius [18].

The Nature Conservancy Report

An intensive analysis to determine the effect of climatic change on 15,000 known native vascular plant species found in North America was conducted by the Nature Conservancy. The researchers assumed that a doubling of carbon dioxide would lead to a 3 Celsius degree increase in global temperatures and based the study on the climatic envelope or maximum and minimum mean annual temperature that each species experiences in its current distribution [19]. The climatic envelope of each of the 15,000 species was compared to the projected rise in average annual temperatures. The researchers found that approximately 7 to 11 percent or some 1,060 to 1,670 of the species under investigation would be beyond their climatic envelope and at risk for extinction. States in the southeast are projected to have the greatest loss with 25 percent of Florida's flora at risk. This may be due to the number of Appalachian Mountain species in these states that are already at their southern range limits. To put these finding into perspective, during the last two centuries in North America only 90 plant species are believed to have become extinct. Rare species, which make up approximately 27 percent of North America's flora, were especially at risk with 10 to 18 percent threatened with extinction while only 1 to 2 percent of the more common species were considered endangered. In order to determine the potential for migration in the event of global warming, a dispersal-ability scale was calculated based on full data availability for 8,668 species. The scale takes into account factors such as pollination by wind, dispersal by birds and insects, and generation time with most species having an intermediate dispersal potential. The analysis reveals that in a 3 Celsius degree global warming scenario those species with characteristics that limit long-range dispersal would suffer the greatest risk. Additionally, plants that require specific habitat such as wetlands would also be threatened. While the Nature Conservancy's model relies primarily on temperature and does not take into account a number of other environmental factors, it does represent a general picture of the impact climatic change could have on the flora of North America and should give us cause for concern

GIS Assessments

The principal advantage of a GIS is its ability to allow the user to perform a spatial analysis, which can be described as the investigation of the locations and shapes of geographic attributes and the interactions between these features. Spatial analysis is essential for determining site suitability and potential, for approximating and calculating geographic relationships, and for deducing and comprehending the problems of place. In short, spatial analysis allows one to address those issues associated with location. GIS is a highly effective information and communication technology due to its power to graphically convey knowledge through the universal language of maps. The first modern GIS, the Canadian Geographic Information System (CGIS), was developed in the early 1960s to inventory Canada's natural resources and is acknowledged as a milestone in the development of GIS. The CGIS classified land according to its capability for forestry, agriculture, recreation, and wildlife, and many of the GIS terms and concepts used today originated with the CGIS [20]. The Canadians understood that in order for the CGIS to be an effective environmental tool, accurate and relevant data must be incorporated into the system. The success of the CGIS is evidenced by its continued operation today in mitigating pollution, managing resources, and in land-use planning [21].

For example, in order to examine detailed spatial environmental data, satellite imagery was integrated with a GIS for a region in northern Wisconsin, which allows an assessment of changes in the forest landscape over time [22]. Another GIS was developed to assess the response of alpine plant species distribution to various climatic and land-use scenarios and found that alpine plant species with restricted habitat availability above the tree line will experience severe fragmentation and habitat loss [23]. In Munich, Germany, a GIS was utilized to examine the spatial pattern and environmental functions of the urban forest linking environmental planning and urban forestry with general land-use and structure planning [24]. A GIS analysis of vegetation structure with forest functions and value in Chicago, Illinois, revealed that local urban forests remove 5575 metric tons of air pollutants and sequester approximately 315,800 metric tons of carbon annually [25]. In Chattanooga, Tennessee, a practical GIS was created to map tree locations, and track the type and size of every tree along city streets and in downtown parks in order to maintain a database of tree size and health conditions [26]. And in a unique approach to GIS-based modelling, researchers found that the future threat to the forests of Europe due to climate change is predicted to increase in Scandinavia and Eastern Europe [27].

GIS is generally acknowledged as an influential instrument for modelling and simulation. However, there are a number of factors related to GIS visualization that must be considered. Foremost among these are the spatial data required to generate an accurate forecast. Longitudinal data are necessary to establish past and future long-term patterns and trends. Yet, appropriately extensive climate records might not be available for a given location, which is one of the problems associated with trying to resolve the effect of global warming on urban forests. Although GIS is a proven tool for assessing environmental impacts on forests and woodlands, numerous challenges remain. For instance, when developing GIS models urban forests tend to be treated as isolated elements, which can lead to miscalculations in predicting landscape changes. And while there has been substantial improvement in simulating disturbances within landscapes, it is presently difficult to model global vegetation change at the landscape scale. Despite these and other shortcomings, a well designed GIS can serve as a frontline defence against environmental impacts and is an invaluable instrument through which communities can profit by joining in a process to incorporate spatial information into shared governance for sound and sustainable urban forest management and planning.

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