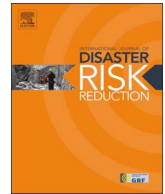




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Analysis of the interrelationship between houses, trees and damage in a cyclone affected city: Can landscape design and planning utilising trees minimise cyclone impact?

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ABSTRACT

Under scenarios of climate change the likelihood of more intensive extreme weather events like tropical cyclones is expected to increase and many tropical regions most at risk from cyclones are still developing economically. With increased urbanisation predicted over the next 20–50 years to cope with population growth, it is important that planning for urban development in these regions considers amelioration of danger, especially the impacts associated with cyclone damage. Approaches to risk management can learn a lot from past experiences with cyclonic events. The knowledge that was accumulated after the devastation of Darwin, Australia by Cyclone Tracy in 1974 provides important evidence that can contribute towards risk mitigation and disaster management in the future. Applying a mixed methods approach, this study examines historical information collected at the time of Cyclone Tracy to help understand the role of the urban forest and positioning of housing in reducing cyclone damage. It includes a review of whether the pattern of tree cover, which is influenced by geophysical and socio-cultural factors, mitigates or exacerbates cyclone damage. The results of the study show that although the relationship is complex, trees appear to have a role to play in ameliorating cyclone damage under certain conditions. This potential gain, along with the other benefits trees offer to tropical urban areas, means that trees are an important consideration for future urban planning in developing regions.

1. Introduction

Climate change is thought to be one of the most significant challenges facing the world and in particular urban centres, in the 21st Century [1]. Under scenarios of climate change the likelihood of more intense extreme weather events like tropical cyclones is expected to increase [21,27,69]. Cyclones are storm systems that are characterised by a low pressure centre, thunderstorms, very strong winds and torrential rain that can bring devastating consequences for urban centres. Tropical cyclones form over tropical or sub-tropical seas between 5 and 30 degrees latitude [44], a region characterised by developing economies, with some of the most vulnerable and disadvantaged people living in these areas. Steiner [60]. It is not possible to stop cyclones occurring but measures can be taken to lessen the severity of impacts, reducing possible loss of life and damage to infrastructure that can cause issues for socio-economic functioning after an extreme event (Hoque et al. 2016). It is important that population growth in the next

20–50 years and associated urban construction activity in developing tropical regions is carried out in the context of planning for urban development that considers amelioration of cyclone impacts, strategies to minimise the risks associated with cyclone damage and possible ways of reducing the exposure of people to these potentially deadly natural hazards.

When constructing urban areas certain physical features can help to reduce damage to buildings from natural hazards and protect lives. Action can also be taken to reduce urban vulnerability and improve resilience to extreme events. This can include the construction of more wind resistant homes and buildings and the inclusion of features like shutters which can act as shock absorbers against debris and strong winds [12]. Proactive human behaviour can also increase the level of preparedness to face these extreme events which can have the knock on effect of reducing personal vulnerability. Insight to risk management solutions can also be gained from past experiences with cyclonic events and learnings from the patterns of previous damage [60].

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Planning to reduce the impacts of cyclones is of particular concern to regions like monsoonal northern Australia that experience cyclones each year and fast developing cities like Darwin, in the Northern Territory, that are located in this zone and that have already borne witness to the extreme devastation that cyclones can cause. The knowledge that was accumulated after the devastation of Darwin by Cyclone Tracy in 1974 has the potential to provide important scientific and anecdotal evidence that can contribute towards risk mitigation and disaster management in the future. This paper presents the findings of a study that examined historical information collected at the time of Cyclone Tracy, and ecological studies looking at the impact of subsequent severe cyclones that have hit northern Australia, to help understand the role of trees and positioning of housing, relative to landscape characteristics, in reducing cyclone damage.

Trees under cyclonic conditions have the potential to be both a source of, and a buffer for, flying debris impacting on houses. Tropical Cyclone Tracy, which struck Darwin city on Christmas Eve in 1974, can provide a valuable insight into the impact of cyclones on both trees and houses and the relationship between the two. From reviewing available historical information, it is evident that arboreal landscape design, planning and management in tropical landscapes has the potential to ameliorate the impact of cyclone damage providing that the trees planted can cope with the stresses imposed and do not contribute to the hazard. The science of integrating and managing trees for ecological or arboreal services, particularly, in urban landscapes, is a growing field of research with particular interest associated with climate change adaptation and mitigation ([43]; Mellaney et al. 2015). However, to date, most cyclone research in urban landscapes has been reductionist in approach, focusing on the role of structural and material attributes of houses in relation to cyclone damage ([24,55]; Pielke and Landsea 1998), with the work that has focused on trees and cyclones mainly examining their response from a debris source perspective [64,67]. Little research to date has taken the more holistic approach needed to examine complex interacting factors and the possible positive role played by trees on urban landscapes during cyclones. In contrast, in non-urban environments, but in similar bioclimatic regions, there has been more in-depth research into the response of trees to cyclones and role of trees in the wider natural environment [14,57,68,69]. By taking a more holistic spatial landscape ecological approach to the analysis of tree response in urban areas under cyclonic situations it is possible to develop a greater understanding of the ecology of cyclone impacts and effects and knowledge acquired that is more relevant to urban landscape planning for both houses and trees. This is particularly important given the growing value placed on incorporating urban green infrastructure into urban design and planning [49].

In this paper the authors examine the influence of geophysical and socio-cultural factors on tree and housing characteristics using a spatial landscape analysis. Presented are findings from the case study using Cyclone Tracy that demonstrate the complex nature of the relationships between these factors. This research highlights the need for greater understanding of the relationship between trees and urban environments and provides justification for further in depth analysis into the role of trees in mitigating or exacerbating cyclone caused housing damage. This paper provides a valuable contribution to the discussion about sustainable urban design for growing cities in tropical regions in the face of climate change.

1.1. Background

It is expected that by 2030 61% of the world's population will live in urban areas [71]. As development intensifies and human use of land grows, there is inevitably greater competition for land and as a result there is more of a need for good landscape and urban design and planning [17]. Effective planning and design needs to take into account biological, social and physical components of the landscape and make strong links to landscape architecture. Sustainable urban planning

needs to pay particular attention to the effect urban development has on environmental processes and be aware of important feedback mechanisms between the urban and more natural elements of the environment. A popular opinion of a sustainable city is one that has buildings and infrastructure that are built to conserve energy. Of particular concern to urban developments in areas affected by cyclones and other extreme climatic events and natural hazards is how to make a city sustainable in the sense of being able to sustain and withstand the impact of these events, particularly if they become more frequent or intense.

It is known that urban development changes local climatology [71]. In fact, urbanisation has been noted as something that alters the local environment, by causing an increase in air temperature and altering water cycles, and by affecting ecological processes and landscape functioning [2]. Urbanisation also changes the structure of landscapes so that patterning of vegetation as well as natural processes are altered. This means that urbanisation causes the landscape to become 'compositionally more heterogeneous', 'geometrically more complex', and 'ecologically more fragmented' ([2] pg 1; [74]). The implications of what these changes mean under situations associated with extreme climatic events and natural disasters and how appropriate landscape design can ameliorate negative impacts is something that needs to be better understood.

Due to the potential catastrophic impact of cyclones there is a recognised need to consider the vulnerability of urban areas to these events especially given the severe impact they can have on the socioeconomic systems that operate within urban environments [29]. Vulnerability can be described as being 'exposure to an event', 'sensitivity of a system to an event', and the 'system's ability to adapt to an event' [29]. The key to vulnerability is exposure, sensitivity, and adaptive capacity. In order to assess vulnerability one needs to understand the systems exposure to a hazard, as well as its sensitivity and resilience to the hazard. An important part of human vulnerability to global environmental change is associated with the danger of extreme climatic events [29]. Climate change adaptation strategies need to be incorporated into urban and land use planning and actions taken to help empower the people that are the most at risk from extreme climatic events by getting them to participate in activities and strategies that will increase resilience and reduce vulnerability [21]. In areas likely to be affected by extreme climatic events as a regular occurrence, urban design needs to consider the best way to minimise the impact of these events on infrastructure and human wellbeing [66]. This can be done by reducing exposure, decreasing the sensitivity of the landscape or improving the urban environments adaptive capacity and resilience to extreme climatic events.

The physical benefits of trees in urban areas is now well recognised [3,34,38,43,48,66,75]. In urban areas trees can play an important role in evaporative cooling, reducing heat island effects, cooling buildings, providing shade, reducing surface run off following rainfall, reducing noise, reducing particulate pollution, sequestering carbon, reducing crime, and increasing property prices (Roy et al. 2012; [23]; Boland and Hunhammer 1999). There is also evidence to suggest that trees in urban areas make economic, environmental, social, cultural and spiritual contributions to the wellbeing of people [34]. Also, it has been noted that different types of trees have different impacts on the urban environment and the ecosystem services they provide is often species specific [34]. This means that trees can be seen to be economically, socially and culturally important components of urban areas [35]. Urban greenways have also been seen to have multiple functions, helping with urban sustainability and counteracting fragmentation of habitat [65]. Current priorities based on sustainable urban development are making urban planners pay more attention to the important role trees can play in urban environments [3,34,38,43,48,71,75]. However, trees in disaster prone urban areas, including high cyclone and bushfire risk areas, are often considered to exacerbate this risk which results in active removal campaigns undertaken post disaster

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