MSc Thesis

The current and future supply of regulating ecosystem services derived from green space in the tropical city of Paramaribo

Joe Eric McMeekin

MSc: Earth Sciences (Geo-ecological dynamics)
University of Amsterdam
Student ID: 12401234

Daily supervisor: Dr. L.L.J.M Willemen (University of Twente)
Examiner: Dr. J. Z. Shamoun-Baranes (University of Amsterdam)
Assessor: Dr. E. H. van der Zanden (University of Amsterdam)

June 2020

UNIVERSITY OF TWENTE. ITC

UNIVERSITEIT VAN AMSTERDAM

TROPENBOS SURINAME

Acknowledgements

First of all, I would like to sincerely thank my daily supervisor, Dr. L.L.J.M Willemen, for her guidance, assistance and constructive feedback throughout this project. I feel this thesis offered me several opportunities to expand my skillset and proved to be a thoroughly enjoyable, challenging and rewarding experience. It has been a pleasure to work with you on this project.

I also wish to thank all staff at Tropenbos Suriname, particularly Lisa Best, Dr. R. F. (Rudi) van Kanten, and Davita, for welcoming me to Paramaribo and helping me with whatever I needed during this research. I hope to visit you all again someday and wish you and your excellent team all the best with your future projects. Keep up the good work!

Next, I would like to thank Dr. E. H. van der Zanden for her guidance and detailed feedback, despite her new commitments, as well as Dr. N. Schwarz and Tom Remijn for their support during the fieldwork. I am also sincerely grateful to the UTSN twinning facility for covering costs of the fieldwork.

Furthermore, thanks to Dr. J. Z. Shamoun-Baranes for her feedback and being willing to act as examiner on this external project, as well as her inspiring enthusiasm in the teaching of the course "Metropole Ecology" which fuelled my interest in the themes covered in this thesis in the first place. The bicycle trip was a real highlight of my studies!

Additionally, I wish to thank all those in Paramaribo who agreed to be interviewed or who provided data or insight for use within this research. Your time, cooperation and insights proved most valuable.

Finally, thanks to my wonderful girlfriend Dasom for her loyal support (and for saving me when I lost some work), my amazing Mam Karen (Kaz) and sister Amy for their advice and support, and my Dad Eric for his encouragement and choice of cover picture!

Abstract

An extra 2.4 billion people could be living in cities by 2050. Continued global and urban population increase is leading to the expansion of urban areas, which in turn results in extensive land cover change. This expansion therefore has numerous impacts on the local environment and upon local communities. Sustainable management of urban areas and their expansion has therefore never been of more relevance than it is today. A loss of green space as a result of urban expansion can result in a reduction in the benefits, or ecosystem services, that society is able to derive from such areas. This in turn can potentially inhibit sustainable development efforts or increase the exposure of an area and its citizens to natural hazards. The supply of ecosystem services and their response to urban change has been well studied in temperate regions of the planet, particularly in the global north. However, ecosystem service and green space-based research is limited in tropical regions, particularly within South America. This research therefore aimed to address this research gap, with a specific objective to identify the current and future supply of key, locally-important regulating ecosystem services (coastal protection, flood risk mitigation, local climate regulation and carbon storage) derived from green space in Greater Paramaribo; a sprawling, tropical, South-American city. The Natural Capital's InVEST tool was first used to quantify and map the current supply of these regulating ecosystem services. Three future scenarios of land cover reflecting alternative management approaches to green space were then defined and modelled using Dyna-CLUE. Decisions within this scenario development and modelling were based upon stakeholder interviews, as well as past plans and initiatives proposed for the city. The outputs of Dyna-CLUE modelling of future land cover were then utilised to identify potential future ecosystem service supply under each scenario. This then allowed for the effects of urban expansion and the role of green space for ES supply to be quantified and visualised via comparisons with current supply and between scenarios. The results of this study highlight the uneven and fragmented current supply of regulating ecosystem services in Paramaribo and its surroundings. Subsequent future ecosystem service supply analyses revealed losses of mean supply per region in all considered ecosystem services under a business as usual scenario. The introduction of a protection policy somewhat mitigated these predicted losses, though was not sufficient to maintain supply at current levels. A substantial greening of Paramaribo, on the other hand, was found to mitigate the majority of losses predicted under business as usual conditions, and in some cases resulted in increased ecosystem service supply in comparison to current levels. This research suggests that an increased awareness of green space and its benefits, alongside protection of important green space and a greening of the city, could increase the resilience of Paramaribo and its inhabitants to hazards and future challenges as it continues along its development path. However, this will require coordinated efforts from stakeholders and decision makers. In highlighting the relevant, hazard-mitigating role of green space in Paramaribo, this research can potentially add to the valuation of green space in cities elsewhere within the tropics.

Contents

List of Figures

List of Tables

1. Introduction

1.1 The urban century

The future of the world is urban, or at least it is for most of us. There are an estimated 7.7 billion people on the planet today, approximately 55% of whom reside in urban areas (United Nations, 2018, 2019). However, global population continues to rise, with a projected 8.5 billion people on Earth by 2030, and 9.7 billion people by the middle of the century (United Nations, 2019). Urban areas are expected to absorb the vast majority of this future population growth, and an extra 2.4 billion people could be living in cities by 2050 (McDonald, Colbert, Hamann, Simkin, & Walsh, 2018). Consequentially, cities are of vital importance when considering global challenges and sustainability issues arising from, and exacerbated by, this global population growth. The importance of urban areas in dealing with these challenges is highlighted by recognition within scientific literature that we are now in the midst of "*the urban century*" (Elmqvist et al., 2019; McDonald et al., 2018; Puppim de Oliveira, 2019; Revi, 2017).

An inevitable consequence of continued global and urban population increase is an increased demand for urban area. This demand can be somewhat addressed by densification strategies within cities (Pelczynski & Tomkowicz, 2019). However, it more often results in the unsustainable process of urban expansion in which non-urban land is converted into urban land as cities grow and become larger (McDonald et al., 2018; Seto et al., 2011). Managing this urban growth is recognised to be a key challenge humanity is facing in the urban century. The Nature Conservancy explore this in their comprehensive report "*Nature in the Urban Century*" (McDonald et al., 2018). They first bring to attention several benefits urban areas have in comparison to their rural counterparts. These include having improved access to essential public services such as healthcare and sanitation, increased opportunities for education and employment, and enhanced capability for innovation and economic productivity. The combination of such benefits results in cities playing a central role in offering opportunity for the ongoing development of humanity, and explains the attractiveness of living within them. On the other hand, McDonald et al. (2018) explore how there are a multitude of complex challenges relating to cities and their growth in the urban century. For example, in the coming two decades a total area of 1.2 million km^2 of rural land is predicted to be urbanised. Such land use change can have result in loss or degradation of local ecosystems and their biodiversity, can increase exposure of human populations to hazards such as flooding, and can result in both direct and indirect losses of agricultural lands which are vital for food security (Emmett et al., 2016; Ke et al., 2018; Miller & Hutchins, 2017; van Vliet, 2019). There is therefore a need for mitigation efforts to be directed towards the impacts associated with urban growth.

The central role of cities in the 21st century is also recognised in international policy and agenda, such as within the United Nations 2030 Agenda For Sustainable Development (United Nations, 2015). This outlines 17 Sustainable Development Goals (SDGs), each with specific aims and associated targets. SDG 11, entitled Sustainable Cities and Communities, has the specific focus to make urban areas "*safe, resilient and sustainable*". Among other issues, this goal recognises that urban change is exerting pressure upon the living environment and public health. Failing to address this pressure would therefore likely inhibit fulfilment of SDG 11, and in doing so limit sustainable development. Understanding urban environments and the spatial and temporal impacts of urban change is therefore arguably more important than ever before, and scientific research is required in all regions of the planet in order to widen this understanding, thereby contributing to the improvement of sustainability efforts.

1.2 Green space and ecosystem services

As urban growth received increased attention over recent decades, so has the potential role of green space within cities for its contribution to human well-being and its ability to mitigate certain hazards introduced or exacerbated by urban expansion (Demuzere et al., 2014; Jennings, Larson, & Yun, 2016; Kabisch, 2015; McDonald et al., 2018). Green space, a term typically used to describe parks, shrubs, gardens, grass, street trees and forested areas surrounding and within cities, is widely accepted to provide a multitude of societal benefits and is considered important for human health and well-being (Derkzen, van Teeffelen, Nagendra, & Verburg, 2017; Rojas-Rueda et al., 2019; Twohig-Bennett & Jones, 2018). The aforementioned SDG 11 further highlights recognition for such benefits, by specifically aiming to "*provide universal access to safe, inclusive and accessible green and public spaces"* (United Nations, 2015). However, as indicated by Derkzen et al. (2017), urban growth and expansion can result in changes to the functionality of green space and as a result, benefits to human health and well-being derived from it can often be lost. Consideration for the impacts of urban expansion on such green space-derived benefits is therefore of increasing relevance in the global drive for sustainability, and is the focus of this research.

The term ecosystem services (ES) is typically used to refer to benefits humanity derives from the natural environment (Demuzere et al., 2014; Gómez-Baggethun & Barton, 2013; Kabisch, 2015). This study uses the CICES (The Common International Classification of Ecosystem Services) classification of ES, which refines and builds upon the typology of ES originally suggested in the Millennium Ecosystem Assessment (Burkhard & Maes, 2017; Haines-Young & Potschin, 2012, 2018; MA, 2005). CICES classifies ES under three categories; provisioning (of raw materials and energy needs), regulating (regulation and maintenance of the environment) and cultural (non-material characteristics of ecosystems that affect people's physical and mental state) services. Urban ES are specifically provided by ecological infrastructure within cities, but also within surrounding hinterlands beyond the city boundary which are directly affected by energy and material flows from urban and suburban areas (Gómez-Baggethun et al., 2013). Green space is recognised to provide multiple urban ES within each of the three CICES categories, as exemplified in Table 1 (Haase et al., 2014; Kabisch, 2015; McDonald et al., 2018; Tzoulas et al., 2007; Vargas-Hernández, Pallagst, & Zdunek-Wielgołaska, 2018).

Table 1: Examples of provisioning, regulating and cultural urban ES derived from green space. Examples are derived from Demuzere et al. (2014), Gómez-Baggethun & Barton (2013) and Kabisch (2015). The ES considered in this research are indicated in bold text and their selection later explained in section 1.5.

CICES ES category	Green space-derived ES examples
Provisioning	Raw materials (e.g. wood and fibre)
	Food provision (e.g. fruit, vegetables and seeds)
	Medicinal resources
Regulating	**Coastal protection**
	Flood risk mitigation (via runoff retention)
	Local climate regulation (via a cooling effect)
	Carbon storage
	Air quality regulation
	Noise reduction
	Biodiversity regulation
Cultural	Recreation, mental and physical health
	Tourism
	Education and knowledge
	Aesthetic value

Green space can be managed within urban environments in order to promote or increase desirable ES supply. Research in which ES supply - specifically defined as the "*provision of a service by a particular ecosystem, irrespective of its actual use*" (Burkhard & Maes, 2017 (pg. 368)) - is quantified and spatially visualised can facilitate such management efforts and is therefore beneficial for decision makers involved. Numerous studies have therefore taken on this task (e.g. Davies et al., 2011; Derkzen, van Teeffelen, & Verburg, 2015; Wu et al., 2019; Zank, Bagstad, Voigt, & Villa, 2016). However, urban growth and expansion as discussed in section 1.1 generally results in a loss of green space, which can in turn lead to losses of ES supply (Metzger, Rounsevell, Acosta-Michlik, Leemans, & Schröter, 2006; Peña, Onaindia, Fernández de Manuel, Ametzaga-Arregi, & Casado-Arzuaga, 2018; Zhang et al., 2018). Such losses can in turn impact the resilience of urban communities and result in increased exposure to hazards (Güneralp, Güneralp, & Liu, 2015).

1.3 Spatial assessment of ES supply and land cover change

Given the outlined relevance, a large and rapidly growing field of research seeks to analyse ES supply. There have therefore been a multitude of methods and tools developed to conduct such analyses (Bagstad, Semmens, Waage, & Winthrop, 2013; Ochoa & Urbina-Cardona, 2017). Commonly used ES assessment tools such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), ARIES (ARtificial intelligence models of ecosystem services), LUCI (Land Utilisation Capability Indicator) and SWAT (Soil and Water Assessment Tool) typically integrate ecological and geographical information to quantify ES supply and display this in spatially explicit ES supply maps (Bagstad et al., 2013; Burkhard & Maes, 2017; Ochoa & Urbina-Cardona, 2017). These maps in turn can allow for the effective communication of complex spatial information and can raise awareness among decision makers. After all, maps are often central to decisions regarding landscape and urban planning, resource management, and land use optimisation (Burkhard & Maes, 2017). A key benefit to such tools is that they are applicable to a variety of different locations and scales, and they often have low data requirements (Burkhard & Maes, 2017; Ochoa & Urbina-Cardona, 2017). However, as pointed out by Burkhard and Maes (2017), such decision support tools are often relatively simple and have multiple associated assumptions and limitations. Some researchers therefore develop their own approaches which are often based upon more complex statistical models or are more location and context-specific due to the inclusion of expert or stakeholder-informed input values, or primary data such as direct field measurements or survey responses (Burkhard & Maes, 2017).

To assess potential future ES supply, future scenarios of land cover change are usually defined and developed (Burkhard & Maes, 2017; Jiang, Deng, Tang, Lei, & Chen, 2017; Nelson & Daily, 2010). These scenarios are usually based upon key drivers of land cover change and they can be used to explore how certain policy or management decisions might influence ES supply. Furthermore, they allow for identification of areas where management efforts may be best focused to limit potential reductions in ES supply (Burkhard & Maes, 2017). Over the past two decades, a multitude of land change models have been developed in order to simulate future changes in land use (Mas, Kolb, Paegelow, Camacho Olmedo, & Houet, 2014; van Vliet et al., 2016). These models can vary with regards to their complexity, and can be spatial or non-spatial, static or dynamic, and contain parameters based upon statistical correlation or on descriptions of the process of interest (Mas et al., 2014). Examples of frequently used models include the CLUE (Conversion of Land Use and its Effects) framework, DINAMICA EGO, and Land Change Modeller, all of which have been applied to model urban growth scenarios in previous research (Mas et al., 2014).

Regulating ES, upon which this study focuses, is the most commonly considered category within ES assessments focusing on cities (Haase et al., 2014; Ochoa & Urbina-Cardona, 2017). This is in part due to recognition that they play a major role in contributions towards human well-being in urban contexts, via for example their ability to mitigate common urban hazards such as increased flood risk or air pollution (Gómez-Baggethun & Barton, 2013; Haase et al., 2014; Larondelle, Haase, & Kabisch, 2014). They are therefore considered vital services for promoting healthy, liveable and resilient cities (Cortinovis & Geneletti, 2019). On top of their importance, Haase et al. (2014) also point out that there are well-proven indicators and supporting empirical studies which exist and can assist with assessment of regulating services, whereas for the categories of provisioning and cultural services, knowledge gaps still need to be addressed for more effective assessment.

1.4 The need for location-specific green space and ES research in the tropics

This study conducts a spatial ES analysis which considers future land cover scenarios, with a particular focus on ES derived from green space in the tropical and sprawling city of Paramaribo, Suriname. Paramaribo offers an ideal case study for such research as the role of green space is not well studied within cities located in the tropical climatic zone (23.5° north and south of the equator), despite this being where the majority of developing nations are located, and consequentially where most urban growth is occurring (Dobbs et al., 2018; Haase et al., 2014; Haase, Schwarz, Strohbach, Kroll, & Seppelt, 2012; United Nations, 2018; Zhang, 2015). This was specifically highlighted by Richards et al. (2019) in their recent comprehensive review on urban ES. They called for this tropical city research deficit to be corrected in order to address potential implications it could have on how benefits are often transferred across case studies, as well as on how urban ES are conceptualised and quantified. This research therefore attempts to contribute to this research gap and in doing so aims to assist with the widening of scientific understanding of green spaces and their associated ES in tropical climates.

However, climatic zones alone are not the only differences between cities around the world. Location-specific research can also offer insight into how several other social, ecological and political factors might influence ES in cities. Factors such as culture, infrastructure, topography, development status, demographics, governance and management directions also contribute, alongside climate, to the clear diversity and uniqueness which cities demonstrate around the world (Larondelle & Haase, 2013; Schwarz, 2010). For example, the megacity of Seoul in South Korea, with its high-rise skyscrapers, dense population, and extreme seasonal temperature variation, is notably different to the more historical and culturally diverse city of Amsterdam in the Netherlands, with its relatively low population, extensive cycling infrastructure and unique network of canals. Both of these urban contexts are different again to the bustling and sprawling tropical city of Ho Chi Minh in the rapidly developing nation of Vietnam, and to the small but historically important city of Stirling, located in a topographically diverse region of Scotland. Each of these cities face differing and location-specific challenges, and would therefore most likely require differing approaches with regards to green space and its management. Notably, South America has been highlighted as being a particularly understudied region of the planet with regards to green space and its associated ES (Balvanera et al., 2012; Haase et al., 2014), with Dobbs et al. (2018) pointing out that current research within the field "*rarely accounts for the diverse and complex socio-political and ecological drivers*" characteristic of the continent. They go on to argue that weak governance and inequality play key roles in South American cities, alongside land use policy and the biophysical context considered as most influential in the global north.

Location-specific research focusing on urban dynamics and ES supply derived from green space is therefore required within these understudied climatic zones (the tropics) and regions (South America). This study aims to contribute to these research gaps by quantifying and mapping the current and future supply of four regulating ES within the tropical, South American city of Paramaribo in Suriname.

1.5 Green space and key regulating ES in Paramaribo

As well as offering contribution to the climatic and regional research gaps outlined in the previous section, this study also aims to offer insight for local management and decision makers. Paramaribo is no exception when considering the aforementioned diversity of cities. It faces unique challenges which are specific to local political, socio-economic and environmental circumstances. These challenges include underdeveloped and unorganised urban planning and governance, inequality, common flooding events (see Figure 1), bureaucracy and corruption (Fung-Loy, Van, Ku Leuven, Hemerijckx, & Leuven, 2019; Verrest, 2010). Furthermore, the city is growing. The population of Greater Paramaribo increased by 14% between 2000 and 2015 resulting in a continued urban sprawl (Fung-Loy et al., 2019). This has largely been attributed to the urban pull effect which the city and its services have on rural residents (Fung-Loy et al., 2019; IDB, 2017c). The urban sprawl is extending beyond the boundary of Paramaribo as the city itself has limited free space left available, and the expansion is largely uncontrolled and unplanned by the government. Suriname lacks a sufficient system of land registration, and information on the ownership, status, and availability of land is limited and unreliable (Verrest, 2010). Furthermore, there is a lack of finances, technology, data and expertise within the government (Fung-Loy et al., 2019; Verrest, 2010).

In addition, the benefits of green space are not well known or valued in Suriname, and are therefore usually ignored within urban planning and management (Tropenbos Suriname, 2019). Consequentially, there is no specific policy being enforced which recognises and protects green space within or around the city. As a result, and in response to continued urban growth and expansion, trees and other vegetation have had to increasingly make way for concrete surfaces, residential areas, and infrastructure in recent years (see Figure 1) (Fung-Loy et al., 2019; IDB, 2017b; Tropenbos Suriname, 2019). This research therefore aims to highlight and compare the current and potential future role of green space within Paramaribo should certain management directions be adopted by decision makers, with a focus on the role of green space in some key challenges faced by the city.

Figure 1: ***Left:*** **A flood event in Paramaribo in 2009 (Verrest, 2010).**
Right: **A typical street with high impervious cover and lack of green space in central Paramaribo (McMeekin, 2019)**

Four regulating ES derived from green space in Paramaribo are considered in this study, specifically; coastal protection (from erosion and inundation), flood risk mitigation (via runoff retention), local climate regulation (via a cooling effect), and carbon storage (in aboveground biomass). These ES were selected based upon; (i) confirmation of their importance and relevance in Paramaribo by a small survey conducted in March 2019 with members from NGOs, the private sector and the local Surinamese government; (ii) recognition that they are relevant for human well-being in research on other cities (Cortinovis & Geneletti, 2019; Derkzen et al., 2015; Salmond et al., 2016), and; (iii) the relation of them to pressing hazards and issues Paramaribo is facing as indicated by stakeholders, and within local reports and literature. Only regulating ES were selected since, as discussed in section 1.2, these are recognised to play a major role in contributions towards human well-being in cities. Furthermore, their quantification is also well supported by empirical research and is for the most part achievable with the commonly used ES assessment tools introduced in section 1.3, whereas more knowledge gaps still exist for other categories of ES and the availability of tools to assess them is more limited.

The first of these selected regulating ES, coastal protection, relates to the recognition that coastal vegetation such as mangrove, coastal forest and marsh can protect shorelines and reduce coastal hazard impacts (Arkema et al., 2013; Gedan et al., 2011; Guannel et al., 2015; McIvor, Möller, Spencer, & Spalding, 2012; Spalding, McIvor, Tonneijck, Tol, & van Eijk, 2014). The protection green space provides is primarily a result of vegetation being able to reduce wave height, moderate current strength, and decrease wave runup extent on beaches (Guannel et al., 2015). In turn, this offers benefits such as the prevention of coastal flooding and the reduction of coastal erosion, thereby preventing economic damage or even loss of life (Das & Vincent, 2009; Guannel et al., 2015). Suriname is susceptible to coastal flooding and erosion, and Paramaribo is recognised as being particularly exposed due to its low elevation, a highly dynamic coastline, and degradation of mangroves in the area (Guzman et al., 2017a, 2017b; IDB, 2017b). Sea level rise, intensification of storm surge and wave impacts, and increased storm frequency and intensity resulting from ongoing global climate change will increase this exposure, as it will for many other coastal cities around the world (Gedan et al., 2011; Guzman et al., 2017a, 2017b; Mcgranahan, Balk, & Anderson, 2007; Spalding, Ruffo, et al., 2014). The inclusion of this ES within this analysis will, therefore, offer improved understanding of the role green space plays in protecting Paramaribo's coastline, in turn offering insight into potential strategies for dealing with increasing challenges due to climate change.

As well as coastal flooding, increased inland flood risk is also a common challenge facing cities around the planet, which is again potentially exacerbated by climate change. Surface runoff during precipitation events generally has higher velocity due to the prevalence of smooth and impervious surfaces such as concrete, pavements and road surfaces (Cameron et al., 2012; Demuzere et al., 2014; Kabisch, 2015). The second of the selected ES, flood risk mitigation, relates to the ability of green space to reduce runoff during precipitation events via the interception of water by leaves and stems, and via reducing infiltration rates in underlying soils (Farrugia, Hudson, & McCulloch, 2013; Kabisch, 2015). Furthermore, vegetation can absorb water via its roots. Green space therefore essentially reduces peak discharge and induces groundwater recharge, in turn reducing strain on urban drainage systems and reducing the risk of pluvial flooding (Cameron et al., 2012; Demuzere et al., 2014). Again, this is a pressing issue in Paramaribo (Figure 1)(IDB, 2017b; Verrest, 2010). In their recent flood risk assessment for Paramaribo, The World Bank point out that Suriname is "*one of the most vulnerable countries in the world to the impact of flooding"*, indicating that pluvial flooding associated with heavy rainfall is a frequent occurrence in Paramaribo (Guzman et al., 2017b). They go on to point out a number of anthropogenic factors which make the situation worse, including the ongoing expansion of the city, development upon flood prone areas, inadequate drainage, and uncontrolled runoff from the built environment. Green space could potentially help with the latter of these in Paramaribo, thereby mitigating flood risk.

A further challenge in urban areas, again relating to the increased area of artificial surfaces such as concrete and roads, is a phenomenon in which temperature within the city is warmer than in surrounding rural areas. This is known as the urban heat island effect, and is a result of differences in the urban energy balance due to altered albedo, reduced evapotranspiration and latent heat flux (Chapman, Watson, Salazar, Thatcher, & McAlpine, 2017; Luber & McGeehin, 2008). Once again, this effect is recognised to be enhanced by global climate change, exacerbating impacts such as an increased exposure of urban residents to heat stress and health risks associated with air pollution, and lower work productivity (R. D. Brown, Vanos, Kenny, & Lenzholzer, 2015; Chapman et al., 2017; Luber & McGeehin, 2008). Green space is recognised to provide a cooling effect, in turn mitigating the urban heat island effect (Alexandri & Jones, 2008; Cameron et al., 2012; Chapman et al., 2017; Takebayashi & Moriyama, 2007). The selected ES of local climate regulation relates to this mitigation potential. Research into this generally considers either the surface urban heat island (variation in surface temperature) or canopy layer heat island (variation in air temperature) (Anniballe, Bonafoni, & Pichierri, 2014). Remijn (2020) has recently highlighted the cooling role of green space as well as the presence of a 5.2°C surface urban heat island in Paramaribo via remote sensing analyses. This study instead considers the potential cooling effect green space can have on air temperatures in Paramaribo.

As discussed, anthropogenic climate change is likely to exacerbate the coastal, flooding and heat-related hazards associated with the previous three discussed ES. The final ES considered in this research, carbon storage, does not directly relate to localised hazard mitigation like the previous three, but instead relates to efforts to address this overarching global climate change issue. Although carbon stored within green space in urban areas is relatively small on national and global scales, it is still recognised as important and necessary to conserve in order to limit continued increases in atmospheric greenhouse gas concentrations (Chen, 2015; Holt, Mears, Maltby, & Warren, 2015; Jiang et al., 2017; Strohbach & Haase, 2012). Understanding carbon dynamics in urban environments, and how they respond to processes such as urban expansion, is consequentially recognised to be a key research challenge and policy concern (Chen, 2015). Several tropical and South American countries, including Suriname, are part of the REDD+ (Reducing Emissions from Deforestation and forest Degradation) program (Suriname REDD, 2020). This attempts to minimise deforestation and offers economic incentives for standing forests. There is therefore economic interest for Suriname to conserve its carbon stocks, which in combination with global recognition for the need to address climate change, highlights the importance and relevance of this ES for Paramaribo.

1.6 Objectives and research questions

The primary objective of the research was;

To identify the current and future supply of key regulating ecosystem services derived from green space in the Greater Paramaribo area.

The following secondary objectives were identified so that their combined fulfilment would allow for completion of the primary research objective.

1. To quantify and map the current supply of four key regulating ecosystem services derived from green space in Greater Paramaribo.
2. To define and develop three alternative future scenarios in which urban expansion and land cover change, and therefore changes in green space, are estimated and visualised in Greater Paramaribo for the year 2035.
3. To analyse how the identified land cover scenarios would affect future ecosystem service supply derived from green spaces in Greater Paramaribo.

The following primary research question was considered in order to address the primary objective;

What is the current and future supply of key regulating ecosystem services derived from green space in the Greater Paramaribo area?

The following sub-questions, which relate to the secondary objectives above, were also identified.

1. What is the current supply of four key regulating ecosystem services derived from green space in Greater Paramaribo?
2. What are three plausible scenarios for future urban expansion and land cover change, and how would these alter the spatial distribution of green space in Greater Paramaribo by 2035?
3. What impact would the identified future land cover scenarios have on future ecosystem service supply derived from green space in Greater Paramaribo?

As outlined in section 1.5, the key regulating services these objectives and research questions refer to are coastal protection, flood risk mitigation, local climate regulation and carbon storage.

This research also forms part of a larger twinning project between the Faculty of Geo-information Science and Earth Observation of the University of Twente in the Netherlands and the knowledge-based Non-Governmental Organisation (NGO) Tropenbos Suriname (TBIS). This twinning project, entitled "*Towards a Green and more Liveable Paramaribo*", recognises the following central problem; "*The benefits of urban greenery are insufficiently known in Suriname, are insufficiently valued, and are not included in urban planning and management"* (Tropenbos Suriname, 2019). The project therefore aims to "*promote a green Paramaribo in which ecosystem services contribute to a healthy and more liveable environment for its inhabitants*."

2. Methods and data

2.1 Study area

Paramaribo is the capital city of South America's smallest country, Suriname (Figure 2). According to the Köppen classification system, Suriname has an Af – tropical rainforest climate. Over 90% of the 163,820km^2 area of the country is forested, making it the most forested country in the world (Fung-Loy et al., 2019; Suriname REDD, 2020). Over half of the 575,000 population reside within Paramaribo and its surrounding area (Tropenbos Suriname, 2019; World Bank, 2018). The study area covers the Greater Paramaribo region, comprised of the districts of Paramaribo (central), Wanica (to the west and south of Paramaribo), and a part of Commewijne (to the east of Paramaribo and the Suriname River). Each of these districts are divided into "ressorts", the smallest administrative unit in Suriname, 12 of which make up Paramaribo from the total of 22 belonging to the wider Greater Paramaribo study area (Figure 2).

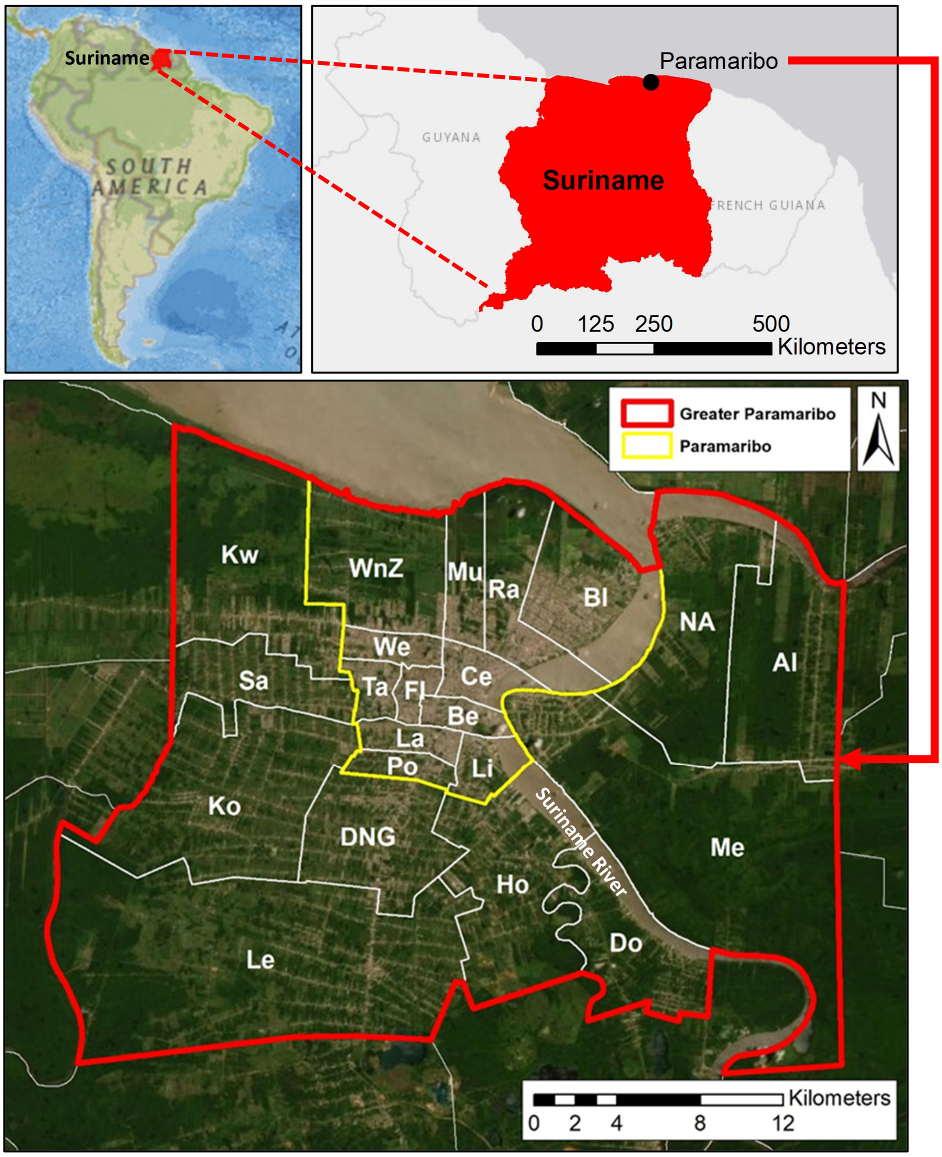

Figure 2: ***Top left:*** **The location of Suriname in South America.** ***Top right:*** **The location of Paramaribo in Suriname.** ***Below:*** **The study area of Greater Paramaribo (red) with the administrative boundary of Paramaribo indicated (yellow) as well as ressort boundaries (white).**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

2.2 Research overview

The methodological steps taken in order to address the secondary objectives and research sub-questions outlined in section 1.6 are outlined in the upcoming sections and summarised in flowchart form in Figure 4. This flowchart highlights how the spatial modelling involved in the research was underpinned by two key central aspects; fieldwork and land cover data.

The first of these underpinning central aspects was a two week fieldwork period in Paramaribo in November 2019. This allowed for familiarisation of the study area and insight into the local context with regards to green space. It also offered the opportunity to obtain local data and to network with relevant stakeholders during attendance at a TBIS organised workshop on 26th November 2019 entitled "*Wooded and urban landscapes: towards a climate smart Suriname"* (TBIS, 2019).

The second central aspect was a key input for the spatial modelling efforts; a classified Sentinel 2-based land cover map of Greater Paramaribo, produced during research within the aforementioned twinning project (Taus, IN PREP). This raster map, which has a spatial resolution of 10 metres and an overall accuracy of 84%, specifies eight land cover classes; trees, mangrove, mixed low vegetation, grass, built-up, infrastructure, bare soil and water (see Appendix 1) (Taus, IN PREP). The map was reclassified in this study so that built-up and infrastructure classes were combined into an "urban" class (Figure 3). This decision was taken as several model parameters required input values specific to each land cover class, and differentiating between the original classes proved largely infeasible due to lack of supporting literature. Furthermore, it allowed for simplification of the future land cover modelling process discussed in the upcoming section 2.4.

Of the seven land covers considered, green space was defined as being one of four classes; trees, mangrove, mixed low vegetation or grass. These combine to cover 76% of the entire study area of Greater Paramaribo, with trees covering 26%, mangrove covering 1%, mixed low vegetation covering 28% and grass covering 21%. The non-green space classes account for 24% of the study area, with 10% covered by urban, 8% by bare soil and 6% by water. However, green space only covers 48% of the area within the Paramaribo administrative boundary, with most of this in the northern ressorts and 40% of it either mixed low vegetation or grass cover and only 8% tree or mangrove cover.

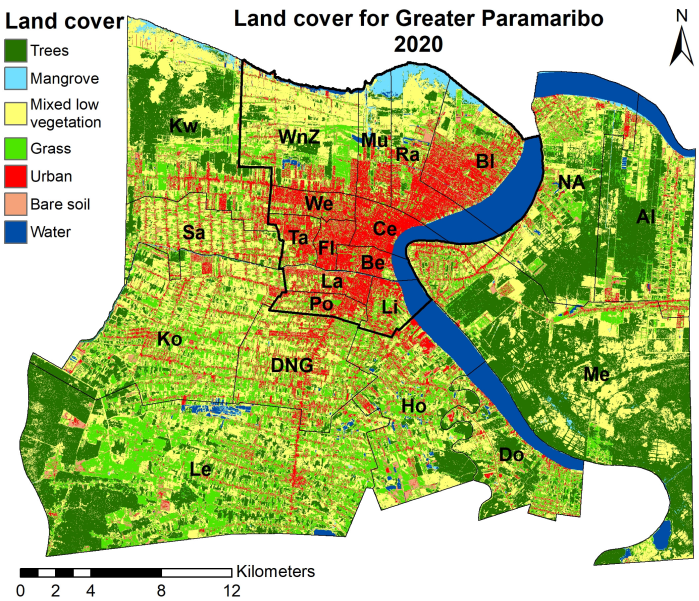

Figure 3: Map showing current land cover in Greater Paramaribo.

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

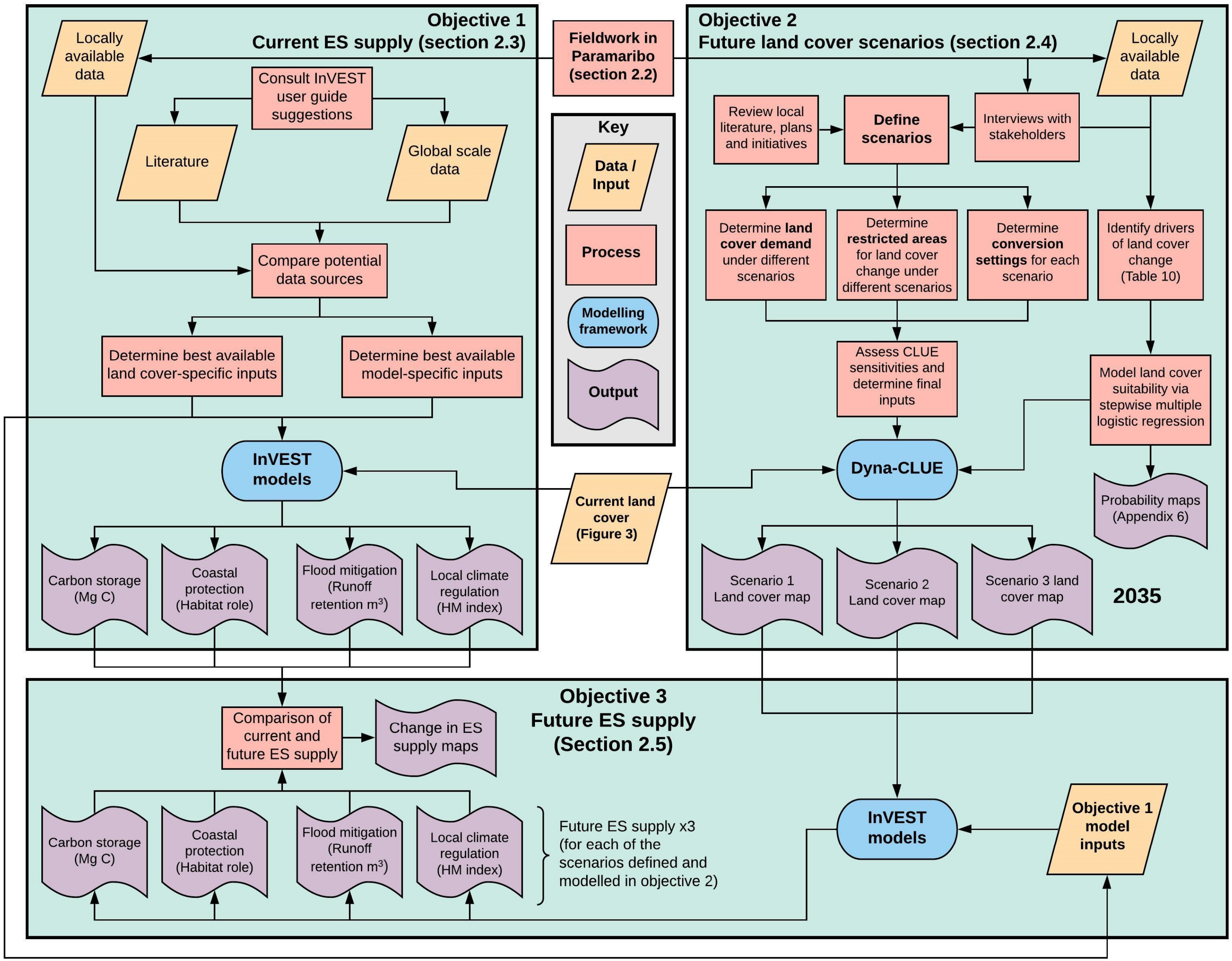

Figure 4: Workflow outlining main methodological steps for each secondary objective. Note: Shapes and colours are explained in the key in the centre.

2.3 Assessing current ES supply

2.3.1 Approach and software

ES were modelled and mapped via utilisation of the Natural Capital Project's InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software. This is a free, open-source suite of models which can "*map and value the goods and services from nature that sustain and fulfil human life*" (Natural Capital, 2020). InVEST is designed to be used as a tool to assist with the assessment and management of natural resources by entities such as governments, non-profit organisations and corporations. It was deemed a suitable tool for this research because; (i) it is the most commonly used tool for the spatial assessment of ES (Ochoa & Urbina-Cardona, 2017); (ii) it is best suited to the analysis of multiple ES and models exist for each of the four ES considered within this study (Natural Capital, 2020); (iii) the models have relatively low input data requirements in comparison to more complex approaches (Natural Capital, 2020) and; (iv) the models are primarily land use based. The low data requirements were considered particularly beneficial since there is limited data available in Paramaribo and direct data collection was outside the scope of this research. All spatial data visualisations, modifications and analyses where carried out in ESRI ArcMap version 10.6.1.

InVEST model runs were carried out on version 3.8.0 and were all based upon the aforementioned land cover data (Figure 3). In their user guide, Natural Capital provide a number of suggestions and recommended global data sources for each of the inputs into their InVEST models (Sharp et al., 2020). However, effort was made throughout the process to include as much relevant local scale data or stakeholder informed inputs as possible in order to ensure that model outputs reflected the local context and to limit the assumptions associated with using more general sources or widely available data. Such practices are considered to offer more robust and stakeholder-relevant outputs (Andrew, Wulder, Nelson, & Coops, 2015; Bagstad, Cohen, Ancona, Mcnulty, & Sun, 2018; Burkhard & Maes, 2017; Willemen, Burkhard, Crossman, Drakou, & Palomo, 2015). Default user guide values, more general global data sources or literature-derived inputs were generally only used if local data was considered to be insufficient or outdated, or was not available at all. The following sections outline the method, model structure and main data input behind each of the models used. All presented parameter descriptions, equations or formulas relating to each of the models are sourced from the InVEST user guide (Sharp et al., 2020).

2.3.2 Coastal protection

The InVEST Coastal Vulnerability model was used to assess coastal protection offered by green space along the Greater Paramaribo coastline (Sharp et al., 2020). This model differs slightly from the others utilised in this study since it is not specifically land cover raster based. Furthermore, it does not directly quantify an ES supply. It instead provides an index of coastal exposure to erosion and inundation. More specifically, the model plots points at a user-defined interval along the coastline of interest and calculates this exposure index relative to elsewhere along the coastline. This calculation within the model is based upon five bio-geophysical variables; relief, wind exposure, wave exposure, surge potential and protection from natural habitats. Four of these variables have a model-defined rank (R) between 1 (very low exposure) and 5 (very high exposure) based upon the percentile group within which a particular shore point falls relative to the rest of the shore points (Table 2). For example, if a point was assigned a relief rank of 1, it would have a percentile value between 81 and 100, meaning elevation at that particular point is higher than at 81%-100% of the other points along the shoreline. Unlike the other ranks, the natural habitat rank is specified by the user based upon the habitats included and their considered protective value. This offers the opportunity to assess the relative role of these habitats in protecting against this exposure, since exposure with and without habitat presence is calculated by the model and the difference specified in the final output (Sharp et al., 2020). The variables and their associated ranks are presented in Table 2.

Table 2: Bio-geophysical variables and associated ranking system used for computation of coastal exposure index by the model (adapted from Sharp et al., 2020).

Increasing exposure →

Rank (R)	**1**	**2**	**3**	**4**	**5**
Relief	81 to 100 percentile	61 to 80 percentile	41 to 60 percentile	21 to 40 percentile	0 to 20 percentile
Wind exposure	0 to 20 percentile	21 to 40 percentile	41 to 60 percentile	61 to 80 percentile	81 to 100 percentile
Wave exposure	0 to 20 percentile	21 to 40 percentile	41 to 60 percentile	61 to 80 percentile	81 to 100 percentile
Surge potential	0 to 20 percentile	21 to 40 percentile	41 to 60 percentile	61 to 80 percentile	81 to 100 percentile
Natural habitats	High protective value	Moderate-high protective value	Moderate protective value	Low protective value	No habitat

The natural habitat exposure rank ($\boldsymbol{R_{Hab}}$) for a given point along the shoreline is calculated within the model via first determining which habitats are present within a user-specified search radius referred to as a "*protection distance*" (Sharp et al., 2020). When presence of all N habitats within these radiuses has been determined, an array $\boldsymbol{R}$ containing all ranks $\boldsymbol{R_k}$, $1 \leq k \leq N$ associated with these habitats is created (Sharp et al., 2020). These rank values are then used in the following formula within the model:

$$R_{Hab} = 4.8 - 0.5\sqrt{\left(1.5\max_{k=1}^{N}(5 - R_k)\right)^2 + \sum_{k=1}^{N}(5 - R_k)^2 - \left(\max_{k=1}^{N}(5 - R_k)\right)^2}$$

The habitat with the lowest rank value is weighted to be 1.5 times higher than all other habitats present for a particular point (Sharp et al., 2020). This enables points with multiple habitats present to receive a lower final exposure than those with only one protective habitat present and therefore introduces the assumption that a higher number of habitats present is beneficial for coastal protection.

The exposure index (**EI**) is specifically calculated within the InVEST coastal model as the geometric mean of all bio-geophysical variable ranks (**R**):

$$EI=(R_{Relief}R_{WindExposure}R_{WaveExposure}R_{SurgePotential}R_{Hab})^{1/5}$$

Further detailed information about each of the rank calculations taking place within the model can be found in the InVEST user guide (Sharp et al., 2020). A "habitat role" is then determined by the model based upon differences between calculated exposure with and without the inclusion of the natural habitat rank variable ($\boldsymbol{R_{Hab}}$).

For the purpose of this research, this natural habitats rank variable ($\boldsymbol{R_{Hab}}$) offered the opportunity to assess the relative role of green space in protecting against coastal exposure. Therefore, trees, mangrove, mixed low vegetation and grass were considered as these natural habitats and each assigned a rank (based upon Table 2) and protection distance, beyond which green space was assumed to offer no protection against erosion or inundation. Silver et al. (2019) point out that these protection distances are more of a "*technical shortcut*" to designate protective habitat as opposed to an ecological parameter as the model does not include numerous factors (such as distance from the coast, channel configuration or habitat size) which may influence the distance over which protective effects from habitats could be present. Literature on the distance from the coastline at which a certain habitat could be considered to offer a coastal protection service was also not discovered. Values were instead based upon local reports relating to coastal flooding and protection, the InVEST user guide, and upon input values used in other studies using the same model. The assigned ranks and protective distances are summarised in Table 3.

Table 3: **Ranks and protective distances assigned to green space classes in Greater Paramaribo within the InVEST Coastal Vulnerability model.**

Land cover class	Rank	Rank justification	Protection distance (m)	Protection distance justification
Mangrove	1	Mangroves are recognised to be of vital importance for the coastal resilience of Greater Paramaribo and Suriname (Erftemeijer & Teunissen, 2009; Guzman et al., 2017a). This is also the suggested rank in the InVEST user guide (Sharp et al., 2020) and is the value used for mangrove in other research utilising this model such as by Silver et al. (2019) and Zhang et al. (2020).	2000	Larger patches of mangrove as classified on the land cover map of Greater Paramaribo (Figure 3) can extend 1.5 – 2km inland and coastal flooding has been observed 2km inland during surge coinciding with high tide (Guzman et al., 2017a). A distance of 2000m was also used by Zhang et al. (2020) in their InVEST-based coastal protection study.
Trees	2	Assumed to be not as influential as mangroves in the local context of Suriname based upon reports relating to coastal protection and their focus on the importance of mangroves (Erftemeijer & Teunissen, 2009; Guzman et al., 2017a).	1000	Suggested as suitable in the InVEST user guide for coastal forest land cover.
Mixed low vegetation	3	Assumed to include coastal swamp classes based upon frequent overlaps with an ecosystem map provided by The Planning Bureau (SPS, 2017). Zhang et al. (2020) used this rank for “shrub swamp” and Hopper and Meixler (2016) used it for “shrubland” in their use of this InVEST model.	100	Relative to other distances and value used for shrubland and marsh classes by Hopper and Meixler (2016)
Grass	4	Assumed to offer more protection than no habitat as some sediment accumulation could arguably occur, but assumed lower than mixed low vegetation.	50	Relative to distances used for other land cover classes and the value used for “coastal grassland” by Hopper and Meixler (2016).

Since habitat area is not included within the model, it was decided that a minimum “patch size” of 1ha would be used. This is an estimation due to lack of such values in the literature, though is loosely based upon sufficient “habitat width” values discussed in research such as by Spalding et al. (2014) and Narayan et al. (2016). A patch size was deemed necessary as it prevented single pixels from influencing the final output – without defining this almost every point was considered to be protected by every green space class. This is a limitation of the model and its binary nature of presence or absence of habitat without accounting for habitat area. A resolution of 10 metres between shore points was specified to match that of the land cover data and other ES supply outputs. All other inputs into the model are summarised in table 4.

For the quantification and mapping of ES supply in line with objective 1, and further analysis associated with this, the final InVEST Coastal Vulnerability model output utilised was the “habitat role”. As mentioned, this value represents the difference between the coastal exposure index with and without green space presence for the coastline of Greater Paramaribo, and therefore a higher habitat role value reflects a more important protection role derived from green space. The final output is therefore a relative “habitat role” in coastal protection and is simply a value specifying this difference in exposure index.

Table 4: Inputs used within the InVEST Coastal Vulnerability model to determine the role of green space in coastal protection. More detailed descriptions are available in the InVEST user guide (Sharp et al., 2020).

Model parameter	Data type / input value	Description	Source / processing steps
Landmass	Polygon vector	Allows the model to differentiate between land and ocean and therefore indicates the coastline along which the model plots points and carries out subsequent exposure calculations. Both major river shorelines were included with the assumption that they could be affected by storm surge.	Generated for this research using ArcGIS to modify the OSM coastal land polygon (OSM, 2020) according to land classes on the underpinning land cover map. This was then simplified with a tolerance of 100m to smooth the pixel effect caused by the raster data (since sensitivity tests revealed this was causing wind and wave calculations within the model to confuse the direction segments of coastline were facing).
WaveWatchIII	Point data	Contains wind and wave data used to calculate wind and wave exposure ranks.	Default dataset included with InVEST (Sharp et al., 2020) since no regional-specific data was available.
Maximum fetch distance	12000 (metres)	Determines which shoreline points are exposed to ocean waves.	Default user guide recommended value for coastlines which are not close to other landmasses (Sharp et al., 2020).
Bathymetry	Raster	Used by the model for calculations relating to surge and wave exposure ranks.	The global GEBCO 2019 bathymetric grid (resolution = 15 arc seconds) (GEBCO Compilation Group, 2019).
Digital Elevation Model (DEM)	Raster	Used by the model for calculation of the relief exposure rank.	The global SRTM 30m Digital Elevation Model (NASA, 2000).
Elevation averaging radius	100 (metres)	Used to approximate variation in coastal relief and to account for data gaps in DEM data during model calculations of relief exposure rank.	Model iterations testing the sensitivity of this value revealed that lower values than 100m returned null values for some shore points.
Continental shelf contour	Polyline vector	Used by the model for calculations relating to the surge exposure rank.	Default InVEST-provided polyline used (Sharp et al., 2020).
Area of interest	Polygon vector	Indicates the specific coastline of interest and intersects the continental shelf contour to indicate which wind/wave data is included in exposure calculations.	Generated for this research using ArcGIS to combine Greater Paramaribo with a 200km buffer extending into the ocean from the landmass polygon in order to intersect the continental shelf line and include sufficient wind/wave point data from all possible directions.
Habitats table (see Table 3)	.csv table	A lookup table containing ranks and protective distances used by the model to calculate the natural habitat exposure rank. The table is also used to direct the model to polygon vectors of each habitat type.	Assigned ranks and protective distances to each green space class (trees, mangrove, mixed low vegetation and grass)(see Table 3). Polygon vectors for each class were generated using the underpinning land cover data and patches ≥ 1ha were selected using ArcGIS.

2.3.3 Flood risk mitigation

The recently released Urban InVEST Flood Risk Mitigation model (Natural Capital, 2020; Sharp et al., 2020) was used to quantify the flood risk mitigation service offered by green space in Greater Paramaribo. This model is largely based upon the Curve Number (CN) method which uses predefined curves to describe the relationship between rainfall events and runoff, and is based upon land cover and soil characteristics (Dile, Karlberg, Srinivasan, & Rockström, 2016; Sharp et al., 2020). The CN method, which has been shown by (Dile et al., 2016) to be applicable in tropical regions, allows the InVEST model to estimate runoff and runoff retention during a storm event of choice (Sharp et al., 2020).

Within the InVEST model, runoff ($\mathbf{Q}$) (mm) is estimated for a given pixel ($\mathbf{i}$) using the following formula:

$$Q_{p,i} = \frac{(P - \lambda S_{max,i})^2}{P + (1-\lambda) S_{max,i}} if > \lambda S_{max,i}; Q = 0 \ otherwise.$$

Where;
P = design storm depth
λS_{max} = rainfall depth required to initiate runoff (considered by the model to be 0.2 for simplification)
$S_{max,i}$ = potential retention (in mm). This is a function of the curve number (**CN**), which is defined by land cover and soil properties, and is determined by the following formula:

$$S_{max,i} = \frac{25400}{CN_i} - 254\ (S_{max}\ in\ mm)$$

The runoff retention (**R**) is then calculated by the model using the following equation:

$$R_i = 1 - \frac{Q_{p,i}}{P}$$

This InVEST model therefore primarily requires input data specifying land cover, soil characteristics and the storm event of interest. These model inputs are summarised in Table 5. A lookup table also requires CN values corresponding to each soil hydrological group for each land cover class. These were largely centred around CN values used by the Inter-American Development Bank (IDB) for flood risk research within Paramaribo (IDB, 2017b). However, this IDB research does not differentiate between hydrological soil classes and uses different land cover classifications than those in this study. Therefore, these values were adjusted based upon values presented in other tropical or global sources. Final CN values are outlined in Table 6.

Table 5: Inputs used in the Urban InVEST Flood Risk Mitigation model to determine runoff retention in the study area.

Model parameter	Data type / input value	Description	Source / processing steps
Design storm event	132.7 (mm)	Rainfall depth in a storm of choice. This value is used in the runoff equation indicated above (**P**)	The depth of a 10-year storm event in Paramaribo was chosen (IDB, 2017b). This was considered as most relevant by local project partners TBIS.
Soil hydrological group	Raster	Soil hydrological groups with pixel values of 1,2,3 or 4 which correspond to the primary groups A, B, C or D respectively. This is used to derive the CN value used within the retention equation above.	Obtained from FutureWater as suggested by the InVEST user guide (due to absence of local soil data) (De Boer, 2016; Sharp et al., 2020). Groups C, C/D and D were present in Greater Paramaribo. The raster was therefore reclassified so that intermediate Group C/D was assumed as Group C; a decision taken based upon discourse with local stakeholders who advised that at least some drainage of the soil could be assumed for the majority of the study area. A python script was used to fill missing data based upon the majority of surrounding cells. The raster was resampled from a resolution of 500m to a resolution of 10m to attempt to limit pixilation issues with the final output. Resampling was also based upon a majority approach.
Watersheds	Polygon vector	Primarily used for optional valuation aspects of the model which were not utilised in this research, though this input is still required to specify the area of interest.	Delineated from the global SRTM 30m Digital Elevation Model (NASA, 2000).
Biophysical table (see Table 6)	.csv table	A lookup table containing CN values per soil hydrological group and land cover class.	Assigned CN values per soil hydrological group and land cover class are provided in Table 6.

Table 6: CN Values assigned to each land cover class and soil hydrological group in the biophysical table.
Note: Land cover classes with IDB (2017b) referenced were assigned values based upon local flood risk research in Paramaribo but these were altered according to other sources to account for differing land cover classes and soil hydrological groups.

Land cover class	CN Group C	CN Group D	Source
Trees	67	74	(Shamshad, Leow, Ramlah, Wan Hussin, & Sanusi, 2008)
Mangrove	70	77	(Shamshad et al., 2008)
Mixed low vegetation	77	79	(IDB, 2017b; NRCS-USDA, 2007)
Grass	79	84	(IDB, 2017b; Sharp et al., 2020)
Urban	90	92	(IDB, 2017b; Sharp et al., 2020)
Bare soil	90	92	(IDB, 2017b; Shamshad et al., 2008)
Water	99	99	(Sharp et al., 2020)

The Urban InVEST Flood Risk Mitigation model provides two primary outputs; a map of estimated runoff in mm and a map of estimated runoff retention in m^3, the latter of which was used to quantify the ES supply of flood mitigation for Greater Paramaribo.

2.3.4 Local climate regulation

The Urban InVEST Cooling model, also recently released, was used to estimate the cooling effect of green space in Greater Paramaribo (Sharp et al., 2020). The model considers shade, albedo and evapotranspiration as well as the cooling effect offered by large green spaces.

An evapotranspiration index (**ETI**) is first calculated by the model according to the following formula:

$$ETI = \frac{K_c \cdot ET0}{ET_{max}}$$

Where;

Kc = crop coefficient values assigned to each land cover class by the user
ET0 = reference evapotranspiration
$\mathbf{ET_{max}}$ = maximum value of evapotranspiration rate in the study area

User-defined shade and albedo values between 0 and 1 are then combined with the evapotranspiration index in the following equation to determine the cooling capacity index (**CC**) for a given pixel (**i**):

$$CC_i = 0.6 \cdot shade + 0.2 \cdot albedo + 0.2 \cdot ETI$$

The weighting of 0.6: 0.2 :0.2 for these is intended to reflect the greater influence shade has on cooling compared to albedo or evapotranspiration (Sharp et al., 2020). A heat mitigation (HM) index is then determined by the model based upon the CC value per pixel but accounting for the cooling effect large green spaces (defined by default as any green space larger than 2ha) can have on the surrounding area (Sharp et al., 2020). HM is equal to the CC value for a pixel unaffected by large green space, but otherwise set to a distance-weighted average of CC values from the large green space to account for this cooling effect up to a user-defined maximum cooling distance.

A rural reference air temperature and a magnitude of UHI within the area of interest are further inputs into the model which allow for estimations of heat reduction throughout the city. The model inputs used for this research are outlined in table 7.

Table 7: Inputs used within the Urban InVEST Cooling model to quantify and map heat mitigation in the study area.

Model parameter	Data type / input value	Description	Source / Processing steps
Reference evapotranspiration	Raster	Used by the model to determine **ET0** and $\mathbf{ET_{max}}$ for the calculation of the evapotranspiration index (**ETI**)	Global Reference Evapotranspiration Database v2 (Global-PET) clipped to Greater Pararmaribo (Trabucco & Zomer, 2018)
Areas of interest	Polygon vector	Indicates the area of interest and divisions within it for aggregated results	Greater Paramaribo with ressort boundaries as divisions. Shapefiles provided by TBIS.
Baseline (rural reference) air temperature	23.0 °C	Air temperature where the urban heat island is not observed for the period of interest	The mean night-time air temperature recorded for the entire month of January 2020 from a rural temperature recording drop placed just outside of the study area. Longer-term data was not available. Night-time temperatures were considered as the urban heat island is more pronounced at night and heat stress consequentially more relevant at night time due to lack of opportunity to cool off (Oleson et al., 2015).
Magnitude of the UHI effect	2.3 °C	The difference between the rural reference temperature (above) and the maximum air temperature observed in the city.	The mean rural air temperature data was compared with mean air temperature data from 10 temperature "drops" (see Appendix 2) within the city for the same period. This UHI magnitude is lower than the magnitudes of 5.1 °C (wet season) and 5.3 °C (dry season) found by Remijn (2020). However, these values were determined by land surface temperature analyses using daytime temperatures, whereas this research is considering the canopy urban heat island (air temperature) at night time, so a similar magnitude was not expected.
Air temperature maximum blending distance	500m	A search radius used to account for air mixing	The default value as suggested in the InVEST user guide. Sensitivity tests revealed little influence of this value at the scale of this research and no reason was found in literature to alter it.
Green area maximum cooling distance	90m	Maximum distance over which large green spaces (>2ha) have a cooling effect. Used in determining the HM index based upon CC value (see description above this table)	90m – This distance was determined by taking a mean of observed cooling effect distances from green space greater than 2ha as determined by (Kalpoe, IN PREP). Air temperature measurements were carried out using Kestrel Heat Stress trackers (version 5400)(Kalpoe, IN PREP). This is similar to the default value in the InVEST user guide of 100m suggested for use in the absence of local studies, and similar to values indicated within other research (e.g. Shih, 2016; Vaz Monteiro, Doick, Handley, & Peace, 2016) and was therefore deemed suitable.
Biophysical table (see Table 8)	.csv table	Specifies Kc, shade and albedo values per land cover class and indicates which are counted as green space.	Assigned values are presented in Table 8.

Identifying crop coefficient (Kc) values proved difficult for Greater Paramaribo since most available in the literature are for agricultural purposes and are often for specific crop species. Therefore, closest available values to the more general, non-species-specific land cover classes used in this study were used as outlined in Table 8. Values between 0 and 1 for both shade and albedo were also assigned to each land cover class. Shade values were estimations based upon the "*proportion of tree canopy*" definition provided in the InVEST user guide. Albedo values represent the proportion of reflected solar radiation (Sharp et al., 2020). Mid-point values from the ranges indicated by (Stewart

& Oke, 2012) for identical or similar land cover classes were used here. Shade and albedo values input to the biophysical table are presented in Table 8.

Table 8: Kc (crop coefficient), shade and albedo values used in the Urban InVEST Cooling model.
Note: Kc values are based upon Allen, Pereira, and Smith (1998) as suggested within the InVEST user guide. Shade values estimations are based on proportion of tree cover, and albedo values based upon mid-point values of similar land cover classes indicated by Stewart and Oke (2012).

Land cover class	Kc (crop coefficient)		Shade		Albedo	
	Value	Justification	Value	Justification	Value	Justification
Trees	1	Common value for several tropical tree species in Allen et al. (1998)	0.9	Tree cover present	0.15	Dense trees
Mangrove	1	Common value for several tropical tree species in Allen et al. (1998)	0.9	Tree cover present	0.15	Dense trees
Mixed low vegetation	1.1	Short vegetation and wetland values from Allen et al. (1998)	0.1	Some occasional small tree cover assumed	0.225	Bush / scrub
Grass	0.95	Value for “turf” in Allen et al. (1998)	0	No tree cover	0.2	Low plants (includes grass)
Urban	0	Assumed zero since no vegetation present	0	No tree cover	0.25	Lightweight low-rise urban
Bare soil	0.3	Value from example InVEST data (Sharp et al., 2020)	0	No tree cover	0.275	Bare soil
Water	1.05	Value for water in tropics in Allen et al. (1998)	0	No tree cover	0.06	Water

The primary model output used for further analysis of ES supply was the Heat Mitigation (HM) index mapped to the same resolution as the land cover map (10m).

2.3.5 Carbon storage

The InVEST Carbon Storage and Sequestration model was used to quantify and map carbon storage provided by green space in Greater Paramaribo (Sharp et al., 2020). The sequestration aspect of the model is an optional component which was not utilised in this research since the focus was on carbon storage rather than its dynamics through time. The model requires estimates (in Mg C / ha) for the amount of carbon stored in at least one of four carbon pools (aboveground biomass, belowground biomass, soil and dead organic matter) for each land cover class in a land cover raster. These estimates are specified by the user in a .csv lookup table. The model then aggregates the carbon densities per land cover class and maps storage in Mg of carbon per pixel (therefore per $100m^2$) according to land cover raster data.

For the purpose of this research, only estimations for carbon stored in the aboveground biomass carbon pool were included since; (i) this is a common practice in research considering carbon storage offered by green space (Davies et al., 2011; Derkzen et al., 2015; Strohbach & Haase, 2012; Wu et al., 2019); (ii) despite efforts, no locally representative datasets were obtained with estimations in pools other than aboveground biomass; (iii) combining general approaches or globally available estimations for missing pools was deemed to be likely to increase uncertainty when combining them with regional measurements used for aboveground carbon stock, and (iv) carbon stored within vegetation is more likely to be impacted by land use change in the short term (Hutyra, Yoon, & Alberti, 2011; Wu et al., 2019).

Table 9 outlines the input data used within the InVEST Carbon model for this research. For the individual estimates of aboveground carbon stock relating to each of the four green space land cover classes, regionally-specific values were used for both trees and mangrove as these were recommended as “best available” data by local stakeholders. These values were considered to be representative of the tree and mangrove cover in the study area due to their associated descriptions and specified locations (see Table 9). Furthermore, they are consistent with other ranges reported for Suriname (Arets et al., 2011) and Guyana (Cedergren, 2009), among others (SBB, CELOS, CATIA, & NZCS, 2017). Therefore, they were considered a suitable, location-specific alternative to more general sources suggested in the InVEST user guide. However, no such location-specific estimations were available for the classes of mixed low vegetation or grass. Therefore, estimates based upon tropical IPCC greenhouse gas inventory data were used, as suggested in the InVEST user guide (IPCC, 2006, 2019; Sharp et al., 2020).

Producing a “minimum” or “conservative” carbon storage estimate was deemed more desirable than an overestimation and was the primary reasoning behind specifying other non-green space land cover classes (urban, water and bare soil) to have carbon storage values of zero. In line with the conservative tier 1 approach proposed by IPCC (2006), in which urbanisation is assumed to cause carbon stock to become entirely depleted, it was assumed that non-green space does not contribute to carbon storage in Greater Paramaribo. Assigning zero to such classes is also common practice adopted in multiple recent studies considering the ES of carbon storage (for example see; Davies et al., 2011; Grafius et al., 2016; Jiang et al., 2017; Pavani et al., 2018; Sallustio et al., 2015; Wu et al., 2019; Xiang et al., 2018).

Table 9: Aboveground carbon storage values assigned to each of the land cover classes in the InVEST Carbon model

Land cover class	Carbon storage assigned (Mg C / ha)	Description and source
Trees	149.62	Based on estimates for trees in the “*Young Coastal Plain*” of Suriname – an area “*from mangroves to forest belt*” which includes Paramaribo (SBB et al., 2017). This area is recognised to be influenced by human activity and trees within it are estimated to have a slightly lower carbon stock than that for the primary forest belt further inland. This therefore accounts for some disturbance in line with research on urban trees (Velasco & Wee Chen, 2019; Zhao, Tang, & Chen, 2016), though not excessive disturbance, reflective of large patches of trees within Paramaribo visited during the fieldwork which appeared only slightly disturbed by human activity.
Mangrove	123.69	Derived from aboveground carbon stock measurements of Suriname’s mangroves (Gianni et al., 2019), of which the closest geographical value to Paramaribo was selected. This is from a site slightly outside of the Greater Paramaribo study area, to the north of the ressort of Nieuw Amsterdam (NA). This was considered a best available value.
Mixed low vegetation	35.75	Derived from IPCC (2019) which indicates tropical shrublands to have a dry aboveground biomass of 71.5 Mg ha^{-1}. This value was then divided by two since a conversion of 50% is typically used to convert biomass to carbon (Basuki, van Laake, Skidmore, & Hussin, 2009; Brown, 1997; IPCC, 2019; Smith, Heath, & Hoover, 2013).
Grass	3.10	Derived from IPCC (2006) which indicates tropical grassland to have an aboveground biomass of 6.2 Mg ha^{-1}. As with mixed low vegetation, this value was then divided by two based on the same 50% biomass to carbon conversion factor (Basuki et al., 2009; Brown, 1997; IPCC, 2019; Smith et al., 2013).
Urban, bare soil and water	0	A conservative estimate in line with IPCC (2006) guidelines and as used in multiple studies considering the ES of carbon storage (Davies et al., 2011; Grafius et al., 2016; Jiang et al., 2017; Pavani et al., 2018; Sallustio et al., 2015; Wu et al., 2019; Xiang et al., 2018).

The final output derived from the InVEST carbon storage model was carbon storage in Mg C per 100m^2 mapped to the same resolution (10m) as the underpinning land cover map for Greater Paramaribo.

2.3.6 Assessing hotspots and coldspots of regulating ES supply

To identify areas consistently providing either high or low ES supply, a small hotspot and coldspot analysis was carried out. This analysis excluded coastal protection since this was quantified for the coastline alone and could therefore not be compared with the quantification of flood risk mitigation, local climate regulation or carbon storage which was spatially mapped for the entire study area. A 33% quantile approach was used to define hotspots and coldspots of ES supply, since; (i) This is a commonly used approach in such analyses (Bagstad, Semmens, Ancona, & Sherrouse, 2017), and; (ii) alternative approaches such as a 25% quantile approach were found to be unsuitable due to skewed data distribution in the local climate regulation output. ES supply values falling within the upper 33% of value distribution were therefore considered as offering high ES supply, the lower 33% of value distribution as offering low ES supply, and the middle 33% of value distribution offering moderate supply. The three rasters quantifying ES supply (runoff retention, HM index and carbon storage) were reclassified according to this and overlain using the raster calculator tool in ArcGIS in order to determine consistent areas of high and low supply. These areas define hotspots and coldspots of regulating ES supply respectively.

2.4 Modelling future land cover scenarios

2.4.1 General approach and software

For the second objective, three potential future land cover scenarios were defined and their spatial distribution of land cover change modelled between 2020 and 2035. A period of 15 years was deemed suitable and is commonly used for such future scenario research (Fung-Loy et al., 2019; Haase et al., 2012; Wang, van Vliet, Pu, & Verburg, 2019). For the purpose of this study 15 years was considered to offer good balance between there being enough time for significant land cover change to occur and the increasing uncertainty with predicting land cover change over longer periods of time.

The CLUE (Conversion of Land Use and its Effects) modelling framework was used to model the three future land cover scenarios (Verburg & Overmars, 2009). This framework is commonly used to simulate large scale land use change, but is also applicable to smaller scale research and to simulate urban expansion (CLUE, 2020). It has been used alongside InVEST to assess how future scenarios influence supply in a number of studies (Jiang et al., 2017; Liang, Liu, & Huang, 2017; Zhang, Huang, He, & Wu, 2017). The specific model within the CLUE framework which was used is entitled Dyna-CLUE, which is a modified version of the CLUE-s model (the Conversion of Land Use and its Effects at Small regional context) (CLUE, 2020). This model is spatially explicit and allows land cover change to be simulated based upon empirical relationships between land cover and its determining and change-driving factors in combination with dynamic modelling of competition between different land cover types.

There are four primary user input categories within the model which combine to create a set of conditions upon which the model can base calculations to find an optimal solution. These categories are; (i) land use requirements (demand); (ii) land use type specific conversion settings (elasticity and conversion matrix); (iii) spatial policies and restrictions; and (iv) land cover suitability. Within the demand category the user specifies land use requirements by inputting change in area per land cover class per year. The demand therefore defines the objective of the simulation and reflects land use change policy targets. The elasticity setting in the model ranges from 0 to 1 and reflects a land cover class's elasticity to change, with 0 being easy conversion and 1 meaning irreversible change. A conversion matrix is used to specify which land cover classes the present land cover class can (1) or can not (0) be converted into. For example, it is infeasible for water to become grass, so this conversion would be set to zero in the conversion matrix. The spatial policies and restrictions aspect allows the user to indicate areas where land cover change is restricted due to protective policy or tenure status. Finally, the land cover suitability aspect refers to the preference of a land cover occurring at a particular location; empirically estimated from a set of biophysical or socio-economic variables considered to be determinants of land cover change (CLUE, 2020; Verburg & Overmars, 2009). Dyna-CLUE allocates the most probable changes in land cover based upon the restrictions and suitability defined by the inputs within each of the four categories.

2.4.2 Stakeholder interviews

Decisions within the four main aforementioned model categories of Dyna-CLUE were largely based upon stakeholder interviews. Six key stakeholders were asked a series of questions about their expectations for urban growth and where this will and will not occur by the year 2030. They were then asked about what they expect to happen to green space during the same time period. These questions were specifically designed to inform the defining of scenarios and the settings to be used within the Dyna-CLUE model. The stakeholders interviewed were affiliated with the following; Built Heritage Suriname (SGES), Ministry of Public Works, Tropenbos Suriname (TBIS), Spatial Planning Association of Suriname (SPASU), Anton de Kom University of Suriname (AdeKUS), and the Ministry of Spatial Planning, Land and Forest Management. All interviews were conducted in English and lasted between 20 and 60 minutes. They were recorded for the purpose of revision but have been deleted in the interest of confidentiality and as agreed in the associated declaration of consent. The specific interview questions, as well as the consent form used during these interviews, are provided in Appendix 3 and Appendix 4.

2.4.3 Scenario development

Scenarios were developed according to responses from stakeholder interviews outlined in the previous section in combination with insights from local literature. Regarding policy, the interviews confirmed there to be no enforced policy protecting or promoting the increase of green space within Paramaribo or the wider Greater Paramaribo area. Several stakeholders expressed concern that there is no awareness of the benefits green space can offer among key decision makers, politicians, and a large proportion of the general population. They therefore considered it unlikely that any major green space policy would emerge and be enforced within the next 15 years, though generally expressed interest and enthusiasm in such a policy emerging.

With regards to urban expansion, all stakeholders expect the sprawling effect discussed by (Fung-Loy et al., 2019) and (IDB, 2017c) to continue, particularly along the two primary roads to the south of the city. Several pointed out how the city itself was considered to be relatively “full” or have “nowhere left to build”, indicating that this exacerbates the sprawl and that most urbanisation is occurring on the rural-urban fringe. Interviews with spatial planners highlighted an exception to this however, indicating expectations for development of some currently undeveloped green areas in the southern ressorts of Livorno, Latour and Pointbuitten. Nevertheless, the majority of open green space patches within the city are primarily abandoned plots (but still owned) and are not expected to be built upon in the near future since the whereabouts of most owners is unknown. Many are believed to now live in the Netherlands and to have little incentive to develop or sell their plots of land in Paramaribo. For this reason, many of these patches have remained unchanged within the city for several years already.

Other areas in which urban development is expected include some areas to the north, despite ongoing flooding issues, and on the eastern side of the relatively recently constructed Jules Wijdenbosch bridge in the district of Commewijne. Interestingly, this bridge is the only land connection between the two sides of the Suriname River within the Greater Paramaribo study area. Since its opening in 2000, urban growth has been steadily increasing on the Commewijne side.

With regards to land cover, stakeholders were again in agreement and expect all types of green space area (trees, mangroves, grass and trees) to decrease in response to the increased demand for urban area in Greater Paramaribo, with trees predicted to decrease slightly more than the other green space classes considered within this study since; (i) they offer a useful resource (wood) and forestry operations are underway in certain areas of Greater Paramaribo; and (ii) they are often perceived to cause problems (e.g. root damage to roads, increased insect and pest numbers, crime) and be a "waste of space" within the city. With regards to grass and mixed low vegetation, stakeholders found it difficult to say which was more likely to be lost due to urban expansion, though pointed out that some swamp or marsh areas (mainly classified as mixed low vegetation in the underpinning land cover map) would be unsuitable. They predicted mangroves to be least impacted by urban sprawl in the coming 15 years as it is often difficult to utilise the remaining land for other needs.

As mentioned, these insights were combined with further insight from some recent plans or initiatives suggested for Paramaribo. These include plans proposing an ICZM (Integrated Coastal Zone Management) area (Erftemeijer & Teunissen, 2009) and the IDB's Action Plan for Paramaribo (IDB, 2017a) which is underpinned by studies into hazard and risks (IDB, 2017b) and urban growth (IDB, 2017c) and seeks to promote more sustainable growth of Paramaribo. This formed the basis of the three scenarios discussed in the upcoming sections before being summarised in Table 11.

2.4.3.1 Scenario 1 – Business as usual

The first scenario was developed with a business-as-usual context in mind. It asks the question; what if nothing changed with regards to green space policy or protection for the next 15 years and urban growth and sprawl carries on as it has been? It therefore tries to capture patterns of land cover change seen as most likely to occur by local stakeholders between 2020 and 2035 and is largely informed by the interviews discussed in the previous section.

2.4.3.2 Scenario 2 – Protection of key green space

The second scenario aims to highlight how protecting key green space during continued urban growth in Paramaribo could influence trade-offs between urban expansion and the consequential loss of green space and its associated ES supply. In this scenario, trees and mangroves are specifically protected within the Paramaribo administrative boundary and a 2km wide greenbelt around the city boundary. Furthermore, there is a Greater Paramaribo-wide target for zero-net loss of trees or mangroves by 2035. Inspiration behind this scenario comes partially from recognition for a "need for protection" in stakeholder interviews, but also from suggestions for a strict protection policy during the aforementioned TBIS organised stakeholder workshop which aimed to encourage and collate ideas for addressing the de-greening of Paramaribo currently taking place in response to the demand for urban area (TBIS, 2019).

For this scenario, a city boundary was estimated based upon the underpinning classified land cover map (Figure 5). A 2km buffer around this was then used as a greenbelt (Figure 5). In recent years, the introduction of a greenbelt around Paramaribo has been suggested (but never implemented) and is mentioned by both IDB (2017c) and Erftemeijer and Teunissen (2009). It was also briefly mentioned during the stakeholder interviews. The general idea behind it relates to a proposed ring road around the city and it seems to have been suggested that this could offer the opportunity to develop a protected ring of green space in which urban development would be more controlled (Erftemeijer & Teunissen, 2009; IDB, 2017c). Some inspiration for this idea seems to have been partially drawn from success of the Ottowa greenbelt in Canada (IDB, 2017c). The concept has also proven successful elsewhere on the planet, including in several UK cities of varying size, Seoul in South Korea, and in Australian and US cities (Bengston & Yeo-chang, 2005; Han & Go, 2019).

2.4.3.3 Scenario 3 – Greening of Paramaribo and its surroundings

The third scenario aims to consider how a "greening" of Paramaribo (via increasing the area of key green space) would influence ES supply under the same urban expansion as scenarios one and two. Restoring mangroves along the coast and planting trees within the city were frequent suggestions in the aforementioned stakeholder workshop. This scenario also includes a 2km wide greenbelt as used in scenario 2. However, in this case a significant increase in tree cover is targeted here on top of the protection. Additionally, a 2.5km wide coastal zone is included in which an increase in mangrove cover is specifically targeted (Figure 5). This zone is based upon minimum widths proposed in previous suggestions for a coastal buffer zone for the purpose of mangrove restoration and coastal resilience against flooding (Conservation International Suriname, 2015; Erftemeijer & Teunissen, 2009; Guzman et al., 2017a, 2017b; IDB, 2017b).

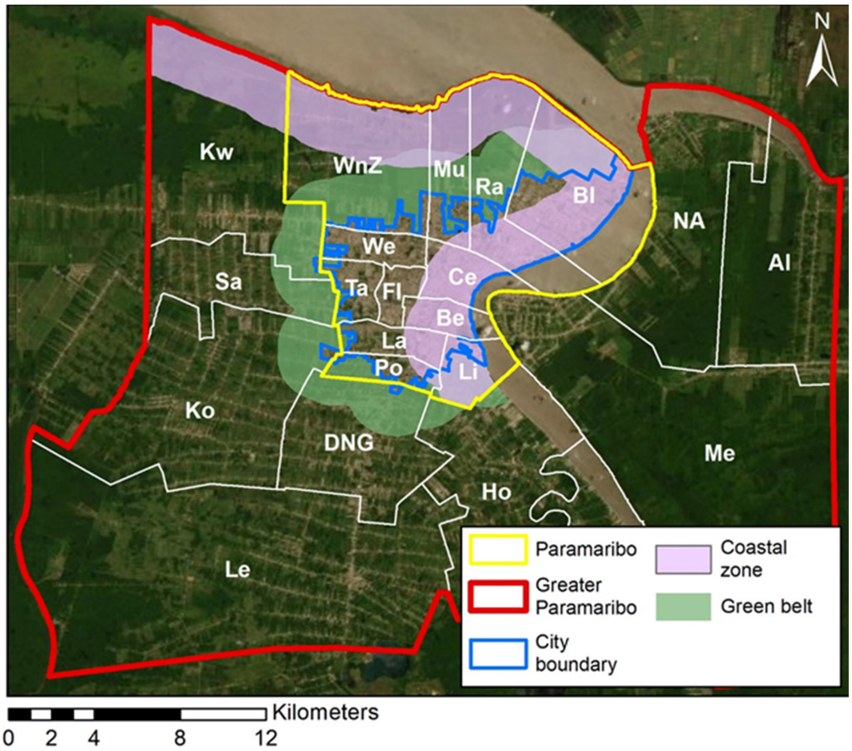

Figure 5: Map indicating introduced areas for protection and greening. The greenbelt is specifically used for protection of trees and mangroves in scenario 2 (protection policy). Greening efforts in scenario 3 are targeted in the greenbelt (tree cover increase) and coastal zone (mangrove cover increase).

2.4.4 Dyna-CLUE settings, data and sensitivities

The same urban expansion demand of a 27.5% increase in urban land area required by 2035 was used as a starting point for all scenarios. This growth rate is based upon projections in the IDB's urban growth study which used a similar study area (IDB, 2017c). This is considered as a conservative and minimum urban growth estimation as other research indicates potential for the percentage of urban increase to be higher (Fung-Loy et al., 2019; Heirman & Coppens, 2013). It was decided that the amount of urban growth would be a constant value between all scenarios to allow for more effective exploration of alternative green space approaches. Other demands were adjusted based upon the specific objective. All demand values were calculated assuming a linear increase each year, with the exception of the tree and mangrove increase demand in scenario 3. Here, linear increase was assumed after 8 years to prevent tree and mangrove cover from increasing until then to mimic growth. This was to bypass a Dyna-CLUE limitation which prevents the inclusion of a time-step in the conversion matrix if the region feature is used (Table 12). To convert the interview and past initiative-informed scenarios into Dyna-CLUE settings, several assumptions and estimations had to be made to convert the qualitative insights into quantitative inputs. Both water and bare soil were considered as "other" and restricted from any change. The final settings used are summarised in Table 12, which allows for comparison of differences between scenarios. Unless specified, all other Dyna-CLUE settings were left as default and consistent between scenarios.

Finally, analysis regarding the land cover suitability aspect of the model was carried out using R statistical software (R Development Core Team, 2010). Logistic regression models were built for both the urban and the four green space (trees, mangrove, mixed low vegetation and grass) land cover classes using a backwards stepwise procedure and a series of explanatory location variables (Table 10). A VIF (Variance Inflation Factor) analysis was then performed upon each regression model to check for collinearity between explanatory variables and necessary variables were removed to resolve any cases of this. A balanced 10% sample of pixels from binary presence / absence land cover rasters for each of the five classes was used to avoid spatial autocorrelation otherwise caused by the clustering of land cover types. The statistical relation between the location of a particular land use and a series of location variables (Table 10) deemed influential to the presence or absence of the land cover classes considered was subsequently determined, and the resulting probability values were considered suitability indicators. The beta coefficients for each explanatory variable were therefore input into the Dyna-CLUE model for each land cover class, as well as ASCII Grids representing each of the location variables in order for the model to determine the suitability of locations for different land cover types. The R script for this regression analysis is available in Appendix 5.

Table 10: Location variables considered within the multiple regression models (prior to VIF analyses) and included within the Dyna-CLUE model as ASCII Grids. Note: Processing steps indicated were carried out in ArcGIS as part of this research.

Location Variable	Description / source
Distance from coast	Euclidean distance raster generated from the coastline vector produced for use within the InVEST coastal protection model.
Distance from major junction	OSM primary, secondary and tertiary road data was downloaded (OpenStreetMap contributors, 2019), and all major junctions (primary-primary, primary-secondary, secondary-secondary, and primary-tertiary) were identified and converted to point data. A Euclidean distance from these points was then used to produce the raster.
Distance from primary road	Euclidean distance from primary road OSM data (OpenStreetMap contributors, 2019).
Distance from secondary road	Euclidean distance from secondary road OSM data (OpenStreetMap contributors, 2019).
Elevation (DEM)	SRTM DEM data as used in the InVEST coastal protection model (NASA, 2000).
Distance from centrum	Euclidean distance from the edge of the Centrum ressort. Based on ressort boundaries provided by TBIS.
Distance from bridge	Euclidean distance from the Jules Wijdenbosh bridge (OpenStreetMap contributors, 2019)
Swamp / marsh	Binary raster indicating swamp and marsh boundaries determined from an "ecosystem map" provided by SPS (SPS, 2017).
Distance from poor SES	Euclidean distance raster generated from different data mapping different classes of socioeconomic status (SES) provided by Fung-Loy et al. (2019).
Distance from rich SES	
Distance from middle SES	
Distance from middle to low SES	
Geology	Shapefile data provided by NIMOS (National Institute for Environment and Development in Suriname) converted into raster format for this research.
Distance from classified water	Classified water from the underpinning land cover map was converted to shapefile format and a Euclidean distance raster generated based upon this.

Table 11: Summaries of scenarios developed for the modelling of future land cover in Greater Paramaribo.

	Scenario		
	1. Business as usual	**2. Protection Policy**	**3. Greening of Paramaribo**
"What if…" basis behind the scenario	What if Paramaribo continues to **expand / sprawl unrestricted** (as it has been) with **no policy protecting green space**?	What if a region-wide target, supported by specific **protection policy in and around Paramaribo**, aims for a **net loss of zero tree and mangrove cover** within Greater Paramaribo?	What if an ambitious greening plan is enforced in which **tree and mangrove cover are increased by 20%** within either a **greenbelt, coastal zone or vacant "low quality" green space within the city**?
Summary of scenario	Urban expansion and sprawl continue until 2035 under a business as usual scenario. There is no specific policy to protect green space within Greater Paramaribo. Vacant plots and main parks within the city remain as they are now with the assumption that city is "full" and that the remaining plots are already owned, often by people now residing overseas, and are unlikely to become urbanised within the next 15 years.	The same urban expansion and sprawl continues until 2035 with a Greater Paramaribo region-wide target of zero net loss trees and mangroves. Furthermore, all trees and mangroves within the Paramaribo administrative boundary and a 2km wide greenbelt around the city are specifically protected and cannot be removed for any reason. As with scenario 1, vacant plots and main parks within the city remain as they are now with the assumption that the city is "full".	Urban expansion and sprawl continue until 2035 with key green space protected as in scenario 2. However, tree and mangrove cover increase due to substantial planting and restoration efforts. These greening efforts are targeted in the greenbelt introduced in scenario 2 and an additional 2.5km coastal zone introduced for this third scenario. Furthermore, 20% of grass and mixed low vegetation within the city itself is assumed available for these greening efforts.
Protection of green space	None	Trees and Mangroves are protected within the Paramaribo administrative boundary and within a 2km "green protection belt" surrounding the urban boundary.	Trees and Mangroves are protected within the Paramaribo administrative boundary and within a 2km "green protection belt" surrounding the urban boundary and a 2.5km wide "coastal zone".
Greening efforts	None	None	A 20% increase in tree coverage within a 2km green belt surrounding the city boundary and on a 20% random selection of vacant plots within the city boundary. A 20% increase in mangrove cover in a 2.5km wide coastal zone.

The final land cover maps produced by Dyna-CLUE for each scenario were visualised alongside areas of land cover change maps which were calculated using a reclassification and raster calculator approach in ArcGIS. This allowed for clear comparisons to be made between current and potential future land cover and its distribution under the different scenarios.

Table 12: Summary of settings used in Dyna-CLUE for each of the considered future scenarios. Setting descriptions are based upon Dyna-CLUE user guide.

<table>
<tr><th rowspan="2">Dyna-CLUE setting</th><th colspan="3">Scenario</th></tr>
<tr><th>1. Business as usual</th><th>2. Protection policy</th><th>3. Greening of Paramaribo</th></tr>
<tr><td>Demand
Defines the objective of the simulation and reflects land use change policy targets.

Note: The phrase “required decrease” refers to the total decrease in area required to balance the increase in area resulting from land cover with an increase in demand</td>
<td>27.5% increase in urban cover
35% of required decrease in tree cover
5% of required decrease in mangrove cover
30% of required decrease in mixed low vegetation cover
30% of required change in grass cover
0% change in other</td>
<td>27.5% increase in urban cover
0% change in tree cover
0% change in mangrove cover
50% of required decrease in mixed low vegetation cover
50% of required change in grass cover
0% change in other</td>
<td>27.5% increase in urban cover
20% increase in tree cover
20% increase in mangrove cover
50% of required decrease in mixed low vegetation cover
50% of required change in grass cover
0% change in other

Note: Demand input file is adjusted so that increase of tree and mangrove demand only occurs after 8 years. This is to allow for growth period time for trees in this scenario since use of the region feature to target the increase prevents time steps from being added to the conversion matrix (see below)</td></tr>
<tr><td>Elasticity
“Reversibility of land use change” and “relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change)”</td>
<td>Trees 0.6
Mangrove 0.7
Mixed low vegetation 0.2
Grass 0
Urban 1
Other 1</td>
<td>Trees 0.7
Mangrove 0.8
Mixed low vegetation 0.2
Grass 0
Urban 1
Other 1</td>
<td>Trees 0.8
Mangrove 0.9
Mixed low vegetation 0.2
Grass 0
Urban 1
Other 1</td></tr>
<tr><td>Conversion matrix
Defines to what other land use types the present land use type can be converted to (1) or not (0)

Note: T = Tree, M = Mangrove, ML = Mixed low vegetation, G = Grass, U = Urban, O = Other</td>
<td><table>
<tr><th></th><th>T</th><th>M</th><th>ML</th><th>G</th><th>U</th><th>O</th></tr>
<tr><th>T</th><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>M</th><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>ML</th><td>108</td><td>108</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>G</th><td>108</td><td>108</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>U</th><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>O</th><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
Note: The 108 values introduce a minimum time period of 8 years before grass or mixed low vegetation can be converted into a tree. This is to allow for tree growth time and was verified as a minimum period beyond which substantial cover offering at least some benefit could be possible.</td>
<td><table>
<tr><th></th><th>T</th><th>M</th><th>ML</th><th>G</th><th>U</th><th>O</th></tr>
<tr><th>T</th><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>M</th><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>ML</th><td>108</td><td>108</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>G</th><td>108</td><td>108</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>U</th><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>O</th><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
Note: The 108 values introduce a minimum time period of 8 years before grass or mixed low vegetation can be converted into a tree. This is to allow for tree growth time and was verified as a minimum period beyond which substantial cover offering at least some benefit could be possible.</td>
<td><table>
<tr><th></th><th>T</th><th>M</th><th>ML</th><th>G</th><th>U</th><th>O</th></tr>
<tr><th>T</th><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
<tr><th>M</th><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
<tr><th>ML</th><td>15</td><td>14</td><td>1</td><td>1</td><td>16</td><td>0</td></tr>
<tr><th>G</th><td>15</td><td>14</td><td>1</td><td>1</td><td>16</td><td>0</td></tr>
<tr><th>U</th><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><th>O</th><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
</table>
Note: Values of 15, 14 and 16 point Dyna-CLUE to region files within the working folder. These regions allow for only the conversions specified within this matrix to occur within them. This allows for the targeted greening and region 14 is the coastal zone, region 15 the greenbelt and region 16 is used to ensure the open 20% city plots cannot simply be converted to urban.</td></tr>
<tr><td>Spatial policies and restrictions
Indicate areas where land is restricted through policy or tenure status</td>
<td>• Grass and mixed low vegetation within a self-defined and Tropenbos verified city boundary (to reflect tenure / abandoned plot status and “city full apart from edges” comments from stakeholders)
• 2 main parks are restricted (Palmatuin and Southern area of Cultuurtuin) to reflect how stakeholders don’t see these being lost even though they aren’t specifically protected.</td>
<td>• Same as scenario 1 (2 parks and open plots restricted within the city boundary)
• All trees and mangroves within Paramaribo administrative boundary and all trees and mangroves within a 2km buffer (greenbelt) around the same city boundary as used in scenario 1 are protected</td>
<td>• Same as scenario 2 restrictions with the addition of a 2.5km coastal zone
• However, only 80% of grass and mixed low vegetation within city boundary (to allow the other 20%, which was randomly selected using a python script, to be available for greening.</td></tr>
</table>

Finally, a small sensitivity analysis was carried out via repeated model runs on the University of Twente's processing server. Sensitivity analyses, although somewhat rare in land cover modelling studies, can be used as a validation step to assess how certain model parameters or variables influence final outputs, thereby offering insight into model robustness and adding nuance required for interpretation of model result interpretation (Van Vliet et al., 2016) As typical with spatial modelling, certain parameters within the Dyna-CLUE model are somewhat inexplicit or ambiguous and require estimations from the user. It was therefore decided that two such inputs would be tested with model runs to assess the influence they had over the final land cover allocation and output. This sensitivity assessment therefore had the following aims; (i) to ensure land cover allocation determined by the model was as close to the input demand as possible with consistent settings between all scenarios, and; (ii) to ensure the spatial distribution of land cover allocation was feasible and reflected stakeholder input.

Two such settings within Dyna-CLUE were used to assess this. Firstly, two "iteration variable" values were used to specify the average and maximum deviation between demand and actual allocation, as these were found to be the cause of repeated "no solution found" errors in preliminary model runs. These errors occurred with default values of 0.35% (average deviation) and 3% (maximum deviation) and were found despite allocated land seeming to sufficiently meet these deviation criteria. The approach to determine the necessary setting for model success while limiting demand versus allocation difference was therefore to first increase these values to 2.5% (average deviation) and 5% (maximum deviation) – since these were the first values which resulted in a successful model run - and then to decrease them by increments of 0.25% until model failure again occurred, comparing the final allocation with demand for each output.

Secondly, the elasticity values for trees and mangroves were changed in increments of 0.1 to test sensitivity of the final land cover distributions to this input since it was difficult to determine which values should be used for these settings based upon the 0 (easy conversion) to 1 (irreversible change) scale. Visual comparison of final land cover outputs was used to assess this and to determine final inputs.

2.5 Assessing future ES supply

2.5.1 General approach

The final objective involved using the outputs from objective 2 (2035 land cover maps under three different scenarios) as inputs to the same InVEST models used in objective 1, as summarised in Figure 4. All other InVEST settings and input data outlined in section 2.3 remained the same. This allowed for ES supply to be quantified for the year 2035 under these three scenarios, subsequently allowing for comparisons to be made between them as well as with current ES supply.

2.5.2 Scenario comparisons and synergies and trade-offs

The future ES supplies for each scenario were visualised using change in supply maps. These were generated using ArcMap's raster calculator to subtract the current ES supply raster data from the future ES supply raster data to determine the difference in supply. These differences were therefore absolute differences expressed in the same units as the ES supply was originally quantified in. Simple analyses of mean ES supply per ressort and region (Greater Paramaribo vs Parmaribo) were carried out to assist with these comparisons and to offer insight into where change in supply was most pronounced. Change in hotspots and coldspots of supply for each scenario in comparison to current supply hotspots and coldspots (see section 2.3.6) were also identified and mapped. Synergies and tradeoffs between the ES considered were considered by comparing changes in mean supply values for Greater Paramaribo and Paramaribo under each of the three future scenarios.

3. Results

3.1 Current ES supply

The following sub-sections present InVEST outputs quantifying and mapping the current supply of key considered regulating ES in Greater Paramaribo, thereby addressing secondary objective 1.

3.1.1 Coastal protection in 2020

Figure 6 shows the variation in current habitat role in reducing coastal exposure along the coastline of Greater Paramaribo as determined within the InVEST Coastal Vulnerability model. The model estimates a mean habitat role of 0.55 for the entire coastline of Greater Paramaribo, and a slightly higher mean habitat role of 0.59 for Paramaribo coastline only. The model therefore estimates green space as having a slightly more important role in coastal protection within the Paramaribo administrative boundary than outside of it. However, Figure 6 also indicates that the protective service offered by green space is most varied within Paramaribo. For instance, stretches of coastline along the east of the city, in the ressorts of Centrum (Ce), Rainville (Ra) and Blauwgrond (Bl), have no coastal protection supplied by green space, with Centrum having the lowest mean habitat role value (0.33) in the entire study area. On the other hand, the supply of coastal protection is particularly high along the more exposed northern ressorts of Paramaribo, with Weg naar Zee (WnZ) having the highest mean habitat role (0.71) in the entire study area. The high supply along the northern coast coincides with frequent mangrove cover, the most influential of the considered green spaces in offering coastal protection, as well as patches of tree and mixed low vegetation cover. However, elsewhere in the region, there is less variation in the type of protective habitat present. This is particularly the case along the less exposed coastline to the south of Paramaribo, which is mainly protected by trees only (see the ressorts of Domburg (Do) and Meerzorg (Me) for example).

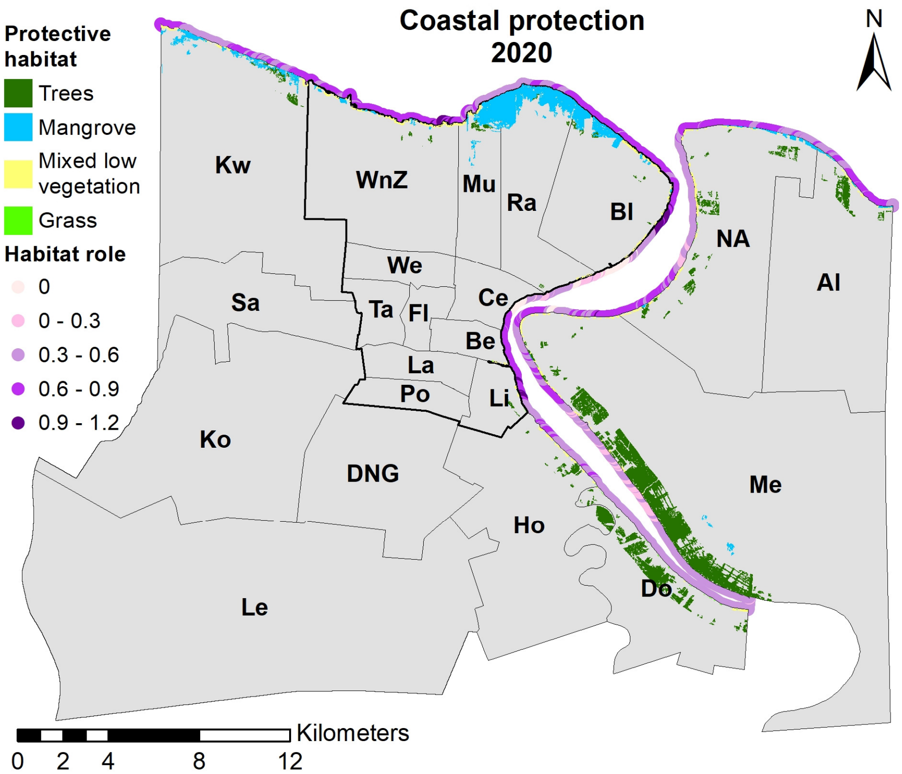

Figure 6: Current supply of coastal protection in Greater Paramaribo quantified and mapped as habitat role in reducing coastal exposure, with green space considered as offering a protective service indicated.

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

3.1.2 Flood risk mitigation in 2020

The spatial distribution of the current supply of flood risk mitigation derived from green space in Greater Paramaribo, quantified by the InVEST Urban Flood Risk Mitigation model as runoff retention (in m^3 per pixel and thus per $100m^2$) during a 10-year storm, is shown in Figure 7. The model estimates a total runoff retention of 4.37×10^7 m^3 within Greater Paramaribo. This equates to a mean runoff retention value of $5.1m^3$ per $100m^2$. In Paramaribo, the total runoff retention is estimated as 6.8×10^6 m^3, resulting in a lower mean runoff retention of $3.9m^3$ per $100m^2$.

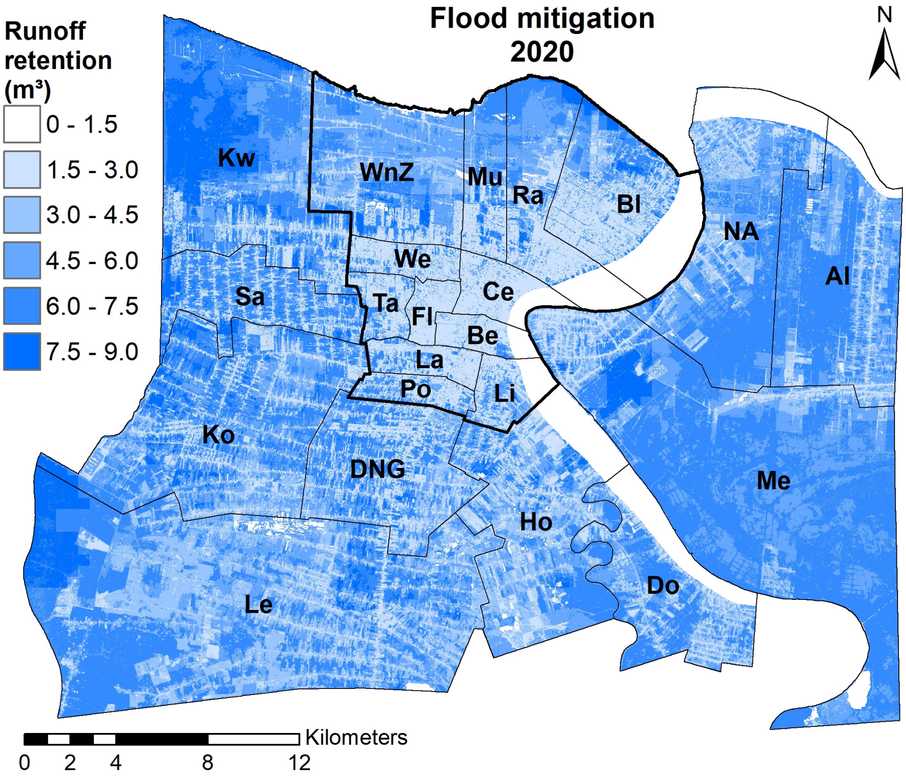

Figure 7: Current supply of flood risk mitigation in Greater Paramaribo quantified as runoff retention (m^3) during a 10-year storm event (132.7mm).

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

Figure 7 also highlights a clear fragmentation of supply, particularly on the western, Parmaribo-side of the Suriname River. Runoff retention is generally lowest in the central ressorts of Paramaribo, with Centrum (Ce) ($2.5m^3$ per $100m^2$) and Beekhuizen (Be) ($2.6m^3$ per $100m^2$) having the lowest mean supplies of the 22 ressorts in the study area. A general trend of increasing and less-fragmented supply with increasing distance from these central ressorts is also apparent, with the more rural outskirts of Greater Paramaribo generally having higher runoff retention. The highest mean supply per ressort of $6.14m^3$ per $100m^2$ is found in such a location; the north-western ressort of Kwatta (Kw). Within the Paramaribo administrative boundary however, the highest mean supplies are found along the northern ressorts of Weg naar Zee (WnZ), which has a mean runoff retention of $5.0m^3$ per $100m^2$, and Munder (Mu), which has a mean runoff retention of $4.8m^3$ per $100m^2$.

3.1.3 Local climate regulation in 2020

The spatial distribution of heat mitigation, quantified by the InVEST Urban Cooling model as a heat mitigation (HM) index, is shown in Figure 8. The mean HM (a higher value of which indicates a larger cooling effect from green space) for the entire study region of Greater Paramaribo is 0.66, whilst within the Paramaribo administrative boundary the mean HM is 0.39. This translates to a model-predicted night-time mean air temperature within Paramaribo of 24.4°C which is 0.8°C warmer than that estimated for outside of the administrative boundary (23.6°C).

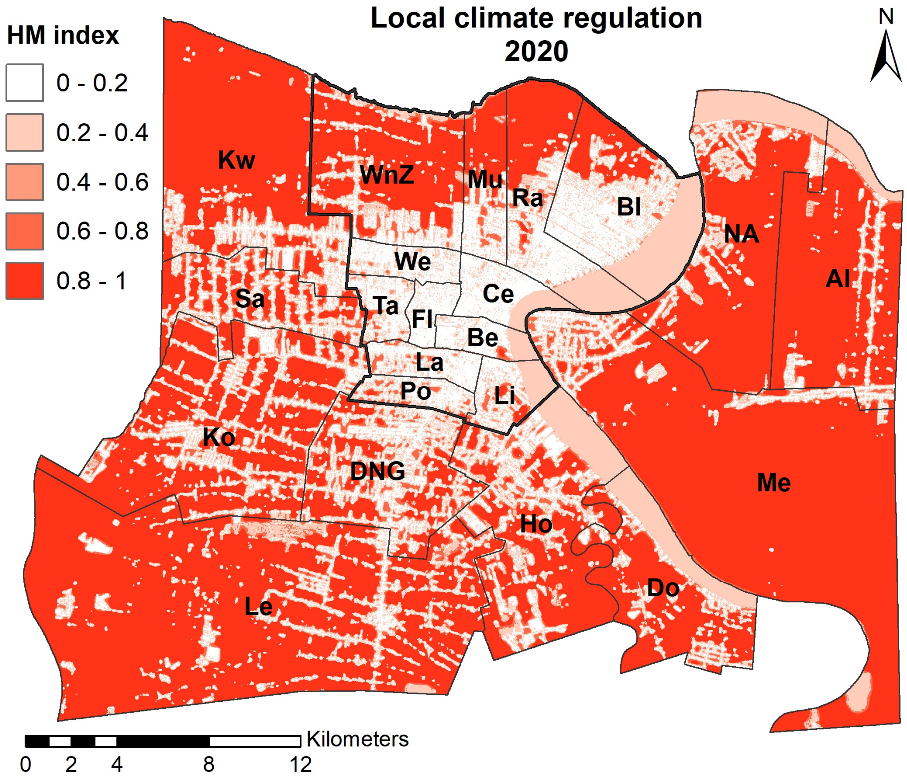

Figure 8: Current supply of local climate regulation in Greater Paramaribo quantified as a Heat Mitigation (HM) index.
Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

Figure 8 reveals there to be little variation in HM towards the outskirts of the city due to the cooling effect caused by larger patches of green space. As with flood risk mitigation, a fragmentation of supply is clear and is again particularly apparent on the western side of the river. A clear area of low supply is concentrated in Paramaribo, particularly towards the centre of the city (Figure 8). Consequentially, central ressorts have the lowest mean supply in the whole of Greater Paramaribo, with Flora (Fl) having the lowest mean HM (0.09), and Centrum (Ce) closely following this with a mean HM of (0.11). These ressorts are also predicted as having the highest night-time mean air temperatures in the study area, with estimations of 25.1°C and 25.0°C for Flora and Centrum respectively. The central areas with low HM supply are surrounded by areas of high HM causing steep gradients of increasing HM to occur over relatively short distances. The highest mean supply of HM in the study area (0.89) occurs in the south-eastern ressort of Meerzorg (Me), which has a predicted mean night-time air temperature of 23.3°C, the coolest ressort in the study area.

3.1.4 Carbon storage in 2020

Figure 9 shows the spatial distribution of current aboveground carbon storage in the Greater Paramaribo study area. The InVEST Carbon Storage model estimates Greater Paramaribo to have total of 4.37 x 10^6 Mg of carbon stored in aboveground vegetation, with a mean storage of 0.51 Mg C per 100m^2. Paramaribo contributes 3.58 x 10^5 Mg of carbon to this Greater Paramaribo total and has a lower mean carbon storage of 0.21 Mg C per 100m^2, values reflected in large areas of low supply concentrated within the Paramaribo administrative boundary in Figure 9.

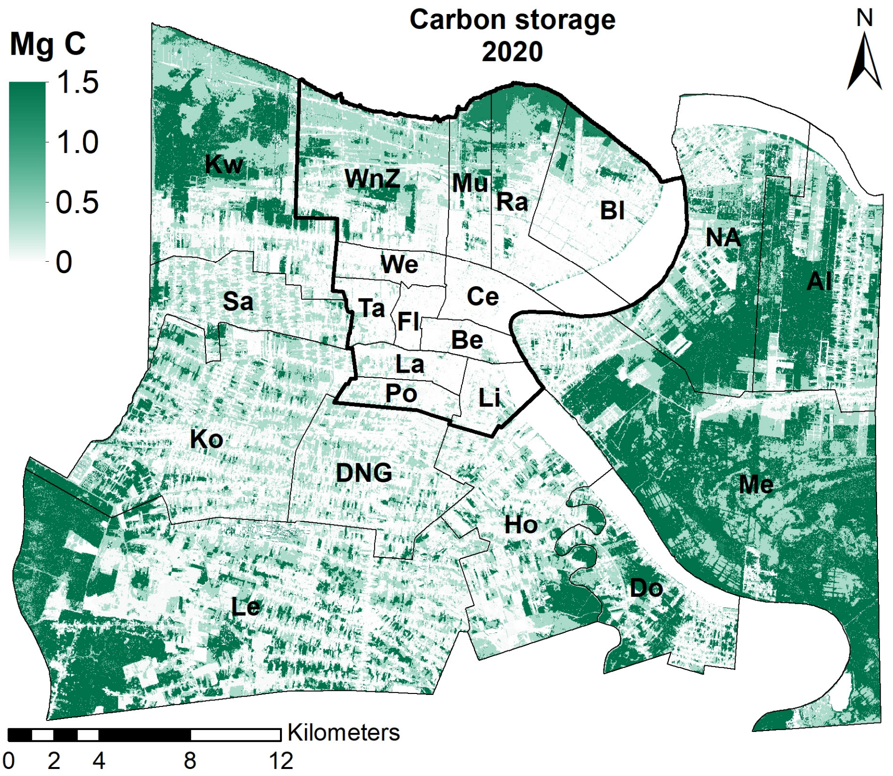

Figure 9: Current supply of carbon storage in Greater Paramaribo quantified and mapped as aboveground carbon storage (in Mg C per pixel and thus per 100m².).

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

Notably, carbon storage on the western side of the river is generally lower, with areas of high supply more fragmented and sparsely distributed than on the eastern side (Figure 9); a result in line with patterns of supply for both flood risk mitigation and local climate regulation. Figure 9 also reveals a general increase in carbon storage with increasing distance from the central ressorts of Paramaribo (Centrum (Ce), Flora (Fl) and Beekhuizen (Be)). These ressorts have the lowest mean carbon storage values in Greater Paramaribo, with Centrum and Flora both having mean storage values of 0.01 Mg C per 100m², and Beekhuizen having the slightly higher mean of 0.03 Mg C per 100m². At the other end of the spectrum, the highest mean carbon storage in Greater Paramaribo occurs in the ressort of Meerzorg (Me) (0.94 Mg C per 100m²), a ressort with extensive tree cover which also has the highest supply of heat mitigation. Within Paramaribo alone, high mean storage values are found in the northern coastal ressorts, with Munder (Mu) having the highest supply of 0.40 Mg C per 100m² among these.

3.1.5 Hotspots and coldspots of regulating ES supply in 2020

Hotspots and coldspots of regulating ES supply are spatially visualised in Figure 10. As discussed in section 2.3.6, this analysis excluded coastal protection and focused on highlighting areas consistently providing relatively high or low supply of the remaining three considered regulating ES; flood risk mitigation, local climate regulation and carbon storage. Figure 10 reveals a clear coldspot of supply concentrated in central Paramaribo as well as a complete lack of hotspots within central ressorts such as Centrum (Ce) and Flora (Fl). The only areas with some small hotspots of supply within Paramaribo are the northern coastal ressorts, where large patches of tree and mangrove cover are still present in the more rural areas beyond the main city boundary. The coldspots of supply in central ressorts of Paramaribo extend in a somewhat linear fashion out beyond the administrative boundary and into the surrounding Greater Paramaribo region, particularly towards the west and south of the city, though to a lesser extent across to the eastern side of the river into the ressort of Meerzorg (Me) (Figure 10). This linear pattern, reflective of the urban sprawl pattern evident on the underpinning land cover map (Figure 10), causes fragmentation of otherwise moderate areas of supply. Hotspots of supply are generally found in the more rural outskirts of Greater Paramaribo, particularly in the north-western ressort of Kwatta (Kw), the south-western ressort of Lelydorp (Le) and ressorts to the east of Paramaribo and the Suriname River. Overall, Figure 10 highlights the consistency of spatial patterns observed and discussed for individual regulating ES, and suggests a general synergy between them.

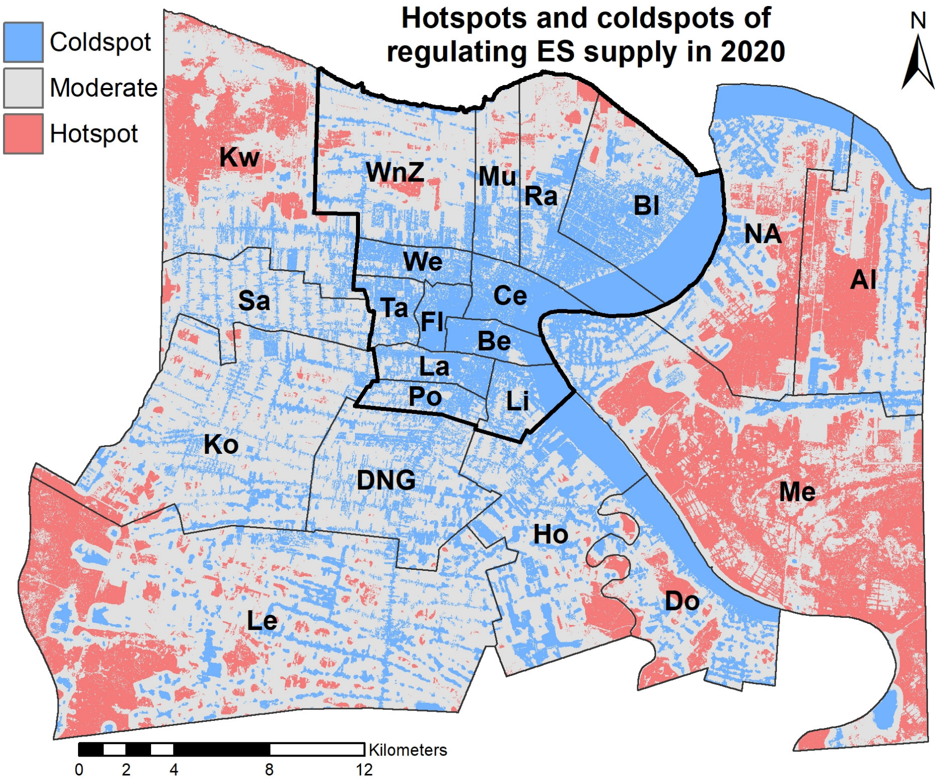

Figure 10: Hotspots and coldspots of regulating ES supply (flood risk mitigation, local climate regulation and carbon storage). Note: Coldspots are defined as areas where supply values for all 3 ES are within the lower 33% quantile of their distribution and hotspots as areas where supply values are within the upper 33% quantile of their distribution, as explained in section 2.3.6.

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

3.2 Future land cover scenarios for 2035

The following sub-sections present Dyna-CLUE modelling outputs produced in the addressing of secondary objective 2 which sought to model future land cover in Greater Paramaribo for the year 2035 under alternative scenarios.

3.2.1 Dyna-CLUE intermediate steps and sensitivities

Results presented in this section were essentially an intermediate step in the Dyna-CLUE modelling process. However, they are still presented here as they offer insight into the subsequent future land cover scenario maps presented in upcoming sections, particularly with regards to the spatial allocation of land cover which was largely based upon the beta coefficients determined within the constructed logistic regression models (Table 13) (also see section 2.4.4).

Table 13: Summary of multiple logistic regression model results for each of the land cover classes considered within future land cover scenario models, with beta coefficient, significance and AUC indicated. (Sample size = balanced 10% of pixels for all models).

	Beta coefficient				
	Trees	**Mangrove**	**Mixed low vegetation**	**Grass**	**Urban**
Intercept	-3.02E+00 ***	-1.73E+00 ***	-1.10E+00 ***	1.95E-01 ***	2.62E+00 ***
Distance from coast	-7.89E-05 ***	-2.21E-04 ***	1.38E-05 ***	1.05E-04 ***	2.14E-05 ***
Distance from junction	1.38E-04 ***	3.19E-04 ***	6.33E-05 ***	-1.81E-04 ***	-6.78E-05 ***
Distance from primary road	-1.27E-04 ***	1.69E-04 ***	-4.94E-05 ***	7.39E-05 ***	4.86E-06 **
Distance from secondary road	-3.28E-05 ***	1.26E-04 ***	6.74E-05 ***	4.98E-05 ***	-6.42E-05 ***
Elevation	2.17E-01 ***	1.61E-01 ***	-8.07E-02 ***	-5.17E-02 ***	-2.79E-02 ***
Distance from Centrum	*Removed from all regression models due to high VIF values indicating collinearity*				
Distance from bridge	1.20E-04 ***	*High VIF*	7.51E-05 ***	6.59E-06 ***	-1.28E-04 ***
Swamp / marsh	-2.71E-01 ***	4.08E-01 ***	5.67E-01 ***	-4.39E-01 ***	2.52E-02 *
Distance from poor SES	-5.26E-05 ***	-1.53E-04 ***	-3.97E-05 ***	4.34E-05 ***	-4.27E-05 ***
Distance from rich SES	-1.37E-04 ***	-9.42E-05 ***	8.74E-05 ***	8.26E-05 ***	-9.87E-05 ***
Distance from middle SES	3.78E-04 ***	3.27E-05 ***	-1.44E-04 ***	-5.24E-04 ***	-2.45E-04 ***
Distance from middle to low SES	*Removed from all regression models except urban due to high VIF*				-1.15E-03 ***
Geology	6.95E-02 ***	-2.74E-02 ***	7.42E-03 ***	1.63E-02 ***	-1.10E-02 ***
Distance from classified water	5.22E-04 ***	-2.06E-03 ***	1.07E-04 ***	-3.07E-05 ***	-1.57E-04 ***
Area under the curve (AUC)	**0.86**	**0.92**	**0.64**	**0.71**	**0.86**

Note: * indicate significance with *** = <0.001, ** = 0.001, and * = 0.05

The explanatory variable "distance from Centrum" was removed from all regression models due to a high VIF value indicative of collinearity (Table 13). The regression model for urban land cover revealed the remaining 13 explanatory variables to be statistically significant. For trees, mixed low vegetation and grass, 12 of the 14 considered variables were found to be statistically significant after the additional removal of "distance from middle to low socioeconomic status (SES)" from each of the associated regression models, again to limit collinearity revealed by high VIF values. Finally, the mangrove model found 11 of the 14 variables statistically significant, with "distance from bridge" and "distance from middle to low SES" removed to limit collinearity once again indicated by high VIF values. Table 13 indicates how the trees, mangrove and urban models had high AUC values (0.86, 0.92 and 0.86 respectively). They were therefore considered to offer good discrimination between the presence and absence of their respective land covers. However, grass (0.71), and to a larger extent, mixed low vegetation (0.64), had relatively low AUC values and were therefore considered to offer more moderate discrimination between the presence and absence of these land covers. The beta coefficient values outlined in Table 13 were considered as suitability indicators for the presence or absence of a particular land cover, and as explained in section 2.4.4, input into Dyna-CLUE for the modelling of future land cover. The probability of each of the five land covers occurring at a particular location determined by this intermediate regression analysis step was also spatially visualised, maps of which are provided in Appendix 6.

With regards to the partial analysis of Dyna-CLUE sensitivities, repeated model runs (10 for each scenario) revealed the lowest deviation settings to achieve successful model completion for all three scenarios were 1.75% (average deviation) and 3% (maximum deviation). These settings should determine how much deviation there can be between land cover demand and actual model allocation. However, the actual deviation between demand and model allocation appeared well within these limits, with the majority of deviation values below 1% and a maximum across all scenarios of 1.36%. It therefore remains unclear why lower deviation values specified within Dyna-CLUE settings resulted in model failures. Nevertheless, the aforementioned low level of deviation between the specified land cover demand and the final Dyna-CLUE land cover allocation was deemed negligible and therefore outputs considered suitable for the subsequent future ES analyses. With regards to the Dyna-CLUE elasticity setting and its impact on final model outputs, values for tree and mangrove of lower than 0.6 and 0.7 respectively were found to cause considerable reallocation of small patches of these land covers into large conglomerated patches. This was deemed to be an oversimplification given the removal and growth efforts required by these land covers. Therefore, 0.6 and 0.7 were used as a basis for the business as usual scenario, and were increased by 0.1 and 0.2 for the protection and greening scenarios respectively. This increase was to reflect higher resistance to change in line with the defined scenario conditions, as highlighted in Table 12.

3.2.2 Scenario 1: Business as usual

Figure 11 shows the modelled land cover for the year 2035 under a business as usual scenario, alongside a map highlighting areas which have experienced land cover change since 2020 as well as the final land cover Dyna-CLUE allocated to these areas. Important to note is that with the exception of urban cover, which increases by 27.5%, the areas where land cover changes occur in Figure 11 are not changes in response to their respective demand increasing. They are instead areas where green space is predicted to change from one class to another, the final cover of which is mapped.

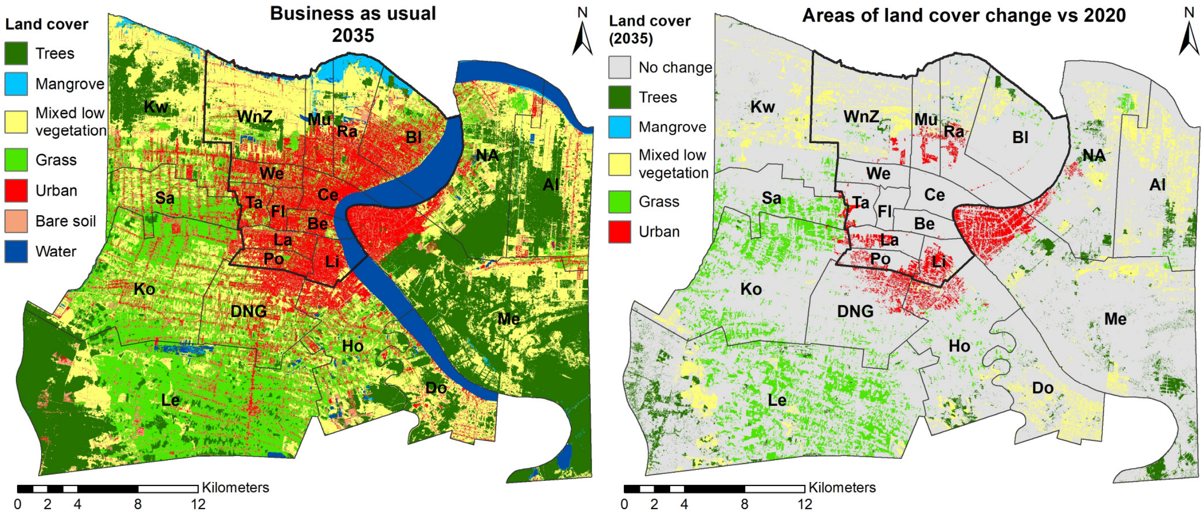

Figure 11: ***Left:*** **Land cover as allocated by Dyna-CLUE for the year 2035 under a business as usual scenario.** ***Right:*** **Land cover change map indicating areas which undergo change from 2020 and the final land cover allocated to these areas in 2035 under business as usual.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

As highlighted by Figure 11, the Dyna-CLUE model predicts urban expansion to primarily occur to the south of Paramaribo, as well as to the east of the city on the opposite side of the Suriname River. The area of Greater Paramaribo to the west of the city experiences the lowest occurrence of urban encroachment, with only a few small patches of expansion evident (Figure 11). Within Paramaribo, some expansion and densification of urban areas is predicted along the southern boundary of the city, and some green areas in the northern ressorts are predicted to make way for patches of new urban land. The majority of new urban land (93%) is a result of conversion from either grass to urban (68%) or mixed low vegetation to urban (25%). Therefore, only a relatively small amount of tree and mangrove cover are directly converted into urban, though these land covers still experience losses in area overall as specified by their initial demand input into Dyna-CLUE (see Table 12).

3.2.3 Scenario 2: Protection policy

Figure 12 shows the modelled land cover for the year 2035 under a protection policy scenario in which key green spaces (trees and mangrove) were specifically protected within Paramaribo and a 2km wide greenbelt, and in which a target for zero net loss of trees and mangrove for the entire of Greater Paramaribo was enforced. As with the business as usual scenario presented in the previous sub-section, the only land cover increasing in area under this scenario is urban, which was modelled to increase by 27.5% regardless of scenario. Therefore, areas of green space change indicated are again not in response to increasing demand, but are in response to predicted change from one green class to another.

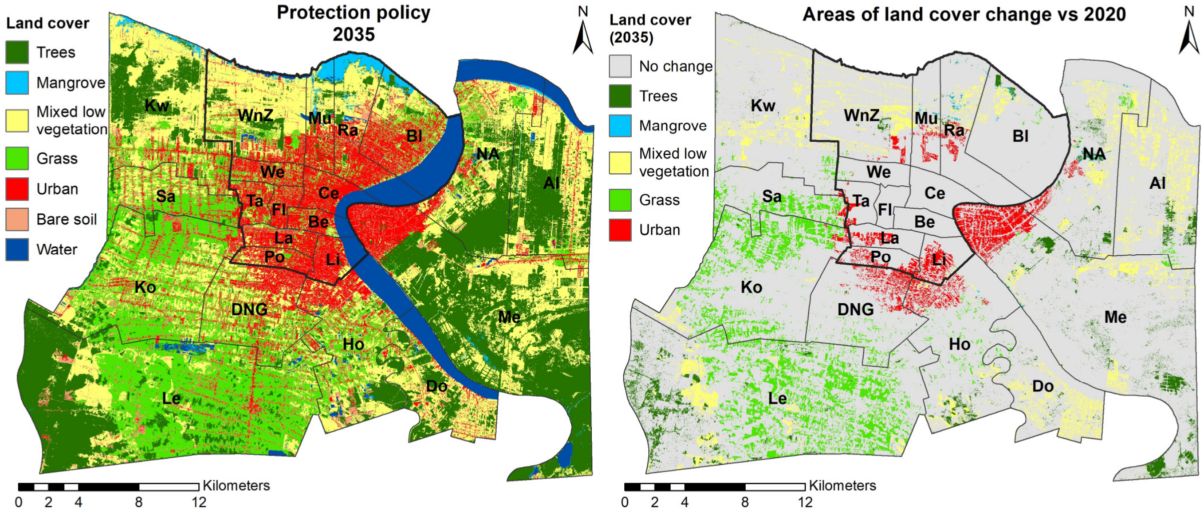

Figure 12: ***Left:*** **Land cover as allocated by Dyna-CLUE for the year 2035 under a green space protection policy scenario.** ***Right:*** **Land cover change map indicating areas which undergo change from 2020 and the final land cover allocated to these areas in 2035 under the protection policy scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

Urban expansion patterns are highly similar when comparing Figure 11 and Figure 12. For the protection policy scenario urban is again predicted to primarily expand to the south of the city, with some densification, and consequentially a loss of green space in ressorts along the southern boundary of Paramaribo (Figure 11). Significant expansion also occurs on the eastern side of the Suriname River, as was the case with the business as usual scenario.

However, although perhaps not immediately apparent, there are subtle differences between the maps presented in Figure 11 and Figure 12. For instance, slightly less urban expansion occurs in the northern ressorts of Paramaribo under the protection scenario, since forested areas are specifically protected in these areas. This protected status also results in patches of trees and mangroves remaining more stable throughout the entire study area. Furthermore, under protection policy, an even higher proportion of the newly predicted urban land for 2035 (97%) was converted from areas of grass (70%) and mixed low vegetation (27%), with protection therefore resulting in a smaller direct loss of trees and mangrove in response to the increase in urban demand than under business as usual.

3.2.4 Scenario 3: Greening of Paramaribo

The predicted spatial distribution of land cover for year 2035 under a greening scenario, in which a there is a targeted 20% increase in tree and mangrove cover, is indicated in Figure 13. As with the previous two scenarios, a change map depicting areas where land cover change occurs (and to what cover it changes to) between 2020 and 2035 is also provided. Again, urban change indicated in this map is in response to the consistently modelled 27.5% increase in area. However, unlike the previous two scenarios, tree and mangrove cover were also increased by 20% under this scenario, so the change map also reflects these increases.

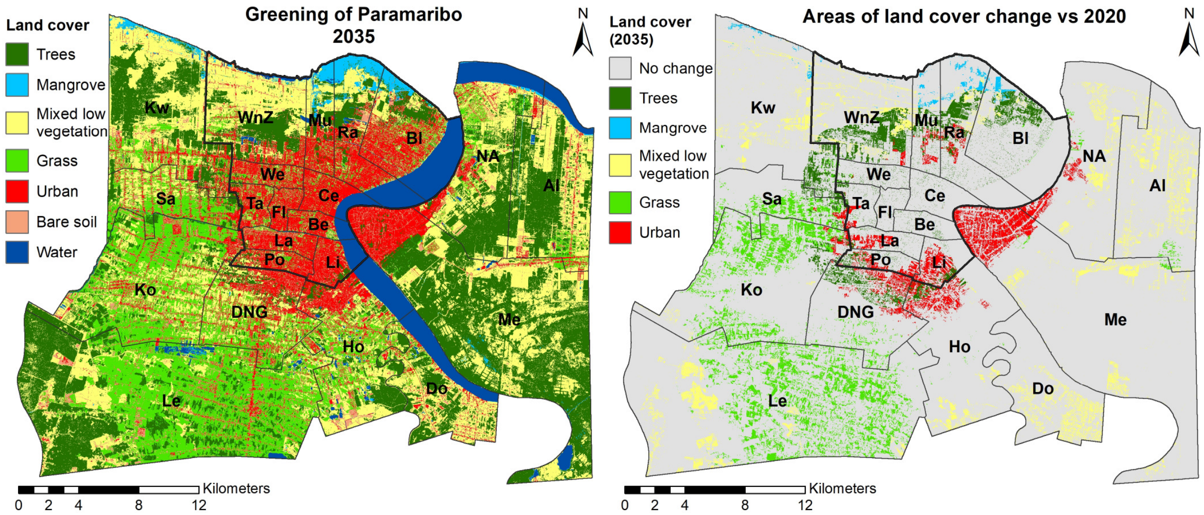

Figure 13: ***Left:*** **Land cover as allocated by Dyna-CLUE for the year 2035 under a greening of Paramaribo scenario.** ***Right:*** **Land cover change map indicating areas which undergo change from 2020 and the final land cover allocated to these areas in 2035 under the greening of Paramaribo scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

A clear greening of the city and its surroundings can be seen in Figure 13, with increased mangrove, and in particular increased tree cover, present both within and surrounding Paramaribo. The largest patches of new tree cover are sited within the northern ressorts of Paramaribo. However, large patches are also predicted in areas surrounding the administrative boundary, though the increase in tree cover becomes a little more fragmented to the west and south of the city in comparison to the concentrated gains in the north (Figure 13). Mangrove increase predominately occurs within the Paramaribo boundary and essentially results in an expansion or widening of the already abundant mangrove cover in the northern ressorts. Further smaller increases in mangrove cover are predicted elsewhere along the northern coast.

Urban expansion follows similar trends to those predicted for the previous two scenarios, with the majority occurring to the south and to the east of Paramaribo. However, comparison between Figure 11, Figure 12 and Figure 13 reveal that for the greening of Paramaribo scenario, urban area is predicted to extend slightly further in these directions. All new urban land in this greening of Paramaribo scenario was converted from grass (66%) and mixed low vegetation (34%), meaning no tree or mangrove cover was lost as a result of urban expansion.

3.3 Future ES supply

The following sub-sections present the potential future supply of the four considered regulating ES under the three alternative land cover scenarios presented in the previous section. These analyses were carried out to address the third and final of the secondary objectives focused on within this study. Key values indicating mean changes in ES supply per scenario for the areas of Greater Paramaribo and Paramaribo are later summarised in Table 16 to allow for a more synthesised comparison.

3.3.1 Coastal protection in 2035

Under business as usual, 10 of the 13 coastal ressorts experience a decrease in the mean supply of coastal protection with the mean habitat role for the entire coastline of Greater Paramaribo decreasing by 0.10. A more pronounced mean supply decrease of 0.15 occurs along coastline specific to Paramaribo. Figure 14 offers spatial insight into this loss, revealing large decreases of supply along the eastern (riverbank) side of the city, with a particularly large loss (-0.59) in the mean supply for the central ressort of Beekhuizen (Be) for example. More moderate losses of supply also occur, such as along the northern coast of Paramaribo. Only a few small segments undergo slight increases in coastal protection derived from green space under business as usual (Figure 14).

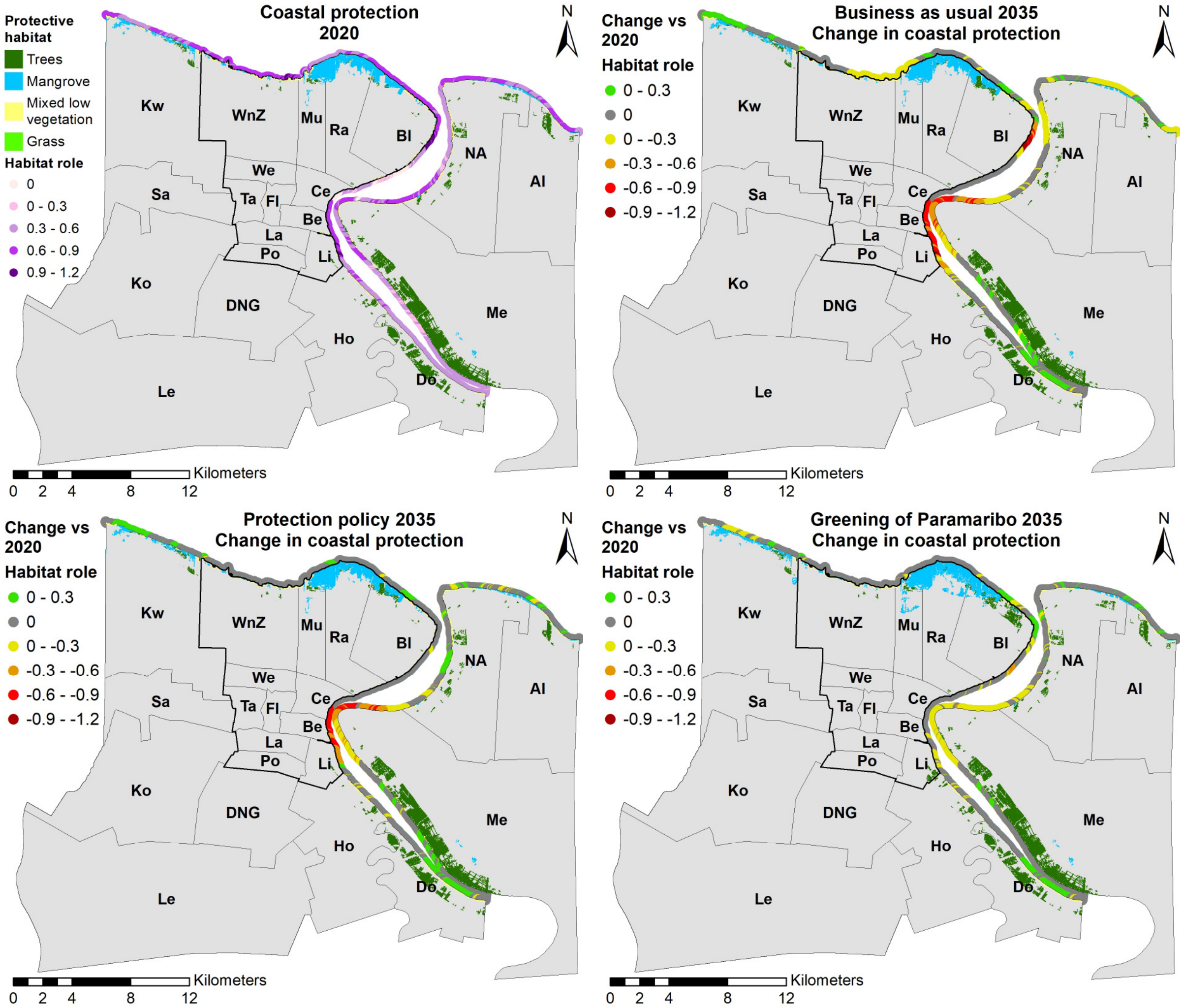

Figure 14: ***Upper-left:*** **Current coastal protection in Greater Paramaribo.** ***Upper-right:*** **Change in coastal protection by 2035 under a business as usual scenario.** ***Lower-left:*** **Change in coastal protection by 2035 under a protection policy scenario.** ***Lower-right:*** **Change in coastal protection by 2035 under a greening of Paramaribo scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen.

The introduction of a protection policy somewhat limits losses of coastal protection which occur under business as usual, though overall losses of supply still occur when the mean habitat roles for Greater Paramaribo (-0.05) and Paramaribo (-0.08) are considered. However, under this scenario only 4 of the 13 coastal ressorts experience losses in mean supply of coastal protection. Figure 14 highlights the locale of this change, with most of the decrease again occurring along the eastern coastline of Paramaribo's central ressorts. Meanwhile, the role of green space in coastal protection either remains stable or slightly increases in other coastal areas under a protection policy.

Finally, the greening of Paramaribo scenario prevents overall losses in the ES supply of coastal protection when considering the entire coastline of Greater Paramaribo as well as the coastline specific to Paramaribo, with no change in mean supply for these coastlines predicted. Figure 14 reflects this conservation of supply, with habitat role along large stretches of coastline remaining unchanged from levels in 2020. Areas that do change only do so moderately, with the largest decrease in mean supply only amounting to a loss of 0.03 in Livorno (Li), and the largest increase only +0.02 in Domburg (Do).

3.3.2 Flood risk mitigation in 2035

Figure 15 reveals considerable differences between the current supply of flood risk mitigation and the potential future supply under the three considered scenarios, with both increases and decreases in runoff retention during a 10 year storm spread throughout the study area.

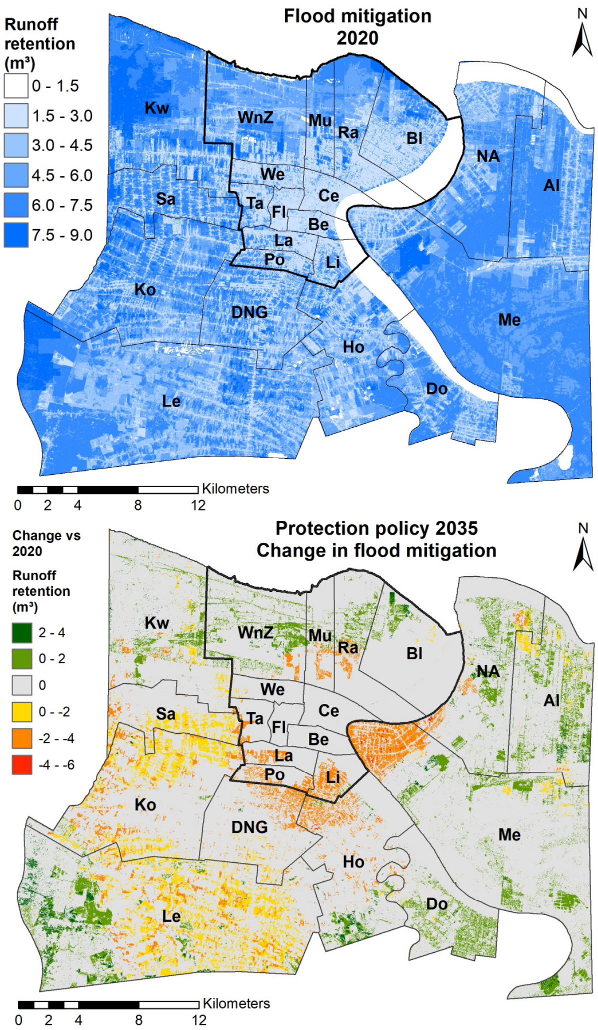

Figure 15: ***Upper-left:*** **Current flood risk mitigation in Greater Paramaribo.** ***Upper-right:*** **Change in flood mitigation by 2035 under a business as usual scenario.** ***Lower-left:*** **Change in flood mitigation by 2035 under a protection policy scenario.** ***Lower-right:*** **Change in flood mitigation by 2035 under a greening of Paramaribo scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

Under business as usual, 16 of the 22 ressorts are estimated to have lower mean runoff retention by 2035, resulting in an overall estimated loss of runoff retained in Greater Paramaribo during a 10-year storm (see Table 14). This loss is particularly experienced within the Paramaribo boundary, where a loss of 0.11m^3 of mean runoff retention per 100m^2 occurs. As evident in Figure 15, notable losses of runoff retention are concentrated in the newly urbanised areas to the south and west of the city, with the ressort of Livorno (Li) most severely affected (-0.81m^3 per 100m^2).

Table 14: Runoff retention in Greater Paramaribo and Paramaribo during a 10 year rainfall event (132.7mm) under the different scenarios considered.

Year:	2020		2035					
Scenario:	Current supply		Business as usual		Protection policy		Greening of Paramaribo	
Region	Runoff retention (m^3)	Runoff retention (as % of rainfall)	Runoff retention (m^3)	Runoff retention (as % of rainfall)	Runoff retention (m^3)	Runoff retention (as % of rainfall)	Runoff retention (m^3)	Runoff retention (as % of rainfall)
Greater Paramaribo	4.37×10^7	38.1	4.30×10^7	37.5	4.31×10^7	37.6	4.36×10^7	38.1
Paramaribo	0.68×10^7	29.5	0.66×10^7	28.7	0.67×10^7	29.0	0.70×10^7	30.5

The protection policy scenario somewhat reduces the loss of runoff retention predicted under business as usual, though a large loss is still estimated for the entire study area (Table 14). As with business as usual, this loss is particularly concentrated to the south and east of Paramaribo where most urban expansion takes place (Figure 15). Of the ressorts in these areas, Livorno (Li) is again worst affected, losing 0.76m^3 of runoff retention per 100m^2, a loss only slightly lower than that predicted for the area under business as usual. On the other hand, some of the more rural ressorts such as Domburg and Alkmaar can be seen to experience gains in flood mitigation supply; a pattern slightly more pronounced under protection policy than under business as usual.

The greening of Paramaribo scenario almost entirely conserves current supply when the mean runoff retention for the entire study area is considered, as a decrease of only 0.01m^3 per 100m^2 occurs. Notably however, and unlike the previous two scenarios, an increase in the volume of runoff retained occurs within Paramaribo (see Figure 15 and Table 14), resulting in the mean supply increasing from 3.92m^3 to 4.04m^3 per 100m^2 for the city. A total of 10 of the 22 ressorts still experience a loss, though these are generally lower than under the business as usual or protection policy scenarios. Livorno (Li) once again experiences the largest decrease in mean supply (-0.66m^3 per 100m^2), though this is not as severe as the losses predicted for this southern ressort under the previously discussed scenarios. Figure 15 also indicates how several ressorts, particularly within Paramaribo, experience considerable increases in flood risk mitigation supply under the greening of Paramaribo scenario. Northern ressorts in particular experience gains, with Weg naar Zee (WnZ) most positively affected (+0.39m^3 runoff retained per 100m^2).

3.3.3 Local climate regulation in 2035

Figure 16 outlines the changes relative to current supply in local climate regulation, quantified via the heat mitigation (HM) index, under each of the considered scenarios. Under all scenarios, notable decreases occur in areas which have undergone urban expansion, specifically to the south and east of Paramaribo.

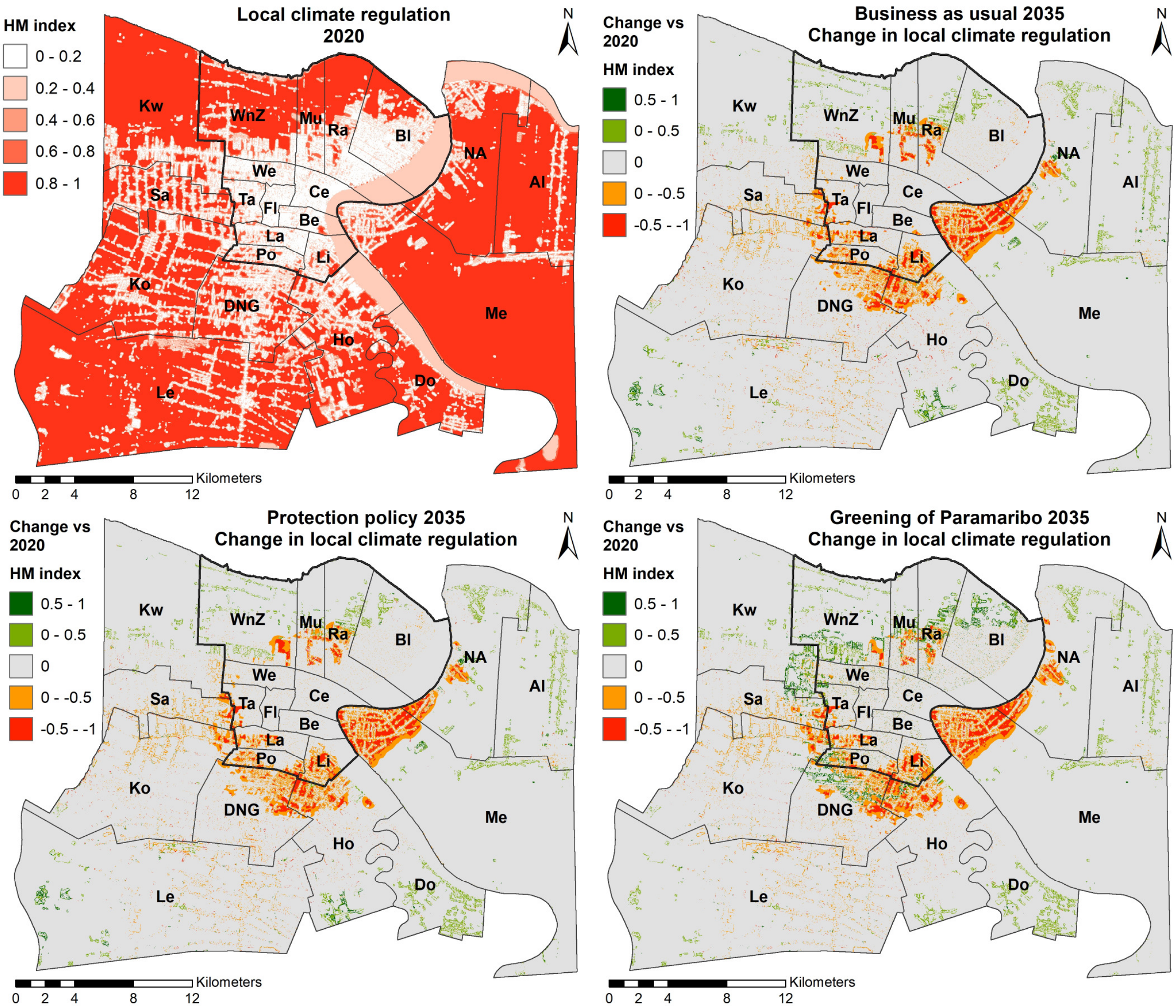

Figure 16: ***Upper-left:*** **Current local climate regulation in Greater Paramaribo** ***Upper-right:*** **Change in local climate regulation by 2035 under business as usual.** ***Lower-left:*** **Change in local climate regulation by 2035 under a protection policy scenario.** ***Lower-right:*** **Change in local climate regulation by 2035 under a Greening of Paramaribo scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

Under business as usual the mean HM for the entire study area of Greater Paramaribo only decreases by 0.01, and for Paramaribo alone by 0.02, in comparison to current supply. This is predicted to result in minor mean night-time air temperature changes for Greater Paramaribo (0.03°C increase) and Paramaribo (0.06°C increase). However, when considering more localised effects on specific ressorts, differences become slightly more apparent. 15 of the 22 ressorts are predicted to have lower mean HM values, with the largest decreases again occurring along the southern boundary of the city. Livorno (-0.12) and Pontbuiten (-0.09) are estimated to experience the largest decreases in mean HM supply. Mean night-time air temperature in these ressorts is consequentially predicted to be 0.28°C and 0.21°C warmer by 2035 under business as usual. Elsewhere, several areas remain relatively stable under business as usual. For example, the central ressorts of Centrum and Flora are predicted to remain the same with regards to HM supply, with estimated air temperatures therefore remaining stable.

Under an introduced green space protection policy, mean HM for both Greater Paramaribo and Paramaribo are predicted to change in the same manner as they did in the business as usual scenario; decreasing slightly by 0.01 and 0.02 respectively. Mean air temperature is also predicted to barely change under this scenario, with an estimated increase of 0.02°C and 0.05°C for Greater Paramaribo and Paramaribo respectively. Of the 22 ressorts, 13 are expected to show slight decreases in mean HM, the largest being a loss of 0.11 in Livorno. Air temperature in this ressort is predicted to increase by 0.27°C, only 0.01°C lower than the predicted increase for the same area under business as usual. No considerable gains in HM or lower temperatures are predicted under a protection policy scenario, and like business as usual, several ressorts, including those central to Paramaribo, show no significant changes.

The Greening of Paramaribo scenario shows there to be both areas of increase and decrease in the resulting future ES supply prediction, as depicted on Figure 16. Again, these changes generally occur around Paramaribo's current urban-rural fringe. Under this scenario, only slight changes are once again apparent when considering mean HM in the entire study area of Greater Paramaribo as a decrease of 0.01 is expected. However, this scenario slightly differs from the previous two in that it predicts mean HM to show no change within Paramaribo. These changes equate to an increase of 0.01°C for mean air temperature across the whole of Greater Paramaribo, and no change in air temperature for Paramaribo alone. Change is also more apparent on a ressort level, since three fewer ressorts experience a decrease in mean HM than under protection policy, and five fewer than under business as usual. The largest decrease occurs in the commonly referred to Livorno (Li), which has 0.09 lower mean HM under the greening scenario than at present. With regards to air temperature, the ressort of Livorno undergoes the largest rise, with an increase in mean air temperature of 0.23°C, slightly lower than the rise predicted for previously discussed scenarios. Some ressorts to the north-west of the city do experience a slight cooling under the greening scenario in comparison to current air temperatures, with Weg naar Zee (WnZ) and Welgelegen (We) experiencing the slight decreases of 0.04°C and 0.05°C respectively.

3.3.4 Carbon storage in 2035

Figure 17 allows for comparison between current carbon stored in the aboveground vegetation of Paramaribo and change in the potential future carbon storage under the three scenarios considered. There are clear differences in the potential future supply of this ES between current supply and each of the scenarios.

Firstly, under a business as usual scenario, notable losses of carbon storage are evident by 2035 in comparison to 2020 (Figure 17). A loss of 0.12 x 10^6 Mg of carbon in the entire study area occurs, with 0.01 x 10^6 Mg C of this loss occurring within the Paramaribo administrative boundary (Table 15). On a mean supply per ressort basis, 13 of the 22 ressorts experience a loss in mean carbon storage, with Koewarasan (Ko) most affected (-0.15 Mg C per 100m^2) by business as usual. Interestingly, this is not a region in which significant urban expansion was predicted, though there was a notable loss of tree cover (see Figure 11). Areas where gains in supply are predicted under this scenario are generally where patchy areas of forest are predicted to become denser, such as in the south-western ressort of Lelydorp (Le) (Figure 17).

Table 15: Total carbon stored in aboveground vegetation in Greater Paramaribo and Paramaribo under the different scenarios considered.

	Total aboveground carbon storage (Mg C)			
Year:	**2020**	**2035**		
Scenario:	**Current supply**	**Business as usual**	**Protection policy**	**Greening of Paramaribo**
Greater Paramaribo	4.37 x 10^6	4.25 x 10^6	4.35 x 10^6	4.63 x 10^6
Paramaribo	0.36 x 10^6	0.35 x 10^6	0.39 x 10^6	0.60 x 10^6

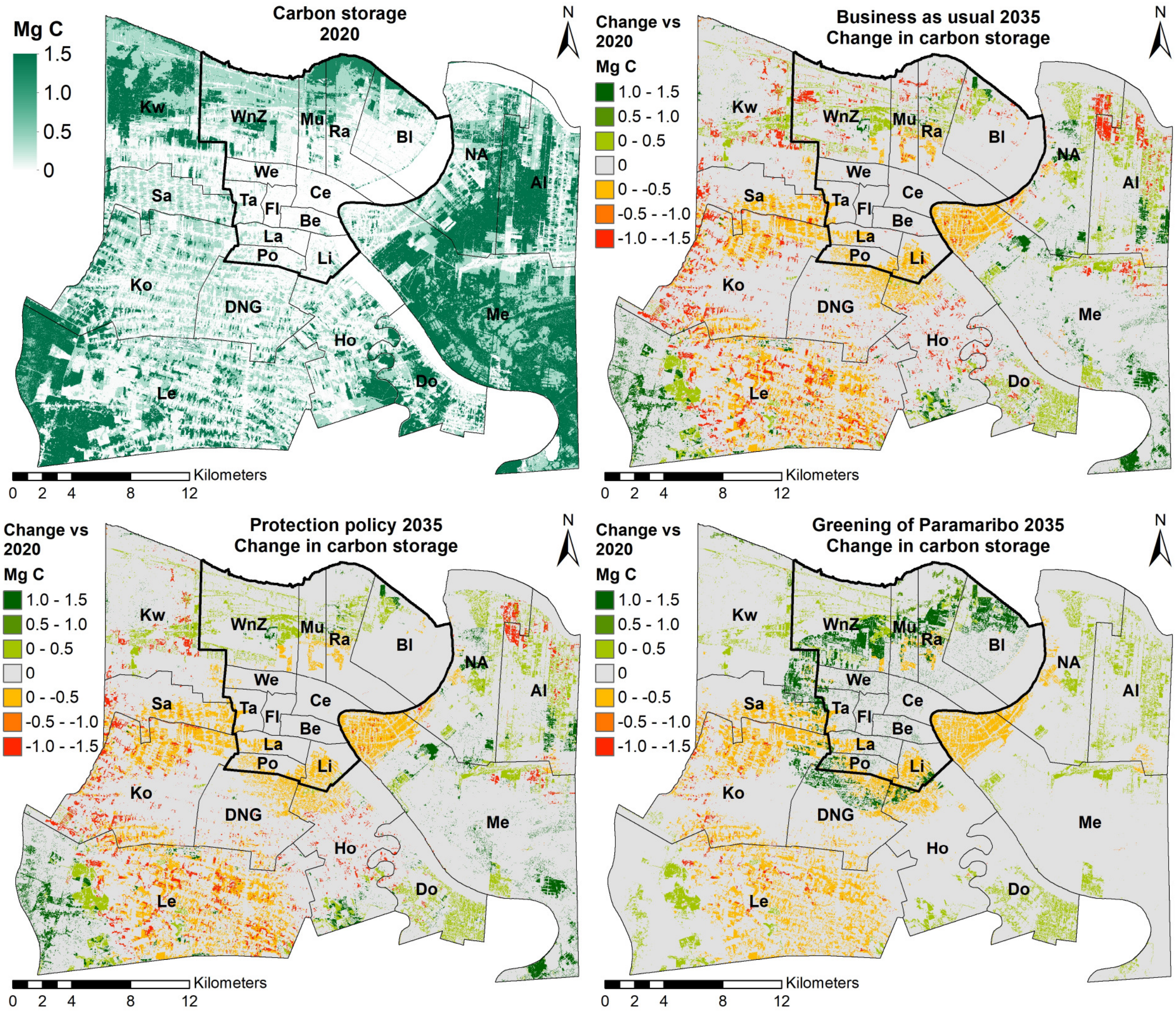

Figure 17: ***Upper-left:*** **Current carbon storage in Greater Paramaribo.** ***Upper-right:*** **Change in carbon storage by 2035 under business as usual.** ***Lower-left:*** **Change in carbon storage by 2035 under a protection policy scenario.** ***Lower-right:*** **Change in carbon storage by 2035 under a greening of Paramaribo scenario.**

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

Under the protection policy scenario, losses of aboveground carbon storage are generally lower and less common than in the business as usual scenario, particularly within Paramaribo (Figure 17). However, in Greater Paramaribo an overall loss, albeit smaller than under business as usual (see Table 15), still occurs (-0.02 x 10^6 Mg C), reducing the mean storage value compared to current levels by 0.01 Mg per 100m^2. Interestingly however, and as suggested by gains evident in Figure 17, carbon storage within Paramaribo actually increases by 0.03 x 10^6 Mg under the protection scenario, resulting in a mean storage increase of 0.02 Mg C per 100m^2. On a ressort level, conservation of supply in comparison to business as usual is also evident as only 9 of the 22 ressorts experience a loss in mean carbon storage, and some experience overall gains with northern ressorts in Paramaribo such as Weg naar Zee (WnZ) benefiting the most (+0.05 Mg C per 100m^2).

The Greening of Paramaribo scenario results in a clear increase in carbon storage in and surrounding Paramario (Figure 17). Large gains are evident in the introduced green belt, the location where the increase in demand for trees was targeted. Gains can also be seen throughout central Paramaribo in the open spaces assumed and delegated as available for greening in Dyna-CLUE settings (see Table 12). A predicted increase of 0.26 x 10^6 Mg of carbon storage in Greater Paramaribo occurs under this scenario (Table 15). The mean carbon storage value therefore increases from 0.51 Mg C per 100m^2 to in 2020 to 0.54 Mg C per 100m^2 in 2035. This increase is most pronounced within Paramaribo, which gains 0.24 x 10^6 Mg C, raising the mean storage from the current 0.21 Mg C per 100m^2 to 0.35 Mg C per 100m^2. On a ressort level, 18 of the 22 ressorts within Greater Paramaribo, and all 12 of the ressorts of Paramaribo, experience an increase in mean carbon storage under greening. The largest gains of supply again occur in the northern coastal ressorts of Paramaribo, with Weg naar Zee (WnZ) again profiting most (+0.22 Mg C per 100m^2). Central ressorts also see slight gains, such as an increase of 0.04 Mg C per 100m^2 in Flora (Fl).

3.3.5 Hotspots and coldspots of regulating ES supply in 2035

Areas of consistent hotspots and coldspots of supply for the three spatially analysed ES (flood risk mitigation, local climate regulation and carbon storage) are indicated in Figure 18 according to the three considered scenarios. Areas of additional hotspots and coldspots in comparison to their current counterparts (see section 3.1.5) are also highlighted.

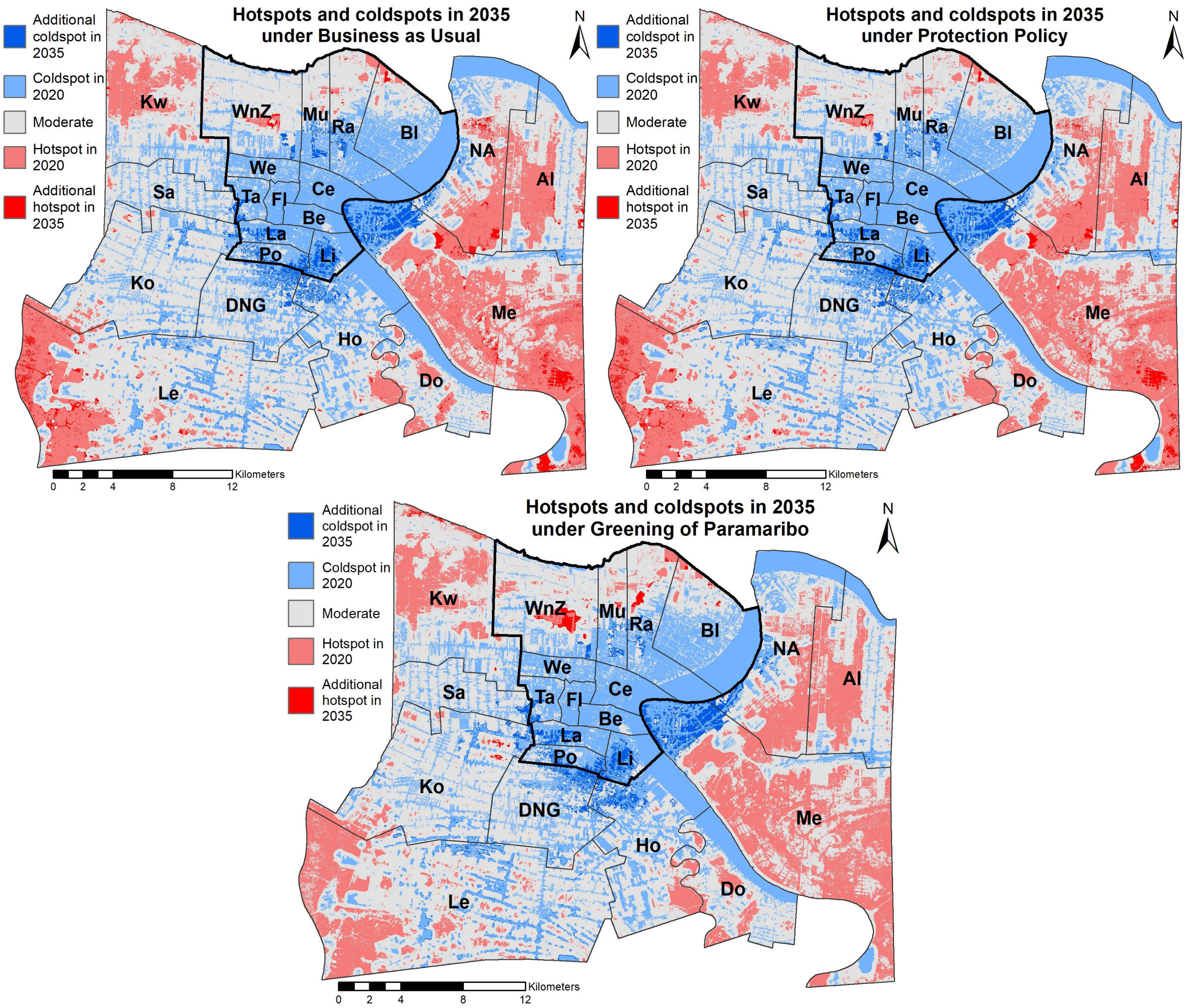

Figure 18: Hotspots and coldspots of regulating ES supply under business as usual (upper left), protection policy (upper right) and greening of Paramaribo (lower). Areas of additional hotspots and coldspots per scenario are also indicated.
Note: Hotspots and coldspots are defined based upon a 33% quantile approach as explained in section 2.3.6.
Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

This hotspot / coldspot analysis highlights most of the general trends discussed for each of the three ES in the previous sub-sections, with a large, clear coldspot of supply concentrated in central Paramaribo, and hotspots found more towards the rural outskirts of the study area, both evident regardless of scenario (Figure 18). This analysis therefore reveals that large areas of Greater Paramaribo remain unchanged with regards to hotspots and coldspots under all of the considered scenarios. A clear expansion of coldspots of supply is however evident, which again occurs in all three scenarios, to the south and east of the city in areas where urban expansion is predicted most. However, there are some slight differences in hotspots and coldspots of supply in 2035 between each of the considered scenarios. Business as usual for instance shows a slightly larger expansion of coldspots and slightly more hotspots are lost in comparison to other scenarios. Greening of Paramaribo on the other hand results in some additional new hotspots within and around Paramaribo, such as in the northern ressorts of Paramaribo or the ressort of Koewarasan (Ko) just beyond the western boundary of the city (Figure 18). Overall however, the influence of scenarios on hotspots and coldspots of ES supply is considered to be largely limited, though the analysis provides evidence that urban expansion will result in the expansion of coldspots of regulating ES supply, and that greening has the potential to increase hotspots of supply within Paramaribo.

3.3.6 Scenario comparisons and ES synergies and trade-offs

Changes in mean ES supply per region under the three scenarios considered are summarised in Table 16. The business as usual scenario results in loss of ES supply for all four scenarios, both for the entire study area of Greater Paramaribo as well as when only within the administrative boundary of Paramaribo is considered. For all ES with the exception of carbon storage, the loss of ES supply is predicted to be more pronounced within Paramaribo than for the entire Greater Paramaribo area.

Table 16: Comparison of changes in mean supply of the considered regulating ES (in quantified units in relation to their current supply) under the three future land cover scenarios considered.

Scenario	Region	**Change in mean coastal protection** (habitat role)	**Change in mean flood mitigation** (Runoff retention m^3 per $100m^2$)	**Change in mean local climate regulation** (HM index)	**Change in mean carbon storage** (Mg C per $100m^2$)
Business as usual	Greater Paramaribo	-0.1	-0.08	-0.01	-0.02
	Paramaribo	-0.15	-0.11	-0.02	-0.01
Protection policy	Greater Paramaribo	-0.05	-0.07	-0.01	-0.01
	Paramaribo	-0.08	-0.07	-0.02	+0.02
Greening of Paramaribo	Greater Paramaribo	0	-0.01	-0.01	+0.03
	Paramaribo	0	+0.12	0	+0.14

The introduction of a green space protection policy also generally results in overall losses in mean supply per region with the exception of carbon storage, as the supply of this regulating service slightly increases (+0.02 Mg C per $100m^2$) within Paramaribo (though still decreases over the entire study area) (Table 16). However, the losses of mean supply under the protection policy scenario are lower than those predicted for business as usual for all ES apart from local climate change mitigation, which instead shows no variation in comparison to business as usual (Table 16). Once again, the losses are generally more apparent within Paramaribo as opposed to within the entire area of Greater Paramaribo. However, the effect of green space protection appears particularly beneficial for flood risk mitigation, as it reduces losses of mean supply in Paramaribo so that they become equal to those estimated for Greater Paramaribo (-0.07m^3 per 100m^2); a notable improvement than expected under business as usual (-0.11m^3 per 100m^2).

The greening of Paramaribo scenario is predicted to be most effective at mitigating losses of regulating ES supply predicted under the previously discussed scenarios as it results in fewer and lower losses of ES supply, with slight losses only occurring for flood risk mitigation and local climate regulation when accounting for the entire Greater Paramaribo area. However, greening efforts are predicted to prevent all losses of mean supply predicted under business as usual or protection policy scenarios within the administrative boundary of Paramaribo, with supplies of coastal protection and local climate regulation remaining as they were in 2020, and with supplies of flood risk mitigation and carbon storage showing clear increases (+0.12m^3 of runoff retention per 100m^2 and +0.14 Mg C per 100m^2 respectively) within Paramaribo.

With regards to synergies and trade-offs, Table 16 suggests there to be primarily synergies between the considered regulating ES as they generally respond similarly to alternative land cover scenarios. This is also supported by the hotspot analyses (see Figure 10 and Figure 18) which reveal large areas of hotspots and coldspots indicating consistently high or low supply between the three regulating services considered. Additionally, ressort analyses also indicate synergies, as mean supply per ressort values generally show similar trends with regards to ressorts offering relatively high and low supply, and values generally respond to land cover change in a similar fashion to one another, regardless of ES. These synergies result in the consistent reduction of ES supply losses when comparing the protection policy scenario to the business as usual scenario, and when comparing the greening of Paramaribo scenario to both business as usual and the protection policy scenarios, as outlined in Table 16. All mean region and ressort-based ES supply values determined for each scenario can be viewed in Appendices 7-10.

4. Discussion

4.1 The current and future supply of regulating ES in Greater Paramaribo

Fulfilling the primary objective of this research, which was "to identify the current and future supply of key regulating ecosystem services derived from green space in the Greater Paramaribo area", the supply of coastal protection, flood risk mitigation, local climate regulation and carbon storage within Greater Paramaribo has been quantified and mapped under current and three potential future scenarios of land cover. In doing so, this study provides one of the first assessments of multiple urban ES in the understudied tropics.

4.1.1 Patterns of current ES supply

First and foremost, the spatial distributions of current supply for the regulating ES of flood risk mitigation, local climate regulation and carbon storage within Greater Paramaribo are notably similar with regards to their uneven distribution throughout the study area. Concentrated, relatively low "coldspots" of supply are consistently found in the central urban ressorts of Paramaribo, and relatively high "hotspots" of supply are generally located more towards the rural outskirts of Greater Paramaribo. The ES of coastal protection shows a similar pattern, with the lowest levels of supply derived from green space again found along coastline of areas central to the city. These patterns are in line with previous research which has utilised InVEST to map regulating ES supply, such as studies highlighting the uneven distribution of carbon storage in urban settings in China for example (Fu, Xu, Zheng, & Chen, 2019; Jiang et al., 2017; Zhang et al., 2018). Larondelle and Haase (2013) also highlight how this general uneven distribution of supply is common in European cities, attributing low supply to the high cover of impervious surfaces in central areas, and high supply elsewhere to the presence of forested areas and a low cover of impervious surfaces. On top of the high urban cover present within Paramaribo however, green spaces within the city primarily consist of grass and mixed low vegetation, both of which were considered less influential than trees or mangrove for supply of the considered regulating ES (see section 2.3). This lack of "high quality" green space within the city, an issue also recognised by local stakeholders (TBIS, 2019; Tropenbos Suriname, 2019), therefore likely enhances this clear pattern of concentrated low supply found in central areas.

With regards to areas with relatively high regulating ES supply in Greater Paramaribo, large, aggregated hotspots are particularly abundant on the eastern, Commewijne side of the Suriname River. This area is characterised by extensive tree cover and low urban cover, and since it has only recently been connected to Paramaribo since the opening of the Wijdenbosch bridge in 2000 (Fung-Loy et al., 2019), land cover, and consequentially ES supply, has been subject to less disturbance from human activity and urban expansion than areas to the south and west of Paramaribo. This suggests that the river therefore previously acted as a barrier of sorts, preventing urban sprawl and its associated disturbance to green space in this eastern section of the study area.

The footprints of human disturbance are, however, much more apparent on the western, Paramaribo-side of the river, and are reflected in a clear fragmentation of regulating ES supply. Narrow, linear segments of low supply generally extend outward from Paramaribo into surrounding, more rural areas. These linear arrangements reflect one of the primary explanatory factors for the spatial pattern of urban sprawl; the underlying road network (Zhan & Ukkusuri, 2019). Fung-Loy et al. (2019) point out how the sprawling of Paramaribo is occurring due to the urban pull effect "*all while coping with inadequate spatial planning and a lack of data, finances, technology and expertise at the government level*". This shows how there has been little thought for the impacts of urban sprawl from the government level and perhaps explains why it appears to have had such a fragmenting impact on regulating ES supply.

4.1.2 Societal impacts of current ES supply

The uneven and fragmented spatial distributions of ES supply highlight that the societal benefits derived from the considered regulating ES, and therefore ultimately from green space, are also unevenly distributed across Greater Paramaribo. Previous research recognises that urban sprawl-derived fragmentation can have negative implications on eventual ES provision (benefits actually experienced by people) (Haddad et al., 2015; Mitchell et al., 2015). In Paramaribo, the spatial distributions of supply most notably result in variation in the exposure of residents to key hazards which the city is facing. For example, an important consequence of fragmented and uneven runoff retention offered by green space is that areas with relatively low supply have an increased flood risk (Demuzere et al., 2014; Kabisch, 2015; Salmond et al., 2016). Flooding in Paramaribo is already a serious and worsening problem (Guzman et al., 2017b; IDB, 2017b, 2017a; Verrest, 2010), and the low supply of runoff retention characteristic to central areas is likely exacerbating this issue during intense rainfall events. This study estimates that up to 82% of rainwater could become runoff in central areas of the city, which is substantially more than the prediction of 60% for non-vegetated cities indicated by Demuzere et al. (2014). On top of inland flooding however, the low, fragmented supply of protection derived from green space along segments of Paramaribo's coastline increases the exposure of the central and populated areas of the city to coastal flooding, a further hazard recognised to be a key challenge faced by the city (Guzman et al., 2017a; IDB, 2017b). This combination of increased exposure to both pluvial and coastal flooding hazards likely increases the vulnerability of central areas of Paramaribo to extreme rainfall events and coastal storms (Gómez-Baggethun et al., 2013; Wisner, Gaillard, & Kelman, 2012). Therefore, low runoff retention and coastal protection due to a lack of sufficient high quality green space is potentially exacerbating Paramaribo's flooding problems, and increasing the vulnerability of Paramaribo's residents to the destructive, economic and potentially life-threatening impacts of this hazard (Arkema et al., 2013; Das & Vincent, 2009; Demuzere et al., 2014; Wisner et al., 2012; Yao, Chen, Wei, & Sun, 2015).

As well as flood-related hazards, the uneven distribution and fragmentation of the supply of heat mitigation, with particularly low levels again found in ressorts central to the city, likely has further important societal consequences. This research predicts that a lack of heat mitigation offered by green space within Paramaribo contributes to higher night-time air temperatures within the city boundary than outside of it. This canopy urban heat island effect is most pronounced in central ressorts which are characterised by their high impervious surface cover and mainly absent green space cover. Remijn (2020) examined this phenomena in more depth, though instead focused upon the surface urban heat island. Remijn (2020) found that green space significantly mitigates against the higher urban surface temperatures found within the city of Paramaribo, a conclusion in line with observations from modelling results in this study. As with the flood-related hazards, a lack of supply of the regulating ES of local climate regulation within Paramaribo due to lack of adequate green space likely has implications for local residents. Previous research indicates that such implications can include a decreased energy efficiency, low work productivity and an increased exposure to heat-related hazards such as heat stress and its associated health risks(Brown et al., 2015; Chapman et al., 2017; Luber & McGeehin, 2008).

However, the consequences of the spatial distribution of carbon storage are perhaps not so important, since unlike the other regulating ES considered, it does not offer a form of localised hazard mitigation. The societal benefits of its supply are instead mostly related to the overarching global challenge of combatting climate change; an issue which is however recognised to exacerbate both heat and flood-related hazards in coastal cities (Chapman et al., 2017; Luber & McGeehin, 2008; Mcgranahan et al., 2007; Spalding, Ruffo, et al., 2014). In addition to the global importance of nations making effort to maintain their carbon stocks, there are potential economic incentives for maintaining carbon stock where possible in Suriname, as the country is involved with the UN's REDD+ (Reducing Emissions from Deforestation and forest Degradation) program (SBB et al., 2017; Suriname REDD, 2020). However, sequestration analyses would be necessary to assess this economic aspect; an area for future research. Although the current carbon storage in Greater Paramaribo has little relevance in the grand scheme of global climate change, it remains an important ES for expanding cities in tropical regions to consider, since if all were to ignore it, the implications could be severe (Chen, 2015; Holt et al., 2015). The estimated 0.21 Mg C per 100m^2 in Paramaribo does however seem somewhat low compared to estimates for temperate cities, such as that by Davies et al. (2011) of 0.32 Mg C per 100m^2 in the British city of Leicester. This again is likely indicative of the lack of high quality green space in Paramaribo.

4.1.3 Potential future ES supply in Greater Paramaribo in 2035

As they were for 2020, the predicted spatial distributions of regulating ES supply in 2035 are unevenly distributed throughout the study area, a pattern found under all of the considered potential future scenarios. Large areas of Greater Paramaribo are predicted to remain unchanged with regards to overall hotspots and coldspots of regulating ES supply. The modelled urban expansion to the south and east of the city, and to a lesser extent in northern coastal ressorts, results in a clear expansion of the concentrated coldspot of regulating ES supply central to Paramaribo; a pattern which occurs largely irrespective of the policy and management approaches introduced via the alternative scenarios. This therefore highlights the recognised vulnerability of ES to land cover change (Metzger et al., 2006). More importantly in the context of this research however, it highlights areas which are likely particularly vulnerable to a future loss of hazard-mitigating benefits from green space. Identifying such areas is recognised to be important for the management of hazards and for informing urban management decisions (Godschalk, 2003; Wisner et al., 2012; Zevenbergen, Veerbeek, Gersonius, & Van Herk, 2008). For instance, this research indicates that losses of runoff retention in some most-affected locations are predicted to be up to a maximum of 5.4m^3 per 100m^2, the equivalent of a loss of 40% in total rainfall volume retained, and losses in heat mitigation estimated to be as high as 0.94, resulting in as much as 0.8°C increase in night-time air temperature. Policy and management efforts directed towards mitigating such losses should be a priority in order to avoid the worsening of already serious challenges faced by the city.

The scenario analyses allowed for some insight into how such efforts could be approached. Mean supply per region and ressort analyses reveal that predicted losses in ES supply are most pronounced under business as usual, indicating this to be the least sustainable direction for the city to follow of the three management approaches considered. This therefore indicates that continued uncontrolled urban growth, with lack of enforced policy protecting green space, will likely exacerbate the implications of the uneven and fragmented distribution of supply discussed in the previous section. This will in turn increase the exposure of Paramaribo's residents to the flooding and heat-related hazards already discussed, especially considering the prediction that losses of ES supply will be larger within Paramaribo than in the surrounding area. Mean supply per ressort values were again indicative that areas experiencing most extensive urban expansion are likely to be most affected. In Livorno for instance, a ressort in the south eastern corner of the city, the largest loss in mean supply per ressort of both flood mitigation (equivalent to a 6.1% reduction in rainwater retained) and heat mitigation (equivalent to a mean night time air temperature increase of 0.28°C) was predicted, as well as the second largest loss of coastal protection (approximately a 55% decrease in the role of green space). This insight into the locale of regulating ES loss offers opportunity for focused efforts to be made to limit and mitigate the associated impacts of urban expansion and the subsequent losses of regulating ES supply.

Interestingly, if a policy was introduced which enforced the protection of high quality green space (trees and mangrove) within Paramaribo as well as a 2km greenbelt around the city limit, it would not be sufficient to offset losses of ES supply resulting from urban expansion predicted by 2035. For example, a loss of 5.7% of total rainwater retained would still occur in the most impacted ressort of Livorno, only slightly lower than the 6.1% loss predicted under business as usual. Similar mitigation of ES supply losses occur for both coastal protection and carbon storage, though local climate regulation remains largely as it was under business as usual. Therefore, such green space protection, whilst offering a general improvement in comparison to business as usual, would still be limited in terms of its effectiveness since increased exposure to the aforementioned hazards would likely still occur. This again relates back to the underlying problem recognised by stakeholders of the current lack of sufficient areas of key green space within the city, highlighting further the role of green space in this tropical city.

If an ambitious greening of Paramaribo and its surroundings occurred, this study suggests that the aforementioned losses of ES supply under a business as usual scenario or protection policy scenario would be largely mitigated in Greater Paramaribo, and entirely mitigated within Paramaribo's administrative boundary when mean values of supply for these areas are considered. Furthermore, carbon storage and flood mitigation would increase substantially within the administrative boundary of the city, in turn offering a potential nature-based solution to managing the persistent flood hazards, and potential economic gain via Suriname's REDD+ program (Frantzeskaki, 2019; Suriname REDD, 2020). However, despite the effectiveness of greening highlighted for Paramaribo, supply is still unevenly distributed and substantial losses of ES supply still occur in certain areas, particularly to the south and east of the city. The introduced greenbelt did not result in as much additional tree cover in these areas as it did in northern ressorts of Paramaribo, suggesting its effectiveness could be somewhat limited. However, the prevalence of additional tree cover in northern ressorts within the greenbelt was largely the result of the probability-based land cover allocation by Dyna-CLUE (see Appendix 6).

Therefore, management approaches targeting vulnerable areas in a more specific manner than the probability-based approach of greening used in this study could potentially address the ressort-level variation which was still predicted. More targeted greening of abandoned or tenure land within the city for instance, as well as targeted greening of neglected space alongside roads and waterways, could help to further limit the impact of losses in ES supply in vulnerable areas to the south and east of the city. The prioritisation of neighbourhoods for targeted greening efforts has been indicated as an approach to offer more strategic implementation of green space within cities (Aboulnaga & Mostafa, 2020; Norton et al., 2015). Such a targeted approach to greening was used in Hangzhou in China for example, and has been recognised to be successful in temperature reduction (Wenting, Yi, & Hengyu, 2012; Wolch, Byrne, & Newell, 2014). Furthermore, as called for in a recent report focusing on Europe (EEA-FOEN, 2016), impacts of urban sprawl could be somewhat limited by focusing on reusing already developed land and preserving the environment via the use of functional zoning approaches. This highlights an issue the scenarios in this research did not address; alternative urban policy approach and design. A more compact city for instance could be an approach to dealing with the impacts of Paramaribo's urban sprawl (IDB, 2017a; Pelczynski & Tomkowicz, 2019; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). Future research could consider alternative urban design and its implications on ES supply, though it is expected that a combination of greening and densification would be most feasible and effective in Paramaribo, as reflected by the suggestion of such a combination by the IDB Paramaribo Action Plan (IDB, 2017a).

An important point highlighted by the future scenario analyses is that urban change predictions can vary significantly within literature. Several predictions for urban change in Paramaribo have already been predicted, each differing substantially from the other. For example, Heirman and Coppens (2013) suggest the urban area in Paramaribo increased from 7500ha in 2000 to 20700ha in 2012. Meanwhile, Fung-Loy et al. (2019) predicted an urban growth of 49% between 2015 and 2030. The IDB on the other hand, predicted lower growth, equivalent to a 27.5% increase in urban area by the year 2035 (IDB, 2017c). This variation likely reflects differing interpretations of past change and alternative projection methods used. Furthermore, it is perhaps indicative of issues surrounding the definition of "urban" – this can change between studies and can also depend upon data resolution (Geyer, 2011; Weeks, 2010). Nevertheless, the variation in predictions for urban change in Paramaribo introduces some uncertainty into the scenario modelling carried out in this study, though this was not the only aspect introducing uncertainty as discussed in the next section.

4.2 Reflection on methods to model and map ES; strengths and limitations

4.2.1 Modelling ES supply with InVEST

InVEST models cover a wide range of ES and their relative simplicity and ease of use compared to more complex, less user-friendly alternatives make the software an ideal package for the analysis of multiple ES (Natural Capital, 2020). Since it is the most commonly used tool for the spatial analysis of ES (Ochoa & Urbina-Cardona, 2017), researchers are able to consult other studies for insights into model decisions or to compare final outputs, which in turn introduces some level of consistency into the world of ES assessments. Additionally, the models were found to be generally flexible, allowing for input of either location-specific measurements, global data, or estimates derived from literature. This flexibility alongside the low data requirements allows for assessments of ES supply in data-scarce regions of the planet such as that carried out in this study.

However, InVEST is also recognised to have several associated drawbacks and limitations (Burkhard & Maes, 2017; Ochoa & Urbina-Cardona, 2017). Overall, this research highlighted two key issues relating to the application of InVEST, specifically; (i) the models often involve broad assumptions which introduce uncertainty (ii) data limitation in tropical regions can occasionally make tailoring InVEST models to reflect the local context problematic.

First of all, the simplicity of InVEST, while ideal for rapid assessment and use by those unfamiliar with more hands-on modelling techniques, comes with the caveat that several broad assumptions are involved, which in turn introduces difficult to quantify model uncertainty (Uusitalo, Lehikoinen, Helle, & Myrberg, 2015). For example, the Urban Cooling model used to assess local climate regulation is centred largely around the calculation of a cooling capacity index involving an empirical weighting step (see section 2.3.4) which is based upon limited case studies (Sharp et al., 2020), and as pointed out by Zardo et al. (2017), introduces high uncertainty.

A further example is provided by the Coastal Vulnerability model, which does not account for habitat size, shape, nor its distance from the coastline in the calculation of coastal protection, despite recognition that such factors play an important role (Gedan et al., 2011; Guannel et al., 2015; McIvor et al., 2012). The model instead merely considers whether protective habitat is present or absent within a user-specified "protective distance" from the shore point of interest. However, this value, referred to as a "*technical shortcut*" by (Silver et al., 2019), is rather arbitrary and literature is either unavailable or inconsistent and somewhat vague in specifying such a distance. For instance, Das and Vincent (2009) indicate that mangrove can offer protective services "*within 10km of the coast*", whilst Zhang et al. (2012) suggest a width of 7-8km was required for "*significant attenuation of storm surge from Hurricane Wilma*", and Del Valle et al. (2019) briefly discuss a range of 2-7km while pointing out that wide mangrove belts are important. Consequentially, selecting such an input value introduces subjective judgment (Uusitalo et al., 2015), likely enhancing model uncertainty. Other researchers have also expressed concern over the nature of protective habitat determination by the InVEST coastal model, with Hopper and Meixler (2016) finding that their scenario comparisons demonstrated "*limitations of the model in comparing a very urbanised coastal system to an undeveloped one*" for example. Additionally, river coastlines may exacerbate the uncertainty issues associated with this protective distance, as the model appears to scan for habitat presence in an entire radius around a shore point. Since there is no way for the user to specify direction, mangrove presence on one bank of the Suriname River seems to have influenced habitat role on the opposite bank. This issue appears to have resulted in larger values of coastal protection in central ressorts of Paramaribo than perhaps there should be, which introduces potential implications regarding the accuracy of the final outputs and reliability of their subsequent interpretations.

The second of the key limitations faced via application of InVEST relates to its associated data requirements and how tailoring these to reflect location-specific tropical cities can be occasionally problematic. As outlined in section 2.3, considerable effort was directed towards this tailoring to the local context via the inclusion of regional input values, such as in the carbon storage model for example, or the use of direct local measurements such as the air temperature drop data utilised in the urban cooling model. However, since InVEST is land cover based, the reliability of outputs is largely dependent on the initial land cover data used. Assigning certain model parameter values such as aboveground carbon storage (see section 2.3.5) or the crop coefficient (Kc) (see section 2.3.4) to the broad land cover classes used within this study (particularly "grass" and "mixed low vegetation") proved somewhat problematic due to lack of such values in the literature, since they are typically more specific to a certain ecosystem, biome or species. Burkhard an Maes (2017) summarise this issue well, stating that "*ES are supplied by ecosystems, not land cover types" (page 362).* They stress caution with the utilisation of land cover data as ecological differences between biomes can "*fade on a land cover map"* which can result in error and uncertainty in ES assessments. Additionally, several general values or global datastets had to be used within InVEST due to absence of local data, such as the global soil hydrological dataset used within the Urban Flood Risk Mitigation model for example (see section 2.3.3). This contained missing data for sections of northern Paramaribo which had to be essentially estimated, and its 500m resolution, though resampled, is still apparent within slight pixelation effects in the final output (Figure 7). This combination of broad land cover classes and occasional use of more general model input sources means the reflection of the local context and precision of estimations are somewhat limited and oversimplified in this research, though as mentioned, effort was made where possible to prevent this.

Despite the limitations associated with InVEST, for the most part assumptions are apparent, and model outputs provide the basis for further analyses. Furthermore, the developers are also approachable and reply promptly to user queries on a dedicated online forum. A previous drawback was that certain models were not particularly suitable for application to an urban-context, though Natural Capital have recently begun to address this via development of their new suite of Urban InVEST models (Natural Capital, 2020), two of which were utilised in this research. However, these have not yet been utilised in published research, which slightly limited the potential for insight into their use and for comparisons of final outputs. Nevertheless, both new urban models, alongside the carbon and coastal models utilised, were found to be suitable for the quantification and mapping of their associated ES in a tropical context. Future research could offer some validation of final outputs and model ES supply in Paramaribo with alternative software or more complex approaches to assess the uncertainty discussed.

4.2.2 Modelling urban and green space change with Dyna-CLUE

Dyna-CLUE proved to be somewhat flexible in practice due to the possibility to make adjustments within its four main categories. These adjustments were able to be tailored to reflect insights gained from interviews with local stakeholders and local literature. The final outputs are considered to be a good reflection of changes that stakeholders expect, as the main trends described in their interview responses are apparent (particularly with regards to their expectations for urban expansion, with most happening to the south and east, and smaller areas of expansion to the north).

However, Dyna-CLUE was also found to have associated limitations. First of all, as revealed with a small sensitivity analysis certain ambiguous input values require arbitrary estimations from the users (such as elasticity) or are somewhat inexplicit with regards to their effects (deviation values). Such settings therefore have potential to introduce model or subjective judgment based uncertainty (Uusitalo et al., 2015), in turn potentially limiting the accuracy or reliability of the modelled future land covers in this research. Future users of Dyna-CLUE are advised to test the sensitivity of inputs such as these, and future models developed for use by the scientific community should attempt to be explicit and transparent about all required input values, providing concrete examples where possible.

Secondly, the allocation of land cover by Dyna-CLUE is largely probability based, and the inclusion or exclusion of certain variables considered to be influential to the presence of a land cover within the regression models could potentially change the final probability of a land cover occurring at a particular location. Furthermore, low AUC values for the land cover classes of mixed low vegetation and grass meant that discrimination between presence and absence of these covers was limited. This seems to have resulted in immediate (in the first year of the 15 years modelled) reallocation or even “swapping” of these two land covers in certain areas, since the model essentially deemed them to be more suitably located elsewhere. This again is perhaps an implication of the broad land cover classification issue found to be somewhat problematic with InVEST. For instance, it is difficult to predict drivers of land cover change for the broad class of mixed low vegetation, as this land cover class could be quite varied in and of itself, potentially including small trees, bushes and shrubs, marsh and swamp areas, or certain types of agriculture, all of which could have differing location-determining factors. The reallocation which occurred likely limits the reliability of some of the ressort-based comparisons used in this research, and suggests that more specific land cover classifications may result in more adequate discrimination between presence and absence of cover.

4.3 Moving forward; Green space in Paramaribo

Paramaribo has clearly experienced urban growth and sprawl in recent decades. Several impacts of this have already been documented, including an increasing socioeconomic segregation, deforestation, and degradation of coastal mangroves (Conservation International Suriname, 2015; Fung-Loy et al., 2019; Guzman et al., 2017a; SBB et al., 2017). This research has highlighted the vulnerability of ES supply in Greater Paramaribo to future urban expansion and indicated a fragmented and uneven distribution of regulating ES supply, with benefits derived from green space particularly low in central ressorts of the city. If the city carries on with business as usual this study predicts a pronounced decrease in benefits derived from green space for the population of Paramaribo. Therefore, based upon the findings of this research, the following suggestions have been comprised for decision makers in Paramaribo. Ideas were also drawn from stakeholder engagement and previous research.

- Measures need to be taken to limit the fragmentation of ES supply caused by urban sprawl. These could include more controlled and planned urban growth and the protection of key green spaces in strategic areas in and around the city (particularly trees and mangroves).
- However, more than just protection of key green space is needed to conserve current supply; an active greening of the city alongside improved spatial planning or zoning is needed, as also highlighted within the IDB Action Plan (IDB, 2017a).
- Trees and mangrove are most important for regulating ES supply, and should therefore be the focus of greening efforts. However, future research should consider their disservices as well as potential trade-offs with other categories of ES (e.g. cultural) as these were not considered in this study.
- Greening of Paramaribo could be targeted to open patches of otherwise unused land within the city, with abandoned plots of land offering ideal locations if owners can be traced or some kind of incentive can be offered. Trees could also be planted in the large graveyards present throughout the city, an idea proposed by members of the Ministry of Spatial Planning, Land and Forest Management, or within new housing allotments as suggested by TBIS. Strategic, targeted greening within central and southern ressorts of Paramaribo could help balance out the uneven distribution of ES supply and increase resilience of residents to future urban expansion.
- A greenbelt and a coastal protection zone could be considered as areas for targeted greening efforts. These ideas have been proposed in the past and this research has confirmed them viable options to mitigate losses or even increase ES supply.
- The Cultuurtuin park in Rainville could be an ideal location for substantial greening efforts, though further urban expansion towards its northern edge should be prevented. The suggestion by IDB (2017c) to use it as a "*gateway to the Caribbean"* through a series of recreational nature paths connecting the city to the ocean could work well alongside a greenbelt and coastal protection zone, and could offer numerous tourism possibilities for visitors to the city.
- Efforts should be undertaken to increase awareness of the benefits associated with green space among the government and policy makers, as well as the residents of Paramaribo. The efforts by TBIS offer a good starting point for this.

Some of the above suggestions could facilitate Paramaribo's movement along its development path and limit future impacts of urban expansion on both the environment and the residents of the city. An interesting point noted during the fieldwork was that Suriname seems to take some level of pride in being the most forested country in the world (Fung-Loy et al., 2019; Suriname REDD, 2020). However, as a visitor walking around the streets of Paramaribo, I felt that its capital city did not really reflect this. Why not have Paramaribo reflect this global status? A green tropical city reflecting the greenest of tropical countries could potentially be a "selling point" to increase tourism to the area, too. Even so, greening of Paramaribo will require collaboration between several different bodies and clear, enforceable policy to support it. On top of this, future research is still needed into potential disservices or trade-offs with other ES (e.g. cultural). Overall though, should Paramaribo choose to continue without consideration for green space benefits, the result could cause an increased exposure to hazards and be detrimental to resilience of the city and its residents to future challenges such as climate change.

5. Conclusion

Few studies exist which consider ES supply derived from green space within tropical cities. This study therefore contributes to the widening of scientific understanding regarding the role of green space in such cities, as well as within the understudied region of South America. A clear uneven and fragmented distribution of regulating ES supply has been highlighted in the sprawling city of Paramaribo, which in turn results in an uneven distribution of their associated hazard-mitigating benefits. Future scenarios have provided insight into how urban expansion and green space change may impact the resilience of the city, with continuation along a business as usual path most likely to result in the most pronounced losses of ES supply, and in turn most likely to increase the exposure of Paramaribo's residents to heat and flood-related hazards. A protection of key green space within and around the city with an introduced greenbelt could help to mitigate these losses, though would likely not be enough to account for all losses in ES supply predicted as a result of urban expansion. However, an active greening of Paramaribo could mitigate losses of ES supply in many areas, and even result in increases of supply in certain cases, thereby improving the resilience of Paramaribo to its hazard-related challenges and benefiting the well-being of its citizens. There are, however, areas predicted to still be particularly vulnerable to urban expansion and its associated impact on regulating ES, particularly to the south and east of the city. More targeted greening efforts could potentially address this, though the identification of such vulnerable areas allows planners and decision makers to visualise where most attention will likely be needed in the coming years.

In highlighting the relevant, hazard-mitigating role of green space in Paramaribo, this research can potentially add to the valuation of green space in tropical cities. However, there is much still to be understood on the dynamics of ES in such regions of the planet. The door is therefore open for the field of ES assessment, with researchers invited to rise to the challenge of highlighting the role of green space in data-scarce, understudied regions of the world where incidentally, most future urban change will occur. By widening understanding further, research can contribute to hazard mitigation and the sustainability of cities, thereby increasing humanity's resilience to anthropogenic climate change and the pressing global challenges associated with the urban century.

6. References

Aboulnaga, M., & Mostafa, M. (2020). Climate Change Adaptation: Prioritising Districts for Urban Green Coverage to Mitigate High Temperatures and UHIE in Developing Countries (pp. 825–837). Springer, Cham. https://doi.org/10.1007/978-3-030-18488-9_68

Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, *43*(4), 480–493. https://doi.org/10.1016/j.buildenv.2006.10.055

Allen, R., Pereira, L., & Smith, M. (1998). Crop evaporation. Guideline for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56. Rome, Italy, (56).

Andrew, M. E., Wulder, M. A., Nelson, T. A., & Coops, N. C. (2015, May 4). Spatial data, analysis approaches, and information needs for spatial ecosystem service assessments: A review. *GIScience and Remote Sensing*. Taylor and Francis Inc. https://doi.org/10.1080/15481603.2015.1033809

Anniballe, R., Bonafoni, S., & Pichierri, M. (2014). Spatial and temporal trends of the surface and air heat island over Milan using MODIS data. *Remote Sensing of Environment*, *150*, 163–171. https://doi.org/10.1016/j.rse.2014.05.005

Arets, E., Kruijt, B., Tjon, K., Atmopawiro, V. P., Kanten, R. F. Van, Crabbe, S., … Ruysschaert, S. (2011). Towards a carbon balance for forests in Suriname, 57.

Arkema, K. K., Guannel, G., Verutes, G., Wood, S. A., Guerry, A., Ruckelshaus, M., … Silver, J. M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change*, *3*(10), 913–918. https://doi.org/10.1038/nclimate1944

Bagstad, K. J., Cohen, E., Ancona, Z. H., Mcnulty, S. G., & Sun, G. (2018). The sensitivity of ecosystem service models to choices of input data and spatial resolution. *Applied Geography*, *93*, 25–36. https://doi.org/10.1016/j.apgeog.2018.02.005

Bagstad, K. J., Semmens, D. J., Ancona, Z. H., & Sherrouse, B. C. (2017). Evaluating alternative methods for biophysical and cultural ecosystem services hotspot mapping in natural resource planning. *Landscape Ecology*, *32*(1), 77–97. https://doi.org/10.1007/s10980-016-0430-6

Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem Services*. https://doi.org/10.1016/j.ecoser.2013.07.004

Basuki, T. M., van Laake, P. E., Skidmore, A. K., & Hussin, Y. A. (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology and Management*, *257*(8), 1684–1694. https://doi.org/10.1016/j.foreco.2009.01.027

Bengston, D. N., & Yeo-chang, Y. (2005). Seoul's Greenbelt: An experiment in urban containment. *In: Bengston, David N., Tech. Ed. Policies for Managing Urban Growth and Landscape Change: A Key to Conservation in the 21st Century. Gen. Tech. Rep. NC-265. St. Paul, MN: US Department of Agriculture, Forest Service, North Central Research Station*, 27–34.

Brown, R. D., Vanos, J., Kenny, N., & Lenzholzer, S. (2015). Designing urban parks that ameliorate the effects of climate change. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2015.02.006

Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: a primer*.

Burkhard, B., & Maes, J. (2017). *Mapping Ecosystem Services*. (B. Burkhard & J. Maes, Eds.), *Advanced Books*. Pensoft Publishers. https://doi.org/10.3897/ab.e12837

Cameron, R. W. F., Blanuša, T., Taylor, J. E., Salisbury, A., Halstead, A. J., Henricot, B., & Thompson, K. (2012). The domestic garden-Its contribution to urban green infrastructure. *Urban Forestry & Urban Greening*, *11*, 129–137. https://doi.org/10.1016/j.ufug.2012.01.002

Cedergren, J. (2009). *Measurement and Reporting of Forest Carbon in Guyana : Guyana : Preparing for REDD Implementation* (MRV No. 6).

Chapman, S., Watson, J. E. M., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecology*. https://doi.org/10.1007/s10980-017-0561-4

Chen, W. Y. (2015). The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: A nationwide estimate. *Cities*, *44*, 112–120. https://doi.org/10.1016/j.cities.2015.01.005

CLUE. (2020). CLUE model | Environmental Geography. Retrieved May 5, 2020, from https://www.environmentalgeography.nl/site/data-models/data/clue-model/

Conservation International Suriname. (2015). Integrated coastal zone management-Suriname. *"Building with Nature" Coastal Protection*, (1).

Cortinovis, C., & Geneletti, D. (2019). A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*, *38*, 100946. https://doi.org/10.1016/j.ecoser.2019.100946

Das, S., & Vincent, J. R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(18), 7357–7360. https://doi.org/10.1073/pnas.0810440106

Davies, Z. G., Edmondson, J. L., Heinemeyer, A., Leake, J. R., & Gaston, K. J. (2011). Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology*, *48*(5), 1125–1134. https://doi.org/10.1111/j.1365-2664.2011.02021.x

De Boer, F. (2016). *HiHydroSoil : A high resolution soil map of hydraulic properties (Version 1.2)*. *Report FutureWater: 134*.

Del Valle, A., Eriksson, M., Ishizawa, O. A., & Miranda, J. J. (2019). *Mangroves for Coastal Protection*.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., … Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, *146*, 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025

Derkzen, M. L., van Teeffelen, A. J. A., & Verburg, P. H. (2015). REVIEW: Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. *Journal of Applied Ecology*, *52*(4), 1020–1032. https://doi.org/10.1111/1365-2664.12469

Derkzen, M. L., van Teeffelen, A. J., Nagendra, H., & Verburg, P. H. (2017, December 1). Shifting roles of urban green space in the context of urban development and global change. *Current Opinion in Environmental Sustainability*. Elsevier B.V. https://doi.org/10.1016/j.cosust.2017.10.001

Dile, Y. T., Karlberg, L., Srinivasan, R., & Rockström, J. (2016). Investigation of the Curve Number Method For Surface Runoff Estimation In Tropical Regions. *Journal of the American Water Resources Association*, *52*(5), 1155–1169. https://doi.org/10.1111/1752-1688.12446

Dobbs, C., Escobedo, F. J., Clerici, N., de la Barrera, F., Eleuterio, A. A., MacGregor-Fors, I., … Hernández, H. J. (2018). Urban ecosystem Services in Latin America: mismatch between global concepts and regional realities? *Urban Ecosystems*, *22*(1), 173–187. https://doi.org/10.1007/s11252-018-0805-3

EEA-FOEN. (2016). *Urban sprawl in Europe - Report No 11/2016*. https://doi.org/10.2800/143470

Elmqvist, T., Andersson, E., Frantzeskaki, N., McPhearson, T., Olsson, P., Gaffney, O., … Folke, C. (2019). Sustainability and resilience for transformation in the urban century. *Nature Sustainability*, *2*(4), 267–273. https://doi.org/10.1038/s41893-019-0250-1

Emmett, B. A., Cooper, D., Smart, S., Jackson, B., Thomas, A., Cosby, B., … Jones, D. L. (2016). Spatial patterns and environmental constraints on ecosystem services at a catchment scale. *Science of the Total Environment*, *572*, 1586–1600. https://doi.org/10.1016/j.scitotenv.2016.04.004

Erftemeijer, P., & Teunissen, P. (2009). ICZM Plan Suriname - Mangrove Report, (September), 1–35.

Farrugia, S., Hudson, M. D., & McCulloch, L. (2013). An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *9*(2), 136–145. https://doi.org/10.1080/21513732.2013.782342

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science and Policy*, *93*, 101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Fu, Q., Xu, L., Zheng, H., & Chen, J. (2019). Spatiotemporal Dynamics of Carbon Storage in Response to Urbanization: A Case Study in the Su-Xi-Chang Region, China. *Processes*, *7*(11), 836. https://doi.org/10.3390/pr7110836

Fung-Loy, K., Van, A., Ku Leuven, R., Hemerijckx, L.-M., & Leuven, K. U. (2019). Detection and Simulation of Urban Expansion and Socioeconomic Segregation in the Greater Paramaribo Region, Suriname: Socioeconomic Segregation in Paramaribo Analysis of land cover change patterns in Central and Eastern Europe View project GLP Working Gro. *Tijdschrift Voor Economische En Sociale Geografie*, *110*(3), 339–358. https://doi.org/10.1111/tesg.12350

GEBCO Compilation Group. (2019). GEBCO 2019 Grid. https://doi.org/10.5285/836f016a-33be-6ddc-e053-6c86abc0788e

Gedan, K. B., Kirwan, M. L., Wolanski, E., Barbier, E. B., Silliman, B. R., Gedan, K. B., … Silliman, B. R. (2011). The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climatic Change*, *106*, 7–29. https://doi.org/10.1007/s10584-010-0003-7

Geyer, H. S. (2011). *International handbook of urban policy*. *International Handbook of Urban Policy* (Vol. 3). https://doi.org/10.4337/9780857937100

Gianni, W., Verginia, W., Tjon, A. N. C., Marjanom, G., Feyen, J., Crabbe, S., … Lingaard, M. (2019). Blue Carbon and biodiversity within Suriname’s mangrove forests using a multipurpose NFI. In *IUFRO 2019 Poster*.

Godschalk, D. R. (2003). Urban hazard mitigation: Creating resilient cities. *Natural Hazards Review*. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136)

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235–245. https://doi.org/10.1016/j.ecolecon.2012.08.019

Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'farrell, P., … Kremer, P. (2013). Urban ecosystem services. In *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment* (pp. 175–251). Springer Netherlands. https://doi.org/10.1007/978-94-007-7088-1_11

Grafius, D. R., Corstanje, R., Warren, P. H., Evans, K. L., Hancock, S., & Harris, J. A. (2016). The impact of land use/land cover scale on modelling urban ecosystem services. *Landscape Ecology*, *31*(7), 1509–1522. https://doi.org/10.1007/s10980-015-0337-7

Guannel, G., Ruggiero, P., Faries, J., Arkema, K., Pinsky, M., Gelfenbaum, G., … Kim, C.-K. (2015). Integrated modeling framework to quantify the coastalprotection services supplied by vegetation. *Journal of Geophysical Research: Oceans*, *120*(1), 324–345. https://doi.org/10.1002/2013JC009443

Güneralp, B., Güneralp, I., & Liu, Y. (2015). Changing global patterns of urban exposure to flood and drought hazards. *Global Environmental Change*, *31*, 217–225. https://doi.org/10.1016/j.gloenvcha.2015.01.002

Guzman, A., Castano-Isaza, J., Ferguson, S., Bovolo, I., Lawless, M., Elliot, M., … Jose, S. (2017a). Coastal Resilience Assessment, Paramaribo, Suriname (p. 1). https://doi.org/10.1145/1999320.1999378

Guzman, A., Castano-Isaza, J., Ferguson, S., Bovolo, I., Lawless, M., Elliot, M., … Jose, S. (2017b). Paramaribo Strategic Flood Risk Assessment Final Report, (June 2019), 154. https://doi.org/10.13140/RG.2.2.25495.83361

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., … Elmqvist, T. (2014). A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio*. https://doi.org/10.1007/s13280-014-0504-0

Haase, D., Schwarz, N., Strohbach, M., Kroll, F., & Seppelt, R. (2012). Synergies, trade-offs, and losses of ecosystem services in urban regions: An integrated multiscale framework applied to the leipzig-halle region, Germany. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04853-170322

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2), e1500052. https://doi.org/10.1126/sciadv.1500052

Haines-Young, R., & Potschin, M. (2012). *Common International Classification of Ecosystem Services (CICES, Version 4.1)*.

Haines-Young, R., & Potschin, M. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure*.

Han, A. T., & Go, M. H. (2019). Explaining the national variation of land use: A cross-national analysis of greenbelt policy in five countries. *Land Use Policy*, *81*, 644–656. https://doi.org/10.1016/j.landusepol.2018.11.035

Heirman, S., & Coppens, T. (2013). Causes , Consequences and A ordability of Urban Sprawl in the Caribbean : Case Causes , Consequences and A ordability of Urban Sprawl in the Caribbean : Case Paramaribo, (November).

Holt, A. R., Mears, M., Maltby, L., & Warren, P. (2015). Understanding spatial patterns in the production of multiple urban ecosystem services. *Ecosystem Services*, *16*, 33–46. https://doi.org/10.1016/j.ecoser.2015.08.007

Hopper, T., & Meixler, M. S. (2016). Modeling Coastal Vulnerability through Space and Time. https://doi.org/10.1371/journal.pone.0163495

Hutyra, L. R., Yoon, B., & Alberti, M. (2011). Terrestrial carbon stocks across a gradient of urbanization: A study of the Seattle, WA region. *Global Change Biology*, *17*(2), 783–797. https://doi.org/10.1111/j.1365-2486.2010.02238.x

IDB. (2017a). Action Plan for Paramaribo. Retrieved May 25, 2020, from https://issuu.com/ciudadesemergentesysostenibles/docs/city2015_pub2019_sr_paramaribo

IDB. (2017b). *Paramaribo Action Plan: Hazard & Risk Study*.

IDB. (2017c). *Paramaribo Action Plan: Urban Growth Study*.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*. *IGES* (Vol. 53). https://doi.org/10.1017/CBO9781107415324.004

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use*.

Jennings, V., Larson, L., & Yun, J. (2016). Advancing Sustainability through Urban Green Space: Cultural Ecosystem Services, Equity, and Social Determinants of Health. *International Journal of Environmental Research and Public Health*, *13*(2), 196. https://doi.org/10.3390/ijerph13020196

Jiang, W., Deng, Y., Tang, Z., Lei, X., & Chen, Z. (2017). Modelling the potential impacts of urban ecosystem changes on carbon storage under different scenarios by linking the CLUE-S and the InVEST models. *Ecological Modelling*, *345*, 30–40. https://doi.org/10.1016/j.ecolmodel.2016.12.002

Kabisch, N. (2015). Ecosystem service implementation and governance challenges in urban green space planning-The case of Berlin, Germany. *Land Use Policy*, *42*, 557–567. https://doi.org/10.1016/j.landusepol.2014.09.005

Kalpoe, N. (n.d.). *Towards a green and more liveable Paramaribo: A study into the Cooling Effect of Urban Green Spaces in Paramaribo*. Anton de Kom Universiteit Suriname.

Ke, X., van Vliet, J., Zhou, T., Verburg, P. H., Zheng, W., & Liu, X. (2018). Direct and indirect loss of natural habitat due to built-up area expansion: A model-based analysis for the city of Wuhan, China. *Land Use Policy*, *74*, 231–239. https://doi.org/10.1016/j.landusepol.2017.12.048

Larondelle, N., & Haase, D. (2013). Urban ecosystem services assessment along a rural-urban gradient: A cross-analysis of European cities. *Ecological Indicators*, *29*, 179–190. https://doi.org/10.1016/j.ecolind.2012.12.022

Larondelle, N., Haase, D., & Kabisch, N. (2014). Mapping the diversity of regulating ecosystem services in European cities. *Global Environmental Change*, *26*(1), 119–129. https://doi.org/10.1016/j.gloenvcha.2014.04.008

Liang, Y., Liu, L., & Huang, J. (2017). Integrating the SD-CLUE-S and InVEST models into assessment of oasis carbon storage in northwestern China. *PLOS ONE*, *12*(2), e0172494. https://doi.org/10.1371/journal.pone.0172494

Luber, G., & McGeehin, M. (2008). Climate Change and Extreme Heat Events. *American Journal of Preventive Medicine*. https://doi.org/10.1016/j.amepre.2008.08.021

MA. (2005). *Millennium Ecosystem Assessment*. *Ecosystems and Human Well-being: Synthesis.* Washington, DC.: Island Press. https://doi.org/10.5822/978-1-61091-484-0_1

Mas, J. F., Kolb, M., Paegelow, M., Camacho Olmedo, M. T., & Houet, T. (2014). Inductive pattern-based land use/cover change models: A comparison of four software packages. *Environmental Modelling and Software*, *51*, 94–111. https://doi.org/10.1016/j.envsoft.2013.09.010

McDonald, R. I., Colbert, M., Hamann, M., Simkin, R., & Walsh, B. (2018). *Nature in the Urban Century*.

Mcgranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *IIED)*, *19*(1), 17–37. https://doi.org/10.1177/0956247807076960

McIvor, A., Möller, I., Spencer, T., & Spalding, M. (2012). *Reduction of Wind and Swell Waves by Mangroves. Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40*. *Natural Coastal Protection Series* (Vol. 1). https://doi.org/ISSN 2050-7941.

Metzger, M. J., Rounsevell, M. D. A., Acosta-Michlik, L., Leemans, R., & Schröter, D. (2006). The vulnerability of ecosystem services to land use change. In *Agriculture, Ecosystems and Environment* (Vol. 114, pp. 69–85). https://doi.org/10.1016/j.agee.2005.11.025

Miller, J. D., & Hutchins, M. (2017, August 1). The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *Journal of Hydrology: Regional Studies*. Elsevier B.V. https://doi.org/10.1016/j.ejrh.2017.06.006

Mitchell, M. G., Suarez-Castro, A. F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K. J., … Rhodes, J. R. (2015). Reframing landscape fragmentation's effects on ecosystem services. *Trends in Ecology and Evolution*. https://doi.org/10.1016/j.tree.2015.01.011

Narayan, S., Beck, M. W., Reguero, B. G., Losada, I. J., Van Wesenbeeck, B., Pontee, N., … Burks-Copes, K. A. (2016). The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *PLoS ONE*, *11*(5). https://doi.org/10.1371/journal.pone.0154735

NASA. (2000). The Shuttle Radar Topography Mission (SRTM).

Natural Capital. (2020). InVEST | Natural Capital Project. Retrieved December 5, 2019, from https://naturalcapitalproject.stanford.edu/software/invest

Nelson, E. J., & Daily, G. C. (2010, July 22). Modelling ecosystem services in terrestrial systems. *F1000 Biology Reports*. Faculty of 1000 Ltd. https://doi.org/10.3410/B2-53

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

NRCS-USDA. (2007). Hydrologic Soil-Cover Complexes. In *Hydrology National Engineering Handbook*.

Ochoa, V., & Urbina-Cardona, N. (2017). Tools for spatially modeling ecosystem services: Publication trends, conceptual reflections and future challenges. *Ecosystem Services*. https://doi.org/10.1016/j.ecoser.2017.06.011

Oleson, K. W., Monaghan, A., Wilhelmi, O., Barlage, M., Brunsell, N., Feddema, J., … Steinhoff, D. F. (2015). Interactions between urbanization, heat stress, and climate change. *Climatic Change*, *129*(3–4), 525–541. https://doi.org/10.1007/s10584-013-0936-8

OpenStreetMap contributors. (2019). OpenStreetMap Planet dump. Retrieved from https://planet.openstreetmap.org

OSM. (2020). Open Street Map Land polygons.

Pavani, B. F., Sousa Júnior, W. C., Inouye, C. E. N., Vieira, S. A., & Mello, A. Y. I. (2018). Estimating and valuing the carbon release in scenarios of land-use and climate changes in a Brazilian coastal area. *Journal of Environmental Management*. https://doi.org/10.1016/j.jenvman.2018.08.059

Pelczynski, J., & Tomkowicz, B. (2019). Densification of cities as a method of sustainable development. In *IOP Conference Series: Earth and Environmental Science* (Vol. 362). https://doi.org/10.1088/1755-1315/362/1/012106

Peña, L., Onaindia, M., Fernández de Manuel, B., Ametzaga-Arregi, I., & Casado-Arzuaga, I. (2018). Analysing the Synergies and Trade-Offs between Ecosystem Services to Reorient Land Use Planning in Metropolitan Bilbao (Northern Spain). *Sustainability*, *10*(12), 4376. https://doi.org/10.3390/su10124376

Puppim de Oliveira, J. A. (2019). Sustainability Challenges in an Urban Century: Can We Change Urbanization Paths to Make Cities the Solutions for Rather than the Drivers of Global Problems? *Challenges in Sustainability*, *7*(1). https://doi.org/10.12924/cis2019.07010001

R Development Core Team. (2010). R: A language and environment for statistical computing. R foundation for statistical computing, Vienne, Austria.

Remijn, T. (2020). *The Cooling Effect of Urban Green Spaces in Paramaribo*. University of Amsterdam.

Revi, A. (2017). Re-imagining the United Nations' Response to a Twenty-first-century Urban World. *Urbanisation*, *2*(2), ix–xv. https://doi.org/10.1177/2455747117740438

Richards, D., Masoudi, M., Oh, R. R. Y., Yando, E. S., Zhang, J., Friess, D. A., … Edwards, P. J. (2019). Global variation in climate, human development, and population density has implications for urban ecosystem services. *Sustainability (Switzerland)*, *11*(22), 6200. https://doi.org/10.3390/su11226200

Rojas-Rueda, D., Nieuwenhuijsen, M. J., Gascon, M., Perez-Leon, D., Rojas-Rueda, D., Nieuwenhuijsen, M. J., … Mudu, P. (2019). *Green spaces and mortality: a systematic review and meta-analysis of cohort studies*. *Articles Lancet Planet Health* (Vol. 3). https://doi.org/10.1016/S2542-5196(19)30215-3

Sallustio, L., Quatrini, V., Geneletti, D., Corona, P., & Marchetti, M. (2015). Assessing land take by urban development and its impact on carbon storage: Findings from two case studies in Italy. https://doi.org/10.1016/j.eiar.2015.05.006

Salmond, J. A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., … Wheeler, B. W. (2016). Health and climate related ecosystem services provided by street trees in the urban environment. *Environmental Health*, *15*(S1), S36. https://doi.org/10.1186/s12940-016-0103-6

SBB, CELOS, CATIA, & NZCS. (2017). *State-of-the-art study: Best estimates for emission factors and carbon stocks for Suriname*.

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, *6*(8). https://doi.org/10.1371/journal.pone.0023777

Shamshad, A., Leow, C. S., Ramlah, A., Wan Hussin, W. M. A., & Mohd. Sanusi, S. A. (2008). Applications of AnnAGNPS model for soil loss estimation and nutrient loading for Malaysian conditions. *International Journal of Applied Earth Observation and Geoinformation*, *10*(3), 239–252. https://doi.org/10.1016/j.jag.2007.10.006

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., … Douglass, J. (2020). InVEST 3.8.0 User's Guide.

Shih, W.-Y. (2016). Landscape Research The cooling effect of green infrastructure on surrounding built environments in a sub-tropical climate: a case study in Taipei metropolis. https://doi.org/10.1080/01426397.2016.1235684

Silver, J. M., Arkema, K. K., Griffin, R. M., Lashley, B., Lemay, M., Maldonado, S., … Verutes, G. (2019). Advancing coastal risk reduction science and implementation by accounting for climate, ecosystems, and people. *Frontiers in Marine Science*, *6*(SEP), 556. https://doi.org/10.3389/fmars.2019.00556

Smith, J. E., Heath, L. S., & Hoover, C. M. (2013). Carbon factors and models for forest carbon estimates for the 2005-2011 National Greenhouse Gas Inventories of the United States. *FOREST ECOLOGY AND MANAGEMENT*, *307*, 7–19. https://doi.org/10.1016/j.foreco.2013.06.061

Spalding, M. D., McIvor, A., Tonneijck, F. H., Tol, S., & van Eijk, P. (2014). Mangroves for coastal defence: guidelines for coastal managers & policy makers. *Wetlands International and The Nature Conservancy*, 42. https://doi.org/Wetlands International and The Nature Conservancy

Spalding, M. D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L. Z., Shepard, C. C., & Beck, M. W. (2014). The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean and Coastal Management*, *90*, 50–57. https://doi.org/10.1016/j.ocecoaman.2013.09.007

SPS. (2017). *Agro-Ecological Zoning, Suriname*.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Strohbach, M. W., & Haase, D. (2012). Above-ground carbon storage by urban trees in Leipzig, Germany: Analysis of patterns in a European city. *Landscape and Urban Planning*, *104*(1), 95–104. https://doi.org/10.1016/j.landurbplan.2011.10.001

Suriname REDD. (2020). REDD+ Suriname. Retrieved from https://www.surinameredd.org/en/reddplus/

Takebayashi, H., & Moriyama, M. (2007). Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. *Building and Environment*, *42*(8), 2971–2979. https://doi.org/10.1016/j.buildenv.2006.06.017

Taus, R. (n.d.). *Analyzing the historic change of urban green spaces in Paramaribo by determining the spatial distribution using GIS and Remote Sensing software (MSc Thesis)*. Anton de Kom University of Suriname.

TBIS. (2019). To a Climate Smart Suriname through awareness workshop and Art at Waka Pasi - Tropenbos Suriname. Retrieved May 24, 2020, from https://www.tropenbos.sr/nieuws/to+a+climate+smart+suriname+through+awareness+workshop+and+art+at+waka+pasi

Trabucco, A., & Zomer, R. J. (2018). Global Aridity Index and Potential Evapo-Transpiration (ET0) Climate Database v2. CGIAR Consortium for Spatial Information (CGIAR-CSI). Published online, available from the CGIAR-CSI GeoPortal at https://cgiarcsi.community.

Tratalos, J., Fuller, R. A., Warren, P. H., Davies, R. G., & Gaston, K. J. (2007). Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning*, *83*, 308–317. https://doi.org/10.1016/j.landurbplan.2007.05.003

Tropenbos Suriname. (2019). Groen Paramaribo. Retrieved November 16, 2019, from http://groenparamaribo.org/

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*, *166*, 628–637. https://doi.org/10.1016/j.envres.2018.06.030

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007, June 20). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2007.02.001

United Nations. (2015). Sustainable Development Knowledge Platform. Retrieved September 29, 2019, from https://sustainabledevelopment.un.org/#

United Nations. (2018). *World Urbanization Prospects: The 2018 Revision*. *World Urbanization Prospects: The 2018 Revision*. https://doi.org/10.18356/b9e995fe-en

United Nations. (2019). *World Population Prospects 2019: Highlights*. *Department of Economic and Social Affairs.*

Uusitalo, L., Lehikoinen, A., Helle, I., & Myrberg, K. (2015, January 1). An overview of methods to evaluate uncertainty of deterministic models in decision support. *Environmental Modelling and Software*. Elsevier Ltd. https://doi.org/10.1016/j.envsoft.2014.09.017

van Vliet, J. (2019). Direct and indirect loss of natural area from urban expansion. *Nature Sustainability*, *2*(8), 755–763. https://doi.org/10.1038/s41893-019-0340-0

Van Vliet, J., Bregt, A., Bregt, A. K., Brown, D. G., Van Delden, H., Heckbert, S., & Verburg, P. H. (2016). A review of current calibration and validation practices in land-change modeling SIGEOMODII View project Alternative trajectories for sustainable urban development in China: a scenario-based analysis View project A review of current calibration and validation practices in land-change modeling. https://doi.org/10.1016/j.envsoft.2016.04.017

van Vliet, J., Bregt, A. K., Brown, D. G., van Delden, H., Heckbert, S., & Verburg, P. H. (2016, August 1). A review of current calibration and validation practices in land-change modeling. *Environmental Modelling and Software*. Elsevier Ltd. https://doi.org/10.1016/j.envsoft.2016.04.017

Vargas-Hernández, J. G., Pallagst, K., & Zdunek-Wielgołaska, J. (2018). Urban Green Spaces as a Component of an Ecosystem. In *Handbook of Engaged Sustainability* (pp. 1–32). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-53121-2_49-1

Vaz Monteiro, M., Doick, K. J., Handley, P., & Peace, A. (2016). The impact of greenspace size on the extent of local nocturnal air temperature cooling in London. *Urban Forestry and Urban Greening*, *16*, 160–169. https://doi.org/10.1016/j.ufug.2016.02.008

Velasco, E., & Wee Chen, K. (2019). Carbon storage estimation of tropical urban trees by an improved allometric model for aboveground biomass based on terrestrial laser scanning. https://doi.org/10.1016/j.ufug.2019.126387

Verburg, P. H., & Overmars, K. P. (2009). Combining top-down and bottom-up dynamics in land use modeling: Exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landscape Ecology*, *24*(9), 1167–1181. https://doi.org/10.1007/s10980-009-9355-7

Verrest, H. J. L. M. (2010). Paramaribo. *Cities*, *27*(1), 50–60. https://doi.org/10.1016/j.cities.2009.07.003

Wang, Y., van Vliet, J., Pu, L., & Verburg, P. H. (2019). Modeling different urban change trajectories and their trade-offs with food production in Jiangsu Province, China. *Computers, Environment and Urban Systems*, *77*. https://doi.org/10.1016/j.compenvurbsys.2019.101355

Weeks, J. R. (2010). Defining urban areas. In *Remote Sensing and Digital Image Processing* (Vol. 10, pp. 33–45). Springer International Publishing. https://doi.org/10.1007/978-1-4020-4385-7_3

Wenting, W., Yi, R., & Hengyu, Z. (2012). Investigation on Temperature dropping effect of Urban Green Space in summer in Hangzhou. *Energy Procedia*, *14*, 217–222. https://doi.org/10.1016/j.egypro.2011.12.920

Willemen, L., Burkhard, B., Crossman, N., Drakou, E. G., & Palomo, I. (2015). Editorial: Best practices for mapping ecosystem services. *Ecosystem Services*, *13*, 1–5. https://doi.org/10.1016/j.ecoser.2015.05.008

Wisner, B., Gaillard, J. C., & Kelman, I. (2012). *Handbook of hazards and disaster risk reduction*. *Handbook of Hazards and Disaster Risk Reduction*. https://doi.org/10.4324/9780203844236

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough.' https://doi.org/10.1016/j.landurbplan.2014.01.017

World Bank. (2018). Population, total - Suriname | Data. Retrieved November 16, 2019, from https://data.worldbank.org/indicator/SP.POP.TOTL?locations=SR

Wu, Y., Tao, Y., Yang, G., Ou, W., Pueppke, S., Sun, X., … Tao, Q. (2019). Impact of land use change on multiple ecosystem services in the rapidly urbanizing Kunshan City of China: Past trajectories and future projections. *Land Use Policy*, *85*, 419–427. https://doi.org/10.1016/j.landusepol.2019.04.022

Xiang, H., Jia, M., Wang, Z., Li, L., Mao, D., Zhang, D., … Zhu, W. (2018). Impacts of Land Cover Changes on Ecosystem Carbon Stocks Over the Transboundary Tumen River Basin in Northeast Asia. *Chinese Geographical Science*, *28*(6), 973–985. https://doi.org/10.1007/s11769-018-1006-y

Yao, L., Chen, L., Wei, W., & Sun, R. (2015). Potential reduction in urban runoff by green spaces in Beijing: A scenario analysis. *Urban Forestry and Urban Greening*, *14*(2), 300–308. https://doi.org/10.1016/j.ufug.2015.02.014

Zank, B., Bagstad, K. J., Voigt, B., & Villa, F. (2016). Modeling the effects of urban expansion on natural capital stocks and ecosystem service flows: A case study in the Puget Sound, Washington, USA. *Landscape and Urban Planning*, *149*, 31–42. https://doi.org/10.1016/j.landurbplan.2016.01.004

Zardo, L., Geneletti, D., Pérez-Soba, M., & Van Eupen, M. (2017). Estimating the cooling capacity of green infrastructures to support urban planning. *Ecosystem Services*, *26*, 225–235. https://doi.org/10.1016/j.ecoser.2017.06.016

Zevenbergen, C., Veerbeek, W., Gersonius, B., & Van Herk, S. (2008). Challenges in urban flood management: travelling across spatial and temporal scales. *Journal of Flood Risk Management*, *1*(2), 81–88. https://doi.org/10.1111/j.1753-318x.2008.00010.x

Zhan, X., & Ukkusuri, S. V. (2019). Spatial dependency of urban sprawl and the underlying road network structure. *Journal of Urban Planning and Development*, *145*(4), 04019014. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000526

Zhang. (2015). The trends, promises and challenges of urbanisation in the world. https://doi.org/10.1016/j.habitatint.2015.11.018

Zhang, D., Huang, Q., He, C., & Wu, J. (2017). Impacts of urban expansion on ecosystem services in the Beijing-Tianjin-Hebei urban agglomeration, China: A scenario analysis based on the Shared Socioeconomic Pathways. *Resources, Conservation and Recycling*, *125*, 115–130. https://doi.org/10.1016/j.resconrec.2017.06.003

Zhang, K., Liu, H., Li, Y., Xu, H., Shen, J., Rhome, J., & Iii, T. J. S. (2012). The role of mangroves in attenuating storm surges. *Estuarine, Coastal and Shelf Science*, *102–103*, 11–23. https://doi.org/10.1016/j.ecss.2012.02.021

Zhang, Y., Liu, Y., Zhang, Y., Liu, Y., Zhang, G., & Chen, Y. (2018). On the spatial relationship between ecosystem services and urbanization: A case study in Wuhan, China. *Science of the Total Environment*, *637–638*, 780–790. https://doi.org/10.1016/j.scitotenv.2018.04.396

Zhang, Y., Ruckelshaus, M., Arkema, K. K., Han, B., Lu, F., Zheng, H., & Ouyang, Z. (2020). Synthetic vulnerability assessment to inform climate-change adaptation along an urbanized coast of Shenzhen, China. *Journal of Environmental Management*, *255*, 109915. https://doi.org/10.1016/j.jenvman.2019.109915

Zhao, S., Tang, Y., & Chen, A. (2016). Carbon Storage and Sequestration of Urban Street Trees in Beijing, China. *Frontiers in Ecology and Evolution*, *4*(MAY), 53. https://doi.org/10.3389/fevo.2016.00053

7. Appendix

List of Appendices

Appendix 1: Underpinning land cover classification

Land cover classification was carried out by Taus, (IN PREP) using sentinel 2 imagery from September 2019. The Sentinel Application Platform (SNAP) was used to atmospherically correct the images and then resample them to a resolution of 10m (Taus, IN PREP). Table 17 defines the original classification of land covers by Taus, and Figure 19 shows the original land cover map which I then reclassified for this research. This reclassification simply combined built up and infrastructure into an "urban" class, thereby specifically defining "urban" as a combination of the definitions used for the original classes in Table 17.

Table 17: Land cover classes as defined and mapped by Taus (IN PREP). Those reclassified into urban are indicated in bold text.

Land cover class	Definition
Water	More than 50% of 10 x 10 m covered by water
Built up	More than 50% of 10 x 10 m covered by buildings or houses
Trees	More than 50% of 10 x 10 m covered by trees
Mangrove	More than 50% of 10 x 10 m covered by mangrove
Mixed low vegetation	More than 50% of 10 x 10 m covered by a mixture of low vegetation
Infrastructure	More than 50% of 10 x 10 m covered by hard road surface
Grass	More than 50% of 10 x 10 m covered by grass (both high and low)
Bare soil	More than 50% of 10 x 10 m covered by bare soil

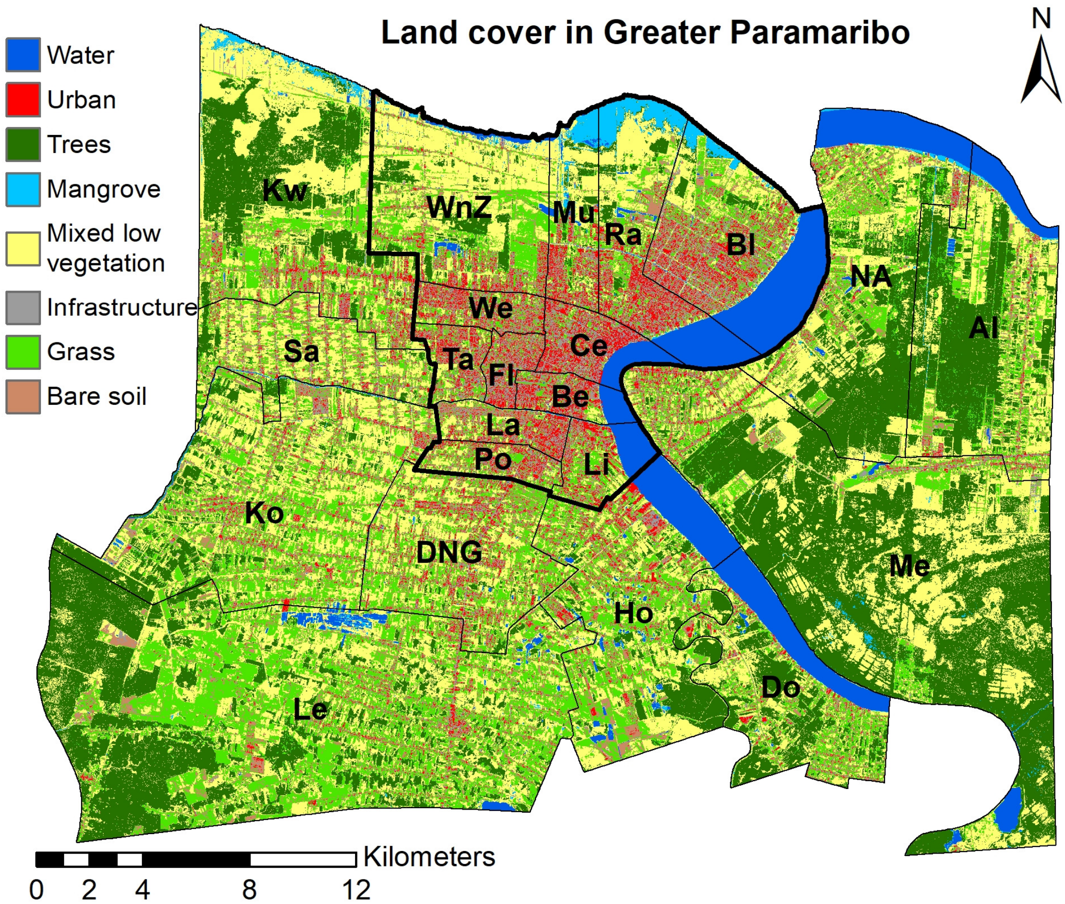

Figure 19: The land cover classification by Taus (IN PREP) which was reclassified for use within this study

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

Appendix 2: Temperature “drops” in Paramaribo used to determine air temperature inputs in the InVEST Urban Cooling model

Figure 20: Air temperature recording drops utilised within this study and the wider TBIS twinning project.

Appendix 3: Interview script and questions.

Introduction

Thank you for taking the time to talk to me. I'd first like to ask you to sign this consent form which outlines the reasons behind this interview and how the information will be used. Please take your time and if you have any questions or concerns please feel free to ask.

I will first briefly explain why I'm in Paramaribo and why I'm interviewing you.

As explained in the consent form, I'm beginning research which is part of the project entitled "Towards a Green and more Liveable Paramaribo" being carried out by Tropenbos Suriname and the University of Twente. I'll be investigating **what benefits** green areas (so parks, trees, grass, mangroves etc) have for the people of Paramaribo and **where these benefits** are most experienced.

I'm also really interested in the future of Paramaribo and within my research I will consider some **future scenarios.** This will allow me to estimate how benefits from green spaces might change in the future. This is what this interview is mainly about – I want to understand how you see the future of Paramaribo. More specifically, I would like to get you to think about how you see Paramaribo changing in the next 15 years, with a particular focus on **urban expansion** and **changes in green space**.

Do you have **any questions** so far?

My first questions are about future urban expansion in Paramaribo. I would like you to think about how different Paramaribo will be by 2035.

1. **Where will urban expansion happen between now and 2035? Why?**
    a. Will there be development in the central districts of the city or rather on the outskirts?
    b. Is there a particular direction or district where urban expansion will occur?
2. **What are your expectations for population growth by 2035?**
    a. Do you have any expectations for how much land will be required to accommodate this population?
3. **Where do you think urban expansion will not happen between now and 2035? Why?**

My next questions are about how the future urban changes we've just discussed could affect green spaces, firstly in Paramaribo and then in the Greater Paramaribo area (pointed out using maps).

4. **What will happen to green space within Paramaribo city between now and 2035?**
    a. Will there be a general increase or decrease in the amount of green space in Paramaribo city?
    b. Where will changes of green space happen within the city? (outskirts, central, districts?)
    c. Will there be a specific type of green which will increase or decrease (e.g. trees or grass)?
    d. Will green spaces change from one type to another within the city (e.g. from grass to trees)?
5. **What will happen to green space in the Greater Paramaribo region between now and 2035?**
    a. Will there be a general increase or decrease in the amount of green in Greater Paramaribo?
    b. Where will changes of green space happen in Greater Paramaribo?
    c. Will there be a specific type of green which will increase or decrease (e.g. trees / grass / mangroves)?
    d. Will green change from one type to another in Greater Paramaribo (e.g. from grass to trees)?

That is all the questions I have on the future urban expansion of Paramaribo and future green space. One final question:

6. **Are you aware of any past or ongoing projects which could give further insight into predicted future urban changes or green spaces in Paramaribo?**

That is the end of my interview. Do you have **any questions** for me?

Thank you for your time. Your answers have been really informative and I'm sure they'll be useful for my research. If you think of any further information which could help please don't hesitate to email me.

Appendix 4: Interview consent form

Declaration of consent

Research Project: Current and future supply of ecosystem services derived from urban green space in the tropical city of Paramaribo (MSc Thesis)

Organization: Tropenbos Suriname & University of Twente & University of Amsterdam

---

The MSc thesis research project investigates the supply of ecosystem services from urban green space in Paramaribo, Suriname. The research is part of a larger project by Tropenbos Suriname and the University of Twente, entitled "Towards a Green and Livable Paramaribo". The purpose of this interview is to understand how Paramaribo is expected to change in the next 10-15 years with regards to urban expansion and changes in green space. This will inform the development of scenarios which will allow for analysis of how current ecosystem services derived from green space might change in the future.

Your personal contact details will be separated from the interview data and will be stored inaccessible to third parties. After completion of the research project, your contact details will be deleted.

Participation in the interview is voluntary. You have the option to discontinue at all times without any disadvantages.

By signing this consent, I agree with the following:

I have read (or it has been read to me) and understand the research project.

I will participate in the interview relating to the research project.

I hereby agree that the explained data are collected and will be used for research purposes.

☐Yes ☐No

I agree that the interview will be recorded. This will be stored inaccessible to third parties and will be deleted after completion of the project.

☐Yes ☐No

____

Forename, Surname (in Block letters)

____

Place, Date, Signature

Appendix 5: R script used to build regression models in order to determine Dyna-CLUE suitability inputs and plot land cover probability maps

```
## Script adapted from that written by T.A. Groen in 2014 (Provided by the University of Twente) ##
setwd("D:/ClueSpara/dyna_clue/stat_files")
# Reading in sample files-------------------------------------------------------------------------------------
t<-read.table(file="stat_trees.txt",header=T)
m<-read.table(file="stat_mangrove.txt",header=T)
g<-read.table(file="stat_grass.txt",header=T)
ml<-read.table(file="stat_mixlow.txt",header=T)
u<-read.table(file="stat_urban.txt",header=T)
#Renaming columns to match the 14 location variables ---------------------------------------------------------
names(t)<- c("Trees","Distance_from_coast", "Distance_from_junction", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES", "Distance_from_middleSES", "Distance_from_midlowSES", "Geology",
"Distance_from_water")
names(m)<- c("Mangrove", "Distance_from_coast", "Distance_from_junction", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES", "Distance_from_middleSES", "Distance_from_midlowSES", "Geology",
"Distance_from_water")
names(g)<- c("Grass", "Distance_from_coast", "Distance_from_junction", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES", "Distance_from_middleSES", "Distance_from_midlowSES", "Geology",
"Distance_from_water")
names(ml)<- c("MixLow", "Distance_from_coast", "Distance_from_junction", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES", "Distance_from_middleSES", "Distance_from_midlowSES", "Geology",
"Distance_from_water")
names(u)<- c("Urban", "Distance_from_coast", "Distance_from_junction", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES", "Distance_from_middleSES", "Distance_from_midlowSES", "Geology",
"Distance_from_water")
#Fitting a GLM ----------------------------------------------------------------------------------------------
glm.trees <- glm(Trees ~.,data=t,family=binomial)
glm.mangrove <- glm(Mangrove ~.,data=m,family=binomial)
glm.grass <- glm(Grass ~.,data=g,family=binomial)
glm.mixlow <- glm(MixLow ~.,data=ml,family=binomial)
glm.urban <- glm(Urban ~.,data=u,family=binomial)
#Stepwise approach -------------------------------------------------------------------------------------------
glm.trees.st<-step(glm.trees )
glm.mangrove.st<-step(glm.mangrove )
glm.grass.st<-step(glm.grass )
glm.mixlow.st<-step(glm.mixlow )
glm.urban.st<-step(glm.urban )
#VIF (Variance Inflation Factor) - to check no multicollinearity ---------------------------------------------
library(car)
vif(glm.trees.st)
vif(glm.mangrove.st)
vif(glm.mixlow.st)
vif(glm.grass.st)
vif(glm.urban.st)
#Removal of variables identified to have high VIF values -----------------------------------------------------
t$Distance_from_centrum <- NULL
t$Distance_from_midlowSES <- NULL
m$Distance_from_centrum <- NULL
m$Distance_from_midlowSES <- NULL
m$Distance_from_bridge <- NULL
ml$Distance_from_centrum <- NULL
ml$Distance_from_midlowSES <- NULL
g$Distance_from_midlowSES <- NULL
g$Distance_from_centrum <- NULL
u$Distance_from_centrum <- NULL
#Redoing stepwise approach without high VIF variables --------------------------------------------------------
glm.trees.st<-step(glm.trees )
glm.mangrove.st<-step(glm.mangrove )
glm.grass.st<-step(glm.grass )
glm.mixlow.st<-step(glm.mixlow )
glm.urban.st<-step(glm.urban )
glm.trees <- glm(Trees ~.,data=t,family=binomial)
glm.mangrove <- glm(Mangrove ~.,data=m,family=binomial)
glm.grass <- glm(Grass ~.,data=g,family=binomial)
glm.mixlow <- glm(MixLow ~.,data=ml,family=binomial)
glm.urban <- glm(Urban ~.,data=u,family=binomial)
# Coefficients for Dyna-CLUE ----------------------------------------------------------------------------------
glm.trees.st$coefficients
```

```
write.table(glm.trees.st$coefficients,file="trees_coef.txt")
glm.mangrove.st$coefficients
write.table(glm.mangrove.st$coefficients,file="mangrove_coef.txt")
glm.grass.st$coefficients
write.table(glm.grass.st$coefficients,file="grass_coef.txt")
glm.mixlow.st$coefficients
write.table(glm.mixlow.st$coefficients,file="mixlow_coef.txt")
glm.urban.st$coefficients
write.table(glm.urban.st$coefficients,file="urban_coef.txt")
glm.other.st$coefficients
write.table(glm.other.st$coefficients,file="other_coef.txt")
#ROC analyses to identify AUC values---------------------------------------------------------------------------------
library(PresenceAbsence)
roc.trees<-data.frame(ID=1:length(t$Trees),
                       PA=t$Trees,
                       model=predict(glm.trees.st,type="response"))
roc.mangrove<-data.frame(ID=1:length(m$Mangrove),
                          PA=m$Mangrove,
                          model=predict(glm.mangrove.st,type="response"))
roc.grass<-data.frame(ID=1:length(g$Grass),
                       PA=g$Grass,
                       model=predict(glm.grass.st,type="response"))
roc.mixlow<-data.frame(ID=1:length(ml$MixLow),
                        PA=ml$MixLow,
                        model=predict(glm.mixlow.st,type="response"))
roc.urban<-data.frame(ID=1:length(u$Urban),
                       PA=u$Urban,
                       model=predict(glm.urban.st,type="response"))
roc.other<-data.frame(ID=1:length(o$Other),
                       PA=o$Other,
                       model=predict(glm.other.st,type="response"))
#ROC Plots -----------------------------------------------------------------------------------------------------
auc.roc.plot(roc.trees, main="ROC Plot Trees")
auc.roc.plot(roc.mangrove, main="ROC Plot Mangrove")
auc.roc.plot(roc.grass, main="ROC Plot Grass")
auc.roc.plot(roc.mixlow, main="ROC Plot Mix Low Vegetation")
auc.roc.plot(roc.urban, main="ROC Plot Urban")
auc.roc.plot(roc.other, main="ROC Plot Other")
#Land cover maps -----------------------------------------------------------------------------------------------
require(raster)
trees.map<-raster("D:/ClueSpara/dyna_clue/cov0.0.asc")
mangrove.map<-raster("D:/ClueSpara/dyna_clue/cov1.0.asc")
grass.map<-raster("D:/ClueSpara/dyna_clue/cov3.0.asc")
mixlow.map<-raster("D:/ClueSpara/dyna_clue/cov2.0.asc")
urban.map<-raster("D:/ClueSpara/dyna_clue/cov4.0.asc")
other.map<-raster("D:/ClueSpara/dyna_clue/cov5.0.asc")
plot(trees.map, main="Trees")
plot(mangrove.map, main="Mangrove")
plot(grass.map, main="Grass")
plot(mixlow.map, main="Mixed Low Vegetation")
plot(urban.map, main="Urban")
plot(other.map, main="Others")
# Making a database that contains all predictor maps and creating a stack of all driving variables-------------------
lst <- list.files(pattern="fil$", full.names=T)
drivers <- stack(lst)
plot(drivers)
# Ensuring names are matching / in the same order as in dataset and raster stack to plot driving variables ----------
names(drivers)
names(drivers)<- c("Distance_from_coast", "Distance_from_junction", "Distance_from_middleSES",
"Distance_from_midlowSES", "Geology", "Distance_from_water", "Distance_from_primary_road",
"Distance_from_secondary_road", "Elevation", "Distance_from_centrum", "Distance_from_bridge", "Distance_from_swamp",
"Distance_from_poorSES", "Distance_from_richSES")
plot(drivers)
# Predict function to make a prediction extrapolated over the whole map ---------------------------------------------
trees.prob<-predict(drivers,glm.trees.st, type="response")
mangrove.prob<-predict(drivers,glm.mangrove.st, type="response")
grass.prob<-predict(drivers,glm.grass.st, type="response")
mixlow.prob<-predict(drivers,glm.mixlow.st, type="response")
urban.prob<-predict(drivers,glm.urban.st, type="response")
writeRaster(trees.prob, filename=file.path("tree_prob.tif"), format="GTiff", overwrite=TRUE)
writeRaster(mangrove.prob, filename=file.path("mang_prob.tif"), format="GTiff", overwrite=TRUE)
writeRaster(mixlow.prob, filename=file.path("mlow_prob.tif"), format="GTiff", overwrite=TRUE)
writeRaster(grass.prob, filename=file.path("grass_prob.tif"), format="GTiff", overwrite=TRUE)
writeRaster(urban.prob, filename=file.path("urban_prob.tif"), format="GTiff", overwrite=TRUE)
```

Appendix 6: Predicted probability maps determined for each of the land covers during regression analyses

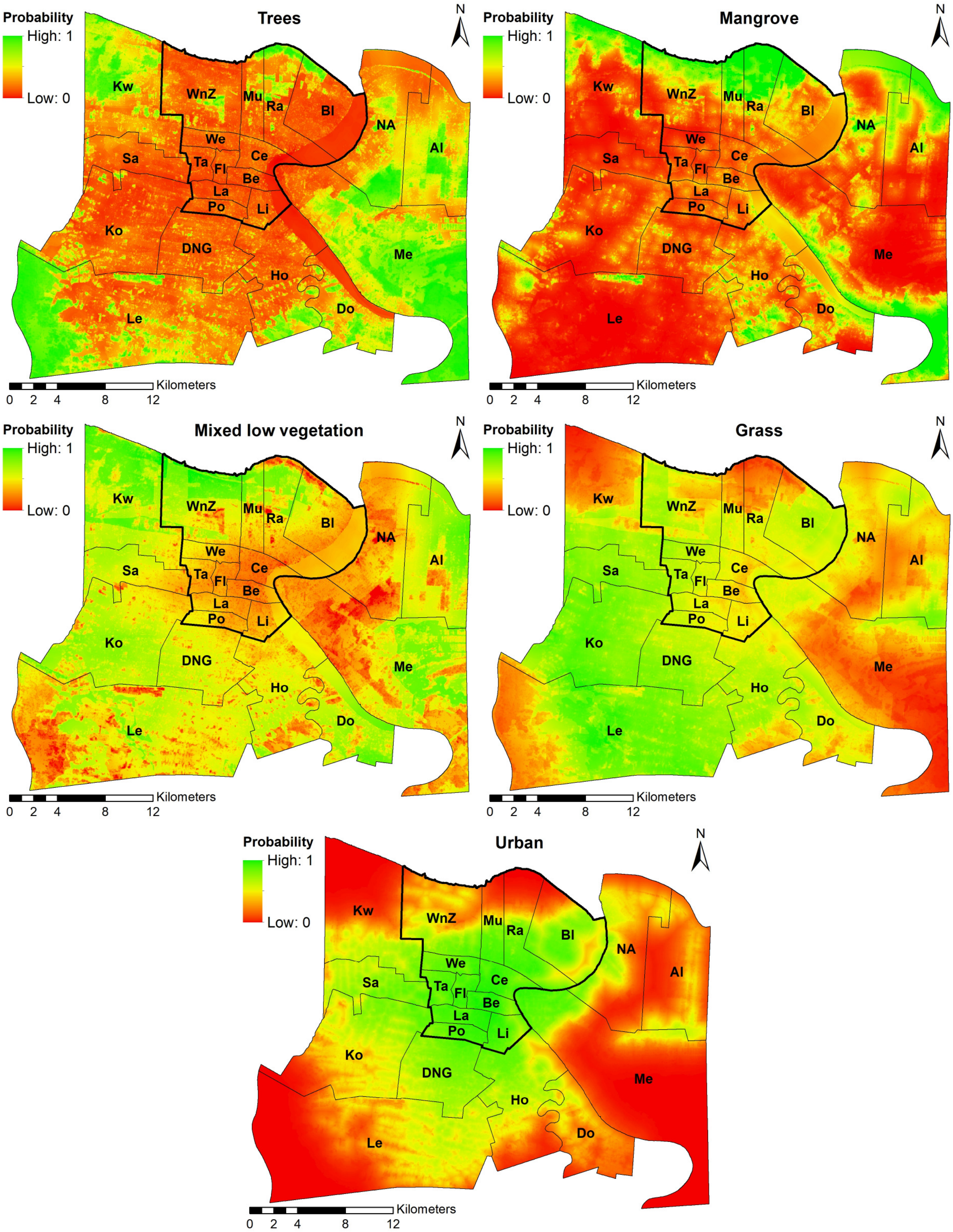

Figure 21: Predicted probability of a land cover occurring at a particular location determined via stepwise multiple regression (see section 2.4.4 and section 3.2.1). R script provided as Appendix 5.

Note: Abbreviations represent the following ressort names; Al = Alkmaar, Be = Beekhuizen, Bl = Blauwgrond, Ce = Centrum, DNG = De Nieuwe Grond, Do = Domburg, Fl = Flora, Ho = Houttuin, Ko = Koewarasan, Kw = Kwatta, La = Latour, Le = Lelydorp, Li = Livorno, Me = Meerzorg, Mu = Munder, NA = Nieuw Amsterdam, Po = Pontbuiten, Ra = Rainville, Sa = Saramaccapolder, Ta = Tammenga, WnZ = Weg naar Zee, We = Welgelegen

Appendix 7: Ressort and regional-based coastal protection analyses

Table 18: Mean exposure index (EI) and habitat role (coastal protection supply) in reducing this under different scenarios and per ressort and region

	Scenario	Current		Business as usual			Protection policy			Greening of Paramaribo		
	Ressort	Mean Exposure (EI)	Mean Habitat role	Mean Exposure (EI)	Mean Habitat role	Change in mean habitat role	Mean Exposure (EI)	Mean Habitat role	Mean Change in habitat role	Mean Exposure (EI)	Mean Habitat role	Mean Change in habitat role
Paramaribo	Weg naar Zee	2.57	0.71	2.62	0.66	-0.05	2.57	0.71	0.00	2.57	0.71	0.00
	Munder	2.07	0.60	2.15	0.52	-0.08	2.07	0.60	0.00	2.07	0.60	0.00
	Rainville	2.47	0.45	2.47	0.45	0.00	2.46	0.46	0.01	2.47	0.45	0.00
	Blauwgrond	2.93	0.59	3.06	0.45	-0.13	2.92	0.59	0.01	2.94	0.58	-0.01
	Centrum	3.09	0.33	3.27	0.15	-0.18	3.27	0.15	-0.18	3.09	0.33	0.00
	Beekhuizen	2.72	0.70	3.31	0.11	-0.59	3.31	0.11	-0.59	2.73	0.69	-0.01
	Livorno	2.82	0.71	3.38	0.15	-0.56	3.22	0.31	-0.40	2.85	0.68	-0.03
Greater Paramaribo	Kwatta	2.25	0.61	2.20	0.65	0.04	2.21	0.64	0.03	2.25	0.60	-0.01
	Houttuin	3.44	0.55	3.55	0.44	-0.11	3.44	0.55	0.00	3.44	0.55	0.00
	Domburg	2.95	0.44	2.93	0.46	0.02	2.93	0.46	0.02	2.93	0.46	0.02
	Meerzorg	2.19	0.48	2.36	0.31	-0.17	2.35	0.33	-0.16	2.21	0.46	-0.02
	Nieuw Amsterdam	2.05	0.57	2.11	0.51	-0.06	2.03	0.59	0.02	2.06	0.57	-0.01
	Alkmaar	2.05	0.62	2.07	0.60	-0.02	2.05	0.62	0.00	2.04	0.63	0.01
Greater Paramaribo (all)		2.49	0.55	2.59	0.45	-0.11	2.54	0.50	-0.06	2.49	0.55	-0.01
Paramaribo		2.70	0.59	2.86	0.44	-0.16	2.79	0.51	-0.08	2.71	0.59	-0.01
Greater Paramaribo only		2.36	0.53	2.43	0.45	-0.07	2.40	0.49	-0.04	2.36	0.52	-0.01

Appendix 8: Ressort and regional-based flood risk mitigation analyses

Table 19: Mean and total runoff retention supply under different scenarios and per ressort and region

	Scenario:	Current		Business as usual				Protection policy				Greening of Paramaribo			
	Ressort	Mean runoff retention (m3 per pixel)	Total Runoff retention (m3)	Mean runoff retention (m3 per pixel)	Difference vs current mean runoff retention (m3 per pixel)	Total Runoff retention (m3)	Difference vs current total runoff retention (m3)	Mean runoff retention (m3 per pixel)	Difference vs current mean runoff retention (m3 per pixel)	Total Runoff retention (m3)	Difference vs current total runoff retention (m3)	Mean runoff retention (m3 per pixel)	Difference vs current mean runoff retention (m3 per pixel)	Total Runoff retention (m3)	Difference vs current total runoff retention (m3)
Paramaribo	Beekhuizen	2.62	165658.69	2.59	-0.04	163436.19	-2222.50	2.62	-0.01	165113.24	-545.45	2.70	0.08	170457.70	4799.01
	Flora	2.95	132060.21	2.95	0.00	132042.01	-18.19	2.95	0.00	132060.21	0.00	3.01	0.07	135047.96	2987.75
	Tammenga	3.97	251019.02	3.72	-0.26	234757.37	-16261.65	3.71	-0.26	234582.52	-16436.50	3.93	-0.05	247996.65	-3022.37
	Centrum	2.49	242039.79	2.48	-0.01	241547.81	-491.98	2.48	0.00	241839.23	-200.56	2.53	0.04	246086.85	4047.06
	Blauwgrond	3.21	1177020.80	3.24	0.03	1187951.49	10930.70	3.27	0.06	1198400.38	21379.59	3.48	0.26	1273728.00	96707.20
	Rainville	4.00	1110225.09	3.95	-0.05	1095942.63	-14282.45	3.99	-0.02	1105347.90	-4877.18	4.17	0.16	1155339.54	45114.45
	Pontbuiten	4.23	279496.61	3.66	-0.57	241956.90	-37539.72	3.64	-0.58	241002.69	-38493.92	3.93	-0.29	260084.37	-19412.24
	Livorno	3.22	285755.35	2.41	-0.81	214146.62	-71608.73	2.46	-0.76	218263.82	-67491.53	2.56	-0.66	226922.25	-58833.11
	Latour	3.82	273324.03	3.29	-0.52	235823.28	-37500.75	3.33	-0.48	238798.58	-34525.44	3.38	-0.44	241796.25	-31527.78
	Weg naar Zee	5.04	1987787.67	5.08	0.04	2004923.33	17135.66	5.14	0.10	2028477.95	40690.28	5.43	0.39	2143567.10	155779.42
	Munder	4.79	630954.87	4.57	-0.22	601829.60	-29125.27	4.68	-0.11	616485.82	-14469.05	4.88	0.09	643161.09	12206.22
	Welgelegen	3.71	268785.36	3.69	-0.02	267322.27	-1463.09	3.70	-0.01	267950.17	-835.19	3.85	0.14	278807.21	10021.85
Greater Paramaribo	Houttuin	4.28	2442261.82	4.17	-0.11	2378883.37	-63378.45	4.18	-0.10	2384466.82	-57795.00	4.20	-0.08	2397297.24	-44964.59
	Koewarasan	5.35	3899099.49	5.07	-0.28	3692793.90	-206305.59	5.08	-0.27	3702644.88	-196454.61	5.20	-0.15	3787248.64	-111850.85
	Saramaccapolder	5.29	1295200.57	5.07	-0.22	1241561.15	-53639.42	5.09	-0.20	1246219.33	-48981.24	5.24	-0.05	1282193.06	-13007.50
	Meerzorg	6.02	7874467.60	5.95	-0.07	7783056.21	-91411.38	5.95	-0.07	7782128.44	-92339.15	5.90	-0.13	7708397.00	-166070.60
	Alkmaar	5.39	2908873.24	5.54	0.14	2986119.93	77246.69	5.55	0.16	2994139.66	85266.42	5.54	0.15	2987481.53	78608.29
	Lelydorp	5.41	8239399.45	5.28	-0.13	8046570.51	-192828.94	5.29	-0.12	8062061.65	-177337.80	5.28	-0.12	8050420.21	-188979.24
	Domburg	4.27	1556724.54	4.43	0.16	1616317.90	59593.37	4.45	0.18	1621111.44	64386.90	4.45	0.18	1623126.32	66401.78
	Nieuw Amsterdam	4.83	2811454.60	4.89	0.06	2844642.78	33188.18	4.90	0.07	2852027.13	40572.54	4.83	0.00	2809766.66	-1687.94
	Kwatta	6.14	4090467.99	6.13	-0.01	4082707.25	-7760.75	6.16	0.01	4099810.74	9342.74	6.29	0.15	4187268.02	96800.03
	De Nieuwe Grond	4.81	1781441.44	4.57	-0.24	1692880.70	-88560.74	4.56	-0.25	1688578.56	-92862.88	4.75	-0.05	1762072.98	-19368.46
Greater Paramaribo (all)		5.06	43703518.22	4.98	-0.08	42987213.22	-716305.00	4.99	-0.07	43121511.18	-582007.04	5.05	-0.01	43618266.60	-85251.62
Paramaribo		3.92	6804187.49	3.81	-0.11	6621718.43	-182469.05	3.85	-0.07	6688361.44	-115826.05	4.04	0.13	7023029.49	218842.01
Greater Paramaribo only		5.35	36899330.73	5.27	-0.08	36365494.79	-533835.94	5.28	-0.07	36433149.74	-466180.99	5.31	-0.04	36595237.11	-304093.62

Appendix 9: Ressort and regional-based local climate regulation analyses

Table 20: Mean heat mitigation (HM) supply and associated night-time air temperature values under different scenarios and per ressort and region

	Scenario:	Current		Business as usual				Protection policy				Greening of Paramaribo			
	Ressort	Mean HM	Mean night-time air temperature (°C)	Mean HM	Difference vs current HM	Mean night-time air temperature (°C)	Difference vs current mean night-time air temperature (°C)	Mean HM	Difference vs current HM	Mean night-time air temperature (°C)	Difference vs current mean night-time air temperature (°C)	Mean HM	Difference vs current HM	Mean night-time air temperature (°C)	Difference vs current mean night-time air temperature (°C)
Paramaribo	Beekhuizen	0.15	25.0	0.14	-0.01	25.03	0.06	0.15	0.00	25.01	0.05	0.15	0.00	25.00	0.03
	Flora	0.09	25.1	0.08	0.00	25.08	0.02	0.08	0.00	25.08	0.02	0.09	0.00	25.06	0.00
	Tammenga	0.17	24.8	0.13	-0.05	24.95	0.12	0.13	-0.05	24.95	0.12	0.16	-0.02	24.88	0.05
	Centrum	0.11	25.0	0.11	0.00	25.06	0.04	0.11	0.00	25.06	0.04	0.11	0.00	25.04	0.02
	Blauw grond	0.31	24.5	0.31	0.00	24.56	0.01	0.31	0.00	24.55	0.01	0.33	0.02	24.51	-0.04
	Rainville	0.49	24.2	0.47	-0.02	24.23	0.06	0.47	-0.01	24.22	0.05	0.50	0.01	24.18	0.00
	Pontbuiten	0.22	24.8	0.13	-0.09	24.97	0.21	0.13	-0.09	24.97	0.22	0.18	-0.04	24.88	0.13
	Livorno	0.24	24.7	0.13	-0.12	25.00	0.28	0.13	-0.11	24.98	0.27	0.15	-0.09	24.94	0.23
	Latour	0.17	24.9	0.10	-0.07	25.04	0.15	0.11	-0.06	25.03	0.14	0.12	-0.06	25.01	0.12
	Weg naar Zee	0.68	23.7	0.67	-0.01	23.76	0.01	0.67	-0.01	23.76	0.01	0.70	0.02	23.70	-0.04
	Munder	0.55	24.0	0.51	-0.04	24.07	0.08	0.52	-0.03	24.06	0.06	0.55	0.00	23.99	0.00
	Welgelegen	0.13	24.9	0.12	-0.01	24.96	0.02	0.12	0.00	24.96	0.02	0.14	0.01	24.89	-0.05
Greater Paramaribo	Houttuin	0.54	24.0	0.52	-0.03	24.10	0.06	0.51	-0.03	24.10	0.06	0.51	-0.03	24.10	0.07
	Koewarasan	0.65	23.8	0.64	-0.01	23.84	0.02	0.64	-0.01	23.84	0.02	0.64	-0.01	23.83	0.01
	Saramaccapolder	0.50	24.2	0.49	-0.01	24.19	0.03	0.48	-0.02	24.19	0.04	0.49	-0.01	24.17	0.01
	Meerzorg	0.89	23.3	0.86	-0.03	23.36	0.06	0.86	-0.03	23.36	0.06	0.86	-0.03	23.36	0.06
	Alkmaar	0.80	23.5	0.81	0.01	23.45	-0.01	0.81	0.01	23.45	-0.01	0.81	0.01	23.45	-0.01
	Lelydorp	0.80	23.5	0.80	0.00	23.46	-0.01	0.80	0.00	23.46	-0.01	0.80	0.00	23.47	0.00
	Domburg	0.61	23.8	0.62	0.01	23.76	-0.02	0.62	0.01	23.76	-0.02	0.62	0.01	23.76	-0.02
	Nieuw Amsterdam	0.70	23.7	0.69	-0.01	23.73	0.02	0.69	-0.01	23.73	0.02	0.68	-0.02	23.75	0.04
	Kwatta	0.79	23.5	0.79	0.00	23.48	0.00	0.79	0.00	23.48	0.00	0.80	0.01	23.45	-0.02
	De Nieuwe Grond	0.44	24.3	0.40	-0.04	24.36	0.10	0.40	-0.04	24.37	0.10	0.42	-0.02	24.31	0.05
Greater Paramaribo (all)		0.66	23.78	0.65	-0.01	23.81	0.03	0.65	-0.01	23.80	0.03	0.65	-0.01	23.79	0.02
Paramaribo		0.39	24.38	0.37	-0.02	24.44	0.06	0.37	-0.02	24.43	0.05	0.39	0.00	24.38	0.01
Greater Paramaribo only		0.73	23.62	0.72	-0.01	23.65	0.02	0.72	-0.01	23.65	0.02	0.72	-0.01	23.64	0.02

Appendix 10: Ressort and regional-based carbon storage analyses

Table 21: Mean and total aboveground carbon storage supply under different scenarios and per ressort and region

	Scenario:	Current		Business as usual				Protection policy				Greening of Paramaribo			
	Ressort	Mean (Mg C/pixel)	Total (Mg C)	Mean (Mg C/pixel)	Difference vs current mean	Total (Mg C)	Difference vs current total (Mg C)	Mean (Mg C/pixel)	Difference vs current mean	Total (Mg C)	Difference vs current total (Mg C)	Mean (Mg C/pixel)	Difference vs current mean	Total (Mg C)	Difference vs current total (Mg C)
Paramaribo	Beekhuizen	0.03	2156.55	0.03	-0.01	1581.70	-574.86	0.03	0.00	2050.45	-106.10	0.08	0.05	5115.99	2959.43
	Flora	0.01	505.33	0.01	0.00	500.38	-4.95	0.01	0.00	505.33	0.00	0.05	0.04	2286.20	1780.87
	Tammenga	0.06	3880.34	0.04	-0.03	2293.62	-1586.72	0.04	-0.02	2650.07	-1230.27	0.14	0.08	9005.55	5125.21
	Centrum	0.01	955.34	0.01	0.00	838.63	-116.71	0.01	0.00	922.70	-32.64	0.03	0.02	3275.46	2320.12
	Blauwgrond	0.14	52678.81	0.15	0.01	56087.93	3409.12	0.17	0.03	62705.93	10027.12	0.30	0.15	109370.80	56692.00
	Rainville	0.33	90186.50	0.33	0.01	92665.07	2478.57	0.36	0.03	98928.47	8741.97	0.50	0.17	137705.49	47518.99
	Pontbuiten	0.08	5043.14	0.05	-0.02	3574.39	-1468.74	0.06	-0.02	3735.24	-1307.90	0.19	0.11	12562.53	7519.39
	Livomo	0.07	6052.46	0.03	-0.04	2243.11	-3809.34	0.04	-0.03	3644.84	-2407.62	0.10	0.03	9013.38	2960.93
	Latour	0.07	5333.66	0.03	-0.04	2189.19	-3144.47	0.04	-0.03	3179.00	-2154.66	0.09	0.01	6187.43	853.77
	Weg naar Zee	0.34	134776.93	0.34	0.00	133275.60	-1501.33	0.39	0.05	154720.82	19943.89	0.56	0.22	222634.74	87857.81
	Munder	0.40	53261.80	0.37	-0.04	48284.89	-4976.91	0.43	0.02	56146.99	2885.19	0.56	0.15	73587.26	20325.46
	Welgelegen	0.04	3166.12	0.04	-0.01	2562.75	-603.38	0.04	-0.01	2781.87	-384.25	0.12	0.08	8798.64	5632.52
Greater Paramaribo	Houttuin	0.32	181467.59	0.31	-0.01	177029.84	-4437.75	0.32	0.00	183475.78	2008.19	0.34	0.02	193710.04	12242.45
	Koewarasan	0.35	255159.81	0.20	-0.15	146093.37	-109066.44	0.21	-0.14	154514.47	-100645.34	0.29	-0.06	209282.81	-45877.00
	Saramaccapolder	0.25	62074.96	0.14	-0.12	33092.50	-28982.46	0.15	-0.10	36779.76	-25295.20	0.24	-0.02	57756.94	-4318.03
	Meerzorg	0.94	1224241.71	0.99	0.05	1291769.81	67528.10	0.99	0.05	1292283.14	68041.43	0.94	0.00	1223432.88	-808.83
	Alkmaar	0.75	403654.23	0.78	0.03	419414.30	15760.07	0.79	0.04	427348.72	23694.49	0.79	0.04	424851.93	21197.70
	Lelydorp	0.57	873842.02	0.53	-0.04	811440.28	-62401.74	0.54	-0.03	821207.29	-52634.73	0.53	-0.05	803486.91	-70355.11
	Domburg	0.49	177686.94	0.52	0.03	190443.75	12756.81	0.53	0.05	194216.64	16529.70	0.54	0.05	195391.25	17704.31
	Nieuw Amsterdam	0.60	348189.96	0.64	0.04	371577.94	23387.98	0.64	0.05	375158.35	26968.39	0.61	0.02	357760.77	9570.81
	Kwatta	0.64	425355.95	0.62	-0.02	409823.93	-15532.02	0.63	0.00	422235.49	-3120.45	0.71	0.07	474570.73	49214.78
	De Nieuwe Grond	0.17	64151.24	0.14	-0.03	51961.81	-12189.44	0.15	-0.03	53968.25	-10182.99	0.25	0.07	90857.18	26705.94
	Greater Paramaribo (all)	0.51	4373821.38	0.49	-0.01	4248744.78	-125076.59	0.50	0.00	4353159.59	-20661.79	0.54	0.03	4630644.92	256823.54
	Paramaribo	0.21	358002.49	0.20	-0.01	346098.69	-11903.80	0.23	0.02	391973.14	33970.64	0.35	0.14	599546.47	241543.98
	Greater Paramaribo only	0.58	4015818.88	0.57	-0.02	3902646.09	-113172.79	0.57	-0.01	3961186.45	-54632.43	0.58	0.00	4031098.45	15279.57