Examining the protective services of mangroves at a regional scale in Indonesia

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Lund 2022

Title: Examining the protective services of mangroves at a regional scale in Indonesia

Author: Mikaela Gomez

Number of pages: 59
Illustrations: 14

Keywords
Mangroves, Nature-Based Solutions, Disaster Risk Reduction, Exposure, GIS, Remote Sensing

Abstract

The purpose of this thesis is to examine how the exposure of the coastal population of Kalimantan, Indonesia changed as a result of coastal mangrove loss and population growth. The change of exposure has therefore been calculated through the loss of mangrove biomass, through deforestation and degradation, over time, as well the increase in population living within $10km^2$ of disturbed mangroves. The results revealed that undisturbed mangroves have been decreasing since 1990 and that deforested and degraded mangroves have followed similar trends. Furthermore, over 20% of the total population of Kalimantan live with 10km of degraded and deforested mangroves. Given that the study covers an extensive area, three hotspots have been identified, where there has been substantial population growth in areas surrounding mangrove forests. A closer look at the governance of mangroves in Indonesia reveals that whilst there are many administrative structures responsible for the management and maintenance of mangroves, there is little cross-collaboration between actors. Furthermore, there is little use of NBS, specifically mangroves within the context of disaster risk reduction. The inclusion of mangroves in Indonesia's Nationally Determined Contributions as well as the recent implementation of a policy to replant mangroves, shows promise that mangroves will be utilised for their protective services and ability to increase local resilience.

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Acknowledgements

First and foremost, I would first like to thank both my thesis advisors. My Professor, Dr Per Becker at Lund University has been quick to respond in times of need and has continuously steered me in the right direction during this process. This thesis would also not have been possible without the guidance of Dr Thomas Häusler at GAF AG, who has been available to answer my questions and give me honest feedback. A further thanks goes to Fabian Enßle at GAF AG, for providing me with the technical support needed throughout this thesis.

Although not an official advisor, I would like to give an especially big thank you to Dr Gomez, for being an independent reviewer of this work. Aside from this, I would also like to express my deepest gratitude for the constant support and confidence she has always shown in my academic endeavours. I would not be where I am today without you.

Accomplishing this thesis took more than academic support, which is why I also have many friends and family to thank for being the best listeners and support givers during this process. Here is a special thank you to my partner and best friend, Nick for acting as sounding board, answering, and provoking my questions, and throughout the process believing in me.

Lastly, I would like to thank all of my professors and peers in this programme for two amazing years of learning, despite the unfortunate pandemic condition we found ourselves under.

Abbreviations

ALOS – Advanced Land Observing Satellite
AOI – Area of Interest
BAPPENAS - National Development Planning Agency
BNPB - The National Disaster Management Authority
BPDB - The Regional Disaster Management Agency
CCA – Climate Change Adaptation
DRR – Disaster Risk Reduction
ETM+ - Enhanced Thematic Mapper Plus
GMW – Global Mangrove Watch
HFA - Hyogo Framework for Action
IFRC – International Federation of Red Cross and Red Crescent
IUCN – International Union for the Conservation of Nature
JAXA - Japan Aerospace Exploration Agency
JRC – Joint Research Centre
M&E – Monitoring and Evaluation
MMAF - Marine Affairs and Fisheries
MOEF - Ministry of Environment and Forestry
NBS – Nature Based Solutions
SAR – Synthetic Aperture Radar
SFDRR – Sendai Framework for Disaster Risk Reduction
TM – Thematic Mapper
TMF – Tropical Moist Forest
UNDRR – United Nations Office for Disaster Risk Reduction
UNEP – United Nations Environment Programme
UNFCCC - United Nations Framework Convention on Climate Change

Summary

Indonesia is one of the most hazard prone countries in the world due to its geographic positioning which exposes the country to various risks such as earthquakes, volcanic eruptions, tsunamis, flooding, and tropical storms. Coastal forests such as mangroves can act as a nature-based solution to reducing the impacts of disasters as well as building resilience through the sustainable management of their ecosystem services. Indonesia has the most extensive mangrove cover in the world, with more than 20 per cent of the world's mangrove forests (Ilman et al., 2016; Lukman et al., 2021). Yet, years of rapid industrialization and massive land-use change such as intense oil palm and shrimp cultivation have led to rampant mangrove deforestation (Ilman et al., 2016) Mangroves lower damage by absorbing the impact from waves, floods, and rising sea levels through their large above-ground aerial root systems; they help in diversifying sustainable income sources, thereby reducing vulnerabilities, and also limit disaster exposure by acting as natural shields between human settlements and coastal hazards (M. Spalding et al., 2014; UNDRR, 2020).

The identification, of potential areas of anthropogenic stress on mangroves and areas of high mangrove loss is thus important in providing information that can be used for both preventative and reactive measures in the natural resource management of mangroves and disaster risk reduction. Furthermore, understanding the current extent of mangroves in Kalimantan will serve as a baseline for monitoring the ecosystem and additionally provide information on where the most extensive mangrove loss is occurring in conjunction with population growth. As such, this thesis has taken a case study approach with the aim of examining how the exposure of the coastal population of Kalimantan has changed as a result of coastal mangrove loss and population growth?

To answer this question, geospatial analysis has been conducted to find how the mangrove extent of Kalimantan has changed in the last 30 years, using a combination of data from the Global Mangrove Watch and the Tropical Moist Forest dataset provide by the JRC. The analysis done calculates the change in extent of undisturbed, degraded, deforested and regrowing mangroves from 1990-2020, in km^2. To answer how exposure has increased, the change in population density has been calculated between 2000- 2020 in relation to the distance from the various mangrove classes. People living in proximity to undisturbed and degraded mangroves may be more exposed to consequences of coastal hazards than those who receive more protection from many undisturbed mangroves.

In the last thirty years undisturbed mangroves in Kalimantan have declined by a total extent of 1208km^2 between 1990 and 2020. The net loss of mangroves is not evenly distributed across Kalimantan, and this study further reveals that degradation of mangroves is occurring more extensively than deforestation of mangroves. The primary activity that has led to mangrove deforestation is the conversion of mangroves to other land use types, namely, aquaculture, oil palm, agriculture, and mining. Degradation on the other hand, appears to be more closely linked to small scale anthropogenic pressures and the unsustainable use of mangroves close to

settlements and development areas. Positively, the most recent years reveal that there is an increasing trend in regrowing mangroves. However, research reveals that it notoriously difficult to re-establsih mangrove ecosystems, so efforts should rather be placed on mitigating their destruction, through sustainable management and protection schemes.

Of the five districts under examination in this study, East Kalimantan has had the highest level of mangrove deforestation and the second highest population growth in the last 20 years. As such efforts need to be prioritised in this region to reduce the level of exposure to coastal hazards. Given that the capital of Indonesia will also be relocating to the coast of East Kalimantan, the issue of reducing exposure will become even more important as large-scale development is likely to coincide with this. In reducing the exposure of the population to coastal hazards, it will also be necessary for the government to assess the trade offs associated with the continued large-scale development of mining activities and palm oil. The long-term negative consequences of these activities do not appear to be cost-effective, as coastal hazards increase under the influence of climate change (The World Bank, 2020).

The last finding of this study speaks more towards the current lack of integrated planning of mangroves in Indonesia. This study has found that mangroves are not considered within Indonesia DRR strategy but have rather been assigned as a climate change adaptation (CCA) strategy. This has created institutional silos where the benefits that mangroves provide are limited to the specific functions of CCA and are therefore not as well considered for their DRR benefits which namely reduce exposure and increase resilience. The inclusion and specific use of language that facilitates the use of mangroves in national DRR and CCA policies will be an important mechanism for integrating mangroves into land use planning along side development. First evidence of this, is found in Indonesia’s NDCs, where there is a clear link to the use of mangroves as a mechanism for pursuing CCA activities and an emphasis on the synergies between these actions and other global agreements such as the Sendai Framework for Disaster Risk Reduction (SFDRR). Any actions taken must, however, be translated into local level action, incorporating the local stakeholders, to achieve sustainable use of the ecosystem to prevent the continued loss of mangrove forests.

The results of this thesis demonstrate that the regular monitoring of mangroves can provide quantitiative information for decision making in different domains. Information on areas subject to high exposure from coastal hazards as a consequence of mangrove degradation or deforestation has been the primary focus of this thesis, but as previously discussed, the potential for this information to be coupled to other factors of risk such as vulnerability and hazard probability would be of further benefit to this monitoring system.

Contents

1. Introduction

Indonesia has the most extensive mangrove cover in the world, with more than 20 per cent of the world's mangrove forests (Ilman et al., 2016; Lukman et al., 2021). Yet, years of rapid industrialization and massive land-use change such as intense oil palm and shrimp cultivation have led to rampant mangrove deforestation (Ilman et al., 2016). According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2020) report, coastal forests like mangroves are capable of extensively reducing the impacts of a number of coastal hazards (UNDRR, 2020). Mangroves lower damage by absorbing the impact from waves, floods, and rising sea levels through their large above-ground aerial root systems; they help in diversifying sustainable income sources, thereby reducing vulnerabilities, and also limit disaster exposure by acting as natural shields between human settlements and coastal hazards (M. Spalding et al., 2014; UNDRR, 2020).

To understand how ecosystems, such as mangroves serve to protect coastal communities from coastal hazards such as flooding a classic risk assessment perspective can be used, whereby the protective services that mangroves offer can be examined in relation to hazards, exposure and vulnerability (Menéndez et al., 2018). From an initial scoping study done on mangroves in relation to disaster risk reduction and climate change adaptation it has been found that a number of studies focus on ways in which mangroves reduce vulnerability and the impact of hazards. However, a gap appears to exist on how the exposure of coastal communities to coastal climate hazards has changed as the global mangrove extent continues to decline. As such, this thesis will use a case study approach to examine and understand how exposure of coastal communities in the Kalimantan region of Indonesia have changed as the extent of mangroves have changed over time. In examining mangroves, change trends can be analysed to identify areas where exposure has increased overtime and can be furthered used to support national policies in protecting mangroves for disaster risk reduction and climate change aadaptation and mitigation purposes (Losada et al., 2018).

1.1. Research Purpose

Despite increasing awareness of the importance of ecosystems and the services they provide, the role of ecosystems in the context of disaster risk reduction is often overlooked, favoured instead for their conservation value and role in tourist development (UNEP, 2014). Whilst these services are also important, ecosystems should be considered more holistically and be prioritised for hazard management, sustainable livelihood recovery and development in order to create higher resilience within the human-environment system. The Hyogo Framework for Action (HFA) (2005-2015): “Building the Resilience of Nations and Communities to Disasters”, came about after many countries faced disastrous consequences from the Indian Ocean tsunami in 2004 out of global recognition to focus more attention on disaster prevention and risk reduction. The HFA has five priorities for action with respect to building resilience to disasters. One of these priorities for action, entitled “Reduce the underlying risk factors”, recommends two key activities that have a direct link to ecosystems and ecosystem management (UNISDR, 2005: 10-11):

1. Environmental and natural resource management with components that include:
    a) sustainable use and management of ecosystems;
    b) implementation of integrated environmental and natural resource management approaches that incorporate disaster risk reduction;
    c) linking disaster risk reduction with existing climate variability and future climate change.
2. Land-use planning and other technical measures with a component on incorporating disaster risk assessment into rural development planning and management.

As previously mentioned, there is substantial evidence to support that mangrove ecosystems provide a host of ecosystems services, including the ability to reduce the impact of certain costal hazards (Estrella & Saalismaa, 2015; Mark Spalding et al., 2014; UNDRR, 2020). Furthermore, as suggested in the HFA, informed land use planning and environmental management can be used not only to strengthen Disaster Risk Reduction (DRR), but to support overall resilience building. Given that Indonesia has the largest extent of mangroves globally (Lukman et al., 2021) and is ranked as one of the most at risk countries in the world, with over 90% of the total population living in hazard prone areas (Mcdonald & Wilcox, 2020), mangroves should be utilised as a nature-based solution (NBS) with the function of reducing the impact of coastal hazards and as well building resilience and promoting climate change adaptation (CCA). Under the influence of climate change, it is likely that the consequences of certain hazards will worsen, not only from the higher intensity and frequency of hazards (Lal et al., 2012) but from the increased level of human exposure as a result of development and population growth. If left unmanaged, development may lead to the further reduction of mangroves, thus further increasing the exposure of populations and assets to coastal hazards (Estrella & Saalismaa, 2015).

The islands of Java (Malik et al., 2017) and Sumatra (Sunyowati et al., 2017) have had the most extensive loss of mangroves and research shows that Kalimantan and Sulawesi are likely to experience similar trends of loss in the future. It was recently announced that Kalimantan is to host the new administrative capital of Indonesia, as Java becomes more unhabitable under the influence of climate change (Mcdonald & Wilcox, 2020). This may lead to more rapid population growth in Kalimantan and more extensive removal of mangroves. As such, parts of Kalimantan may be at risk of experiencing long-term economic losses from increased exposure of people and economic assets as a result of mangrove deforestation and degradation.

The purpose of this study is therefore, to identify potential areas of anthropogenic stress on mangroves and areas of high mangrove loss. This information is important in providing information that can be used for both preventative and reactive measures in the natural resource management of mangroves and disaster risk reduction. Furthermore, understanding the current extent of mangroves in Kalimantan will serve as a baseline for monitoring the ecosystem and additionally provide information on where the most extensive mangrove loss is occurring in conjunction with population growth.

The next section of this thesis states the specific aim followed by a brief overview of the coming chapters.

1.2. Research question

More Specifically this thesis aims to answer the following question:

How has the exposure of the coastal population of Kalimantan, to potential climate hazards,changed as a result of coastal mangrove loss and population growth?

1.3. Thesis structure

This Chapter has introduced the research problem on how the use of NBS, mangroves are underutilised for their protective and resilience enhancing ecosystem systems services in Indonesia and how monitoring of mangroves can be used to enhance DRR policies in Indonesia. Chapter 2, elaborates on the definitions of key concepts used throughout this thesis, so that there is a unified understanding of these concepts between the reader and author. Chapter 3, briefly introduces the study area chosen and provides a brief literature review to provide further context for issues that will be discussed in this thesis. Chapter 4 presents a review of key literature surrounding the policies and governance of mangroves in Indonesia, which will further contribute to the discussion later in this thesis. Chapter 5, describes the data and methodology used to conduct the research. Chapter 6, showcases and analyses the results found. Chapter 7, discusses and further analyses the findings with the aim of providing answers to the objectives of this study Finally, Chapter 8, provides a general conclusion and summary of the key findings.

2. Conceptual Framework

This Chapter aims to provide the reader with a common understanding of the primary concepts used throughout this thesis.

Nature Based Solutions for Disaster Risk Reduction: Before discussing the relationship between NBS in DRR, it is first necessary to understand what is meant by term DRR. DRR is "[t]he concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness for adverse events" (Van Niekerk, 2011:13).

The term NBS, is an umbrella term, that describes the intentional use of ecosystems and the environment for services that they provide. Although, the concept of this is nothing new, it has only in the last two decades gained popularity in national legislative frameworks for integration into rural and urban ecosystem management. As there are many organisations that define the term, this thesis will use the definition of NBS presented by the International Union for the Conservation of Nature (IUCN) "[a]ctions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016,: 2). Since then, the concept of NBS has been widely adopted in research (Li et al., 2021) and policy (PEDRR & FEBA, 2020).

Ecosystems contribute to reducing disaster risk in two important ways that influence the overall resilience of the community. The first, relates to the ability for some ecosystems to reduce the exposure of the population (Losada et al., 2018). Sustainably managed, healthy ecosystems, such as coral reefs, mangroves, dunes can provide a natural protective barrier, reducing the exposure to some natural hazards. The health and sustainable management of the ecosystems is crucial in maintaining the functional and structural integrity that allows them to act as natural buffers. The sustainable management of ecosystems contributes to the second way in which ecosystems contribute interact with the human environment such as through supporting livelihoods and providing essential goods (IUCN, 2021; Malik et al., 2015) such as food, medicine, fuel, and building materials (UNEP, 2014). The provision of these services and goods, helps to decrease social and economic vulnerability which in turn makes the community more resilient when a natural hazard occurs (UNDRR, 2020; UNEP, 2014). The relationship between NBS and DRR is as such the management of the environment in such a way that risks to communities are reduced through protection and overall resilience enhancement of the human-environment system

Climate Change Adaptation: As there is no universal definition for what climate change adaptation is this thesis will use the United Nations Framework Convention on Climate Change (UNFCCC) definition which refers to adaptation as "changes in ecological, social or economic systems in response to climate variability or its effects or impacts" (UNFCCC, 2022). It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (UNFCCC, 2022).

Vulnerability: The concept of vulnerability is defined within this thesis as changes to the extent of the mangroves impacting the vulnerability of the communities that are located alongside and/or behind them. As Coppola (2015) explains vulnerability must be examined in the context of the physical, social, environmental, and economic factors or process that in turn affect people's adaptive capacity to cope with climate stressors.

Exposure: Exposure is the likelihood of valued assets such as a person, community, population or infrastructure to experience a hazardous event (Coppola, 2011). It differs from vulnerability in that it is not concerned with the consequences that may occur if a hazardous event occurs (Coppola, 2011). Studies by Losada et al., (2018) and Spalding et al., (2014) support that people and assets are more exposed to coastal climate hazards such flooding if mangroves are deforested.

Deforestation and Degradation: The definition of deforestation in the Inter-Governmental Panel on Climate Change (IPCC) 2006 "the conversion of forest to non-forest". A similar definition is used by Vancutsem et al.,(2021b) which is "the permanent conversion of moist forest cover into another land cover". Forest degradation is a term, more frequently defined in various ways. Degradation of forests in this thesis will follow the definition presented by Vancutsem et al., (2021) for the TMF dataset where degradation is observed disturbances of moist forest cover over a short period of time. Short term disturbances include logging activities, fires and naturally damaging events such as extreme dry periods (Vancutsem et al., 2021).

3. Context and Background

This Chapter provides a brief description of the study area of Kalimantan, as well as contextual information regarding population dynamics and the history of land use change, and resource exploitation in the region.

3.1. Study Area and Rationale for Selection

Indonesia is located in Southeast Asia and is the largest archipelago country in the world, consisting of approximately 18,107 islands between the Pacific and the Indian Ocean (New World Encylcopedia, 2019b). Its geographic positioning, in the Pacific ring of fire, exposes the country to seismic and volcanic threats, which also increases the risk of exposure to Tsunami's. Aside from these threats, the country also experiences a number of hydrometrological hazards such as flooding, coastal inundation from tropical storms, sea level rise and coastal erosion (Mcdonald & Wilcox, 2020). Stanton-Geddes & Vun, (2019) calculates that over 60% of Indonesia's districts are exposed to a high risk of flooding. These factors, along side the heightened threats under climate change have made Indonesia one of the most hazard prone countries in the world (Stanton-Geddes & Vun, 2019).

The selected study area of Kalimantan as such represents one of the hot spots for potential change in mangrove extent over time in Indonesia. As seen in Figure 1, the region of Kalimantan is located on the southern two-thirds of island of Borneo, which is an island administratively occupied by Indonesia, Malaysia and Brunei Darussalam. Kalimantan contains about 60 percent of the island's population (New World Encylcopedia, 2019a), which is roughly estimated at 14 million (New World Encylcopedia, 2019a) and is comprised of five districts: Northern Kalimantan, Southern Kalimantan, Central Kalimantan, Western Kalimantan and Eastern Kalimantan. Its extensive coastline provides many areas for mangrove ecosystems and is known to have some of the world's oldest and most biodiverse mangrove forests (Spalding et al., 1997). Mangrove ecosystems are most abundantly found on the islands of Kalimantan, Sulawesi, Java and Papua (Ilman et al., 2016). All coastal areas of Kalimantan experience a medium to high risk of experiencing flooding and coastal damage from storm surges once every ten years (ThinkHazard, 2022). Furthermore, coastal erosion has been observed in many parts of Indonesia, including Kalimantan (Camila & Saraswati, 2020). Both of these coastal hazards are likely to intensify in their nature under the influence of climate change, thus creating amplified levels of risk as the current scientific consensus is that warmer oceans are likely to intensify cyclone activity and heighten storm surges..

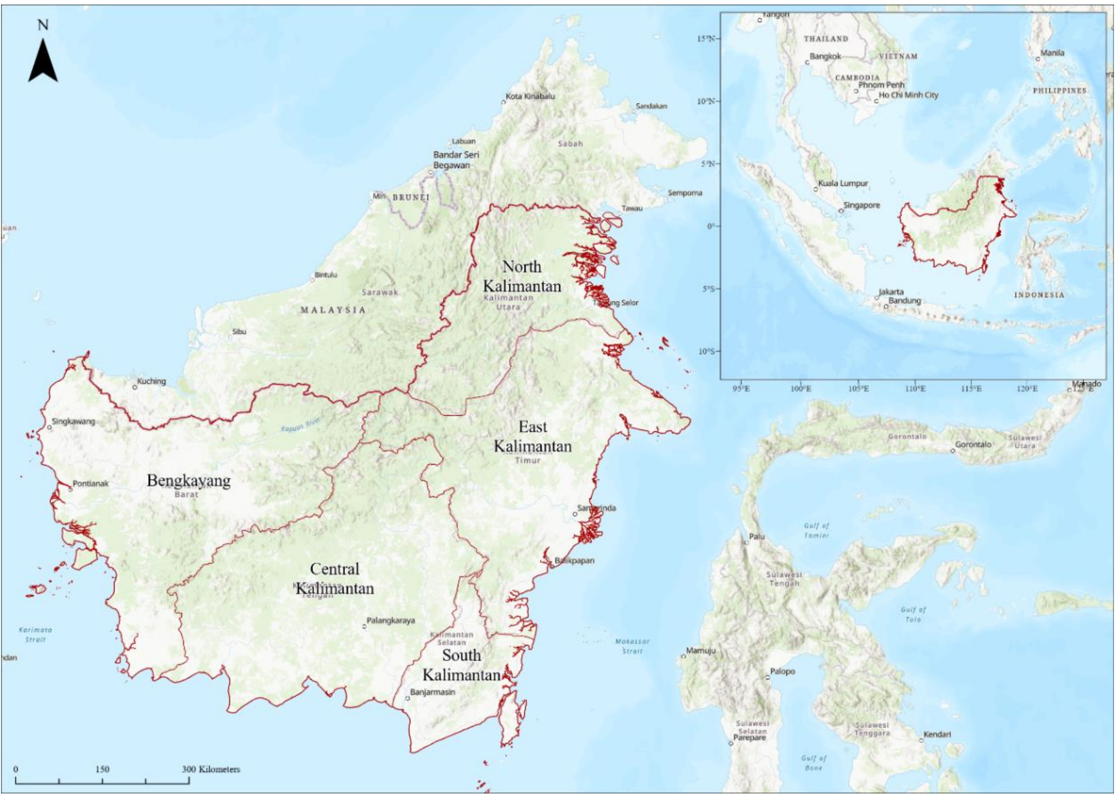

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Figure 1- The area in red shows the area of interest- Kalimantan, Indonesia and the five administrative regions of the island.

3.2. Kalimantan past and present

3.2.1.Population Dynamics

Kalimantan was first established as a region of the Republic of Indonesia, when the country gained independence from Dutch colonial rule in 1949 (Pletcher, 2022). Since then, the population of Kalimantan has been growing but at a much slower rate than other regions in the country. The population of Kalimantan is largely comprised of ethnic, Muslim, Malays and, non-Muslim, indigenous people known as Dayak. According to Sada et al., (2019) there are roughly 2 million Dayaks living in Kalimantan. Although the Dayak communities can be found throughout Kalimantan, West Kalimantan hosts the highest percentage of Dayak people at 42% of the total Dayak peoples in Kalimantan and the fewest Dayak communities are found in East Kalimantan (Cliamte and Land Use Alliance, 2021). Most Dayak village economies are based on the shifting cultivation and the gathering and selling of non-timber forest products (Cliamte and Land Use Alliance, 2021)whilst activities such as fishing and hunting are subsidiary activities. The rest of the population of Kalimantan, are more evenly distributed across coastal cities in South-, East-, West-, and North- Kalimantan. The population growth of various cities and settlements across Kalimantan, appears to be driven by different the different development opportunities occurring in various districts (Pletcher, 2022). Many of these opportunities are related to land use and will be discussed in the following section.

3.2.2.Land use/Land cover changes

The extensive area of Kalimantan is renowned for containing some of the worlds most biodiverse ecosystems (Wulffraat et al., 2017), such as lowland forests, montane forests, peatlands, and coastal and riverine mangroves (Rautner & Hardiono, 2005). These ecosystems provide the habitats necessary for an extensive range of flora and fauna to thrive in as well as providing essential ecosystem services to surrounding communities (Wells et al., 2016; Wulffraat et al., 2017). Unfortunately, theses ecosystems are under threat as they have been facing damage and degradation from exploitation and conversion to other land uses (Wulffraat et al., 2017).

One of Kalimantan's first major industries was mining which began in the 1800s (Rodd et al., 2016) but was performed at a smaller, less intrusive scale. Although the mining industry became more well established in the 1960's thanks to a push in supportive policies (Rodd et al., 2016), it was not until the 1980s that mining, particularly coal and gas extraction, in Kalimantan saw an exponential increase (Fünfgeld, 2016). Mining activities since then have predominantly been occurring in East and Central Kalimantan (Idris & Mansur, 2019). Although mining is not as extensively practiced in Kalimantan anymore, it has had devastating effects on the land, despite the fact that Indonesian law requires mining companies to restore the land they have torn open to extract coal (Fünfgeld, 2016).

Small scale aquaculture, namely shrimp farming, has been one of the lead causes of mangrove removal in Indonesia, particularly in Kalimantan. Although aquaculture has been practiced in Indonesia since the early 1900s, it became more widely utilised after 1980, when the government banned bottom trawling practices for the harvesting of shrimp and other crustaceans (Ilman et al., 2016). As the global demand for shrimp has increased, it has been met with rapid and extensive conversion of coastal land which has been estimated to have reduced Indonesia's original mangrove extent by approximately 50% (Thomas et al., 2018a).

The Mahakam Delta in East Kalimantan, one area, where the loss of mangroves has been particular obvious and linked to the aquaculture industry (Virni Budi Arifanti et al., 2019; Bosma et al., 2012).

In the early 1970s a new regulation pertaining to forest concessions was enacted, which changed permit mechanisms and encouraged new investment (Ilman et al., 2016). This act, made it a clearer and more easy process to obtain logging license permits, including for the logging of mangroves. By 1980, the government had permitted the logging of 455,000 ha of mangroves, spread between Kalimantan and Sumatra (Simbolon, 1991). To combat, much of the illegal logging of mangroves taking place the government issued policies to prohibit the exploitation of mangroves along coastal areas. This was the first written document to recognise the importance of mangrove ecosystems within the Indonesia government. Whilst this type of forestry practice did reduce the extent of mangrove exploitation. Mangroves faced additionally threats from the conversion of surrounding land for other forms of logging and palm oil cultivation. In the 1990's Indonesia's decentralization process empowered the districts to make decisions on logging concessions, which resulted in more concessions in the country and, equally important, a rise in illegal logging. Central and West Kalimantan are covered by 5.1 million ha (Sekala 2013) and 2.5 million ha (Kementrian Kehutanan 2013), respectively, of active logging concessions in production forests, although logging in West Kalimantan has much higher yields, which could be related to ease of access, extraction techniques, terrain, or the type of timber and forest. Legal and illegal logging have taken a toll on the forests right across the island of Kalimantan, including Indonesia, Malaysia and Brunei (Obidzinski et al. 2006).

4. Policy Review: Mangrove's as part of NBS

This Chapter provides a review of how and if mangroves have been incorporated into national frameworks that support DRR and CCA actions. Firstly, an overview is provided on the governmental structures in place for the management of mangroves. This is followed by two sections which provide more context as to how mangroves are being incorporated into CCA through Indonesia's Nationally Determined Contributions and, the overall role of mangroves in DRR.

4.1. Authorities and national policies responsible for mangrove management

There are a number of national laws and policies that are influencing the management of mangroves across Indonesia. Traditionally, these laws and policies have been under the jurisdiction of environmental and land use planning authorities (Banjade et al., 2016). The last decade, has however, promoted the need for the inclusion of actions and policies that support efforts of CCA as well as DRR. Through addressing issues within the governance and tenure systems of Indonesia, this thesis hopes to expand upon some of the underlying issues that are leading to challenges in mangrove management. Thus, the next section will present an overview of current governance mechanisms for mangrove management in Indonesia; this will be followed by a section presenting the status of mangroves in Indonesia's submission of their

Nationally Determined Contribution (NDC) to the Paris Agreement. Lastly, a review of Indonesia's national Disaster Risk and Reduction (DRR) Strategy has been condcuted.

Most forests in Indonesia are governed by The Ministry of Environment and Forestry (MOEF) (Banjade et al., 2017), however, given the semi-aquatic nature of mangroves forests and their value to marine ecosystem, they are also partially managed by the Ministry of Marine Affairs and Fisheries (MMAF) which is responsible for management of coastal and small island areas (Banjade et al., 2017). The management of mangroves, in some cases, also falls under the jurisdiction of the National Development Planning Agency (BAPPENAS) and the Ministry of Agrarian and Spatial Planning Affairs (Banjade et al., 2017), as they engage with mangroves from the perspective of land tenure rights and the spatial planning and management of mangrove zones (Banjade et al., 2016). Whilst the administrative bodies listed above, appear to have the most influence over the management of mangroves, Arifanti, (2020) and Friess et al., (2016) have additionally found that the management of mangroves is also influenced at the provincial, district and village level.

Despite the plethora of governing bodies, it appears that the primary law influencing local mangrove management in state forest zones is the Forestry Law 41/1999 (Muzani, 2014). Under this law, forest areas are recognised in Article 6 as having three primary functions of: production, preservation, and conservation (The State Secretary of the Republic of Indonesia, 1999). Mangroves can be found within all three forest zones but subsequently follow different sub laws depending on which zone they fall under. For example, mangrove forests in production zones can be exposed to logging activities whilst those in preservation and forests are protected from logging. The most restricted utilization of mangrove occurs if they are located in conservation forests where only environmental services, research, and education can be conducted (Banjade et al., 2017). The issue is that the land classified as state forest was delineated under the Dutch colonial rule, where little regard was given to the settlements already established in the area (Szczepanski, 2002). Conflict has consequently arisen between the government and local communities, particularly in cases where the government has granted permits for logging activities and large-scale plantations on land already owned by community members (Lucas & Warren, 2013). Many Indonesians and indigenous people living in forest areas argue that their rights should be protected under the Basic Agrarian Law, which provided protection of larger land areas needed for their traditional practices of shifting cultivation (Lucas & Warren, 2013). The issue of land tenure and use has led to a high level of resistance from local communities across Indonesia to follow forestry laws presented by the state, including those that protect mangroves (Lucas & Warren, 2013; Sidik, 2010).

Apart from the aforementioned law of the protection of mangroves in certain state forest zones, mangroves are also protected under Presidential Decree law No. 32/1990, article 27 (Faridah-Hanum et al., 2014), which aims to protect mangroves along coastlines and riverbanks, thus creating mangrove green belts. The law further details that the coastal green belts should be at least 130 times the size of the largest tidal range (Faridah-Hanum et al., 2014), though it is not clear how tidal ranges are determined.

4.2. Indonesia's Nationally Determined Contributions: Role of Mangroves and NBS

In 2015, the Government of Indonesia signed the Paris Agreement which committed the country to reducing their greenhouse gas emissions by 29% by 2030 against the 2030 business as usual scenario (Ministry of Environment and Forestry Directorate General of Climate Change, 2021). With this pledge the government recognised the importance of their extensive forest cover not only for its high carbon stock value but for its immense potential to sequester carbon dioxide and thus contribute to climate mitigation. The primary adaptation goal within Indonesia's NDC is "to reduce risks, enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change in all development sectors." (Ministry of Environment and Forestry Directorate General of Climate Change, 2021). The inclusion of NBS is one way in which this goal can be achieved.

Mangroves have been recognised in Indonesia's NDCs and specifically linked to actionable measures under the section "Ecosystem and Landscape Resilience". Within this priority area, one of the key programmes is "Coastal zone protection" (Ministry of Environment and Forestry Directorate General of Climate Change, 2021) which has, inter alia, two actions which prioritise the use of mangroves. The first, recognises the need to better integrate the management of mangrove ecosystems into governmental policies and programmes. The second, highlights that a key action in creating resilient coastal zones, will be to enhance education and public awareness on the role of coastal ecosystem protection in natural disaster impact reduction (Ministry of Environment and Forestry Directorate General of Climate Change, 2021). This action may allow for lower cost and community-based approach through building on actions of prevention and sustainable development.

The actions promoted in Indonesia's NDCs, therefore not only focus on the use of mangroves for climate adaptation but have strong synergies with the Sendai Framework for Disaster Risk Reduction (SFDRR), as well as other global agreements such as the RAMSAR convention, and the Sustainable Development Goals (Ministry of Environment and Forestry Directorate General of Climate Change, 2021). Nevertheless, the inclusion mangroves in Indonesia's NDCs is crucial as it provides the policy context needed to steer investments and attract climate finance.

4.3. Indonesia's DRR and Role of NBS

The National Disaster Management Authority (BNPB) is the current ministry responsible for disaster management activities from preparedness to response, of natural hazards in Indonesia (IFRC, 2016). The Regional Disaster Management Agency (BPDB), however, provides support in administrating, monitoring and enforcing the decisions of the BNPB, at provincial, district and city levels. Many international organisations recognise that Indonesia has a well-developed disaster preparedness framework with many laws, polices, and necessary structures to facilitate disaster management alongside the sustainable development goals of the country (Gunawan et al., 2016; IFRC, 2016). The commitment to implement DRR strategies has been driven by the initial adoption of the Hyogo Framework for Action and in more recent years, the SFDRR (Mcdonald & Wilcox, 2020). One of the aspects adopted in the SFDRR was the call for states to strengthen the use of ecosystem-based approaches and environmental resource management for integrated use in DRR and resilience building (United Nations Office for Disaster Risk Reduction, 2015:20).

To provide support for the implementation of the SFDRR, the UNDRR reviews the progress and challenges of implementing actions within the four priority sectors of the SFDRR (Mcdonald & Wilcox, 2020). One of the priorities presented for DRR in Indonesia is to mainstream DRR across various policy platforms, but particularly in development, with the goal of reducing vulnerability and improving capacity development (Mcdonald & Wilcox, 2020). Although this has been a priority, Mcdonald & Wilcox, (2020) have found through their assessment that the measures implemented thus far, do not consider interlinkages across sectors which has limited the number of tangible actions produced by the policies as well as their overall effectiveness in strengthening resilience. This is particularly the case for issues that can serve the purpose of both DRR and CCA. For example, ecosystem services are not directly linked to Indonesia's DRR strategy and are instead mentioned as an important part of the climate adaptation strategy (Mcdonald & Wilcox, 2020).

This Chapter has presented an overview of the main policy mechanisms which are related to mangrove management and DRR. The findings from this review will be further addressed and analysed in Chapter 7 in relation to the role of mangroves in NBS and DRR in Indonesia.

5. Methododolgy and Materials

5.1. Data

This section will review the main data used for the methodology. Each of the datasets presented in Table 1 are global datasets available in the public domain, and therefore provides open access and utility. More detailed information on each of the datasets is described in the sections following Table 1.

Table 1- Specifications of data used. Dashes indicate that either no details have been provided by the original source or that data is no applicable data for the category.

Product	Source Data	Native Spatial Resolution (meters)	Temporal range	Overall Accuracy	Methodology Source
Global Mangrove Watch (GMW)	Landsat, JAXA JERS-1 SAR, ALOS PALSAR, ALOS-2 PALSAR-2	25	1996-2016	94.0%	(Bunting et al., 2018)
Tropical Moist Forest (TMF)	Landsat 4+5: Thematic Mapper (TM) Landsat 7: Enhanced Thematic Mapper Plus	30	1990 - 2020	91.4%	(Vancutsem et al., 2021a)

	(ETM+) Landsat 8: Operational Land Imager				
World Pop Data	Indonesia census data	1000	2000-2020	-	(Lloyd et al., 2019)
Indonesia - Subnational Administrative Boundaries	Global Administrative Areas (GADM)	-	2019	-	(Global Administrative Areas, 2012)

5.1.1.Global Mangrove *Watch (GMW) data set*

The GMW is a global mangrove monitoring system, originally created by the Japan Aerospace Exploration Agency (JAXA) Kyoto & Carbon Initiative to investigate global mangrove extent by generating a baseline map for 2010. Today, the GMW dataset continues to be expanded through a collaboration with Aberystwyth University, solo Earth Observation (soloEO; Japan), and Wetlands International the World Conservation Monitoring Centre (UNEP-WCMC), known as the Global Mangrove Alliance (Thomas et al., 2018:1). The GMW has since updated the 2010 mangrove baseline map to include Landsat spectral composite data and Advanced Land Observing Satellite (ALOS) Phased Arrayed sensor data alongside the Japanese L-band Synthetic Aperture Radar (SAR), used in the original study. This was done to further enhance the accuracy of mapping the mangroves as it allows for better detection of different tree species (Bunting et al., 2018:2). The classification of the mangrove habitat was defined to exist within certain geographic parameters such as distance to water, distance to the ocean, surface elevation, and geographic longitude and latitude to create a habitat mask (Bunting et al., 2018:7). Lastly, the mangroves were identified using the Extremely Randomized Trees classifier (Bunting et al., 2018:7), where over 100,000 training samples were extracted from the mangrove habitat mask and additional mangroves maps by Giri et al., (2011) and Spalding et al., (1997). The resulting map of the global mangrove extent in 2010 provides an estimated total of 137,600 km^2 of mangroves globally. Derivations from this baseline were derived for 1996 (JERS-1) 2007, 2008, 2009 (ALOS PALSAR), 2015 and 2016 (ALOS-2 PALSAR-2) using a histogram thresholding change detection approach (Thomas et al., 2017).

In 2018, the classification accuracy of the GMW data was assessed using over 53 000 randomly sampled points across 20 randomly selected regions producing an overall accuracy of 95.25% (Thomas et al., 2018:3). The user’s and producer’s accuracies of the mangrove classes were estimated at 97.5% and 94.0%, respectively (Thomas et al., 2018:4). However, Bunting et al., (2018:10) remarks that the accuracy may vary between locations. Factors such as cloud cover, the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) scanline error, mangrove species composition and level of degradation influence data availability and accuracy of the dataset (Bunting et al., 2018).

5.1.2.The Tropical Moist Forest (TMF) dataset

The Tropical Moist Forest dataset was developed by The European Commission's Joint Research Centre (JRC). The data shows global forest cover change of tropical moist forests (TMF) over 31 years from 1990- 2021 using Landsat imagery. The resulting mapped TMF has a spatial resolution of 30 meters and covers multiple classes of change: deforestation, degradation and regrowth. This thesis specifically uses the TMFs data on annual change of mangrove from 1990-2020 which depicts the extent and the related disturbances such deforestation and degradation for each year between 1990 and 2020. The annual change data is composed of 6 classes of land cover for each year (Vancutsem et al., 2021). To map the change in TMF over the 30 year period each pixel is continuously monitored for disruptions by examining the time, duration and intensity of changes that occur at the pixel level (Vancutsem et al., 2021:12). Vancutsem et al., (2021:12) defines disruptions as the "absence of tree foliage cover within a Landsat pixel for a single-date observation".

It should be noted that the TMF dataset has mapped changes within mangrove forests by identifying the mangrove maximum extent using the GMW dataset from 1996-2016 as a baseline for undisturbed mangrove forests (Vancutsem et al., 2021b:4). Specific classes of specific classes of change within mangrove forests have then been identified by combining the TMF classes of change (degraded, deforested, regrowing, and recent disturbance) with the GMW dataset (Vancutsem et al., 2021b:6), and can be found in the TMF transition map dataset. See Table 2 for descriptions of each class. The validation of the TMF dataset found an overall accuracy 91.4% but also noted that there is an underestimation of forest area changes by 11.8% (Vancutsem et al., 2021:18).

Table 2 - Class descriptions of the land cover classes used by the TMF Annual change dataset, as defined by Vancutsem et al., (2021).

Name of Class	Class Description
Undisturbed Tropical Moist Forest	Closed evergreen or semi-evergreen forest without any disturbance (degradation or deforestation) observed on the Landsat valid observations up to the year of analysis. This class includes the mangrove and the bamboo-dominated forest
Degraded Tropical Moist Forest	A closed evergreen or semi-evergreen forest (covered by existing or regrowing trees) that has been temporary disturbed during a period of maximum 2.5 years (900 days) and that started at the latest during the current year. It includes different types of degradation such as selective logging, fires, and unusual weather events (hurricane, drought, blowdown)
Deforested Land	Permanent conversion of forest into non-forested land that started at the latest the current year. Disturbances were observed over more than 2.5 years and no vegetative regrowth was detected. It includes three subcategories of converted land cover: (a) water bodies (new dams and river flow changes); (b) tree plantations; and (c) other land cover that

	includes infrastructure, agriculture, and mining. It also includes deforestation areas that follow degradation
Forest Regrowth	A pixel that has been deforested before the current year and that is currently regrowing. A minimum 3-years duration (2018-2020) of permanent moist forest cover presence is needed to classify a pixel as forest regrowth (to avoid confusion with agriculture).
Permanent and Seasonal Water	Permanent and seasonal water defined by the Global Surface Water (GWS) Explorer.
Other land cover	No data and non-forest cover including savannah, deciduous forest, agriculture, evergreen shrubland, non-vegetated cover and afforestation.

5.1.3.WorldPop

WorldPop data is an open access archive of spatial demographic datasets developed in 2013 to create one platform hosting and combing the AfriPop, AsiaPop and AmeriPop population mapping projects (WorldPop, 2022). This thesis uses the unconstrained population density data for Indonesia from 2000-2020 at 1km spatial resolution. The mapping approach used to create the dataset is Random Forest-based dasymetric redistribution (Lloyd et al., 2019).

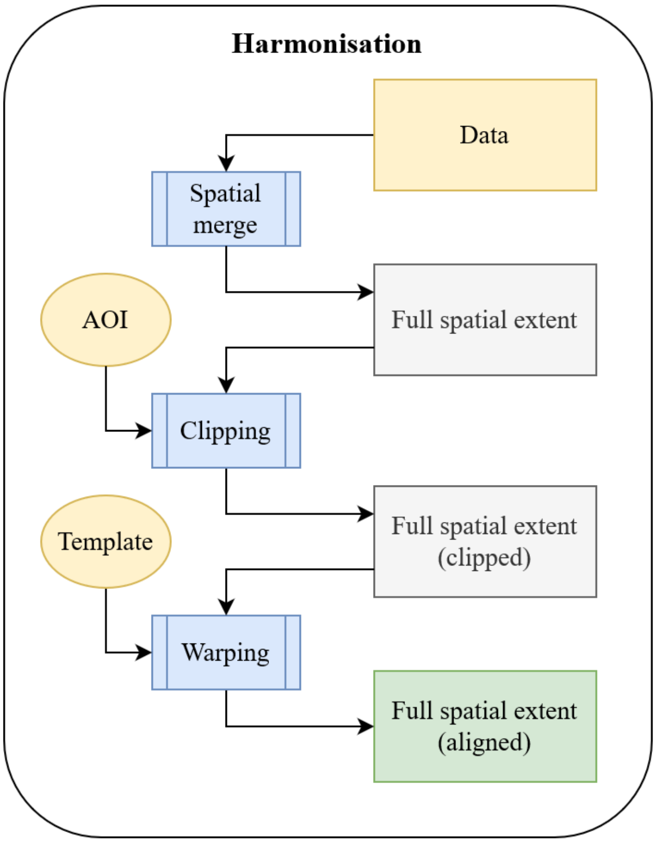
5.2. Data Analysis

This thesis uses GIS and remote sensing techniques to quantitively analyse the data. The approach taken is described in two sections, the first covers data harmonisation which is an important process ensuring that the data sets used are aligned and congruent with one another (European Commission, 2022). This workflow has been visualised in Figure 2. The second section describes the general workflow, seen in Figure 3, of the data and geospatial analysis used to achieve the information needed to answer the research questions posed.

5.2.1.Data harmonisation

The data harmonisation process has been visually presented in Figure 2. This process has been done on the GMW, TMF, and WorldPop data. The GMW, TMF, and WorldPop data were all delivered in multiple tiles covering the island of Borneo and were spatially merged to achieve datasets with the full spatial extent of the area. To create the area of interest (AOI), the region of Kalimantan was separated from other administrative regions of Indonesia. All datasets covering the full spatial extent of the area were then clipped to the geometry of the AOI and lastly warped (reprojected) to match the projection system and cell size of the TMF data. Specifically, this involved reprojecting all data into the Universal Transverse Mercator (UTM) zone 50S coordinate system and resampling the data to 30 meters.

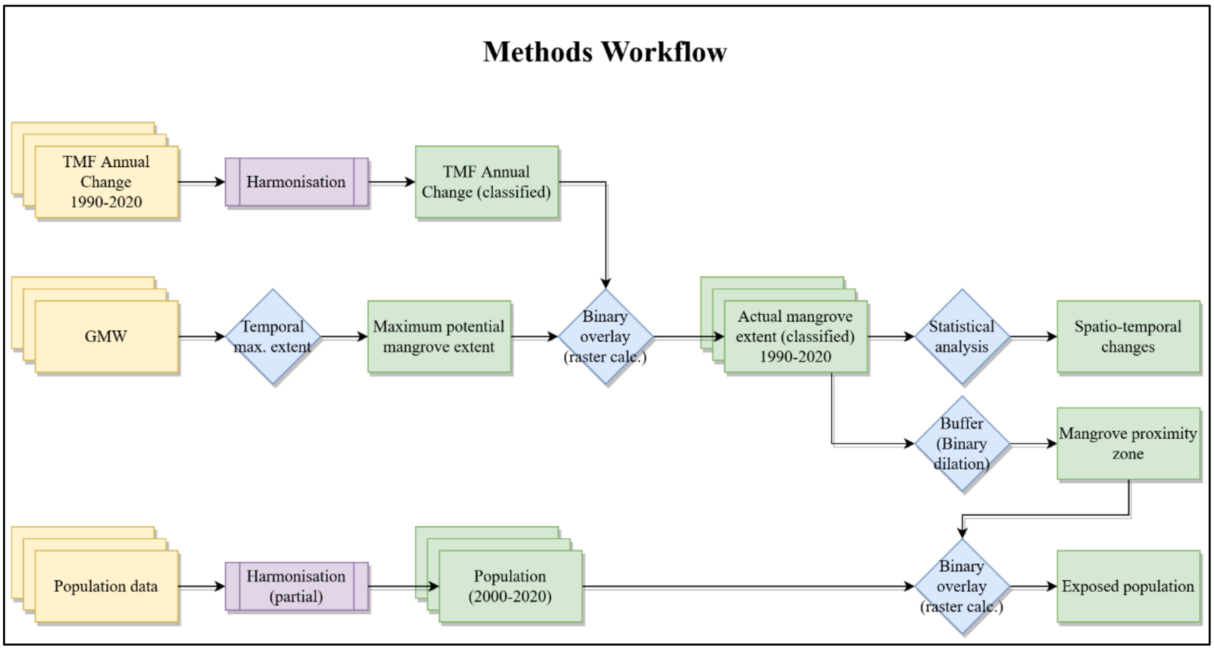
Figure 2- Workflow showing the data harmonization process.



5.2.2.Overall Workflow for Mangrove and Population Change Assessment

The TMF data on mangroves appears within the transition map dataset as various classes of disturbed mangroves (degraded, deforested and regrowing), and has been further aggregated into multiannual monitoring periods (Vancutsem et al., 2021b). As such, the transition map is unable to provide information on interannual changes in mangrove extent. Hence, the TMF dataset was used in conjunction with the GMW data to produce the change in mangrove extent from 1990-2020 on Kalimantan. The GMW dataset for the available years between 1996-2016, was used to find the maximum potential mangrove extent by evaluating all images within the period to find all pixels that were either currently or had been previously classified as mangroves. To find the actual mangrove extent from 1990-2020 a binary overlay was used, whereby the TMF annual change dataset and maximum potential mangrove extent was multiplied. This layer was used to extrapolate mangroves for the years outside the observation period of the GMW dataset, that is from 1990-1996 and 2016-2020. Hence, all forests found within this period were considered as mangroves. If the actual maximum mangrove extent is between 1990-1996 or 2016-2020 it will not be reflected in the results and can thus be considered a limitation of this study. Lastly, a statistical analysis was done to identify trends of change in extent for undisturbed-, degraded- and deforested mangroves.

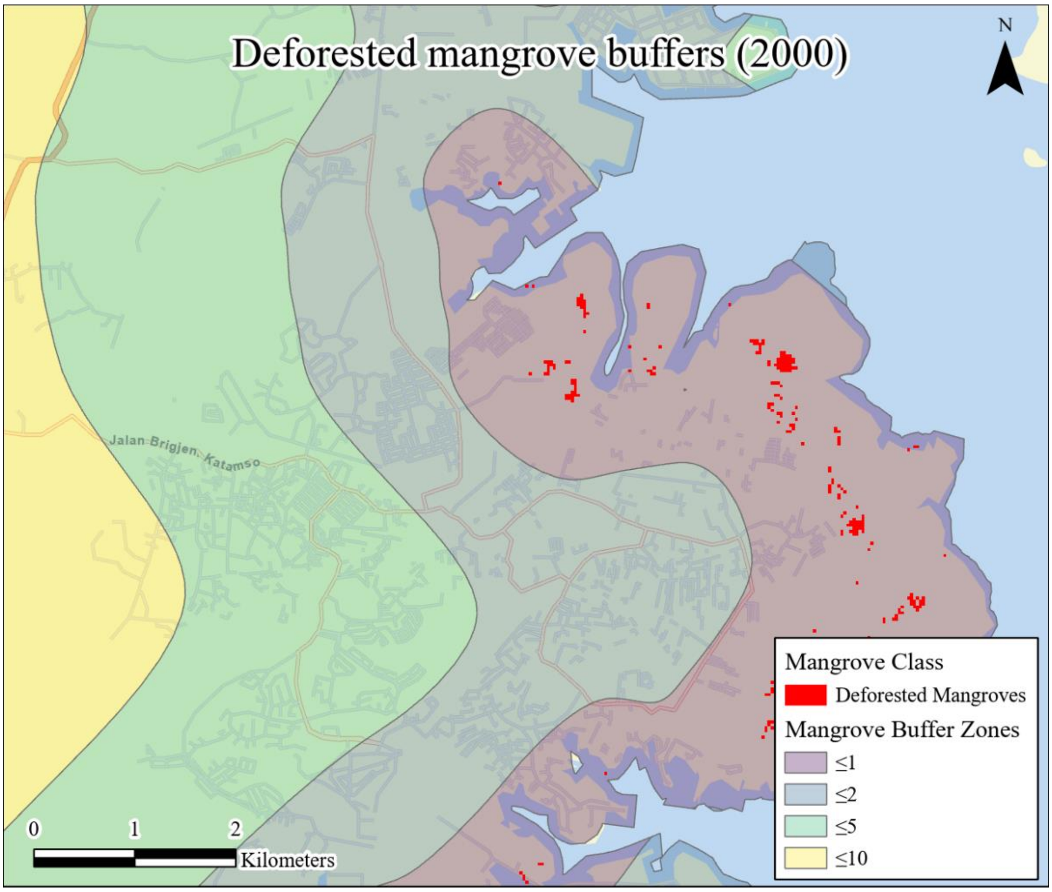
Figure 3- Workflow demonstrating the methods used. The analysis begins with the data which can be seen in yellow, processes are described in purple and blue, and process outputs in green.



5.2.3. Population changes in areas surrounding, deforest mangroves, degraded mangroves, and undisturbed mangroves

The undisturbed-, degraded-, and deforested mangrove classes were buffered for all years using 1, 2.5, 5, and 10 kilometres to find the change in population at various levels of potential exposure. The maximum buffer distance of 10km was selected based on research done by the United Nations Environment Programme (UNEP, 2014), indicating that approximately 120 million people globally live within 10km of the remaining large mangrove habitats. Additional buffers at 1km, 2.5km and 5km were used to obtain a range of people who live within this area of potential exposure. The buffers were created using binary dilation which allows the selected classes to be expanded by a set number of cells. As such each respective class of mangroves was extended by the number of pixels corresponding to buffer widths of 1, 2.5, 5 and 10 kilometres, see Figure 4. The buffered mangroves were used to estimate the number of people living within a given distance to each class in 5-year intervals between 2000-2020 by overlaying them with population data from World Pop. Whilst the mangrove data begins in 1990, no data on population density was available through WorldPop before the year 2000. Hence, this study is limited to population changes occurring after year 2000.

Figure 4- Example of buffers surrounding deforested mangroves in 2000 at 1,2.5,5, and 10km from away from cells classified as deforest mangroves.



To identify hotspots of population change, the population density in 2000 was subtracted from the population density in 2020 to first find the absolute change in population density. Using the population data and the district administrative boundaries of Kalimantan, zonal statistics were used to calculate the mean change in population density across each of the five districts of Kalimantan

6. Results

This Chapter presents the relevant findings of the study in three sections. The first section describes how the mangrove extent in Kalimantan has changed in the last 30 years, with particular focus on undisturbed-, degraded-deforested and regrowing mangroves. The second section identifies trends in population change from 2000 to 2020 and in relation to the distance from the mangrove classes. Lastly, “hotspot” areas showing the greatest change in population in proximity to mangroves have been visualised and qualitatively investigated to identify patterns of spatial-temporal change.

6.1. Change in Mangrove extent

Undisturbed mangroves, in Kalimantan, as depicted in Figure 5, have been steadily declining since 1990. Between 1990 and 2020, undisturbed mangroves experienced a gross loss of 1208 km^2, which is the largest change in area of the mangrove classes investigated. The cumulative sum of the degraded and deforested mangroves can be equated to the loss in undisturbed mangrove and thus follow an inversely proportional pattern of change. Figure 5 shows that after 2000, however, the area of degraded and deforested mangroves begins to increase rapidly. In 1990, the area of deforested mangroves is nearly twice that of degraded mangroves and continues to remain higher than degraded mangroves until 2001, although with a small absolute difference. After 2001, both the relative and absolute difference in area between degraded mangroves and deforested mangroves begins to increase rapidly and by 2005 the degraded mangrove class is more than twice as large as the deforested mangroves. In 2015 the area of deforested mangroves suddenly drops and does not being to increase again until 2017. This pattern of change can also be seen for the degraded mangroves but less pronounced. The area of mangrove regrowth grows by approximately 5.0 km^2 between 1990 and 2000. After 2000, the area of mangrove regrowth begins to increase steadily reaching 91km^2 in 2005. By 2020, the area of mangrove regrowth has increased to just under 300 km^2, which brings it close to the total area of deforested mangroves for the same year.

Figure 5- Area of undisturbed mangroves in Kalimantan recorded yearly between 1990 –2020. Derived from the TMF and GMW datasets

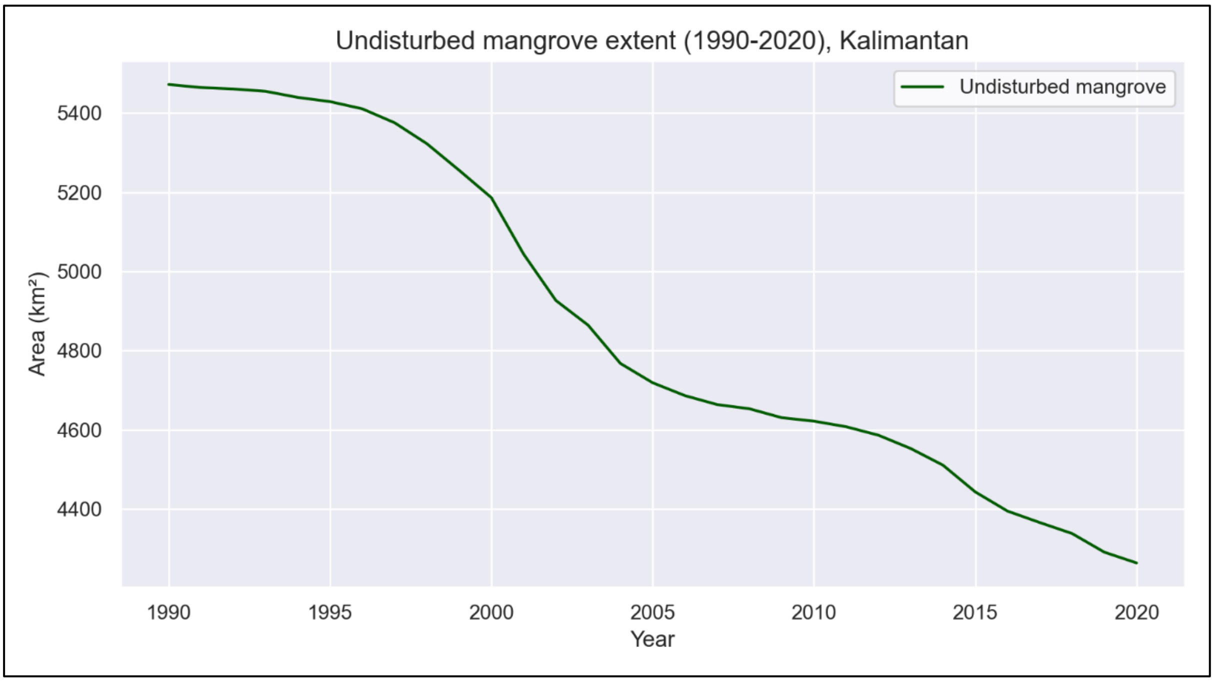
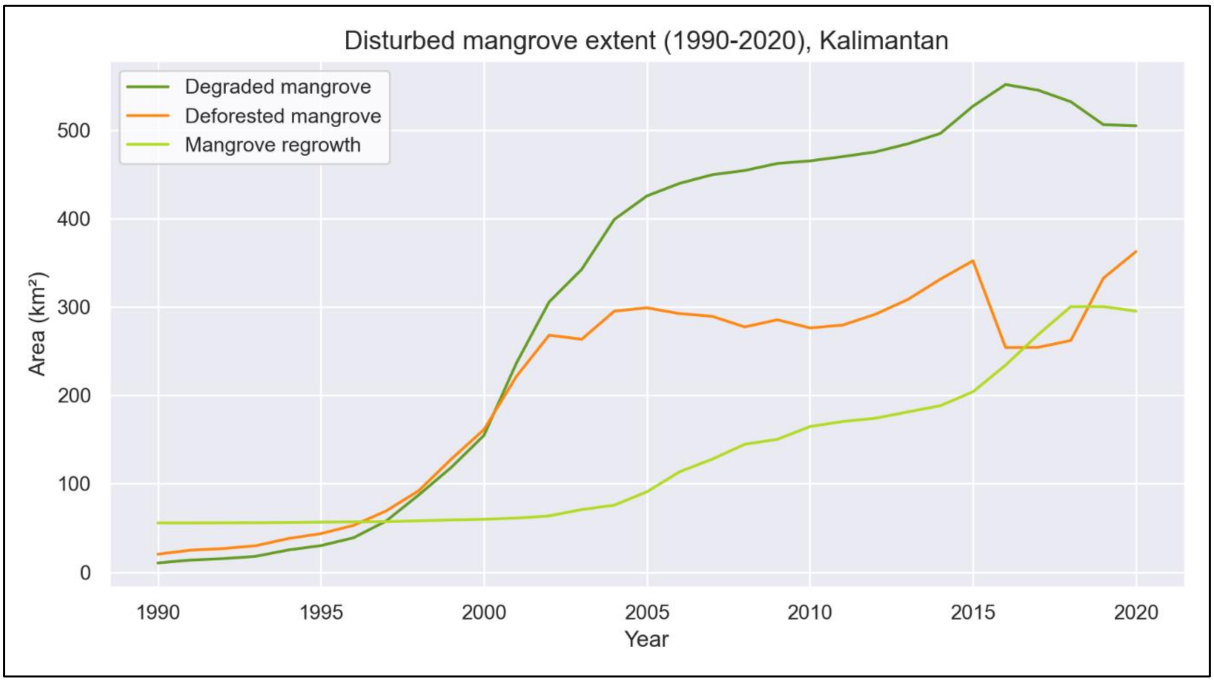


Figure 6- Area of disturbed mangrove and regrowing mangrove extent in Kalimantan recorded yearly between 1990-2020. Derived from the TMF and GMW datasets.

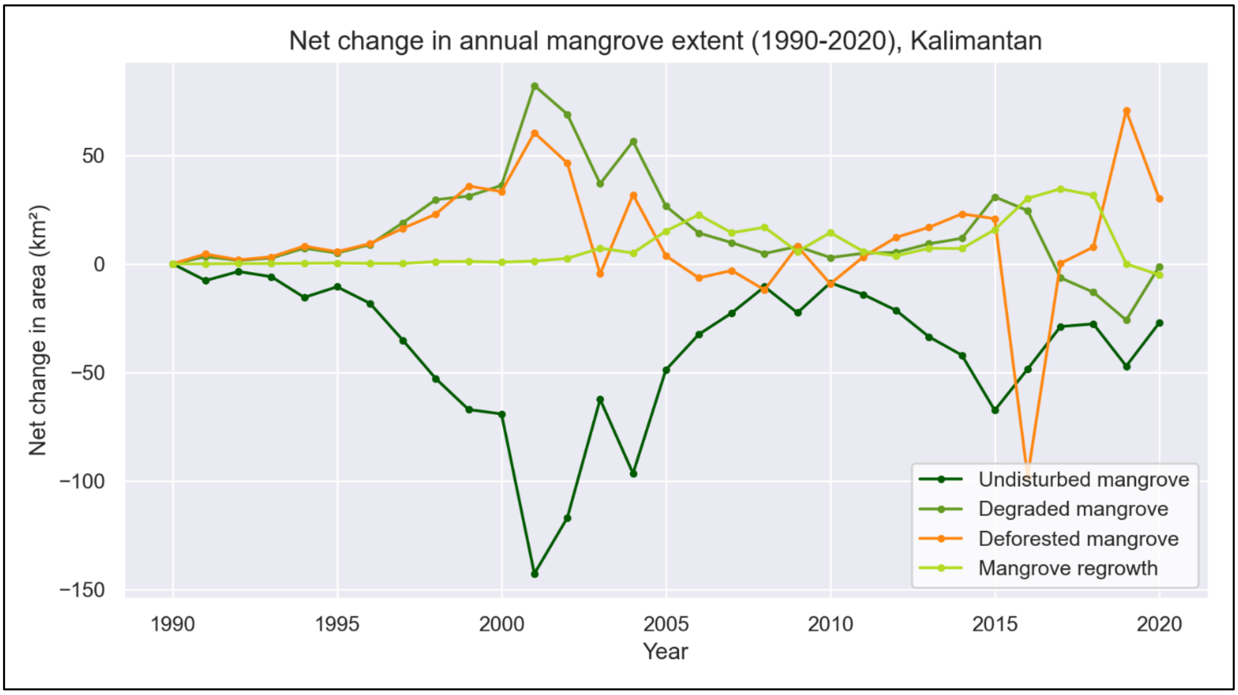


The trends of yearly net change of undisturbed-, degraded-, deforested and regrowing mangrove extent are depicted in Figure 7. As the data assessment starts in 1990, the net change begins at 0. Within the first half decade from 1990 to 1995 there is little change across any of the classes but from 1995 to 2000 the extent begins to increase for degraded- and deforested mangroves, while undisturbed mangrove extent decreases proportionally. The mangrove regrowth extent has a negligible change during this period.

From 2000 to 2010, the net change of undisturbed mangroves begins to decrease rapidly and reaches a peak net change of -142 km^2 between 2000 and 2001. This trend is seen inversely in the degraded- and deforested mangroves, where the former has a net change of roughly 20 km^2 greater than the latter throughout most of the period. Both degraded- and deforested mangrove net change peak in 2001 at 82 and 60 km^2 of annual gain. In 2009 both classes converge at 8 km^2, before the change in deforested mangroves decreases again. The annual net change in area of deforested mangroves remains below zero for three consecutive years from 2006 to 2008, which apart from two outliers 2010 and 2016 is the only point in the record, where the extent of deforested mangroves diminishes. Within the same period, mangrove regrowth steadily increases and reaches a peak in 2006 at 23 km^2, five years after the disturbed mangrove classes peaked in net change.

In the latest decade from 2010 to 2020, all mangrove classes deviate from the trends observed in the previous decades. The change in undisturbed mangrove extent begins to experience larger annual changes, with a decadal maximum net change in 2015 with a loss of 67 km^2. In the first half of the decade until 2015, the net change in degraded mangroves continues the plateau, which began ten years prior in 2005. In 2015, however, the net change in degraded mangrove extent start fluctuating, which begins with a peak in 2015 of 31 km^2 and is followed by an all-time minimum in 2019 of -26 km^2. From 2016, the annual net change in degraded mangrove extent is negative, which has not been observed since the beginning of the assessment period. From 2010, the net change of deforested mangroves increases steadily until 2014, after which there is a sudden, substantial, decrease in the extent of deforested mangroves. In 2017, deforested mangroves begin to increase rapidly and peak in 2019 with an overall net change of 70.5 km^2 in one year. Although, this extreme, rapid decline in mangrove deforestation followed by the acceleration may appear as an anomaly within the data, Vancutsem et al., (2021b), have noted the same pattern for general deforestation during the same period in Indonesia. Lastly, the yearly net change of mangrove regrowth begins to accelerate between 2014 and 2017, reaching a peak net change of 35 km^2 in 2017, before abruptly dropping to a net zero change in 2019. In 2020, mangrove regrowth continues to decrease and experiences a negative net change of -5 km^2. Overall, from the classes examined, undisturbed mangrove is the only class, which experiences a continuous negative annual net change in any of the years between 1990 and 2020.

Figure 7- Yearly net change in the extent of undisturbed-, degraded-, and deforested mangroves from 1990-2020.

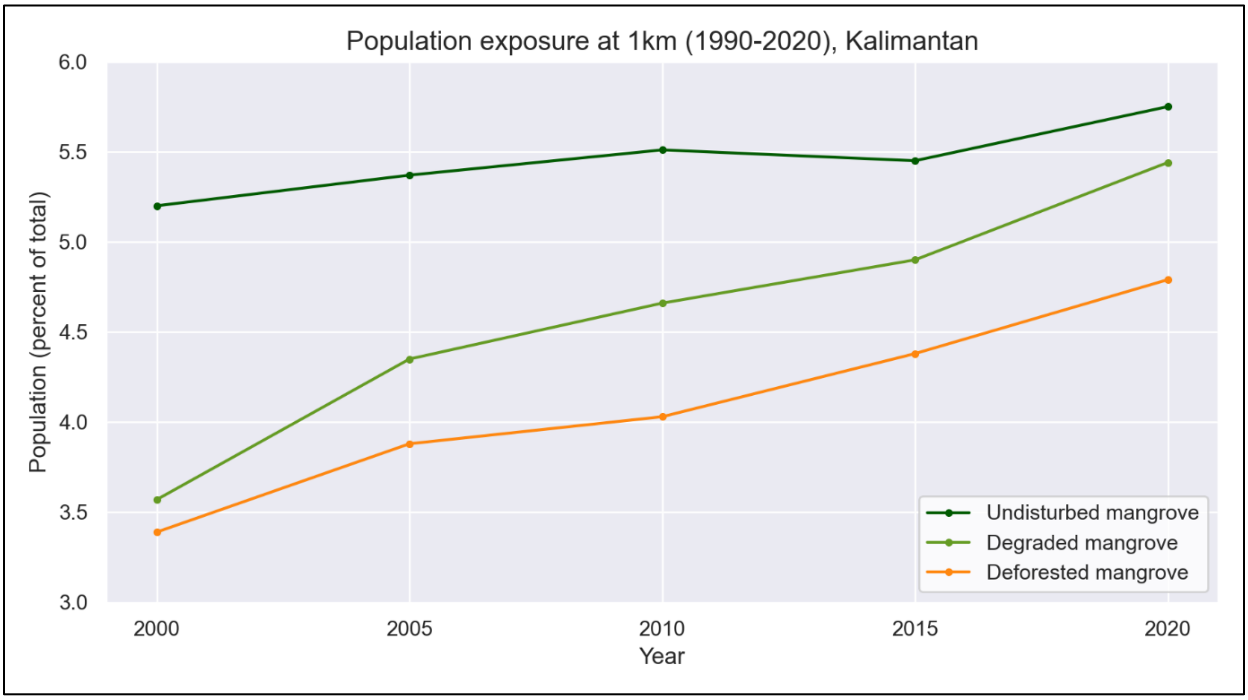


6.2. Potential change in population exposure

This Section will assess the relation of population dynamics in the mangrove buffer zones. Although the potential change in population was calculated at buffer zones of 1, 2.5, 5 and 10 km from undisturbed-, degraded-, and deforested mangroves, the results presented here have only been depicted for the 1km and 10km buffer zones. Results form the 2.5 and 5km buffer zone did not depict extensive change but can still be seen in the population data in Annex 1.

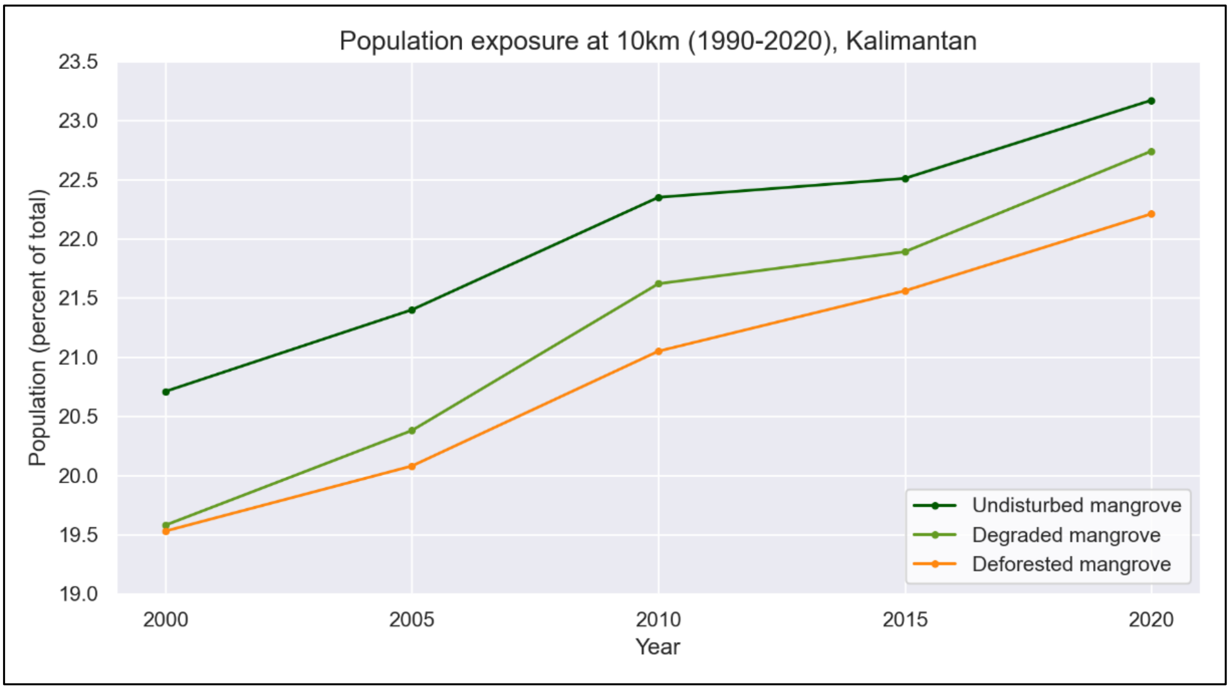
The percentage change of the total population in Kalimantan from 2000- 2020 living within 1 km of undisturbed-, degraded-, and deforested mangroves is illustrated in Figure 6. Within 1 km of these mangrove classes, most people lived and continue to live closest to undisturbed mangroves. From 2000 to 2020, the number of people living within 1km of undisturbed mangroves grew by 0.6% of the total population (from 5.2% to 5.8%) or a total of 450,000 people to 1,000,000 people, within a 15,886 km^2 area. In 2000, the percentage of the total population within 1 km of degraded and deforested mangroves was 3.6% and 3.4%, respectively. By 2020, the amount of people living within 1km of degraded mangroves had almost doubled with an increase of 1.9% of the total population, or a total of 590,000 people across an area covering 14,300 km^2. The number of people living within 1km of deforested mangroves increased by 1.3% resulting in a total of 860,000 people living within a 11,733 km^2 area. In 2020, there is only a 0.3% difference between the number of people living within 1km of degraded mangroves and undisturbed mangroves. The number of people living within 1km of each of the mangrove classes has grown from 2000 to 2020 faster than the regional average.

Figure 8 - Potential exposure change over time, from 2000-2020, of the population of Kalimantan living within 1km of undisturbed-, degraded and deforested mangroves



The next results, depicted in Figure 9 shows the percentage change of the total population (in 2020) in Kalimantan from 2000- 2020, living within 10 km of undisturbed-, degraded-, and deforested mangroves. Compared to Figure 8, the percentage of the people living within 10km of any of the mangrove classes is much higher, starting at 20.7% and increasing by 3.1% by 2020 to 23.2%. This means that in 2020, 4,140,000 people lived within 10 km^2 of undisturbed mangroves in an area covering roughly 46997 km^2. Similarly, to Figure 8 there is only a minor difference of 0.1% between the percentage of people living within 10 km^2 of degraded and deforested mangroves in 2000, but the difference increases over time with more people living close to degraded mangroves than deforested mangroves. Compared to Figure 8, the number of people living within 10km of all mangrove classes increases consistently from 2000 to 2020. Figure 8 shows that there is a decline in the number of people living near (<1km) of undisturbed mangroves between 2010 and 2015. Additionally, there is a similar trend for people living within both 1km and 10km of degraded mangroves. However, at 10km deforested and undisturbed mangroves have a higher rate of change between 2000 and 2020. Figure 8, reveals that there is a smaller difference in the number of people living with 10km of degraded and deforested mangroves than the number of people living within 1km for the same classes.

Figure 9 - Potential exposure change over time, from 1990-2020, of the population of Kalimantan living within 10km of undisturbed-, degraded and deforested mangroves.



The largest net growth in population density and the largest net loss in undisturbed mangroves between 2000 and 2020 did not occur in the same district. See Table 3. Despite having the lowest net gain in population density, North Kalimantan experienced the second highest net loss of mangroves, in an area approximately half the size of East Kalimantan, where the highest loss of mangroves occurred. South and West Kalimantan had a similar net loss of mangroves, yet South Kalimantan had a much larger net gain in population density, the highest amongst the districts in Kalimantan. Central Kalimantan saw the second lowest net growth of population density and had the lowest net loss of mangroves. The reason for these differences in population density versus mangrove loss is explained in the next Section and also in Chapter 7.

Table 3- District statistics of the net change population density and net change in undisturbed mangroves between 2000 and 2020.

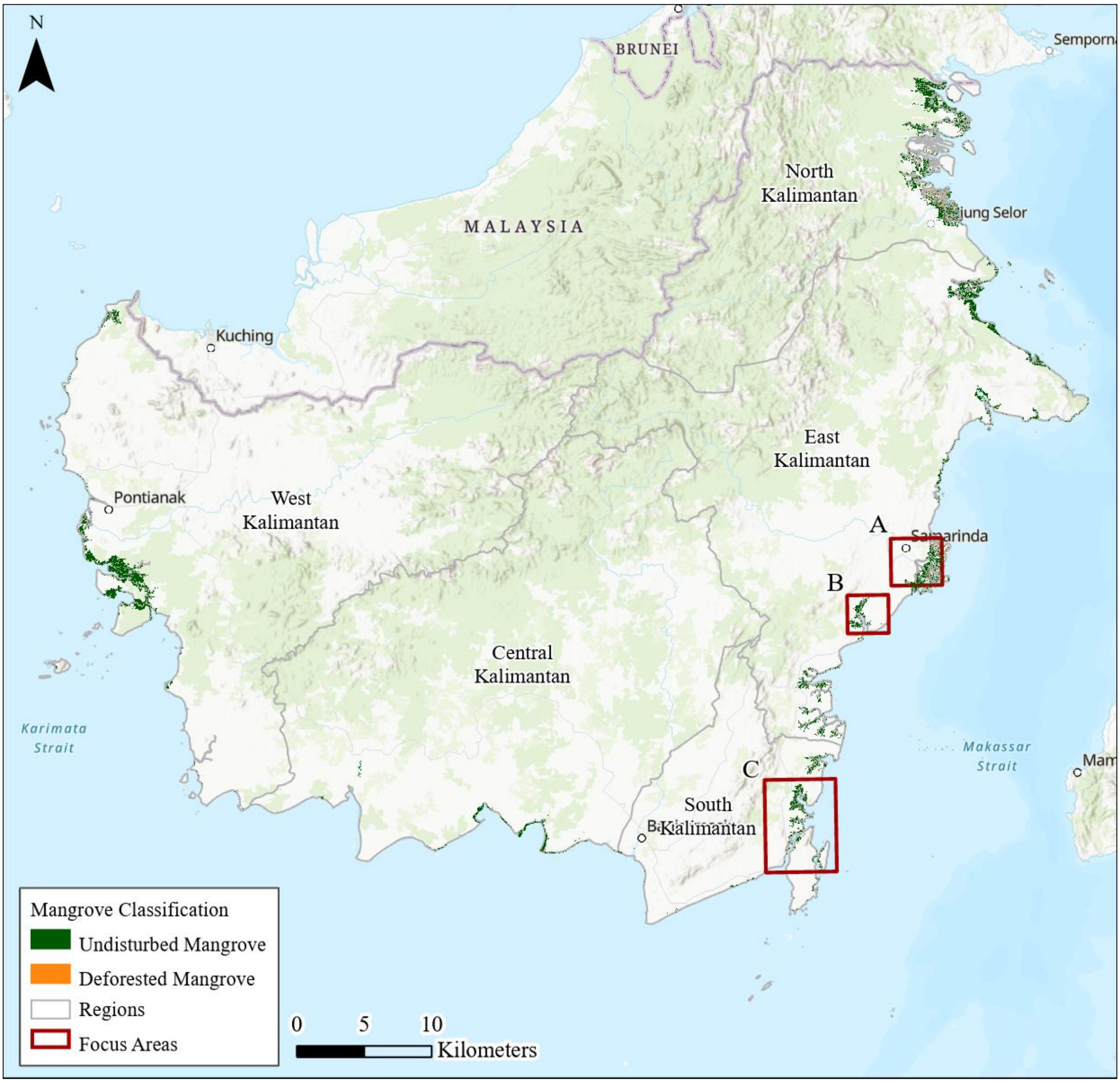
District	**Net loss in area of undisturbed mangroves (km^2) (2000-2020)**	**Net change in pop density (2000-2020); number of people/km^2**	**Area (km^2)**
West Kalimantan	87.90	10.23	147,307
South Kalimantan	84.34	41.24	38,744

Central Kalimantan	55.59	6.20	153,564
East Kalimantan	516.09	18.53	127,347
North Kalimantan	458.97	4.88	71,827

6.3. Hotspots of population change and change in mangrove extent

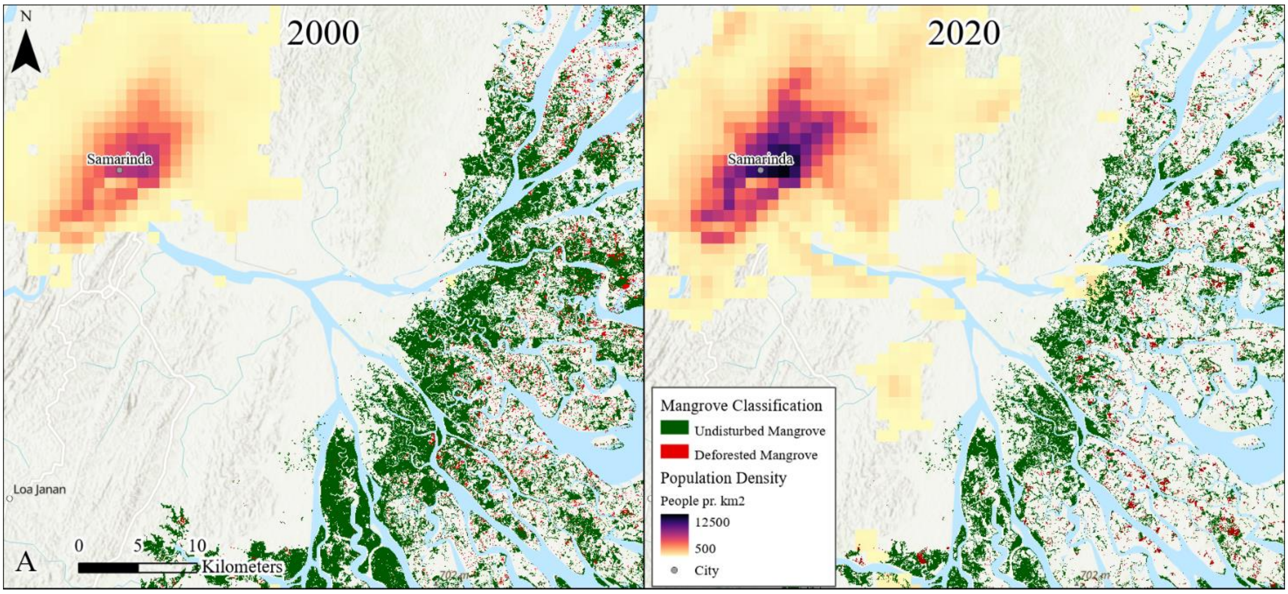
There has been an overall decline in the mangrove extent of Kalimantan with also an increase in population growth in the last two decades. Thus, the results of this study show that more people could potentially be exposed to coastal hazards, particularly where mangroves have been deforested or degraded. However, as shown in the previous Section, not all areas of population growth have experienced equally high levels of mangrove deforestation and degradation. This Section visually presents some examples of the hotspot areas, see Figure 10, where populations have densified since 2000 and the resulting impact on the mangrove extent. As such each hotspot area chosen, displays an image showing the population density and mangrove extent in 2000 and is compared to the same area in 2020. In this way, this thesis aims to visualise, and understand some of the different relationships found between population growth and mangrove extent seen in Table 3, and in Figures 11-14. Full size images of Figures 11-14 can additionally be found in Annex 2 for more detailed examination of the settlement areas and deforestation.

Figure 10- Hotspots for changes in population or mangrove extent. The focus areas in this Figure have been labelled from A-C and can be seen in more detail in Figures 9-12.



Focus Area A is a coastal area in East Kalimantan, which as noted in Table 3, had the highest net loss in mangroves and the second highest population densification. The high mangrove loss can be attributed to areas such as the city of Samarinda. Figure 11, shows the city of Samarinda in East Kalimantan, and the nearby delta/mangrove habitat, which is located approximately 25 km away from the city. Since year 2000, Samarinda has experienced population densification and sprawl towards the base of the delta. In 2000, Samarinda had a small, population-dense urban centre with densities decreasing further towards the outskirts of the city and very little sprawl towards the delta and mangrove habitat. In 2020, the city has densified, and small settlements have emerged outside the city closer to the delta. In the same period, the mangrove habitat has become fragmented and has been increasingly replaced by deforested mangroves. The fragmentation and deforestation of mangroves is most apparent at the base of delta, which remained mostly unspoiled in 2000 but in 2020 shows signs of disturbance. Figure 12, provides a closer examination of part of this delta through the use of a 2 meter resolution, satellite image, from the 7th of June 2020, (Planet Labs PBC, 2018), and an overlay of the actual mangrove extent, calculated in the methodology. In the image shows that, in 2020, there are large areas of degraded mangroves amongst areas of undisturbed mangroves. Many areas of the permanent and seasonal water bodies are likely aquaculture ponds and agriculture, as indicated by their regular geometry and boarders.

Figure 11 -Focus area A, showing change in population density for the city of Samarinda and change in the mangrove extent from 2000-2020



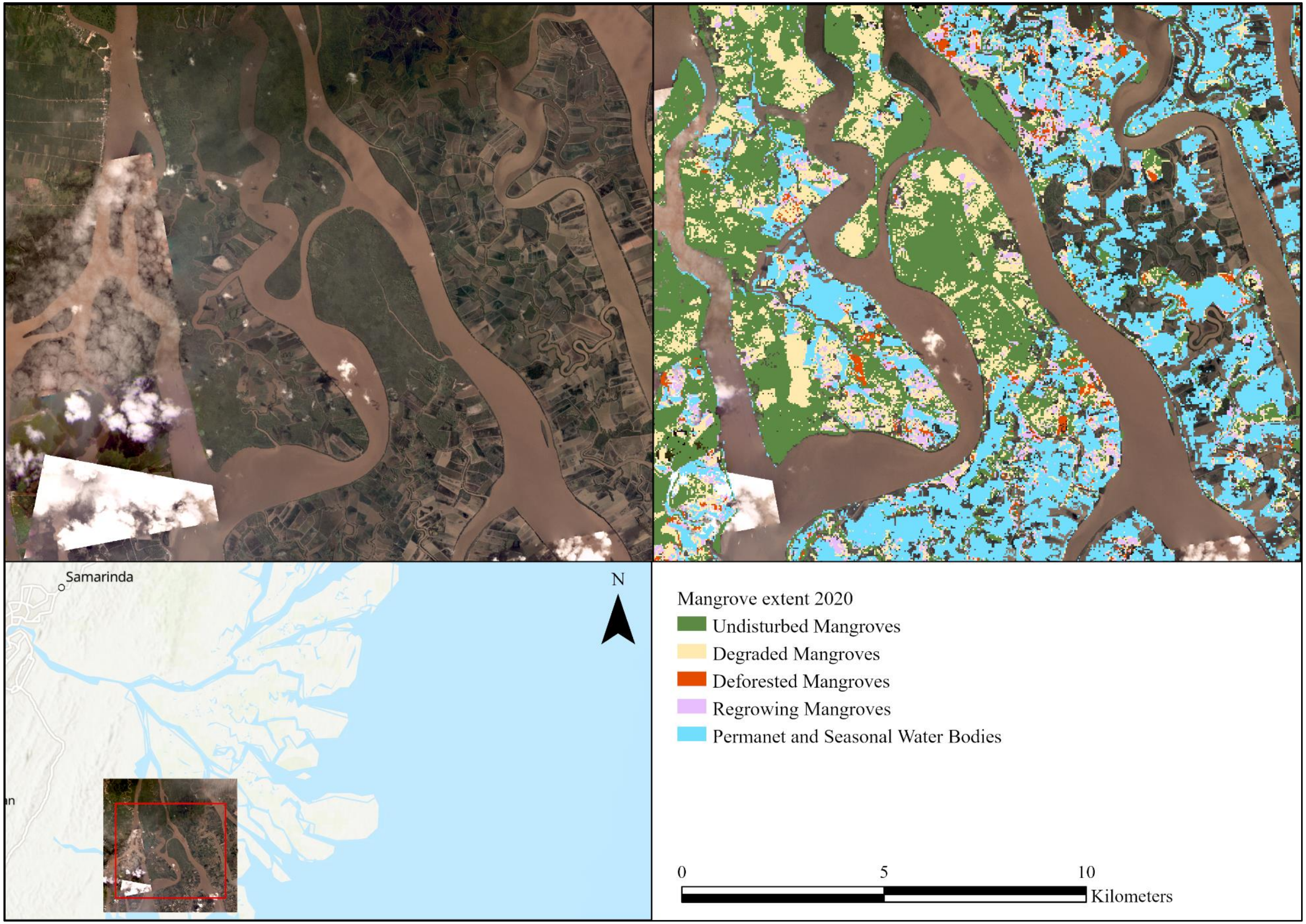
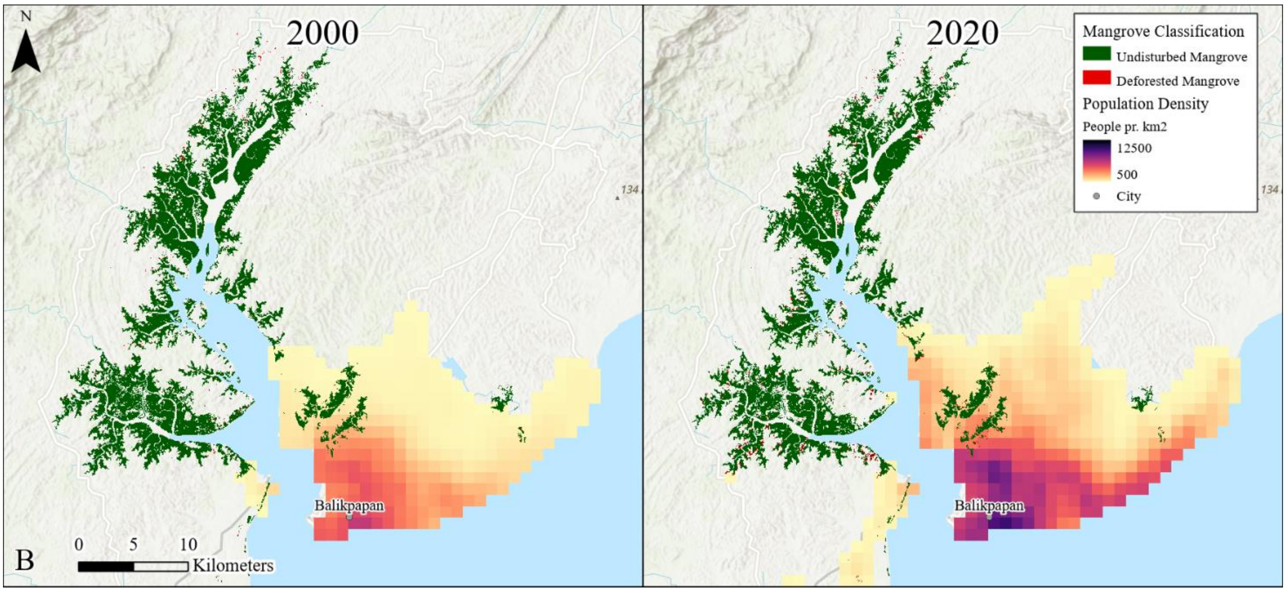


Figure 12 -Displayed on the left, a satellite Image © 2020 Planet Labs PBC at 2-meter resolution of a small area of the Mahakam delta, in East Kalimantan. To the right, the same area with an overlay of the mangrove extent in 2020, calculated from the TMF and GMW Data.

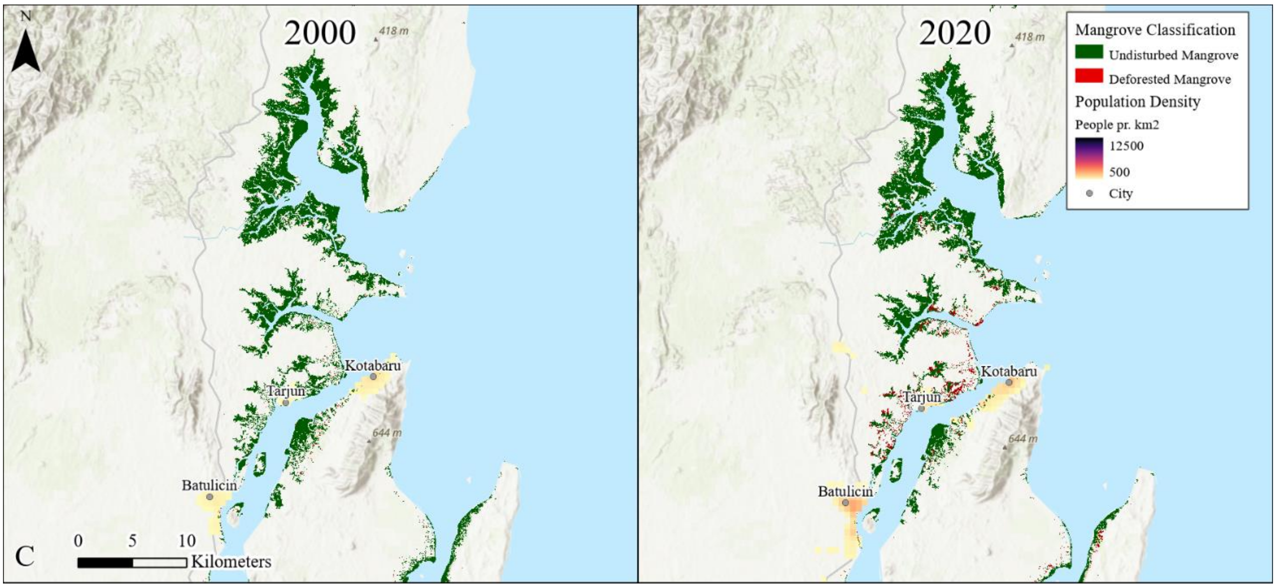
Focus Area B: The city of Balikpapan is located along the coast of East Kalimantan. Through examination of the area, as presented in Figure 13, Balikpan does not show the same extent of mangrove deforestation although there has also been a densification and expansion of the population. Mangroves located within the populated area of the city have been deforested along the outskirts of the habitat in the last 20 years and this trend is likely to continue as the population density surrounding the mangroves increases. Figure 13 also shows that deforestation of the mangroves has occurred south-west of Balikpapan, where the population has grown, and the deforestation coincides with a major road that runs along the mangrove habitat.

Figure 13- Focus area B, the city of Balkipapan (East Kalimantan), showing the population density in 2000 and 2020 as well as undisturbed and deforested mangroves within the same period.



Focus Area C: South Kalimantan had the highest net growth in population density, yet a low net change in mangrove loss. Figure 14, shows an area in South Kalimantan experiencing high population densification and related development. The Figure shows the small settlement of Tarjun as the northern most settlement on the mainland, Kotabaru city on the northern part of the island, and the village of Batulicin in the southern area of the mainland. Within this relatively small area, there has been a high level of development in the last twenty years and many mangroves, particularly those in close proximity to these settlements have been deforested. It can also be seen that to the north of these settlements that there are two larger areas of mangroves that have remained relatively undisturbed. The area of undisturbed mangroves closest to the settlement has experienced more deforestation than the larger area further away. However, it appears that in 2020, some deforestation of mangroves has already begun in the larger area, despite not having immediate population development close by. The road and waterway that surround this area may be providing easier access to the mangroves. Thus this area, provides important examples of areas which are currently under threat of experiencing higher rates of mangrove deforestation, and following the trend presented in East Kalimantan, where population growth and loss of mangrove biomass are correlated.

Figure 14 - Population development and mangrove deforestation along the coast of South Kalimantan



This Section has more closely examined some of the areas of high population growth since 2000 along the coastline of Kalimantan.From the hotspots examined, the city of Balikpan, standout as an anomaly where the mangrove extent has remained relatively undisturbed despite population growth. The consideration of population densities and mangrove loss as well as the resulting potential exposure of communities is further discussed in Chapter 7.

7. Discussion

This chapter aims to analyse and discuss the results of this thesis which were presented in Chapters 5 and 6; this includes the use of geo-spatial data in calculating the mangrove extent, relation of mangrove extent to change in population, and the institutional arrangements in Indonesia for mangrove management as well as it’s role in DRR. The first three sections of this Chapter systematically discuss issues relating to the historic and current situation in Kalimantan on mangrove extent, as well as trends in deforestation, degradation and regrowth. This assessment provides a framework for what opportunities and/or risks the island faces in terms of using mangroves for NBS as part of DRR. The fourth section briefly discusses the result and consequences of coastal population growth and exposure to natural hazards as a result of mangrove loss. Issues relating to the results of governance and management, discussed in Chapter 6, have been further elaborated upon also in this current Chapter. Lastly, the limitations of this study have been discussed, which specify the boundaries of this thesis and provide further transparency on the data and methodology used.

7.1. Mangrove status in Kalimantan

7.1.1.Mangrove extent

To answer the aim of this thesis, it was first necessary to understand the extent of mangrove loss in Kalimantan. Additionally, this information provides a baseline for monitoring of mangroves in various conditions and provides support for planning and policy making in the context of mangrove ecosystem management in the future. This objective was successfully achieved and found that the extent of mangroves had experienced a net loss of 1208 km^2

between 1990 and 2020. This result was not unexpected given previous documentation of deforestation rates and mangrove deforestation in Indonesia (V. B. Arifanti et al., 2021; Bunting et al., 2018; Thomas et al., 2018a). However, coastal development and aquaculture are often seen as the primary threats to coastal ecosystems and mangroves in Indonesia (Ilman et al., 2016; World Bank, 2016); this study shows that these two causal factors are not valid for all districts in Kalimantan.

East Kalimantan had the highest net loss of mangroves and the second highest net gain in population density between 2000 and 2020. In this case, aquaculture has driven development, particularly in the city of Samarinda and the neighbouring Mahakam delta. In the 1980's the Indonesian government banned the use of bottom trawling nets (Ilman et al., 2016), as a result an alternative form of shrimp farming, aquaculture, became popular. The Mahakam delta, with its brackish, shallow water provide an ideal environment for shrimp and crustaceans and mangroves provide protection and reduce strong currents. The global demand for seafood, thus created economic incentives for more people to invest in aquaculture ponds in the last two decades (Virni Budi Arifanti et al., 2019) and the coast of East Kalimantan provide the ideal environment to do so. Indonesia's aquaculture industry is currently continuing to expand and The MMAF has set ambitious growth targets of around 8.5% growth per annum up to 2030 (Henriksson et al., 2019). Wulffraat et al., (2017) predicts that should mangrove deforestation and degradation continue at this rate in the Mahakam delta, by 2030 there will not be many mangroves left.

Another city in East Kalimantan, showed contrasting results to that examined in Samarinda. Another hotspot for population growth in East Kalimantan was the city of Balikpapan. As shown in Figure 13, this city did not experience the same extent of mangrove loss as Samarinda despite similar trends in densification in the last twenty years. Although USAID, (2001) comments that the mangrove habitat surrounding Balikpapan has remained largely intact, it is likely to change as the city continues to develop. Since the establishment of the city in the early 19th century, Balikpapan has primarily been used as a port city to transport oil and gas extracted from the surrounding area (USAID, 2001). It as such, appears that this use of land inadvertently delayed the conversion of mangroves other land uses such as small and large-scale scale farming and aquaculture. It has also been reported that in the early 2000's Balikpan introduced policy measures to manage coastal resources (Hanson et al., 2003), but it is unclear as to what extent these management practices incorporated and protected mangroves in the area. The data from this thesis indicates that mangroves surrounding Balikpapan are now experiencing deforestation, indicating that they may now be under threat from development of the city.

The second highest loss of mangroves, see Table 3, was, however, in North Kalimantan which had the lowest net growth in population density since 2000. Whilst loss in mangroves in this area can also be linked to development, it can be argued that this form of development and land use change is happening at a much larger scale than coastal development linked to the economic prospects of aquaculture farming. Palm oil plantations are responsible for a significant proportion of deforestation in Indonesia (Austin et al., 2019:4; Cahyaningsih et al., 2022:15) and are the only large scale cash crop that currently expand into brackish areas where mangroves grow (Ilman et al., 2016). This study found that largest decline in mangrove extent occurred in North Kalimantan between 1990 and 2000, which coincides with the early boom of palm oil plantations in Indonesia (Baudoin et al., 2017). One of the reasons that the losses of mangroves in Indonesia are more strongly associated with aquaculture and not palm oil, is that their area of overlap is considered “small” compared to the total area of the plantations and deforestation that result from the large-scale palm oil plantation. What is not considered is that, mangroves are also cleared from the coastline to make space for settlements and workers associated with the palm oil plantations. The mangrove ecosystems thus experience a ‘squeeze’ from both sides on their extent and the loss in some areas is significant. This has likely been the case in North Kalimantan, where villages were initially developed along the coastline because the forest areas were very dense and had limited accessibility.

The last hotspot examined, was along the coast of South Kalimantan (Focus Area C: Figure 14 , from Section 5.3). South Kalimantan, as presented in Table 3, has has the highest population densification of all the districts in Kalimantan. This thesis has further identified part of South Kalimantan’s coastline as a hotspot area, where the population of several small settlements has grown substantially by 2020. Alongside this growth, mangrove degradation has occurred extensively, particularly in close proximity to the settlements. Further examination reveals that the provincial government has been exploiting the land through mining practices and conversion of land for palm oil plantations. The extensive loss of tree cover experienced in South Kalimantan has been reported as a contributing factor to heavy flooding experienced throughout the district in recent years.

7.1.2. Mangrove Degradation and Deforestation

The mangrove loss in Kalimantan manifests as mangrove degradation and/or deforestation as noted in the Results Chapter. From the results of examining the geo-spatial data, it can be noted that both deforestation and degradation have followed similar trajectories in terms of mangrove loss in Kalimantan in the last thirty years. This study reveals that deforestation of mangroves has, however, not occurred as extensively as degradation. Many studies examining changes to mangrove extent, do not separate loss into degradation and deforestation, making it difficult to explain the exact reasons for the elevated degradation over deforestation of mangroves. Nevertheless, it is important with the context of this study to distinguish between degraded mangroves and deforested mangroves. This is because deforested mangroves provide no ecosystem services whilst degraded mangroves may still provide limited protection against coastal hazards and, can potentially still provide other services but at a reduced capacity. One way in which degradation of forests can occur is through ecosystem fragmentation, which is a dynamic process that occurs when a larger habitat experiences disturbances that result in division of the habitat into smaller, separate areas of land (Herrera et al., 2016:6).

Although this methodology did not specifically examine ecosystem fragmentation, it appears that these phenomena may be occurring in some parts of hotspots examined, but further examination would be needed to confirm this. Some of the anthropogenic actions that drive deforestation and degradation may also be driver of mangrove fragmentation. This is important to consider as fragmentation threatens the ecological function of mangroves which in turn reduces their ability to enhance resilience of the environment and populations that they protect (Bryan-Brown et al., 2020). Hashim & Catherine,(2013) calculated that dense mangrove forests reduce the impact of waves by more than 15% across 50 meters of highly dense mangroves than 50 meters of sparse mangrove forests. Evidence from this study, as shown through Figures 13 and 14, show that accessibility, both through the development of infrastructure and the initial clearing of mangroves may lead to further degradation and deforestation of mangroves. Fragmented mangroves may additionally aid in creating a positive feedback system of degradation and deforestation as it slowly creates accessibility to denser, healthier mangroves, which may then be exploited (Bryan-Brown et al., 2020). Lastly, fragmentation of mangroves reduces the protection of fish nurseries as well as the biodiversity of other flora and fauna. This may lead to devastating impacts on food security through reduction in fishable biomass (Seary, 2019:3). The identification of such areas could present an opportunity for rapid and effective intervention to prevent further impacts or highlight places where rehabilitation could require little more than a reduction or cessation of damaging actions.

7.1.3.Mangrove Regrowth

Evidence from the results in Chapter 4, show that the extent of mangrove regrowth has remained low since the start of monitoring in 1990, aside from a brief peak in yearly extent from 2014 and 2017. No evidence has been found to suggest that this peak is directly related to a change or provision of new policy regarding mangrove reforestation in Indonesia during this period. However, future monitoring of the mangrove extent in Indonesia is likely to detect an increase in mangrove regrowth after 2021, as the Government of Indonesia has set an ambitious target of rehabilitating 6000 km^2 of mangroves by 2024, under the Mangrove for Coastal Resilience programme (Indonesia Environmental Fund et al., 2022). This substantially exceeds the area of undisturbed mangroves lost since 1990 in Kalimantan but may come closer to the total area of mangroves lost across multiple islands within the country.

The ambitions to re-establish such a vast area of mangroves is likely to be met with some challenges. Several studies, document that the rehabilitation of mangrove areas is complex due to the natural habitat in which they are found (IUCN, 2017; Lewis et al., 2002). Unlike terrestrial forests, mangroves experience high seedling mortality from the disturbances such as hightides, strong waves, and ocean debris (V. B. Arifanti, 2020). If restoration efforts are not pursued before replantation of mangroves, stresses from the existing landscape can increase the likelihood that secondary succession does not occur (Lewis et al., 2002). This has particularly been documented in the context of abandoned aquaculture ponds in South East Asia, where the physical construction of the aquaculture ponds limits the hydrological connectivity as well as the dispersal of mangrove propagates (Ellison et al., 2020).

An additional challenge in ensuring the success of re-established mangroves is the power dynamics within the management scheme employed. If local ownership is not established during the reestablishment of mangroves, it is likely that the mangroves will continue to suffer from mismanagement practices that led to their degradation and deforestation initially. Research done by Damastuti et al., (2022) documenting the results of community-based mangrove management plans in other parts of Indonesia found that when managed affectively, with equal power given to partners in decision making positions, economic activities such as aquaculture can continue in harmony with mangrove ecosystems. Furthermore, of the case studies produced by (Ellison et al., 2020), it was found that bottom-up decision making created more trust and greater acceptance of the mangrove management plans, than cases where a top-down decision-making process was taken. Self -mobilisation of the community is as such key in creating an enabling environment for community governance of mangroves (Damastuti et al., 2022; Ellison et al., 2020) and should be included in the management plans of the rehabilitation of mangroves in the Mangrove for Coastal Resilience programme. The development of multiple pilot programmes can help to provide specific insight on the specific needs of local level conservation of mangroves alongside the continued use of ecosystem services provided.

Given that there are a number of barriers to the successful re-establishment of mangroves, pre-emptive measures that protect mangroves from experiencing degradation and deforestation are a more cost-effective solution. Lewis et al., (2002) found that the reestablishment of mangroves in aquaculture ponds in Thailand would cost between 200-700 USD/ha depending on the extent to which the aquaculture ponds excavated, and the planting method chosen. Additional costs of the monitoring and maintenance should also be factored in and weighed against the cost-benefits that old, well established mangrove forests already provide. The shoreline protection benefits alone of mangroves in Sulawesi, Indonesia have been estimated to save the Government of Indonesia between 694 USD/ha to 3767 USD/ha annually (Malik et al., 2015). Furthermore, shrimp farms have an average five productive years before they are abandoned, of which one year is spent in an establishment phase, where shrimp yields are low. After five years of use, some shrimp ponds have reported a decrease in yield to 45 kg ha^{-1} yr^{-1} from around 300 kg of shrimp ha^{-1} yr^{-1} (V. B. Arifanti et al., 2021). With this perspective it can be seen that the aquaculture offers incredibly short-term financial gains for an immense extent of environmental degradation.

In addition to providing quantitative data on the mangrove extent and losses in Kalimantan in the last 20-30 years, the thesis results also demonstrate the value of using geo-spatial data for assessment and monitoring of coastal ecosystems. The freely available global datasets such as the GMW and TMF are being regularly updated temporally, and therefore will continue to provide a valuable tool for mangrove assessment in the future.

7.2. Population pressure and Coastal development

Through combining the results from the change in mangrove extent with the results from the change in population growth, this thesis was able to fully answer the question “How has the exposure of the coastal population of Kalimantan, to potential climate hazard changed as a result of coastal mangrove loss and population growth?” From the discussion in Section 7.1, it can be noted that the removal of mangroves for different economic land uses has been a main activity in Kalimantan in the past 20-30 years. The examination of the population exposed to the loss of mangrove was undertaken in Chapter 5, and the results indicate that overall, the percentage of people living close to mangroves in Kalimantan has increased since 2000, but more specifically by 2020 more than 40% of the population of Kalimantan live within 10km of degraded and deforested mangroves. Thus, there is a strong correlation between population growth and settlement in the coastal ecosystems with resulting removal of mangroves. Ultimately, this indicates that the population living close to degraded and deforested mangroves in 2020 may suffer from increased consequences given their reduced physical protection from the mangrove ecosystem. It should further be considered that; exposure is often correlated with socio-economic vulnerability as people rarely subject themselves to dangerous living conditions willingly (Mcdonald & Wilcox, 2020). This study does not imply that all those who are exposed are also vulnerable, but rather that in the context of preparedness and disaster management, areas of high exposure should further be examined for increased social vulnerability.

In this regard, the examination of increased exposure and social vulnerability can be an important tool for increasing risk awareness and preparedness measures. People who are more informed on acute risk to themselves and their livelihoods tend to invest more often in mitigation measures (Koks et al., 2015). At the local level this may come in the form of individual risk mitigation practices such as retrofitting houses for flooding events. Whilst individual level practices are important, in the case of Indonesia, where there are approximately 44 medium to large coastal cities with populations over 500,000 people (Ilman et al., 2016), it may be more important that actions are target towards implementing national and community practice that mitigate or reduce risk. At the community level, it appears that, actions can be taken to implement sustainable management of the mangroves to reduce degradation and enhance their function to provide additional ecosystem services (Damastuti et al., 2022; Sunyowati et al., 2017). At the national level, a side from the use of policies to protect mangrove management, it will also be important to assess the areas where mangrove degradation and deforestation are very high. These areas are likely to require additional support such as the implementation of early warning systems or coastal infrastructure to protect those who now face higher levels of exposure (Stanton-Geddes & Vun, 2019).

7.3. Understanding aspects of mangrove governance and links to disaster risk reduction

Although, the examination of governance of mangroves was not a key question within this thesis, it is a crucial aspect in understanding why exposure may increase as well as how the results of this study and the monitoring of mangroves ecosystems support national disaster risk reduction and climate change adaptation policies. To do this, key aspects relating to the governance of mangroves were explored in Chapter 4. One of the key findings from the literature reviewed, was that there is a lack of cross-collaboration between the environmental sectors tasked at working towards CCA and the ministries tasked with operationalising DRR measures. For example, Mcdonald & Wilcox, (2020) review of Indonesia DRR strategy revealed that NBS have not been considered as a form of DRR and are instead only mentioned as being an important part of Indonesia's climate adaptation strategy. The inclusion of mangroves and NBS solutions in Indonesia's NDCs is however a good steppingstone, but more attention is needed at regional and subregional levels to integrate NBS into the policy frameworks. The Asia Regional Plan for Implementation of the Sendai Framework suggests a few ways in which DRR and CCA can be enhanced at regional and sub regional levels. Furthermore, using the guidance of the HFA and SFDRR, can help to facilitate a risk-reducing approach within CCA activities (International Strategy for Disaster Reduction, 2012).

This thesis and the report by Mcdonald & Wilcox, (2020) recognise that there are very few legal and policy frameworks for monitoring and evaluation to measure the success of implementation of environmental and DRR policies. The existing legal and policy framework also contains very limited references to monitoring and evaluation to measure the success of implementation. While the BNPB has been assigned as the main body responsible over M&E in terms of DRR within the Regulation 8 of 2008 concerning the National Agency for Disaster

Management (Mcdonald & Wilcox, 2020), the extent to which it is able to evaluate initiatives across the country remains unclear (IFRC, 2017). The Baseline Status Report for SFDRR country implementation, developed by BNPB in 2015, indicated that Indonesia is yet to achieve systematic monitoring of the SFDRR and acknowledged the gaps in coordination and information sharing among a broad range of DRR concerned agencies.

Other national agreements, namely, Indonesia NDCs, acknowledge the importance and protection of mangrove ecosystems for adaptation purposes and to create long term resilience. However, the interest in mangrove management within these policy frameworks has not been translated to prioritise the monitoring of mangrove ecosystems. A lack of technical and financial capacity has likely hindered the inclusion of monitoring systems for mangrove management within the legal and policy frameworks analysed. As mangrove management can help to achieve a number of national goals, cross-sectoral collaboration may provide the capacity needed to engage more thoroughly in monitoring activities. Monitoring can also aid in the national spatial planning and development schemes, particularly when mangroves are recognised for their natural defence properties (UNEP, 2014), given protection form coastal erosion and flooding. In rural areas where mangroves are already established, their protection may offer a cheaper solution to protection than the establishment of built structures such as sea walls. In areas of rapid development or where mangroves have already experienced high degradation, they may be considered alongside built infrastructure, given that their protective properties alone are limited.

The Government of Indonesia is not yet full utilising mangroves as NBS as evident from the policy review. One main reason for this is that the protection of ecosystems in Indonesia, are often competing with economic development opportunities. Although the country has experienced rapid development over the last two decades, development has not been equally distributed across the country. 43% of Indonesia’s population lives in rural areas and many do not have access to basic resources (The World Bank, 2018). One of the challenges stated in this report is the management of environmental degradation, particularly in Kalimantan, as a trade-off to development (Mcdonald & Wilcox, 2020). With the planned relocation of the capital city to Kalimantan, one of the most biodiverse regions of Indonesia, avoiding the negative trade-offs associated with development will be more crucial than ever to maintain the pathway towards sustainability. The World Bank, (2020), cost-benefit analysis of the long-term economic value of mangroves, suggest that the investment in mangrove conservation, rehabilitation, capacity building and community development bring more benefits compared to short term development practices that cause long lasting damage to mangrove ecosystems.

7.4. Summary of Findings

To conlcude the overall discussion of the results, this thesis aimed to use geo-spatial data, in conjunction with population data and a policy review to answer the main reserch question: “ how has the exposure of the coastal population of Kalimantan, to potential climate hazards, changed as a result of coastal mangrove loss and population growth?” The thesis also used a case study approach to examine and understand the extent to which mangroves provide coastal protective services in Kalimantan.The answer to this question has proven to be complex and multifaceted in its nature. When examined from the perspective of protection through the reduction of physical exposure to coastal hazards, it was found that in 2020, 23% of the total of population live within 10km of undisturbed mangroves and the percentages of people living within proximity to degraded and deforested mangroves has been increasing. However, closer examination of the mangrove extent where populations have densified, has revealed that most mangrove ecosystems are experiencing degradation and deforestation alongside the undisturbed mangroves. Overall, this means that the functional capacity of most mangrove ecosystem to provide protective and resilience enhancing services has declined. Although, there is some evidence of increased mangrove establishment in recent years, there will be a lag time before these mangroves are able to provide the same extent of services as older, more well-established mangroves.

Furthermore, the sustainable management and monitoring of mangrove ecosystem, which could provide the support needed to enhance the functional capacity of the remaining undisturbed and degraded mangroves is lacking. This study found very little evidence that recognised and supports the use of mangroves as a mechanism for DRR, which means that there is little work being done to enhance the DRR services that mangroves do provide.

Thus to answer the research question "how has the exposure of the coastal population of Kalimantan, to potential climate hazards,changed as a result of coastal mangrove loss and population growth?" the findings show that mangroves provide a very limited extent of coastal protective services in Kalimantan.

7.5. Limitations of this study

This study is limited by access and availability of customised geo-spatial data, and field data. The global datasets used were chosen for their accessibly and high accuracy. However, the global scale of the TMF, GMW and population datasets may mean that although the overall accuracy is high, the specific accuracies for the area of Kalimantan, are not validated and therefore uncertainties remain in the results. The TMF dataset noted in their technical report, that when the mapped areas of mangrove were compared to mangroves identified in the Global Forest Cover dataset, there was a discrepancy of 83% for mangrove cover (Vancutsem et al., 2021a). This shows the levels of discrepancy in the global datasets. As studies such as the current thesis does not have access to ground truth data, the evaluation of performance relies on the methodology and data used.

The data used from the WorldPop to calculate the population density of Indonesia over time, uses among other things census-based population data. There is no information provided in the the Worldpop metadata on the accuracy of the population density estimates are or the initial census data.Some studies have been done to verify the accuracy of the Worldpop data but none of these specifically focus on the country of Indonesia.

Additionally interviews with in-country Ministry staff responsible for either mangrove management and/or the implementation of the DRR strategy was not possible in the scope of the study and therefore is considered a limitation. Whilst this study provides more information on potential areas of high population exposure, given the loss or degradation of the mangrove bio-shield that may aid in the protection of people from coastal hazards, exposure alone cannot determine the overall risk (Cardona et al., 2012). It is difficult, if not impossible to determine risk to hazards at the scale in which this study has been conducted given that both exposure and vulnerability are dynamic in nature and vary across temporal and spatial scales, determined by a multitude of influencing factors (Cardona et al., 2012)., which could not be ascertained in the current study. Disaster risk signifies the potential for negative consequences which is determined by the nature of the hazard, the exposure of the population and valued assets, as well as the vulnerability of the people in the environment. Coastal hazards, have in the case of this thesis been used to describe a number of potential threats to coastal populations such as, storm surges, tropical storms, tsunami's, erosion and sea level rise. However, the ability for mangroves to protect against these hazards will vary depending on the nature of the specific hazard as well as the specific mangrove ecosystem in question. Another determinant of risk is vulnerability which refers to the ability of the exposed elements to recover from the adverse impacts of a hazardous event. Measuring vulnerability is highly complex as there are many drivers of vulnerability and many capacities that determine the propensity for communities to incur consequences from natural hazards (Coppola, 2011). As such, this study cannot be seen as assessing disaster risk in Kalimantan to coastal hazards but rather provides the basis for further research having already identified a few areas of high exposure from the loss of mangroves.

8. Conclusion

This thesis has aimed to provide more information on this topic through the use of case study of one of the largest islands in the world, belonging to the country with the highest remaining extent of mangroves. In the last thirty years undisturbed mangroves in Kalimantan have declined by a total extent of 1208km^2 between 1990 and 2020. This net loss of mangroves is not evenly distributed across the island of Kalimantan and can be attributed to activities that both degrade and deforest mangroves. The primary activity that lead to mangrove deforestation is the conversion of mangroves to other land use types, namely, aquaculture, oil palm, agriculture. Degradation on the other hand is more closely linked to smaller scale anthropogenic pressures and the unsustainable use of mangroves close to settlements and development areas. Trends in mangrove regrowth, have only in the last 5 years begun to increase, but evidence suggests that mangrove regrowth strategies may be less cost effective than enhancing and implementing the protection and sustainable use of mangrove ecosystems.

In relation to population exposure, 40% of the total population of Kalimantan live within 10km of degraded and deforested mangroves in 2020. Degraded and deforested mangroves have a reduced capacity to protect people from the direct and adverse impacts of costal hazards. Given that East Kalimantan has had the highest level of mangrove deforestation and the second highest population growth in the last 20 years, efforts need to be prioritised in this region to reduce the level of exposure to coastal hazards. This will be even more crucial as the population is likely to become even higher in the coming years with the relocation of Indonesia's capital to the coastline of East Kalimantan. In reducing the exposure of the population to coastal hazards, it will also be necessary for the government to assess the trade offs associated with the continued large-scale development of mining activities and palm oil. The long-term negative consequences of these activities do not appear to be cost-effective, as coastal hazards increase under the influence of climate change (The World Bank, 2020).

The behaviour towards mangroves appears to be predominantly influenced by two factors. The first factor is directly related to the livelihoods and economic gain established from various activities, that when unmanaged degrade mangrove ecosystem. The second, is the level of understanding of ecosystem services provided by mangroves. Identifying the socio-economic circumstances of individual communities and the nuances of their relationship to mangroves can be beneficial in tailoring conservation efforts so that they are sustainable for the community and mangroves, long term. Including local communities in this way allows information to be shared with various stakeholders on how mangroves serve to protect the coastal area but also what traditional systems of mangrove management should be integrated in the development of conservation practices. This will be crucial for the conservation of mangroves rural and moderately populated coastal area. Conservation and rehabilitation will benefit from clearly defined policies that balance socio-economic needs with environmental and sustainability goals

The last finding is that national-level management on mangrove governance is fragmented. As identified, there are many stakeholders, with different objectives who have jurisdiction over mangrove ecosystems and their use. This has created institutional silos where the benefits that mangroves provide arelimited to the specific functions of either DRR or CCA, but more commonly CCA. The inclusion and specific use of language that facilitates the use of mangroves in national DRR and CCA policies will be an important mechanism for integrating mangroves into land use planning along side development. First evidence of this, is found in Indonesia’s NDCs, where there is a clear link to the use of mangroves as a mechanism for pursuing CCA activities and an emphasis on the synergies between these actions and other global agreements such as the SFDRR. Any actions taken must, however, be translated into local level action, incorporating the local stakeholders, to achieve sustainable use of the ecosystem to prevent the continued loss of mangrove forests.

It should be noted that the Government of Indonesia has understood the value of their national mangrove ecosystems for their various functions as they have planned to rehabiliate 6000km^2 of mangroves. This will be done with the financial support of approximately $400 million from the World Bank (Indonesia Environmental Fund et al., 2022), as part of the Mangrove for Coastal Resilience programme; this initative provides an invaluable opportunity for the Government to not only enhance the mangrove area but to manage them as part of NBS, bridging the gap between DRR and CCA in this field. The results of this thesis demonstrate that the regular monitoring of mangroves can provide quantitiative information for decision making in different domains. Information on areas subject to high exposure from coastal hazards as a consequence of mangrove degradation or deforestation has been the primary focus of this thesis, but as previously discussed, the potential for this information to be coupled to other factors of risk such as vulnerability and hazard probability would be of further benefit to this monitoring system.

9. References

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10. Annex 1

This Annex contains the data used to present the results. The first two tables show the results of the area of mangrove classes between 1990 and 2021 and were used to create figures 5-7, the last table, presents the population data in combination with the buffer zones created to find the population living within 10km of various mangrove classes. This data was used to create Figures 8-9 and Table 3.

Table 3 - Mangrove extent from 1990-2020 calculated using GMW and TMF data. See methods for further specifications

Mangrove extent, Kalimantan						
Date	**Undisturbed mangrove (km2)**	**Degraded mangrove (km2)**	**Deforested land (km2)**	**Mangrove regrowth (km2)**	**Permanent and seasonal water (km2)**	**Other land cover (km2)**
1990	5472.3	10.51	20.4	55.78	909.93	47.79
1991	5464.6	13.76	24.93	55.79	909.8	47.82
1992	5461.06	15.35	26.75	55.91	909.79	47.83
1993	5455.13	17.98	29.94	56.05	909.75	47.84
1994	5439.67	25.18	38.12	56.33	909.57	47.84
1995	5429.08	30.12	43.66	56.72	909.27	47.85
1996	5410.87	38.97	52.98	56.95	909.08	47.85
1997	5375.69	57.91	69.33	57.13	908.78	47.85
1998	5322.84	87.45	92.18	58.11	908.26	47.85
1999	5255.71	118.64	128.02	59.18	907.3	47.85
2000	5186.58	154.73	161.3	59.92	906.32	47.85
2001	5043.87	236.83	221.69	61.2	905.26	47.85
2002	4926.84	305.74	268.13	63.7	904.43	47.85
2003	4864.39	342.62	263.5	70.89	927.44	47.85
2004	4767.83	399.05	295.31	75.9	930.77	47.85
2005	4719.01	425.61	299.01	90.99	934.23	47.85
2006	4686.53	439.8	292.51	113.58	936.43	47.85
2007	4663.87	449.57	289.44	127.87	938.1	47.85
2008	4653.31	454.34	277.44	144.72	939.04	47.85
2009	4630.77	462.33	285.51	150.33	939.9	47.85
2010	4622.01	465.23	276.3	164.72	940.59	47.85
2011	4607.91	470.05	279.48	170.46	940.95	47.86
2012	4586.48	475.32	291.64	174.15	941.25	47.85
2013	4552.88	484.53	308.44	181.3	941.69	47.86
2014	4510.82	496.28	331.45	188.35	941.95	47.85
2015	4443.35	527.13	352.25	204.1	942.03	47.84
2016	4394.85	551.62	254.17	234.26	1033.95	47.85
2017	4365.95	545.19	254.36	268.79	1034.56	47.85
2018	4338.28	532.13	262.1	300.39	1035.95	47.85
2019	4291.18	506.18	332.62	300.39	1038.55	47.79
2020	4263.93	504.91	362.68	295.31	1042.07	47.79
30 year net change	**-1208.37**	**494.4**	**342.28**	**239.53**	**132.14**	**0**

Table 4 - Yearly net change in mangrove extent from 1990-2020.

Net Change in mangrove extent Kalimantan						
Date	**Undisturbed mangrove (km2)**	**Degraded mangrove (km2)**	**Deforested land (km2)**	**Mangrove regrowth (km2)**	**Permanent and seasonal water (km2)**	**Other land cover (km2)**
1990	0	0	0	0	0	0
1991	-7.7	3.25	4.53	0.01	-0.13	0.03
1992	-3.54	1.59	1.82	0.12	-0.01	0.01
1993	-5.93	2.63	3.19	0.14	-0.04	0.01
1994	-15.46	7.2	8.18	0.28	-0.18	0
1995	-10.59	4.94	5.54	0.39	-0.3	0.01
1996	-18.21	8.85	9.32	0.23	-0.19	0
1997	-35.18	18.94	16.35	0.18	-0.3	0
1998	-52.85	29.54	22.85	0.98	-0.52	0
1999	-67.13	31.19	35.84	1.07	-0.96	0
2000	-69.13	36.09	33.28	0.74	-0.98	0
2001	-142.71	82.1	60.39	1.28	-1.06	0
2002	-117.03	68.91	46.44	2.5	-0.83	0
2003	-62.45	36.88	-4.63	7.19	23.01	0
2004	-96.56	56.43	31.81	5.01	3.33	0
2005	-48.82	26.56	3.7	15.09	3.46	0
2006	-32.48	14.19	-6.5	22.59	2.2	0
2007	-22.66	9.77	-3.07	14.29	1.67	0
2008	-10.56	4.77	-12	16.85	0.94	0
2009	-22.54	7.99	8.07	5.61	0.86	0
2010	-8.76	2.9	-9.21	14.39	0.69	0
2011	-14.1	4.82	3.18	5.74	0.36	0.01
2012	-21.43	5.27	12.16	3.69	0.3	-0.01
2013	-33.6	9.21	16.8	7.15	0.44	0.01
2014	-42.06	11.75	23.01	7.05	0.26	-0.01
2015	-67.47	30.85	20.8	15.75	0.08	-0.01
2016	-48.5	24.49	-98.08	30.16	91.92	0.01
2017	-28.9	-6.43	0.19	34.53	0.61	0
2018	-27.67	-13.06	7.74	31.6	1.39	0
2019	-47.1	-25.95	70.52	0	2.6	-0.06
2020	-27.25	-1.27	30.06	-5.08	3.52	0
Mean annual change	**-38.97967742**	**15.9483871**	**11.04129032**	**7.726774194**	**4.262580645**	**0**

Table 5 - Change in Population density within 1, 2.5, 5, and 10 km of varying mangrove classes. The mangrove classes have been defined by the TMF dataset (see methods). Population density data was obtained from WorldPop from 2000-2020.

Undisturbed_Mangroves																	
Year	**Kalimantan Total population**	**Population living in 1km2**	**% of total pop in 1km2 buffer**	**Area of buffer (1km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 2.5km2**	**% of total pop in 2.5km2 buffer**	**Area of buffer (2.5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 5km2**	**% of total pop in 5km2 buffer**	**Area of buffer (5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 10km2**	**% of total pop in 10km2 buffer**	**Area of buffer (10km2)**	**Pop_Denisty_in Buffer Area**
2000	11023682	573196	0.052	16701	34.32038	975938	0.0885	23466	41.58957	1520362	0.138	32598	46.64	2283494	0.2071	47939.8	47.6325209
2005	12328187	661532	0.0537	16506	40.079124	1130938	0.0917	23287	48.56604	1761367	0.143	32389	54.38146	2638233	0.214	47679.4	55.332741
2010	13875204	764905	0.0551	16343	46.804507	1332623	0.096	23131	57.61324	2075829	0.15	32250	64.36729	3100648	0.2235	47546.5	65.2130011
2015	15699881	855037	0.0545	16105	53.092686	1528457	0.0974	22898	66.75091	2375126	0.151	32027	74.16065	3533577	0.2251	47340.2	74.6422226
2020	17868598	1026887	0.0575	15886	64.641412	1833346	0.1026	22681	80.83158	2821542	0.158	31797	88.73675	4140649	0.2317	46997.3	88.1040137
Degraded_ Mangroves																	
Year	**Kalimantan Total population**	**Population living in 1km2**	**% of total pop in 1km2 buffer**	**Area of buffer (1km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 2.5km2**	**% of total pop in 2.5km2 buffer**	**Area of buffer (2.5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 5km2**	**% of total pop in 5km2 buffer**	**Area of buffer (5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 10km2**	**% of total pop in 10km2 buffer**	**Area of buffer (10km2)**	**Pop_Denisty_in Buffer Area**
2000	11023682	393732	0.0357	11074	35.555243	818414	0.0742	19407	42.17088	1379809	0.125	28839	47.84597	2158135	0.1958	44056.8	48.9853205
2005	12328187	535801	0.0435	12923	41.459723	1015924	0.0824	20684	49.11533	1651397	0.134	29835	55.35053	2511950	0.2038	44792.9	56.0792627
2010	13875204	647255	0.0466	13468	48.05891	1232712	0.0888	21182	58.19508	1981507	0.143	30353	65.28275	2999951	0.2162	45426	66.0403518
2015	15699881	768991	0.049	14166	54.285498	1459580	0.093	21659	67.38973	2309170	0.147	30711	75.18929	3436128	0.2189	45713.3	75.167003
2020	17868598	972255	0.0544	14297	68.003556	1798361	0.1006	21735	82.74006	2775064	0.155	30774	90.17572	4063751	0.2274	45817.1	88.6951111
Deforested_Mangroves																	
Year	**Kalimantan Total population**	**Population living in 1km2**	**% of total pop in 1km2 buffer**	**Area of buffer (1km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 2.5km2**	**% of total pop in 2.5km2 buffer**	**Area of buffer (2.5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 5km2**	**% of total pop in 5km2 buffer**	**Area of buffer (5km2)**	**Pop_Denisty_in Buffer Area**	**Population living in 10km2**	**% of total pop in 10km2 buffer**	**Area of buffer (10km2)**	**Pop_Denisty_in Buffer Area**
2000	11023682	373178	0.0339	10787	34.595738	798763	0.0725	19214	41.57279	1358672	0.123	28748	47.26072	2153066	0.1953	44227.3	48.6818102
2005	12328187	478085	0.0388	10878	43.949432	970327	0.0787	18848	51.48101	1596160	0.13	28334	56.33318	2475185	0.2008	43434	56.9873074
2010	13875204	559216	0.0403	10904	51.283519	1154516	0.0832	18911	61.04968	1894711	0.137	28451	66.59528	2920835	0.2105	43487.5	67.164917
2015	15699881	686948	0.0438	11366	60.441246	1392205	0.0887	19411	71.72359	2248274	0.143	29006	77.51194	3385353	0.2156	44155.8	76.6683652
2020	17868598	855603	0.0479	11734	72.918369	1704593	0.0954	19979	85.31936	2704887	0.151	29316	92.26567	3969389	0.2221	44269	89.6652262

Annex 2

This annex contains full size images of Figures 11- 14

Figure 11 - Focus area A, showing change in population density for the city of Samarinda and change in the mangrove extent from 2000-2020

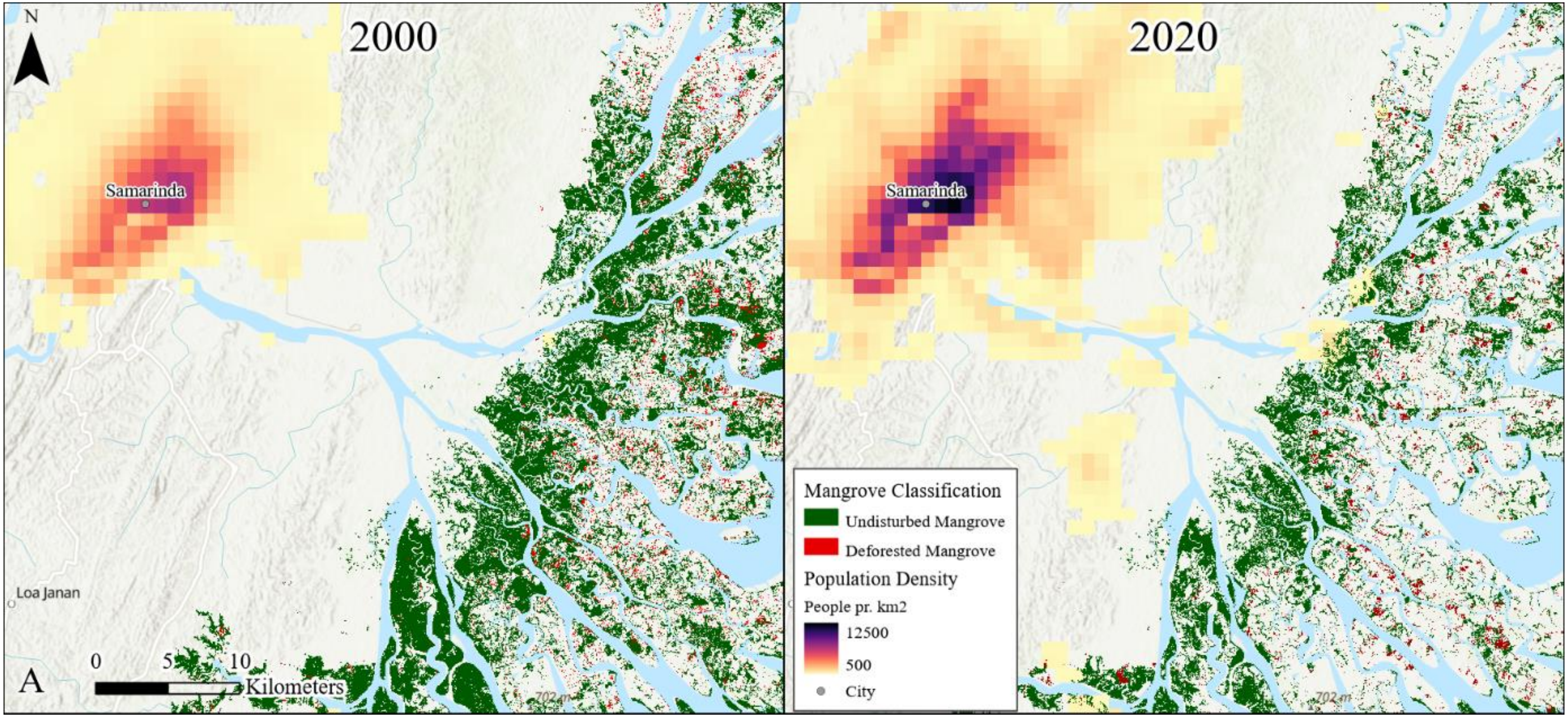

Figure 12- Displayed on the left, a satellite Image © 2020 Planet Labs PBC at 2-meter resolution of a small area of the Mahakam delta, in East Kalimantan. To the right, the same area with an overlay of the mangrove extent in 2020, calculated from the GMW and TMF datasets

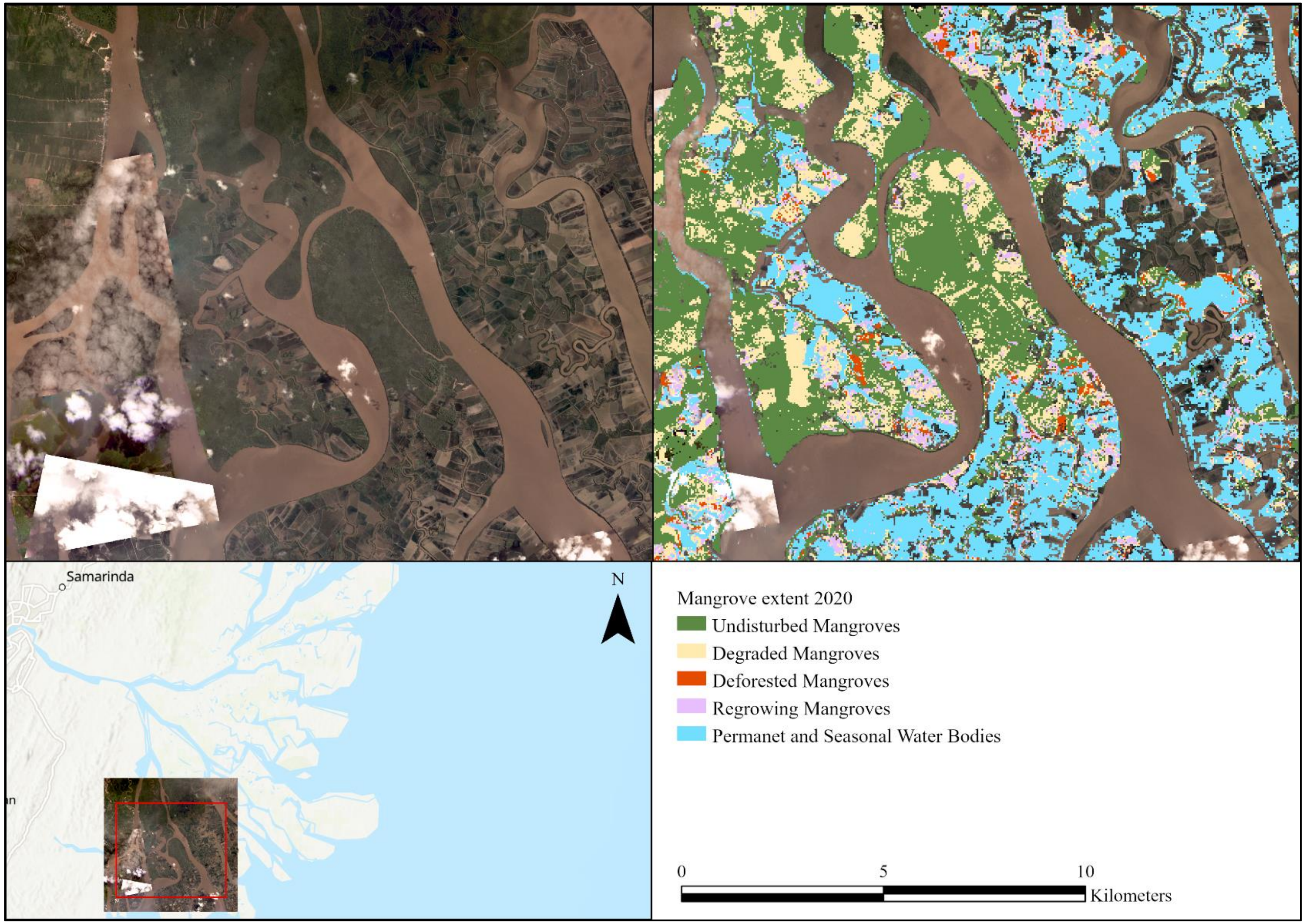

Figure 13 - Focus area B, the city of Balkipapan (East Kalimantan), showing the population density in 2000 and 2020 as well as undisturbed and deforested mangroves within the same period.

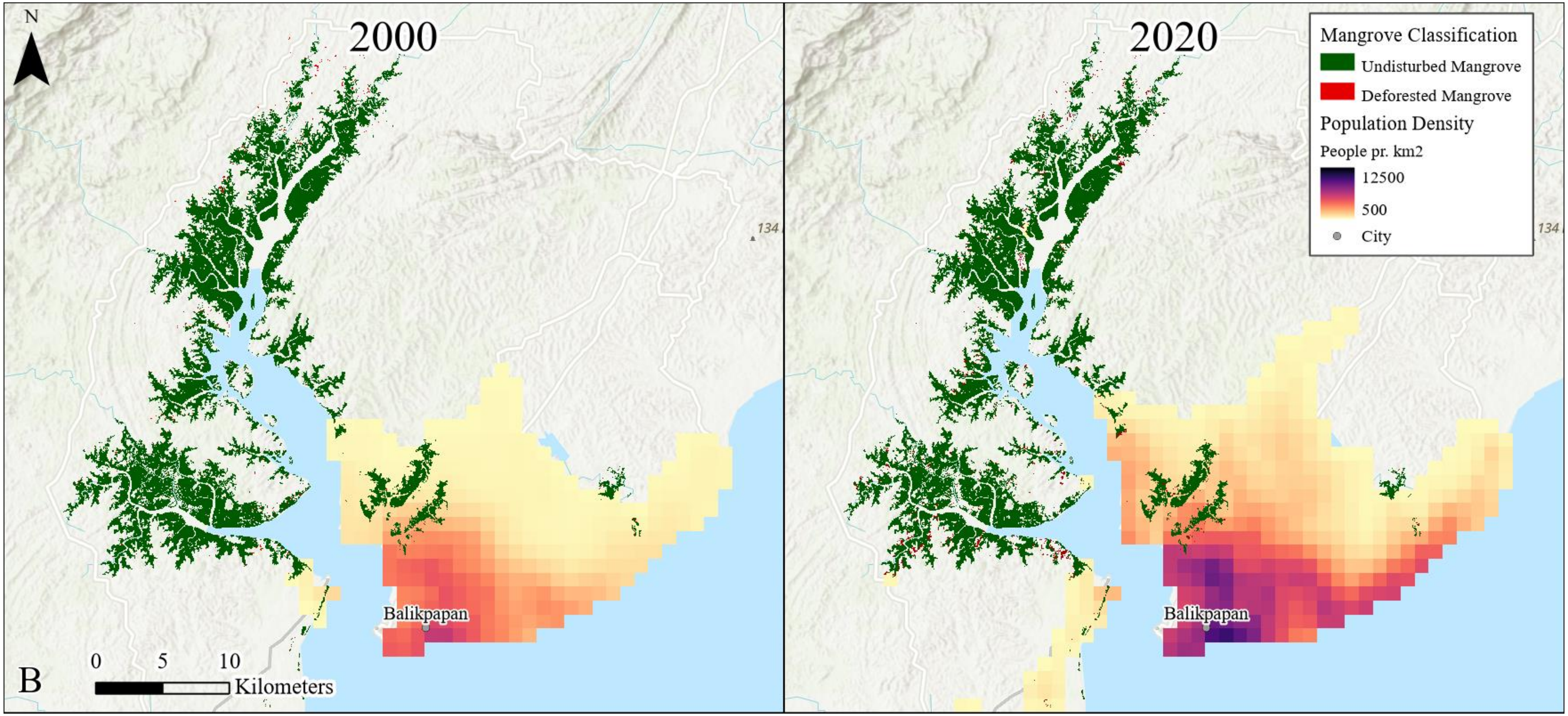

Figure 14 - Population development and mangrove deforestation along the coast of South Kalimantan