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THE WORLD'S MANGROVES
2000–2020

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About 50 people were involved directly in the work. They include FRA Remote Sensing Survey focal points as well as collaborators in FRA 2020 Remote Sensing Survey trainings on image interpretation.

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ABBREVIATIONS

CEO	Collect Earth Online
FAO	Food and Agriculture Organization of the United Nations
FRA	Global Forest Resources Assessment
GMW	Global Mangrove Watch
ha	hectare(s)
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre of the European Commission
m	metre(s)
MVI	Mangrove Vegetation Index
REDD+	reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SDG	Sustainable Development Goal
USD	United States dollar(s)

EXECUTIVE SUMMARY

This report provides global and regional estimates of the area covered by mangrove forests, including area changes between 2000 and 2020. It analyses the drivers of these global, regional and subregional changes for the periods 2000–2010 and 2010–2020 with the aim of improving understanding of these drivers, their interactions and how their relative importance has shifted over time.

In the study that underpins this report, FAO developed and validated an easy, repeatable methodology that integrates remote sensing with local knowledge. An FAO team and 48 image interpreters worldwide collected and analysed data on mangrove area in 2020, change in mangrove area between 2000 and 2020, and the drivers of change over the two decades. It is the first global study of mangrove area to provide information on land use rather than land cover.

Mangroves are salt-tolerant evergreen forests found in intertidal environments at the land–sea interface. They grow at tropical and subtropical latitudes in areas along sheltered coastlines, shallow-water lagoons, estuaries, rivers and deltas, mainly on soft substrates. Mangrove species are distinguished based on morphological and physiological adaptations that enable them to grow in saline environments. Estimates of the number of true mangrove species range from about 50 to more than 70.

Mangrove forests occur in many tropical and subtropical environments, providing hundreds of millions of coastal people with important ecosystems services. Mangroves are among the world's most productive ecosystems and are important carbon sinks. The high primary production of mangroves sustains a rich food web – from detritus decomposers to fish, mammals and birds – supporting provisioning services for food, (especially fish), fibre and fuels alongside cultural services Mangroves also provide regulating services, such as coastal stabilization, nutrient absorption as well as carbon sequestration. Local people obtain a wide range of benefits from the sustainable management, protection and restoration of mangroves. Through the provision of these critical ecosystem services, mangroves make crucial contributions to many of the Sustainable Development Goals of the 2030 Agenda.

To estimate mangrove status and trends, the study delineated mangroves from other forest types based on the dominance of true mangrove species, and defined various mangrove-specific classes for land use, land-use change and deforestation drivers. It used existing remote sensing mangrove maps for the stratification and allocation of samples, and local experts participated in the data collection. The required number of samples, 20 900 in total globally, was determined considering the objective of obtaining accurate estimates of the mangrove area in 2020, the change in mangrove areas in the periods 2000–2010 and 2010–2020, and the main drivers of mangrove loss.

Findings are presented on mangrove area, area change, and drivers of change for each of the five regions of Africa, Asia, North and Central America, South America, and Oceania.

The study estimated the total global area of mangroves in 2020 at 14.8 million ha, of which nearly 44 percent (6.48 million ha) is in South and Southeast Asia. The mangrove area in 2020 was 2.14 million ha in South America, 2.09 million ha in Western and Central Asia, 1.85 million ha in North and Central America, 1.46 million ha in Oceania, 0.73 million ha in Eastern and Southern Africa, and around 200 thousand ha in Western and Central Asia and East Asia.

According to the study, around half the total loss of mangrove area between 2000 and 2020 (677 thousand ha) was offset by the establishment expansion of new mangrove areas not present in 2000 (393 thousand ha). Thus, there was a net decline in global mangrove area of 284 thousand ha over the period.

The rate of net global mangrove loss slowed between the two decadal periods, with the net loss of mangrove area decreasing by 44 percent between the two periods, from 18.2 thousand ha per year in 2000–2010 to 10.2 thousand ha per


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year in 2010–2020. Accordingly, the annual rate of mangrove loss globally declined from 0.12 percent in 2000–2020 to 0.07 percent in 2010–2020. Of the regions, Asia accounted for 68 percent of global mangrove area loss in 2000–2010 and for 54 percent of the loss in 2010–2020. Of the global mangrove area gains, 47 percent in 2000–2010 and 54 percent in 2010–2020 were in Asia.

The main direct drivers of mangrove loss globally between 2000 and 2020 were aquaculture development (27 percent) and natural retraction (26 percent), followed by conversion to oil palm (8 percent), rice cultivation (8 percent) and other forms of agriculture (12 percent). The significance of aquaculture as a driver of mangrove area loss declined between the two decadal periods (from about 31 percent in 2000–2010 to 21 percent in 2010–2020), but the importance of conversion to oil-palm plantations increased substantially (from about 4 percent in 2000–2010 to 14 percent in 2010–2020), mostly in Southeast Asia.

Natural expansion accounted for 82 percent of all gains in mangrove area between 2000 and 2020 and restoration for the rest.

The present study shows the importance of natural retraction – which is at least in part a likely consequence of the impacts of climate change – as a driver of mangrove loss. Climate change can affect mangroves in various ways, including through sea-level rise; increases in atmospheric carbon dioxide; rises in temperature; changes in rainfall; and the predicted increase in the frequency and severity of extreme weather. The climate-change-driven loss of mangroves further exposes vulnerable local communities to disasters such as storm surges, floods and tsunamis – against which healthy mangroves provide a certain level of protection – resulting in a negative feedback loop. The area of mangroves lost to natural disasters increased threefold between the two periods of 2000–2010 and 2010–2020, and this trend is expected to worsen. Natural retraction increased significantly in South America and Oceania over the study period.

The findings of this study have important implications for future work in conserving, restoring and sustainably managing mangroves, including the following:

- In Southeast Asia, the subregion with the largest extent of mangroves globally, efforts to address land-use drivers of mangrove loss should continue, directing agricultural development to conserve remaining mangrove forests.
- In Western and Central Africa, where a high rate of mangrove loss persisted over the two measurement periods, conversion to aquaculture and various forms of agriculture needs to be addressed by promoting sustainable use and livelihood support.
- Mangrove restoration should be given priority in global, regional and national restoration initiatives in view of their crucial benefits for livelihoods, coastal resilience and biodiversity conservation.
- Mangrove restoration, sustainable use and conservation should be further emphasized in nationally determined contributions and in climate-change mitigation strategies in general, given the importance of mangroves as carbon sinks and the co-benefits of adaptation and disaster risk reduction.
- Given the ability of mangroves to naturally colonize suitable habitats, mangrove restoration should focus on creating conducive biophysical and social conditions for the re-establishment and growth of healthy mangrove forests.
- The contributions of climate-change impacts to the retraction of mangroves should be monitored carefully because they further expose coastal communities to disasters.

1 / INTRODUCTION

STUDY OBJECTIVES

The study reported here estimates the area of mangroves globally and regionally, as well as the change in area between 2000 and 2020. It also analyses the direct drivers of area change at the global, regional and subregional levels for the periods 2000–2010 and 2010–2020 with the aim of improving understanding of these drivers and their interactions and to shed light on how the relative importance of the drivers has shifted over time.

An important aspect of the study is the incorporation of local expertise in the interpretation of remote sensing data. This has helped improve the accuracy of mangrove identification and understanding of change drivers because local experts often have a detailed understanding of development activities in mangrove forests and the wider landscapes that may be contributing to change. The local interpreters involved in the study are part of a global network of remote sensing experts established for the Global Forest Resources Assessment (FRA) 2020 Remote Sensing Survey (FAO, 2022).

Another aim of the study was to develop and validate a mangrove assessment methodology that can be used in countries to identify hotspots of change in mangrove area and understand the drivers of such change. This can inform cross-sectoral land-use planning and national policies to ensure that these consider all the benefits provided by mangroves.

This chapter describes mangroves, provides background information on their functions, uses, threats and restoration, and presents previous estimates of mangrove area and change over time. Chapter 2 sets out the methodology used in the study, and Chapter 3 and Chapter 4 present the global and regional findings, respectively. Chapter 5 comprises a discussion of the methodology and findings, and Chapter 6 contains a brief conclusion.

MANGROVE ECOLOGY

Mangroves are salt-tolerant evergreen forests found in intertidal environments at the land–sea interface. They grow at tropical and subtropical latitudes in areas along sheltered coastlines, shallow-water lagoons, estuaries, rivers and deltas, mainly on soft substrates. Mangrove ecosystems represent an interphase between terrestrial and marine communities, which receive daily inputs of water from the ocean and often freshwater, sediments, nutrients and silt deposits from upland rivers.

The term “mangrove” describes both an ecosystem type and the group of woody plants with specialized physiological and morphological adaptations for living in intertidal environments (Tomlinson, 1986). These adaptations include aerial roots for respiration and anchorage in waterlogged muddy substrates; the ability to cope with salinity (e.g. through salt exclusion at the roots and the elimination of excess salt by excretion); propagules adapted to tidal dispersal (i.e. seed vivipary); and highly efficient nutrient-retention mechanisms (Ball, 1988; Hogarth, 2015).

The stature and composition of mangroves vary according to climate, salinity, topography and the edaphic features of the area in which they exist. Mangrove forests may occur as isolated patches of dwarf stunted trees in very-high-salinity or disturbed conditions and, on more favourable sites, as lush forests with canopies up to 40 m in height.


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Human pressure and disturbance can constrain mangrove development by creating stressed and polluted environments. Bands of mangroves dominated by a single species are often observed based on species-specific adaptions to local topography, tidal ranges and salinity. In undisturbed and pristine estuaries, mangroves may extend for several kilometres inland, as they do in the Sundarbans (Bangladesh and India), the Mekong delta (Viet Nam), the Gambia River delta (the Gambia), the Fly River (Papua New Guinea), and the Florida Everglades (The United States of America).

Mangrove species are distinguished based on morphological and physiological characteristics that enable them to grow in saline environments, rather than on taxonomical lineage. Estimates of the number of true mangrove species range from about 50 to more than 70, depending on how "true" mangroves are defined and whether hybrids are counted. Tomlinson (2016) recognized 51 species of true mangroves in 20 genera and 15 families. Spalding *et al.* (2010) recognized 73 species and hybrids in 29 genera and 21 families (of which 36 species were considered "core" mangrove species).

Most mangrove species have wide distributions, although some have restricted ranges. The highest species diversity is in South and Southeast Asia, with minor diversity centres in southern Central America and the Western Indian Ocean (Spalding *et al.*, 2010). Mangrove diversity diminishes quickly at the geographical limits of mangrove growth in the subtropics and in arid zones, where they often appear as small trees. Nevertheless, such mangrove areas may still play essential roles for local people.

At first sight, the most easily recognizable adaptation to intertidal environments developed by mangroves is their aerial rooting system, which is completely or partly exposed to the atmosphere for part of the day but inundated at high tide. Its main functions are the exchange of gases, anchorage of the tree in muddy soils, and nutrient absorption. However, only the most specialized species (i.e. the major components of mangrove forest communities – true mangroves, according to Tomlinson, 1986) have developed aerial root systems; among these, aerial roots may have different structures, depending on the species. For example, stilt roots grow from the trunk and lower branches of *Rhizophora* spp. and, to a limited extent, in the sapling stages of the genera *Bruguiera* and *Ceriops* (they become shallow buttresses in older trees). Pneumatophores – pencil-like extensions of the subterranean rooting system – rise from the ground and can extend long distances from parental trees in *Avicennia*, *Sonneratia* and *Laguncularia*. In the genera *Bruguiera*, *Ceriops* and *Xylocarpus*, pneumatophores may form a series of arches or knee shapes during their horizontal growth (sometimes called knee roots).

Mangrove species have developed various methods for coping with the high-salinity environments in which they grow. They may exclude the uptake of salt at the root and remove excess salt at the leaf. Mechanisms for the latter include salt excretion glands (*Avicennia*, *Aegiceras* and *Aegialitis*), cuticular transpiration, and the shedding of salt-accumulated leaves.

The most specialized mangrove families have developed highly efficient reproduction systems. In the *Rhizophoraceae* family, neither the fruit nor the seed is released. Rather, the seed germinates on the parental tree, and the seedling itself is used as the propagule (known as vivipary) (Juncosa, 1982). In viviparous species, the embryo has no dormancy and is detached only when it is mature and ready to be established. Some species, such as those in the genera *Aegiceras*, *Avicennia*, *Nypa* and *Pelliciera*, have developed cryptovivipary, in which the embryo emerges from the seed but not from the fruit until after the fruit abscises.

FUNCTIONS AND USES OF MANGROVES

Mangrove forests occur in many tropical and subtropical environments that overlap with areas of high human density; they have traditionally been widely used and exploited. Mangroves provide hundreds of millions of coastal people with important regulating services, such as pollution control and protection from disasters. They also support many fisheries and cultural practices. Mangrove ecosystems make crucial contributions to many of the Sustainable Development Goals (SDGs) set in the 2030 Agenda for Sustainable Development. The importance of restoring and protecting mangroves is reflected most clearly in SDG 14 (Life Below Water), which concerns the sustainable use of marine resources. Mangrove ecosystems also contribute to SDG 1 (No Poverty) and SDG 2 (Zero Hunger) by supporting fisheries and producing various forest products; SDG 8 (Decent Work and Economic Growth) by providing work and economic opportunities through fisheries and ecotourism; SDG 13 (Climate Action) by mitigating climate change through carbon sequestration; and SDG 15 (Life on Land) through sustainable forest management and biodiversity conservation. Local people, including women, Indigenous Peoples and marginalized communities, obtain a wide range of benefits from the sustainable management, protection and restoration of mangroves.

Forest products

In most countries, mangroves constitute a relatively small proportion of the total forest area. Nevertheless, they produce many wood and non-wood forest products that are important locally and nationally as sources of income and subsistence. Mangrove wood, which is typically dense and durable, was in high demand in colonial times for shipbuilding and other uses. As the number of large trees in mangrove stands diminished, however, so did the use of mangroves for sawnwood. Nevertheless, mangrove wood is still used as poles for light construction and as fuelwood (either burnt directly or converted to charcoal). Other mangrove forest products include tannins and dyes; pharmaceuticals; thatch; sugar and alcohol (from nipa palm sap); and honey.

Biodiversity support

Mangroves are among the world's most productive ecosystems, and their high primary production sustains a rich food web – from detritus decomposers to fish, mammals and birds (Carugati *et al.*, 2018). Mangroves support biodiversity conservation by serving as habitats, spawning grounds, nurseries and sources of nutrients. They host an estimated 341 threatened reptile, amphibian, mammal, fish and bird species (Leal and Spalding, eds., 2022). Eleven of the 70 known mangrove tree species are

in the IUCN Red List of Threatened Species – two are listed as critically endangered, three as endangered and six as vulnerable (Polidoro *et al.*, 2010).

Supporting fisheries

Mangroves play crucial roles in many marine food chains and support the production of a wide range of commercial and non-commercial fish and shellfish. They do so through two main mechanisms: their primary production; and the structure provided by their aerial roots, which creates a physical environment suitable for many fish species (Hutchinson, Spalding and Ermgassen, 2014). It is widely accepted that mangroves have substantial economic value for both small-scale and large-scale fisheries, although this varies enormously between sites. In a comprehensive literature review, Hutchinson, Spalding and Ermgassen (2014) found that mangroves had a global median value of USD 77 per ha per year for fish and USD 213 per ha per year for mixed species' fisheries (i.e. mixed catch of finfish, molluscs and crustaceans), with values well in excess of USD 10 000 per ha per year in the most productive locations. Hutchinson, Spalding and Ermgassen (2014) also found that fish productivity increased with increasing mangrove productivity and area. Moreover, mangroves with higher structural complexity have a greater beneficial effect. A study in the Saadani National Park in the United Republic of Tanzania, for example, established that a 10 percent increase in mangrove cover could (on average) increase shrimping income by about twofold (McNally, Uchida and Gold, 2011). Thus, it is important to avoid mangrove loss (and to replace mangrove habitat, if lost) and prevent their degradation.

Aquaculture

Mangrove habitats provide ideal conditions for aquaculture – both open-water estuarine mariculture (e.g. oysters and mussels) and pond culture (mainly for shrimps). The expansion of aquaculture has been one of the key drivers of mangrove loss since the early 1970s, especially in Southeast Asia (Goldberg *et al.*, 2020; Friess *et al.*, 2019). Because of its high economic returns, shrimp farming has been promoted in several countries as a means for boosting national economies and alleviating poverty. If poorly planned and unsustainably managed, however, it can lead to uncontrolled deforestation, the pollution of coastal waters, and damage and destroy coastal ecosystems, with the subsequent loss of mangrove ecosystem services and benefits. The aim of international guidance and standards such as the Aquaculture Stewardship Council Shrimp Standard (ASC, 2019) and the International Principles for Responsible

Shrimp Farming (FAO/NACA/UNEP/World Bank/WWF, 2006) is to reduce the sector's environmental impact while boosting its contribution to poverty alleviation. Integrated mangrove-shrimp aquaculture that combines the maintenance and restoration of mangrove cover with shrimp farming has been proposed in Viet Nam and shown to be viable. Although not yet widely adopted, the approach has the potential to optimize production and environmental benefits from the sustainable use of mangrove habitats. It should be noted, however, that these systems are low intensity and typically produce low returns (McSherry *et al.*, 2023). Harvesting can also be a challenge as the ponds can rarely be fully drained, or may have trees and other vegetation present which can tangle harvest nets.

Ecotourism

Mangrove-based ecotourism is a potentially valuable and sustainable source of income for local communities. Many examples exist of successful mangrove-based ecotourism that provides communities with revenue and an incentive to conserve and sustainably manage mangroves while raising the awareness of visitors about the many values of mangroves. Mangrove-related ecotourism activities that can be combined with homestays in nearby villages include exploring mangroves on boardwalks or by boat; observing wildlife; kayaking; and viewing fireflies. Mangroves are also crucial habitat for a number of species of game fish; game fishing can bring significant financial benefits such as those associated with the provision of accommodation, food, fishing guides, and boat and gear rentals (Hutchison, Spalding and Ermgassen, 2014).

Climate change mitigation

Mangroves are among the most carbon-rich ecosystems on Earth. They store an estimated 6.23 gigatonnes of carbon worldwide in their biomass and soils, where it will remain for centuries if undisturbed (Leal and Spalding, eds., 2022). The ability of mangroves to sequester and store large amounts of carbon have brought them to the forefront of the international climate change dialogue, in which the importance of "blue carbon" – which comprises the carbon stored in mangroves, salt marshes and seagrasses – is also well recognized. Mangroves make substantial contributions to the nationally determined contributions (as specified in the Paris Agreement on climate change) of several countries (Friess *et al.*, 2019). Their carbon sequestration and storage potential makes mangroves suitable for payment schemes for ecosystem services, including under REDD+[1] and voluntary carbon standards.

Coastal protection and climate-change adaption

The role of mangroves in protecting coastal communities from storms and coastal erosion will be increasingly important as extreme weather events become more intense and frequent due to climate change (Spurrier *et al.*, 2019). Mangroves also offer protection from tsunamis – for example, the Indian Ocean tsunami in 2004 demonstrated the protective role of mangroves and other coastal forests and trees in mitigating disaster risk and enhancing resilience (Forbes and Broadhead, 2007). Although the level of protection offered by mangroves is debated, there is evidence and consensus that dense coastal forest belts – if well designed and managed – have the potential to act as bioshields for the protection of people and other assets against some tsunamis and other coastal hazards (such as coastal erosion, cyclones, winds and salt spray) (Forbes and Broadhead, 2007; Spalding *et al.*, 2014). At any elevation and distance from the sea front, hazard from waves is consistently lower for areas behind mangroves. Spalding *et al.* (2014) concluded that mangroves can protect coastal areas from hazards by reducing wind and swell waves to lessen

[1] REDD+ = reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.


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wave damage; flooding impacts of storm surges during major storms; tsunami heights, thus helping minimize loss of life and damage to property; and erosion by binding and building up soils as sea levels rise.

Mangroves and other coastal forests cannot fully protect against all levels of hazard. The extent of protection they offer depends on factors such as the width and density of vegetation; the diameter of tree trunks and roots; wave features; land elevation; and underwater topography. Mangroves should be integrated into coastal management planning as part of a multidimensional approach to coastal protection and combined with grey infrastructure, where needed (Dasgupta *et al.*, 2019).

THREATS TO MANGROVES

Mangroves have been converted to other land uses throughout human history. The rate of loss has been much more rapid in the last 50 years, however, with detrimental effects on ecosystem services such as carbon storage, coastal protection, livelihood support and fish production. There is evidence that the rate of mangrove loss is now slowing globally due to greater awareness of the many benefits of mangroves and as more mangrove areas are placed under protection. Nevertheless, mangrove forests continue to be converted to other land uses that generate higher revenue in the short term, including agriculture, aquaculture and infrastructure development. Even when not converted, many mangrove areas are being degraded by wood extraction, water diversion, coastal erosion and extreme weather events. Recent assessments of the distribution and drivers of mangrove loss indicate that conversion to aquaculture and agriculture is the primary driver globally, with Southeast Asia being the hotspot for human-driven mangrove deforestation (Goldberg *et al.*, 2020; Friess *et al.*, 2019; Thomas *et al.*, 2017; Richards and Friess, 2016). Climate change is also putting mangroves at greater risk as sea levels rise and the severity and frequency of storms increase.

Despite the many services and benefits they provide, mangroves are often undervalued and sometimes viewed as wastelands and unhealthy environments. In some places, high population pressure has led to the conversion of mangroves for urban development. Moreover, some governments had in the past prioritized the conversion of mangroves for agriculture and salt production as means for increasing food security, boosting national economies and improving living standards. Mangroves have also been fragmented and degraded through unsustainable harvesting and pollution. Indirectly, mangroves have been degraded and lost by upstream dam construction on rivers, which modifies inputs of sediments, nutrients and freshwater. Although mangrove forests can protect coastal areas from storms and strong winds, they are also susceptible to damage by these.

Awareness of the importance and value of mangrove ecosystems has grown in recent years, leading to the preparation and implementation of laws and regulations to better protect and manage them. Some countries have initiated programmes to re-establish mangrove forests through natural regeneration or active planting. Although this is encouraging, focusing on the extent of mangroves may take attention away from their degradation, which is notoriously difficult to define and monitor over large areas. Mangrove degradation reduces biodiversity and can have important consequences for neighbouring ecosystems due to a collapse in the mangroves' ability to produce organic matter (Carugati *et al.*, 2018). Another concern is fragmentation, which results in the loss of ecosystem functions and can be ubiquitous, even in areas where mangrove cover is relatively stable (Bryan-Brown *et al.*, 2020). Although many governments recognize the importance of mangroves for fisheries, forestry, coastal protection and wildlife, much still needs to be done to conserve these vital ecosystems.

MANGROVE RESTORATION

Significant momentum is building globally for ecosystem restoration, as illustrated by various international and national commitments and initiatives aimed at restoring degraded ecosystems. These include the Bonn Challenge, the New York Declaration on Forests, the United Nations Decade on Ecosystem Restoration, and national restoration targets, including those specified in nationally determined contributions.

Alongside the movement for ecosystem restoration, interest is growing in the rehabilitation, restoration and sustainable management of mangroves given the broad range of products and services they provide, particularly related to climate-change mitigation, coastal resilience, livelihood support and disaster mitigation. Worthington and Spalding (2018) estimated that 812 thousand ha of mangroves were lost worldwide between 1996 and 2016, of which some 663 thousand ha were highly restorable. In addition, 139 thousand ha of existing mangroves were categorized as degraded, where restoration could enhance ecosystem integrity and prevent further degradation and eventual loss.

Many efforts have been made to restore mangroves, including as part of coastal restoration efforts after disasters such as the 2004 Indian Ocean tsunami, which caused considerable damage to large areas of coastline in South and Southeast Asia. These efforts have been piecemeal, however, and the rate of failure has been high. For example, for a large number of coastal restoration cases examined worldwide, Bayraktarov *et al.* (2016) found a mean survival of planted mangroves seedlings of 51 percent. In the Philippines, mangrove plantings have had long-term survival rates of only 10–20 percent (Primavera and Esteban, 2008). Kodikara *et al.* (2017) reported that, in Sri Lanka, 40 percent of the area in 23 restoration sites examined had failed completely, with no surviving plants; only about 20 percent of the area planted had been restored successfully.

Among the factors contributing to the high rate of mangrove restoration failure are an overemphasis on replanting, particularly in unsuitable habitats;

poor site–species matching; a lack of maintenance; inadequate assessment and control of barriers to mangrove recovery; and a lack of support from and participation by local communities in restoration efforts. The natural distribution of mangroves is based on species-specific tolerance to salinity and the duration of tidal immersion. Planting a limited number of easy-to-propagate mangrove species in unsuitable habitats (such as channels, mudflats and seagrass beds) is likely to result in failure. Mangrove restoration should start with an understanding of the natural vegetation present before disturbance. If a site supported mangroves in the past, an assessment of the barriers to natural mangrove regeneration should follow. If propagules are naturally available and any barriers to establishment (such as hydrologic constraints) are removed, mangroves should be able to recolonize suitable habitats without replanting. For example, mangroves have regenerated successfully on large areas of abandoned aquaculture ponds through the restoration of mangrove hydrology (Friess *et al.*, 2019). Where planting is required, the species used should be appropriate for the site, and the planted seedlings should be protected from cutting, browsing and other disturbances. Also, a robust monitoring programme should be put in place based on identified restoration goals and defined success criteria. The data gathered through monitoring can be used to measure success and to indicate the need for adjustments or corrections (Lewis, 2009).

The selection of suboptimal sites for mangrove planting may be driven by political, legal or socio-economic factors. For example, seaward mudflats away from the coast may have fewer challenges regarding tenure, and therefore larger areas can be secured for planting (Friess *et al.*, 2019). Replanting also offers opportunities for publicity and helps draw the attention of the public and potential funders. As a result, monospecific mangrove plantations may be established on sites that do not naturally support mangroves, often resulting in failure, particularly in the absence of maintenance and the lack of involvement of local communities.

Given the current global focus on ecosystem restoration, there are significant opportunities for scaling up the restoration of coastal ecosystems (Saunders *et al.*, 2020). To be effective, efforts should focus on ensuring the long-term viability and quality of the restored mangroves rather than on metrics such as the number of seedlings and hectares planted, despite the attractive headlines these might make.

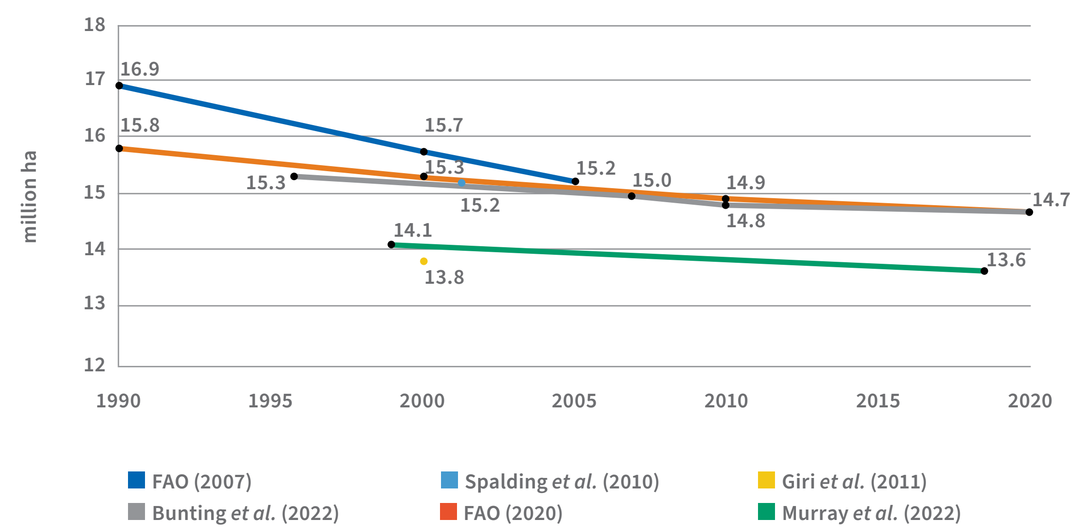
EXISTING ESTIMATES OF MANGROVE AREA AND CHANGE

Despite an extensive literature on mangroves and numerous studies, there is a lack of consistent, reliable and ground-truthed data on the area of mangroves and trends in this over time. The first estimate of total mangrove area worldwide – 15.6 million ha – was made by the Food and Agriculture Organization of the United Nations (FAO)

and the United Nations Environment Programme in 1980 as part of the Tropical Forest Resources Assessment (FAO, 1981a; FAO, 1981b; FAO, 1981c). Spalding *et al.* (1997) estimated global mangrove cover at 18.1 million ha. FAO (2007) estimated the global area of mangrove forests at 15.2 million ha in 2005, down from 16.9 million ha in 1990. Subsequent studies to assess the extent of mangrove area include those of Spalding, Kainuma and Collins (2010) and Giri *et al.* (2011), both based on Landsat data, and Global Mangrove Watch analyses using ALOS-PALSAR[2] (Bunting *et al.*, 2018, 2022).

The different estimates of mangrove extent and change provided by such studies – for example, the area in 2000 was estimated at 15.7 million ha by FAO (2007) and at 13.8 million ha by Giri *et al.* (2011) (**Figure 1**) – are due to differences in data and methodologies used. Although estimates of the rate of mangrove loss also vary, there is consensus that it is declining (**Table 1**).

Figure 1. *Estimates of global mangrove area, 1990–2020*



Source: Compiled by the authors using the sources cited.

Table 1. *Estimates of net annual mangrove loss*

SOURCE	PERIOD	ANNUAL AREA CHANGE (000 ha)	ANNUAL RATE OF CHANGE (%)
FAO (2007)	1980–1990	–186.9	–1.04
	1990–2000	–118.5	–0.72
	2000–2010	–101.8	–0.66
FAO (2020)	1990–2000	–46.7	–0.30
	2000–2010	–36.4	–0.24
	2010–2020	–21.1	–0.14
Bunting *et al.* (2022)	1996–2010	–32.7	–0.22
	2010–2020	–6.6	–0.04
Hamilton and Casey (2016)	2000–2012	–13.7	–0.16
Goldberg *et al.* (2020)	2000–2016	–21.0	–0.13
Murray *et al.* (2022)	1999–2019	–27.8	–0.20

Source: Compiled by the authors using the sources cited.

[2] ALOS-PALSAR = Advanced Land Observing Satellite-Phased Array Type L-band Synthetic Aperture Radar.

2 / METHODOLOGY

DEFINITION OF MANGROVES, APPLIED LAND USE, AND CHANGE DRIVERS CLASSES

Tomlinson (1986) defined true mangroves as plant species that: occur only in mangrove environments and not in terrestrial communities; play a major role in forming the structure of a mangrove community; have morphological specializations for the mangrove environment (e.g. aerial roots and vivipary); have physiological mechanisms for salt exclusion or excretion; and are taxonomically distinct from terrestrial relatives. Species found in mangrove environments that do not possess all these characteristics are categorized as mangrove associates. Such species (e.g. in the genera *Caesalpinia*, *Mora* and *Thespesia*) are often found at the landward edges of mangrove ecosystems (also called "back mangroves"), along river banks and in beach forests. Opinions differ on the classification of true mangroves versus mangrove associates, particularly for fringe species found mainly in the landward transitional zones of mangroves (e.g. *Acanthus* spp. and *Heritiera littoralis*). Species status is unresolved for some hybrids, subspecies and synonyms.

Here, we use Tomlinson's list of true mangroves supplemented with the exclusive mangrove species listed by Saenger, Hegerl and Davie (1983) for the purpose of delineating mangroves from other forest types (**Annex 1**). Areas where these true mangrove species comprise the dominant vegetation were identified as mangroves in our study.

The basic land-use classification scheme of the study is adopted from the FRA 2020 Remote Sensing Survey (FAO, 2022) and expanded to capture the status of and changes in mangrove area, as well as the drivers of these changes.

The following additional mangrove-specific classes for land use and drivers of loss and gain were added following a review of relevant literature (e.g. Richards and Friess, 2016; Hamilton and Casey, 2016; Feka and Ajonina, 2011):

Current land use (2020)

- Mangrove forest – stocked
- Mangrove forest – temporarily unstocked
- Aquaculture
- Rice field
- Settlement (subclasses: human settlement; infrastructure; and mining)

Loss drivers (2000–2010 and 2010–2020)

- Aquaculture[3]
- Rice cultivation
- Oil-palm plantation
- Direct settlement (urbanization and infrastructure)
- Indirect settlement (salinization, wetland drying)
- Timber extraction, including for fuelwood and charcoal production
- Natural disasters
- Natural retraction[4]

[3] Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms that are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as common property resources, with or without appropriate licences, are the harvest of fisheries (FAO, 1998).

[4] In this study, natural retraction is defined as natural changes or movements in riverbeds, sediment inputs or sea levels that lead to the local extinction of a mangrove ecosystem (Annex 2). In the study period, such natural changes were likely exacerbated by the impacts of climate change, such as sea-level rise and more severe weather events (this issue is discussed further in Chapter 5).

Gain drivers (2000–2010 and 2010–2020)

- Natural expansion
- Restoration

As the data and methods used in this study do not allow for the separation of different aquaculture practices, the class "aquaculture" is used here as a catch-all term. However, it should be noted that aquaculture, in relation to mangrove loss, is primarily reflecting pond shrimp aquaculture, and in some rare cases pond farmed fin fish. Thus, most aquaculture practices do not affect mangroves. Annex 2 contains the complete classification legend and detailed definitions.

MANGROVE MAPPING METHODOLOGY

The sampling frame for the study is the same as that used for the FRA 2020 Remote Sensing Survey (FAO, 2022). It is based on a tessellation of the Earth's surface into equal-area hexagons (39.62 ha each) originating from a discrete global grid of equal-sized hexagons. Each hexagon contained a 1-ha square centroid, which was used to collect more detailed information on land use, land-use change, and related drivers.

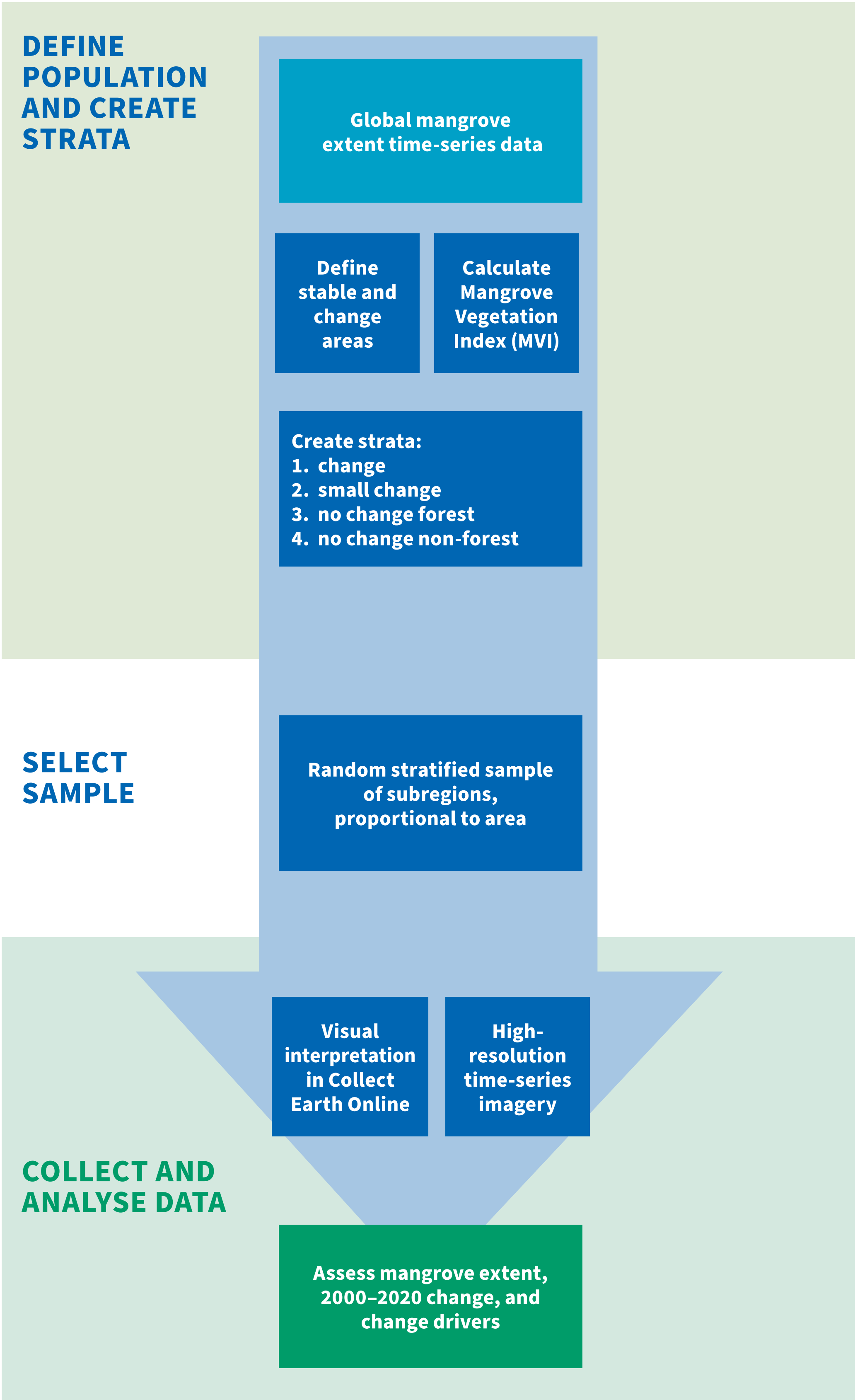
To define the strata for our sampling design, we created three key maps: a Mangrove Vegetation Index (MVI) map, a mangrove presence map, and a mangrove change map (Figure 2). The MVI layers were produced using cloud-free Landsat 7 and Landsat 8 Tier 1 images following Baloloy *et al.* (2020).

First, a 600 m buffer around the Global Mangrove Watch v2 (GMW) layer was created to capture all mangrove areas off the coast. Within this buffered area, pixels from the Joint Research Centre of the European Commission (JRC) mangrove dataset (Vancutsem *et al*., 2021) and the Global Mangrove Forest Distribution v1 2000 dataset (Giri *et al.*, 2011) were selected (Table 2). From the JRC mangrove dataset's classes, we used the undisturbed mangroves, mangrove deforestation (2000–2019), mangrove degradation (2000–2019) and mangrove degraded or regrown before 2000 classes. From the Global Mangrove Forest Distribution v1 2000 dataset we used the mangrove and non-mangrove pixel information for the year 2000.

This combined dataset was used to generate the two maps. The mangrove presence (stable mangrove) layer was generated using only pixels where all datasets agreed on the presence of mangroves. Pixels with disagreements between the datasets were considered as mangrove change areas. We applied a 120 m buffer around both maps to ensure we captured all mangroves and changes.

The final stratification of hexagons into stable and change classes was done using the MVI layers for each of the target years, along with the mangrove presence and change maps.

Figure 2. *Methodology flowchart*



Source: Authors' own elaboration.

Table 2. *Mangrove mapping products used to produce mangrove coverage and mangrove change maps*

NAME	SOURCE
Global Mangrove Forest Distribution, v1 2000	**Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. & Duke, N.** 2011. Status and distribution of mangrove forests of the world using earth observation satellite data: status and distributions of global mangroves. *Global Ecology and Biogeography*, 20(1): 154–159. https://onlinelibrary.wiley.com/doi/10.1111/j.1466-8238.2010.00584.x
European Commission Joint Research Centre dataset on forest-cover change in tropical moist forests, 2000–2019	**Vancutsem, C., Achard, F., Pekel, J.-F., Vieilledent, G., Carboni, S., Simonetti, D., Gallego, J., Aragão, L.E.O.C. & Nasi, R.** 2021. Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science Advances*, 7(10): eabe1603. https://doi.org/10.1126/sciadv.abe1603 **European Commission Joint Research Centre.** Undated. Tracking long-term (1990–2021) deforestation and degradation in tropical moist forests. In: *Forest Resources and Carbon Emissions (IFORCE)*. Cited 20 March 2023. https://forobs.jrc.ec.europa.eu/TMF/index.php
Global Mangrove Watch (1996, 2010, 2015, 2016)	**Bunting, P., Rosenqvist, A., Lucas, R.M., Rebelo, L.M., Hilarides, L., Thomas, N., Hardy, A., Itoh, T., Shimada, M. & Finlayson, C.M.** 2018. The Global Mangrove Watch – a new 2010 global baseline of mangrove extent. *Remote Sensing*, 10: 1669. Datasets downloaded at https://data.unep-wcmc.org/datasets/45

To generate the MVI layers, a temporal window of three years was used for each of the target years; for example, for year 2000 all cloud-free pixels for the period 1999–2001 were used. The MVI layers were calculated using the mean (µ) values of the selected pixels of the appropriate bands (B), as follows:

MVI Landsat 7:

$$MVI = \frac{(\mu B4 - \mu B2)}{(\mu B5 - \mu B2)}$$

MVI Landsat 8:

$$MVI = \frac{(\mu B5 - \mu B3)}{(\mu B6 - \mu B3)}$$

The MVI raster values, together with the stable mangrove raster values and mangrove change areas raster, were used to determine the final stratification of the hexagons. The four possible strata were: (1) change; (2) small change; (3) no change–forest; and (4) no change–no forest.

The following served as criteria for assigning strata:

1. A hexagon was assigned to the "change" stratum if more than 40 percent was covered by pixels of the change raster.
2. A hexagon was assigned to the "small change" stratum if between 5 percent and 40 percent was covered by pixels of the change raster and it had a maximum of 30 percent of pixels from the stable mangrove raster.
3. A hexagon was assigned to the "no change–forest" stratum if it met one of the following criteria:
   - between 5 percent and 40 percent of pixels were from the change raster and more than 30 percent of pixels were from stable mangrove raster;
   - fewer than 5 percent of pixels were from the change raster, more than 10 percent were from the stable mangrove raster, and the 2000 MVI value was greater than 4.5; or
   - fewer than 5 percent of pixels were from the change raster, fewer than 10 percent were from the stable mangrove raster, and the 2020 MVI value was greater than 4.5.
4. A hexagon was assigned to the "no change–no forest" stratum if fewer than 5 percent of pixels were from the change raster, fewer than 10 percent of pixels were from the stable mangrove raster, and the MVI values for 2000 and 2020 were below 4.5.

The study samples to be visually assessed were randomly selected using a statistical analysis based on the number of samples per stratum in the population of each FAO subregion. Previous experience in sampling-based estimates of global forest area (FAO, 2022) indicated that around 20 900 samples were needed to obtain accurate estimates of the mangrove area globally in 2020, change in mangrove areas in the periods 2000–2010 and 2010–2020, and the main drivers of mangrove loss between those periods.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DATA COLLECTION

The study applied a hybrid methodology, meaning that it combined existing remote sensing mangrove maps for stratification and the allocation of samples with the participation of local interpreters for data collection.

The samples were classified by local mangrove experts from interested countries, selected through the FRA Remote Sensing Focal Points Network. Where local experts were unavailable, FAO experts performed the classification. A total of 48 experts from 26 countries participated in collecting data from the 20 900 samples. A separate survey using a similar methodology is underway in Indonesia, which has the largest mangrove area of any country worldwide (**Box 1**).

As for the FRA 2020 Remote Sensing Survey, we collected data in discrete classes at the centroid level (1 ha) and quantitative data for each class at the hexagon level (39.6 ha) (FAO, 2022). The visual interpretation of the samples was done using Collect Earth Online (CEO)[5], a cloud platform developed collaboratively by SERVIR (a joint venture between the National Aeronautics and Space Administration – NASA – of the United States of America and the United States Agency for International Development) and FAO in partnership with SilvaCarbon (an interagency cooperation programme of the Government of the United States of America), the University of San Francisco's Spatial Informatics Group, the United States Forest Service, and Google.

Assessment of the current status of the sample sites was based on Sentinel 2 mosaics, and land-use change was assessed using Landsat mosaics for the target years of 2000, 2010 and 2020, thereby ensuring global consistency. Very-high-resolution images, freely available from Google Earth and Bing Maps, were used as auxiliary data to facilitate the understanding and classification of the samples.

Note that the dual nature of the data collection – that is, obtaining quantitative area percentages from the hexagons and discrete classes from the centroids – can lead to inconsistencies in the resulting estimates of mangrove area. These may arise, for example, when a sample presents a small change in mangrove area in the hexagon between analysis periods but no change in the centroid. In such cases, which were particularly common in Oceania, the area totals calculated from the hexagons do not fully match the totals for change drivers calculated from the centroids.

[5] https://collect.earth

BOX 1

Improving capacity to monitor Indonesia's mangroves

Indonesia has the world's largest extent of mangroves, contributing 21 percent of the total global mangrove area (FAO, 2020). Robust information on these resources is essential given their immense economic, social and environmental importance and high biodiversity. Indonesia has established a national forest monitoring system since 1990s with progressive improvements over time and now called SIMONTANA. Indonesia's Ministry of Environment and Forestry and FAO convened a workshop in Yogyakarta, Indonesia, from 27 June to 2 July 2022 to assess mangroves in Indonesia. The assessment was developed as part of the Global Forest Resources Assessment 2020 Remote Sensing Survey (FAO, 2022) and used a similar sampling-based methodology. For the national exercise, the number of samples was densified to 3 000 samples, and the study period was extended to investigate the extent of mangroves between 1990 and 2022. The aim of the assessment was to provide consistent indicators of mangrove extent, distribution and trends. These new methods used by FAO were also a good exercise for Indonesian staff to combine their local knowledge with new technology developed in order to improve mangrove mapping in Indonesia. The aim was to enhance mangrove mapping for improved accuracy and efficiency.

METHODS

Software and sensors. The assessment of samples was conducted on the online platform Collect Earth Online (CEO). The status of land use in 2022 was based on cloud-free multispectral Sentinel-2 satellite imagery, and in 1990, 2000, 2010 and 2022 was assessed using cloud-free Landsat imagery. Very-high-resolution images from Bing Maps, DigitalGlobe and MapBox were used to support photo-interpretation.

Approach. The Ministry of Environment and Forestry designated 35 staff to participate in the workshop. As requested by the FAO team, each participant had experience in geographic information systems and, most importantly, local field knowledge of their study areas.

The participants consisted of various regional officers from Indonesia's MoEF staff. The participants had expertise, local knowledge of the areas and understanding in using medium satellite resolution for land cover.

Capacity development. In the week preceding the workshop, participants were able to attend an interactive online course involving 14 lessons on various topics, such as the tools to be used in the assessment (i.e. CEO and Google Earth Pro); the methodology of photo interpretation for medium- and high-resolution images; and the definitions and ecological concepts used. The course was created specifically for this country-level workshop because some of the participants were unfamiliar with the methodology and software used for remote sensing.

The lessons included videos demonstrating how to classify samples, as well as explanations – with examples – of each category of land use and land-use change. The examples were based on real cases in the study areas. At the end of each module, participants were required to complete a short exercise on the topics covered.

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The workshop used a dynamic participatory approach in which exercises, tests and joint discussions on complex classification cases were conducted to ensure that participants could use the classification criteria correctly. Evaluations were done to determine the participants' understanding and to identify possible weaknesses that needed to be addressed before interpreting the samples on mangroves. Participants worked together in groups of two or three, each with their own computer, analysing their regions of expertise and communicating with each other during the analysis.


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Participants worked in small groups to photo-interpret remote sensing imagery for their own regions

A field trip was conducted involving the interpreters and FAO staff. The main objective was to help interpreters better understand the relationship between the on-the-ground reality for mangroves and the remotely sensed products they were using as a reference for the classification. The field visit was carried out in a community forest under a management plan and in a mangrove restoration area developed close to aquaculture ponds.

Scenes from the field trip conducted in a community mangrove forest and a mangrove restoration area

DATA VALIDATION

After data collection, FAO reviewed the mangrove estimates generated for each country by comparing them with other available data sources. For any given country where there was a discrepancy between our estimate and those of other sources, FAO carried out an additional quality-control exercise on a randomly chosen 10 percent subsample of the interpreted plots. Where misinterpretations were found for certain land-use/land-use-change classes, all plots pertaining to those classes were reviewed. Any errors detected were corrected.

3 / GLOBAL OVERVIEW OF ASSESSMENT FINDINGS

MANGROVE AREA IN 2020

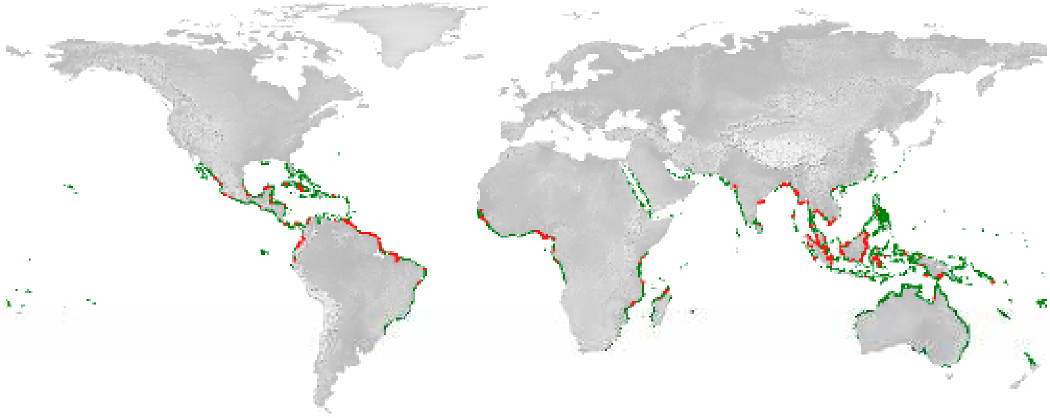
We estimate that the total global area of mangroves in 2020 was 14.8 million ha. Mangroves are distributed unevenly worldwide, with more than two-fifths (43.8 percent, 6.48 million ha) occuring in South and Southeast Asia. The remainder is mostly in South America (2.14 million ha), Western and Central Africa (2.09 million ha), North and Central America (1.85 million ha) and Oceania 1.46 million ha), with much smaller areas in other parts of tropical Asia and Africa (**Table 3** and **Figure 3**).

Table 3. *Estimated mangrove area, by subregion, 2020*

SUBREGION	MANGROVE AREA (million ha)	± 95% CONFIDENCE INTERVAL (%)	% OF GLOBAL MANGROVE AREA
Eastern and Southern Africa	0.73	6.79	4.92
Western and Central Africa	2.09	3.80	14.2
East Asia	0.02	34.7	0.10
South and Southeast Asia	6.48	2.03	43.8
Western and Central Asia	0.02	45.6	0.14
North and Central America	1.85	4.45	12.5
Oceania	1.46	4.81	9.89
South America	2.14	3.40	14.5
World	**14.8**	**1.4**	**100**

Source: Authors' own elaboration.

Figure 3. *Distribution of mangrove samples deforested between 2000 and 2020*



Sources: Background made with Natural Earth. Free vector and raster map data @ naturalearthdata.com. Global mangrove cover shapefile from **Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., Tadono, T., Worthington, T.A.** ***et al.*** 2022. Global mangrove extent change 1996–2020: Global Mangrove Watch version 3.0. Remote Sensing, 14(15): 3657. https://doi.org/10.3390/rs14153657. Mangrove loss samples were generated by the present study.

CHANGE IN MANGROVE AREA

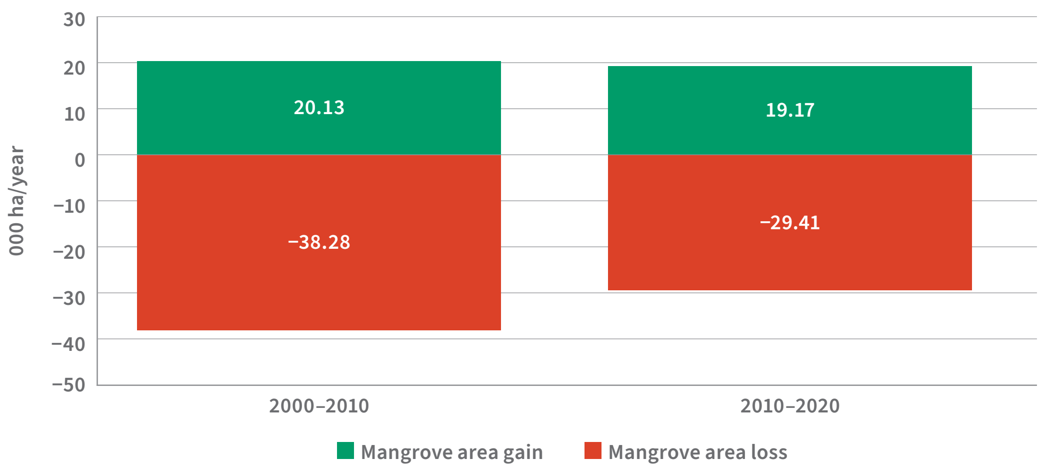
Around half the total loss of mangrove area between 2000 and 2020 (677 thousand ha) was offset by the expansion of mangrove to areas not present in 2000 (393 thousand ha). Thus, there was a net decline in mangrove area of 284 thousand ha over the period.

The rate of gross global mangrove loss decreased by around 23 percent between the two decadal periods, from 38.3 thousand ha per year in 2000–2010 to 29.4 thousand ha per year in 2010–2020. There was a slight decrease in the rate of mangrove area gain, from 20.1 thousand ha per year in 2000–2010 to 19.2 thousand ha per year in 2010–2020 (**Figure 4**).

The rate of net loss of mangrove area decreased by 44 percent between the two periods, from 18.2 thousand ha per year in 2000–2010 to 10.2 thousand ha per year in 2010–2020.

Asia, which hosts almost half the world's mangroves, accounted for 68 percent of global mangrove area loss in 2000–2010 and for 54 percent of the loss in 2010–2020; of the global mangrove area gains,

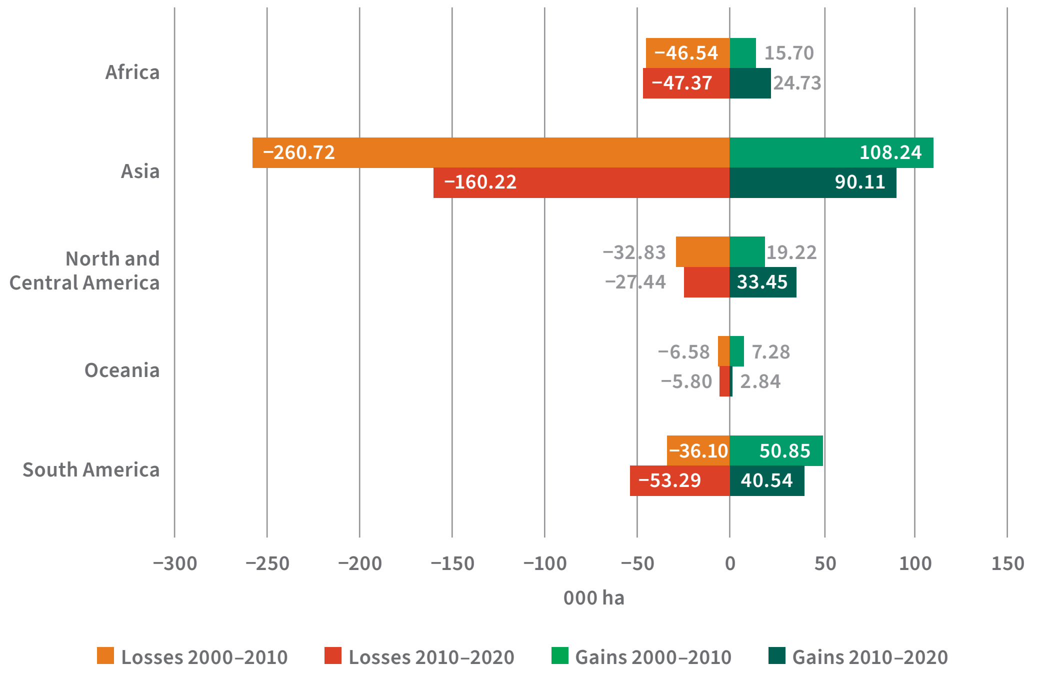
Figure 4. *Annual global mangrove area loss and gain, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

54 percent in 2000–2010 and 47 percent in 2010–2020 were in Asia (Figure 5). The area of mangrove loss and the area of mangrove gain in Asia both decreased significantly between the two decadal periods. The area of mangrove loss and the area of mangrove gain were both slightly lower in Africa in 2000–2010 than in 2010–2020. In South America, the area of mangrove loss was substantially larger in 2010–2020 than in 2000–2010 but the area of mangrove gain was smaller. In North and Central America, the area of mangrove loss was smaller in 2010–2020 than in 2000–2010 and the area of mangrove gain was substantially larger.

Figure 5. *Mangrove area loss and gain, by region, 2000–2010 and 2010–2020*

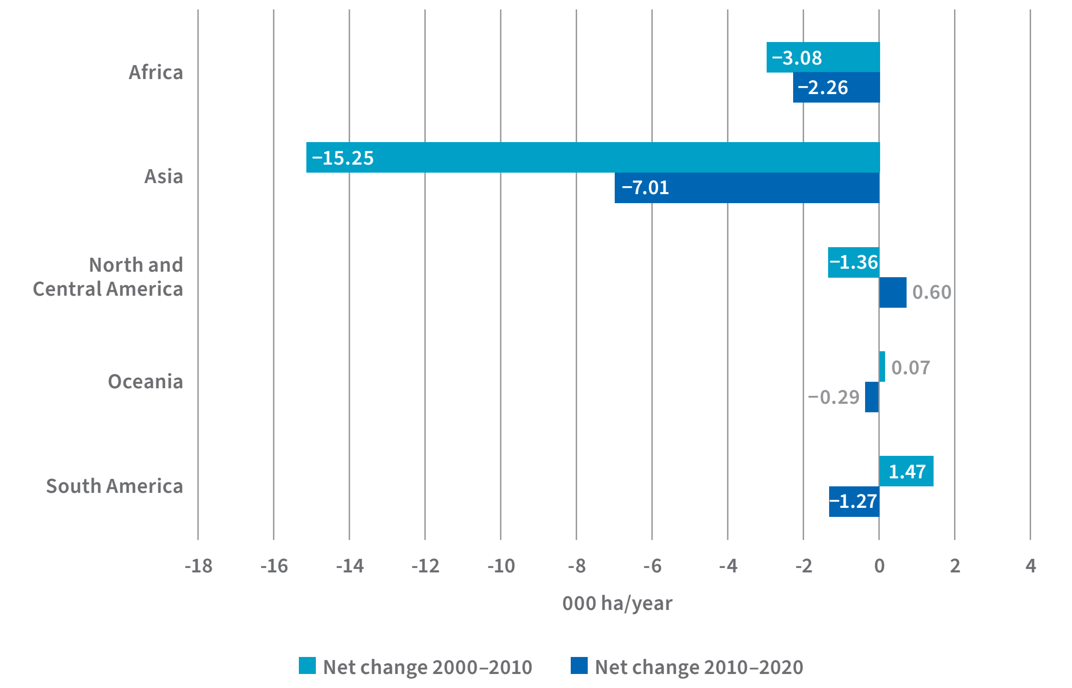


Source: Authors' own elaboration.

Although the largest net loss of mangrove area was in Asia, it was almost halved between the two periods (Figure 6). In Africa, net annual loss decreased by 26.6 percent, from 3.08 thousand ha per year in 2000–2010 to 2.26 thousand ha per year in 2010–2020. North and Central America reversed a negative trend in net mangrove area change, from a net loss of 1.36 thousand ha per year in 2000–2010 to a net gain of 0.6 ha per year in 2010–2020. Conversely, South America and Oceania achieved net gains in 2000–2010 but experienced net losses in 2010–2020 (Figure 6).

The annual global rate of change in mangrove area decreased from −0.12 percent in 2000–2010 to −0.07 percent in 2010–2020 (Table 4). The highest rate of net mangrove loss was in South and Southeast Asia, at −0.23 percent per year in 2000–2010 (the rate declined to −0.11 percent per year in 2010–2020). The net loss of mangrove area in Western and Central Africa was unchanged between the two decades, at −0.12 percent per year; this region had the highest net rate of mangrove loss in 2010–2020. A shift towards a negative net rate of change in Oceania (from no change in 2000–2010 to a rate of −0.01 percent per year in 2010–2020) and South America (from an increase of 0.07 percent per year in 2000–2010 to a loss of −0.06 percent per year in 2010–2020) suggests an increasing threat to mangroves in those two regions. In East Asia (where only two countries, China and Japan, have mangroves), mangrove area increased over the two decades at a rate of 2.32 percent per year.

Figure 6. *Annual net change in mangrove area, by region, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

Table 4. *Rate of annual mangrove area change, by region, 2000–2010, 2010–2020 and 2000–2020*

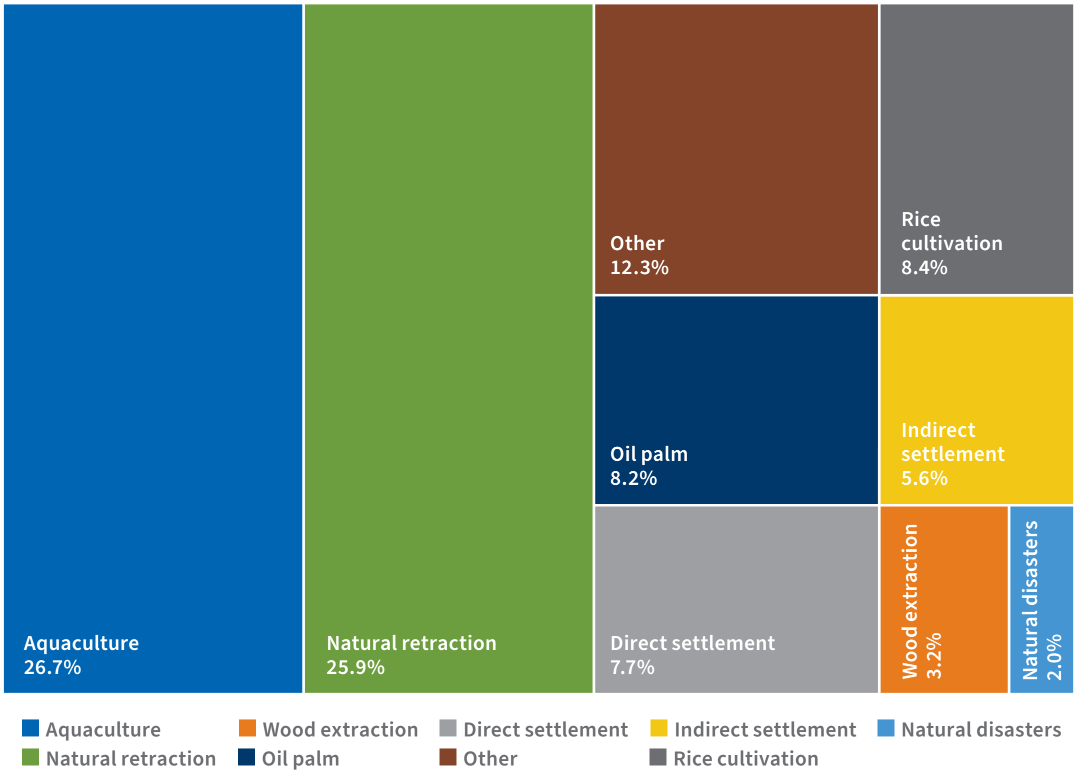
SUBREGION	2000–2010 (%)	2010–2020 (%)	2000–2020 (%)
Eastern and Southern Africa	−0.08	0.05	−0.0
Western and Central Africa	−0.12	−0.12	−0.1
East Asia	2.74	1.90	2.32
South and Southeast Asia	−0.23	−0.11	−0.17
Western and Central Asia	0.00	0.00	0.00
North and Central America	−0.07	0.03	−0.02
Oceania	0.00	−0.02	−0.01
South America	0.07	−0.06	0.00
World	**−0.12**	**−0.07**	**−0.10**

Source: Authors' own elaboration.

DRIVERS OF MANGROVE DEFORESTATION

The main direct drivers of mangrove loss globally between 2000 and 2020 were aquaculture development, constituting 26.7 percent of total loss, and natural retraction, at 25.9 percent. Conversion to oil palm and rice cultivation accounted for 16.6 percent of mangrove loss and conversion to other forms of agriculture and undefined uses for 12.3 percent. Direct and indirect settlement caused 13.3 percent of mangrove loss over the two decades – this comprised the clearing of mangroves for housing, other buildings and infrastructure, and development activities that changed the hydrologic regime or sediment inputs or produced pollution sufficiently extreme to cause mangroves to disappear (Figure 7).

Figure 7. *Global drivers of mangrove loss, 2000–2020*

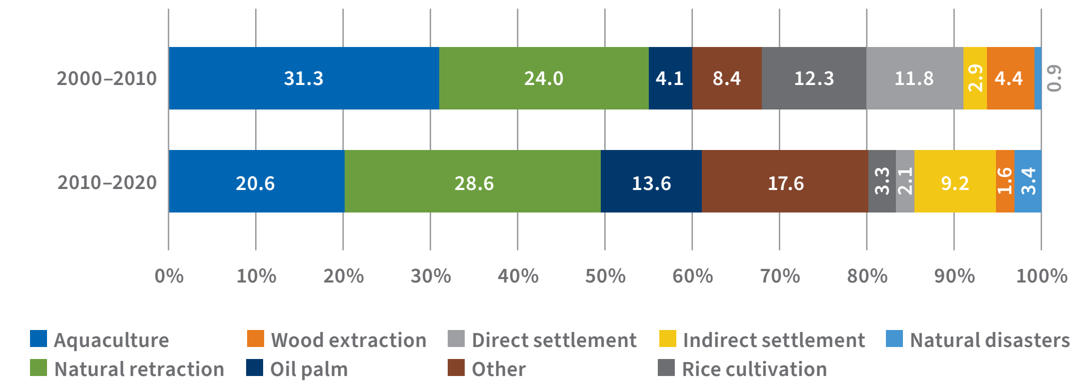


Source: Authors' own elaboration.

The relative importance of the global drivers of mangrove loss shifted considerably between the two periods (i.e. 2000–2010 and 2010–2020) (Figure 8). Aquaculture remained a key driver but its significance diminished, mainly due to the trend in South and Southeast Asia. The roles of conversion for rice cultivation and direct settlement also declined markedly but the relative importance of conversion to oil-palm plantations increased substantially due to an expansion of these in Southeast Asia. The proportion of mangrove loss due to natural retraction also increased in 2010–2020, indicating the intensifying impacts of climate change. Mangrove losses due to indirect settlement and disasters increased noticeably between the two periods.

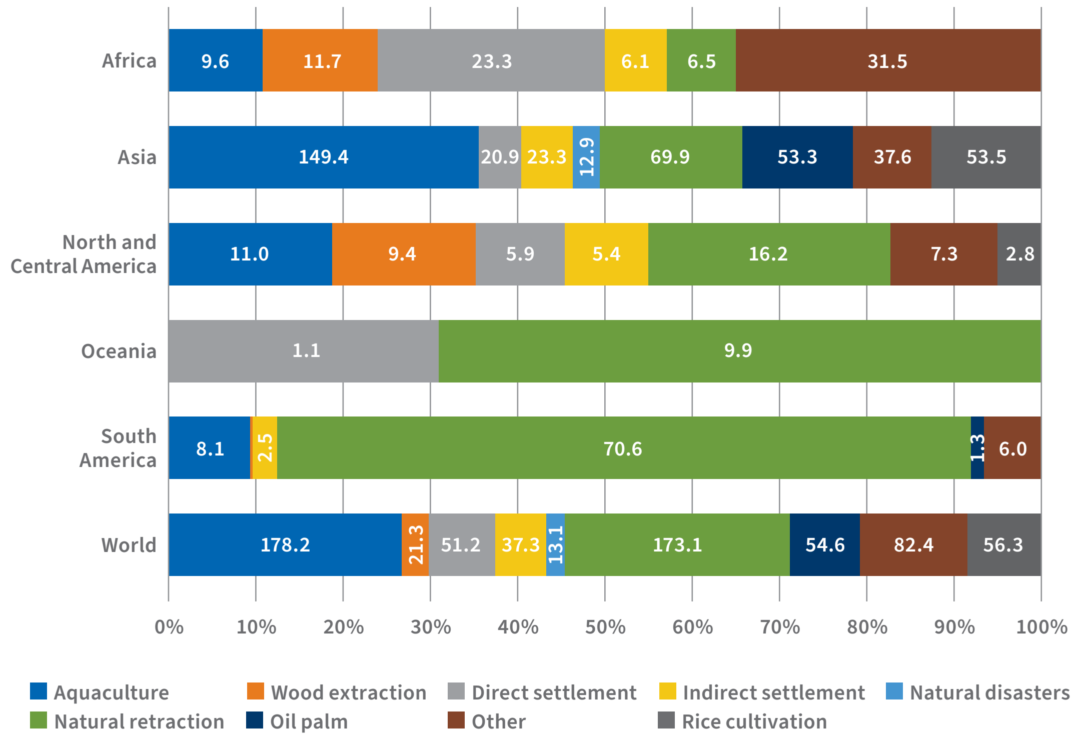
The relative importance of loss drivers differed markedly between regions (Figure 9) (regional and subregional trends are examined in more detail in Chapter 4).

Figure 8. *Relative importance of drivers of mangrove loss, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

Figure 9. *Composition of drivers of mangrove loss, by region, 2000–2020*



Note: Embedded numbers show mangrove area (000 ha).
Source: Authors' own elaboration.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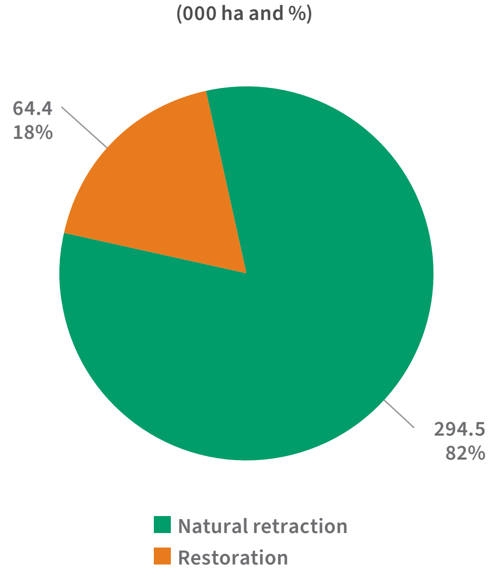
DRIVERS OF MANGROVE GAIN

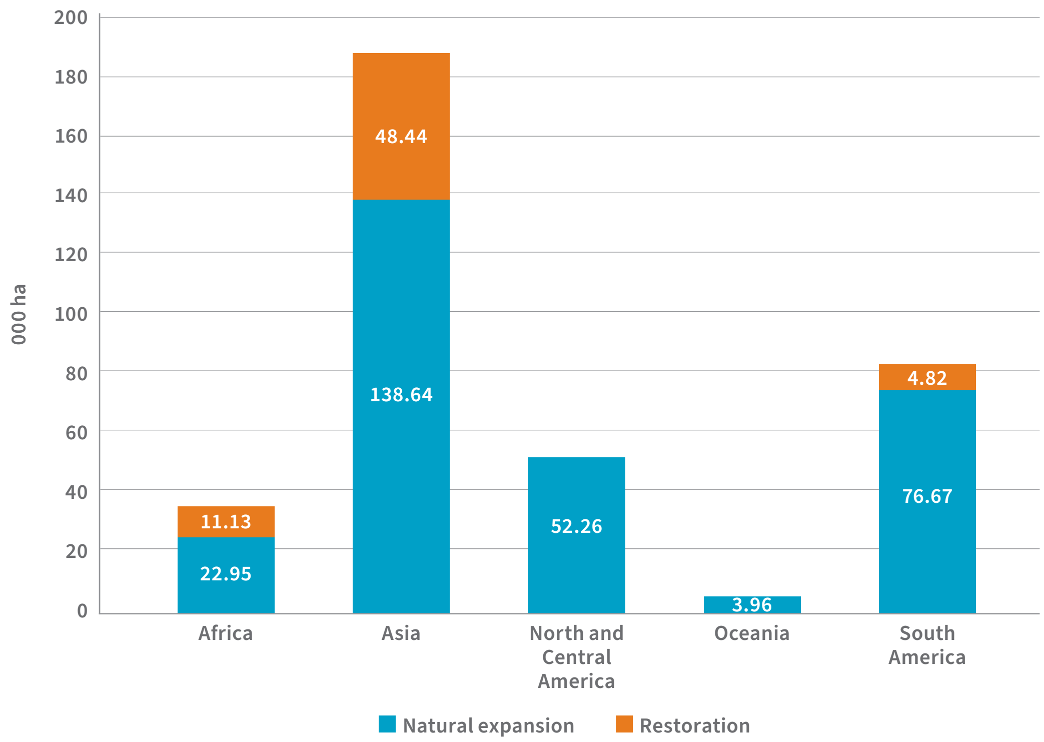
Natural expansion comprised 82 percent of all gains in mangrove area globally over the study period (i.e. 2000–2020) (Figure 10). Nonetheless, restoration efforts were found to have contributed to the increase to differing extents, depending on the region. These interventions had most impact in South and Southeast Asia and Africa, where 25 and 33 percent of mangrove expansion, respectively, was due to restoration activities (Figure 11).

Figure 10. *Proportion of mangrove gain driven by natural expansion and restoration, 2000–2020*



Source: Authors' own elaboration.

Figure 11. *Area of mangrove gain, by driver and region, 2000–2020*

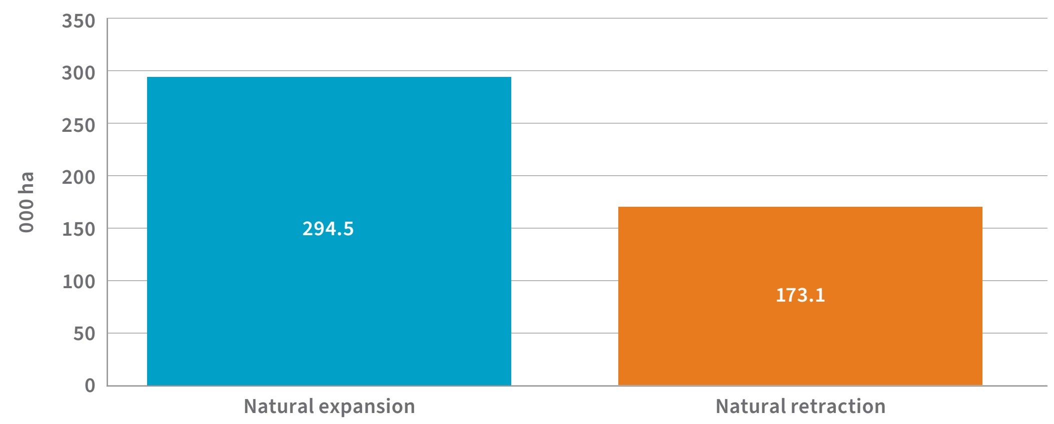


Source: Authors' own elaboration.

NATURAL DYNAMICS

Considering only the natural dynamics of mangrove expansion and retraction (i.e. excluding anthropogenic losses and restoration efforts), the study found that, over the period 2000–2020, mangroves expanded over a much larger area globally (294.5 thousand ha) than they retracted due to natural causes, excluding natural disasters (173.1 thousand ha) (Figure 12). Natural disasters resulted in the loss of another 13.1 thousand ha of mangroves over the period. Even though the net change in mangrove area globally was negative over the period, the area of natural expansion far exceeded the area lost to natural causes (by 58 percent, or by 63 percent when the contribution of natural disasters is included).

Figure 12. *Global natural dynamics of mangroves, 2000—2020*



Source: Authors' own elaboration.

4 / REGIONAL STATUS AND TRENDS

AFRICA

Mangrove status and trends

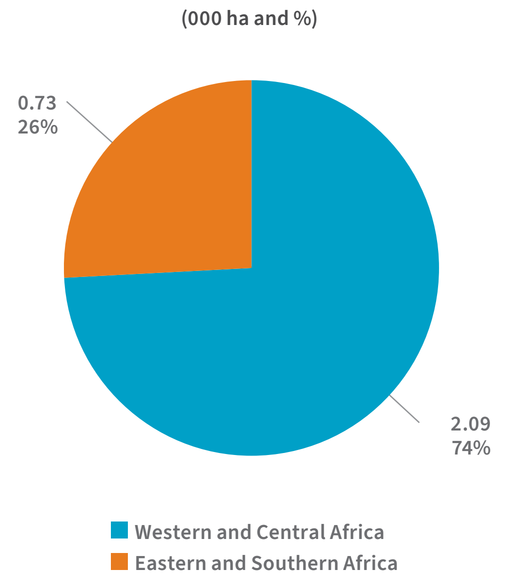
Of the five regions, Africa had the second-largest area of mangroves (after Asia) in 2020, at 2.82 million ha; this was 19 percent of the global mangrove area. Western and Central Africa hosted the majority (74 percent) of Africa's mangroves (**Figure 13**).

The rate of loss of mangroves increased slightly in Western and Central Africa between 2000–2010 and 2010–2020 and decreased in Eastern and Southern Africa, and the rate of gain of mangroves increased in both subregions (**Table 5**). The rate of net change in mangrove area was steady in Western and Central Africa between the two periods, at −0.12 percent; this was the highest rate of mangrove loss of any subregion globally in 2010–2020. Conversely, for Eastern and Southern Africa, a net annual loss of 0.08 percent in 2000–2010 turned to a net increase of 0.05 percent per year in 2010–2020.

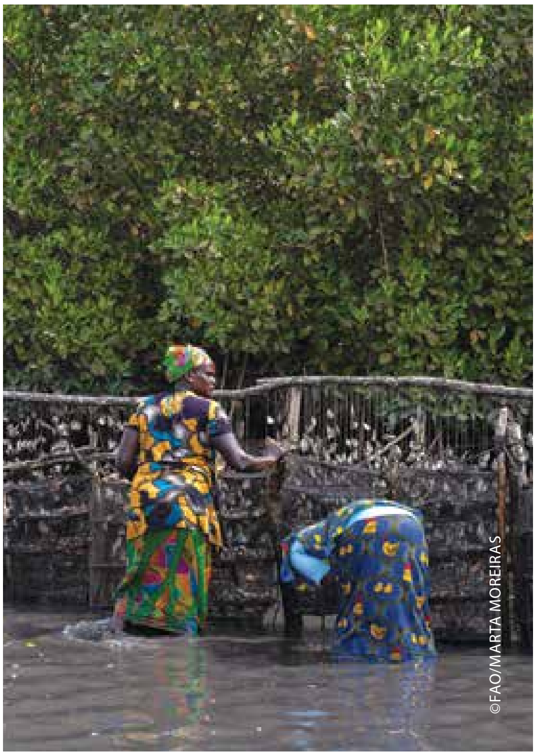
Table 5. *Mangrove area losses and gains in Africa, by subregion, 2000–2010 and 2010–2020*

SUBREGION	LOSS (000 ha)		GAIN (000 ha)		ANNUAL NET CHANGE (%)	
	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
Eastern and Southern Africa	−16.10	−14.06	10.64	17.44	−0.08	0.05
Western and Central Africa	−30.44	−33.32	5.06	7.29	−0.12	−0.12

Figure 13. *Proportion of mangrove area in Africa in 2020, by subregion*



Source: Authors' own elaboration.

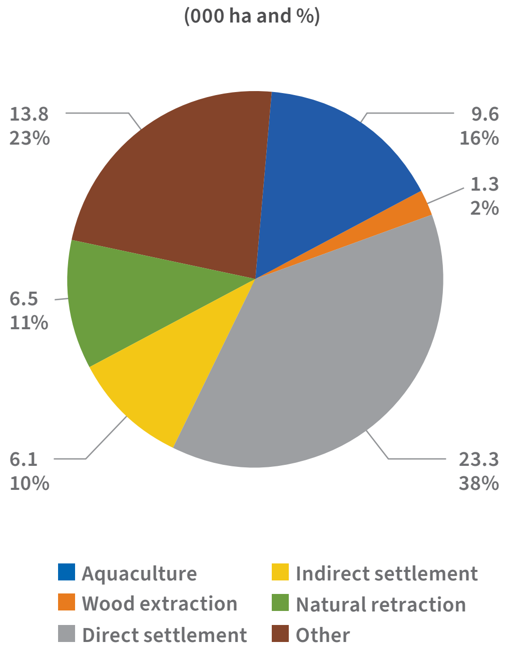


Drivers of mangrove loss and gain

According to our assessment, the main driver of mangrove loss in Africa in 2000–2020 was "other", accounting for 36 percent of the loss. This category encompasses various forms of agriculture (excluding aquaculture and rice cultivation), such as conversion to grasslands for livestock grazing and any other trajectory of change not classifiable among the other available classes. The second-ranked driver was direct settlement (urbanization), at 26 percent, and the third was wood extraction, primarily for fuelwood and charcoal production, at 13 percent (**Figure 14**).

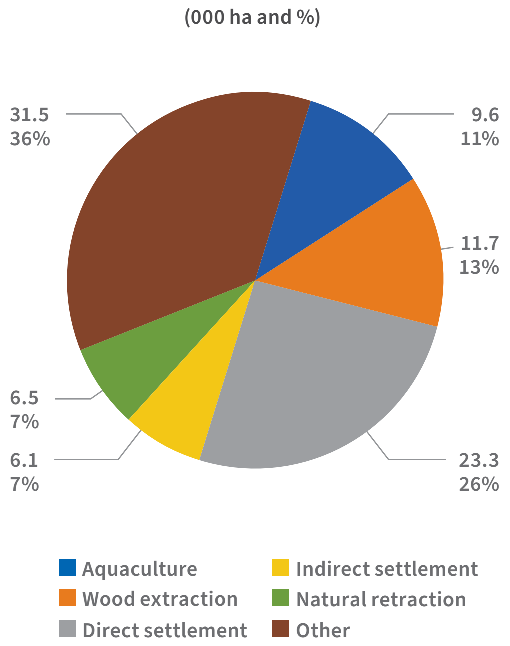
The importance of these drivers varied considerably between the two subregions. The predominant driver of mangrove loss in Western and Central Africa was direct settlement, mainly urbanization, at 38 percent, and "other" accounted for 23 percent (**Figure 15**). In Eastern Africa, the only two discernible drivers were "other" (63 percent of mangrove loss) and wood extraction (37 percent) (**Figure 16**).

Figure 15. *Proportion of mangrove loss in Western and Central Africa in 2000–2020, by driver*



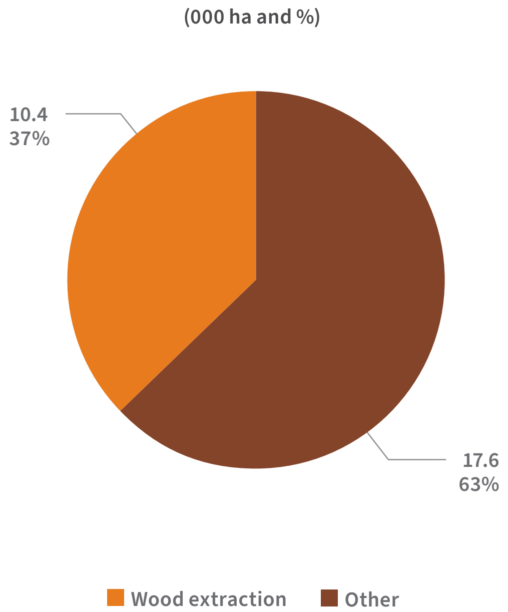
Source: Authors' own elaboration.

Figure 14. *Proportion of mangrove loss in Africa in 2000–2020, by driver*



Source: Authors' own elaboration.

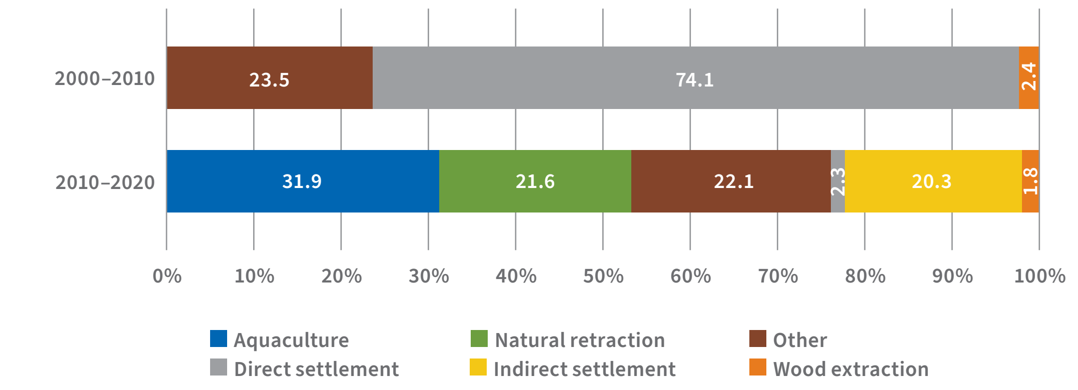
Figure 16. *Proportion of mangrove loss in Eastern and Southern Africa in 2000–2020, by driver*



Source: Authors' own elaboration.

There was a significant shift in the drivers of mangrove loss in Western and Central Africa between 2000–2010 and 2010–2020. Direct settlement, which accounted for 74 percent of mangrove loss in 2000–2010, caused only 2.4 percent of loss in 2010–2020. New drivers with more impact in the latter period were aquaculture, natural retraction and indirect settlement (**Figure 17**).

Figure 17. *Relative importance of drivers of mangrove loss in Western and Central Africa, 2000–2010 and 2010–2020*

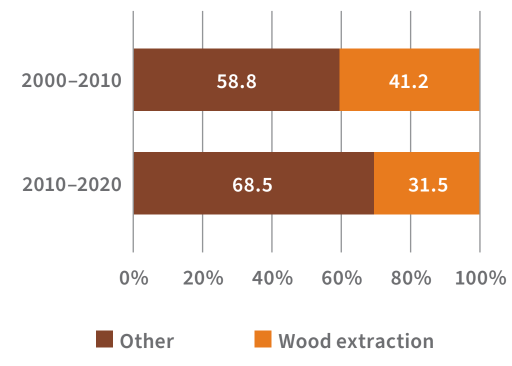


Source: Authors' own elaboration.

Only two drivers of mangrove loss were at play in Eastern and Southern Africa. The role of wood extraction leading to mangrove deforestation declined between the two periods but the importance of "other" increased (**Figure 18**).

Natural expansion was responsible for most (82 percent) of mangrove gain in Western and Central Africa between 2000 and 2020 (**Table 6**). Restoration had a larger role in the expansion of mangroves in Eastern and Southern Africa over the period, accounting for 39 percent.

Figure 18. *Relative importance of drivers of mangrove loss in Eastern and Southern Africa, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

Table 6. *Drivers of mangrove gain in Africa, by subregion, 2000–2020*

SUBREGION	NATURAL EXPANSION	RESTORATION	TOTAL
	000 ha (% of total)		
Eastern and Southern Africa	14.3 (61)	9.19 (39)	**23.5 (100)**
Western and Central Africa	8.61 (82)	1.94 (18)	**10.5 (100)**

ASIA

Mangrove status and trends

The area of mangroves in Asia in 2020 is estimated at 6.5 million ha, which was 44 percent of mangrove area worldwide in that year; Asia had the largest area of mangroves among the five regions worldwide, almost all of it (99.5 percent) in South and Southeast Asia.

There were significant differences in mangrove loss and gain among the subregions in Asia. No loss or gain of area was detected in Western and Central Asia between 2000 and 2020. In East Asia, the mangrove area expanded over the 20-year period at a rate of 2.32 percent annually. South and Southeast Asia experienced a relatively high rate of net loss in 2000–2010, at 0.23 percent, but this declined to 0.11 percent per year in 2010–2020 (**Table 7**).

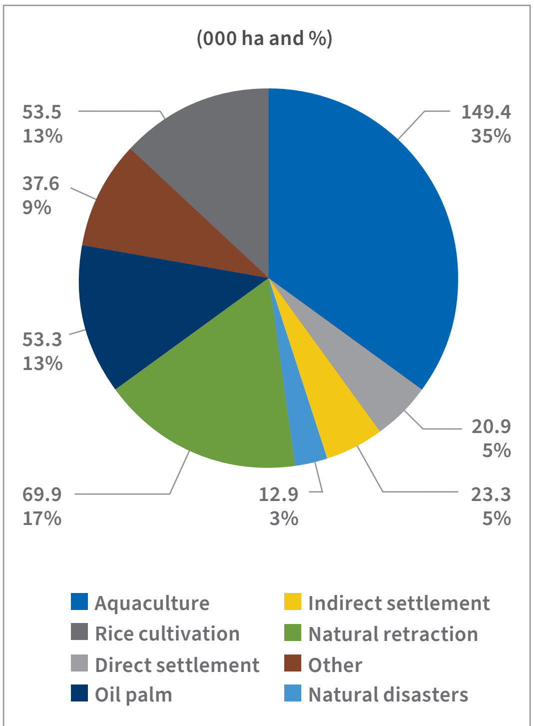
Drivers of mangrove loss and gain

In South and Southeast Asia, the main driver of mangrove loss between 2000 and 2020 was aquaculture, accounting for 35 percent, followed by natural retraction (17 percent). Conversion for rice cultivation and oil-palm plantations was also important, with each land use accounting for 13 percent of the loss (**Figure 19**).

Table 7. *Losses and gains in mangrove area in Asia, by subregion, 2000–2010 and 2010–2020*

SUBREGION	LOSS (000 ha)		GAIN (000 ha)		ANNUAL NET CHANGE (%)	
	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
East Asia	0	0	2.95	2.58	2.74	1.90
South and Southeast Asia	−261	−160	105	87.5	−0.23	−0.11
Western and Central Asia	0	0	0	0	0	0

Figure 19. *Proportion of mangrove loss in South and Southeast Asia in 2000–2020, by driver*

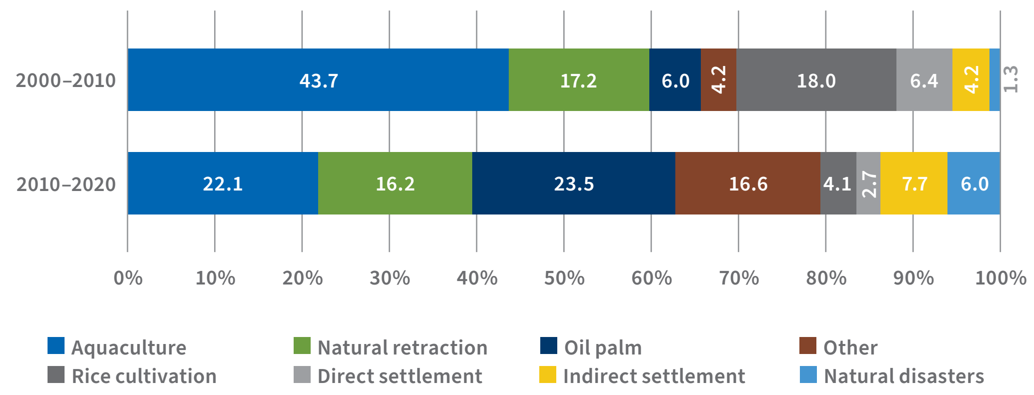


Source: Authors' own elaboration.

A diverse and dynamic set of drivers was responsible for mangrove loss in South and Southeast Asia. Most notably, the role of aquaculture declined substantially between the two measurement periods, as did the role of conversion to rice cultivation and direct settlement. On the other hand, conversion to oil-palm plantations emerged as the predominant driver of mangrove loss between 2010 and 2020. The impact of disasters and indirect settlement on mangrove loss also increased significantly (**Figure 20**).

Restoration efforts played a larger role in the expansion of mangrove area in Asia than in other regions over the 20-year period. In East Asia, the entire gain in mangrove area, although modest, was attributable to restoration interventions. Restoration contributed about one-quarter of the observed gain in mangrove area in South and Southeast Asia over the two decades (**Table 8**).

Figure 20. *Relative importance of drivers of mangrove loss in South and Southeast Asia, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

Table 8. *Drivers of mangrove gain in Asia, by subregion, 2000–2020*

SUBREGION	NATURAL EXPANSION	RESTORATION	TOTAL
	000 ha (% of total)		
East Asia	0	3 (100)	**3 (100)**
South and Southeast Asia	13.9 (75)	45.4 (25)	**184 (100)**
Western and Central Asia	0	0	**0**

NORTH AND CENTRAL AMERICA

Mangrove status and trends

The mangrove area in North and Central America in 2020 is estimated at 1.85 million ha, which was 12.5 percent of the global mangrove area in that year. The region has the fourth-largest mangrove area worldwide.

The total loss of mangrove area decreased slightly in the region between 2000–2010 and 2010–2020, from about 33 thousand ha to 27 thousand ha. The gain in mangrove area was about 19 thousand ha in the earlier period and 33 thousand ha in the latter. Thus, there was an overall negative trend in mangrove area in 2000–2010 and a positive trend in 2010–2020 (**Table 9**).

Table 9. *Mangrove area losses and gains in North and Central America, 2000–2010 and 2010–2020*

REGION	LOSS (000 ha)		GAIN (000 ha)		ANNUAL NET CHANGE (%)	
	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
North and Central America	−32.8	−27.4	19.2	33.4	−0.07	0.03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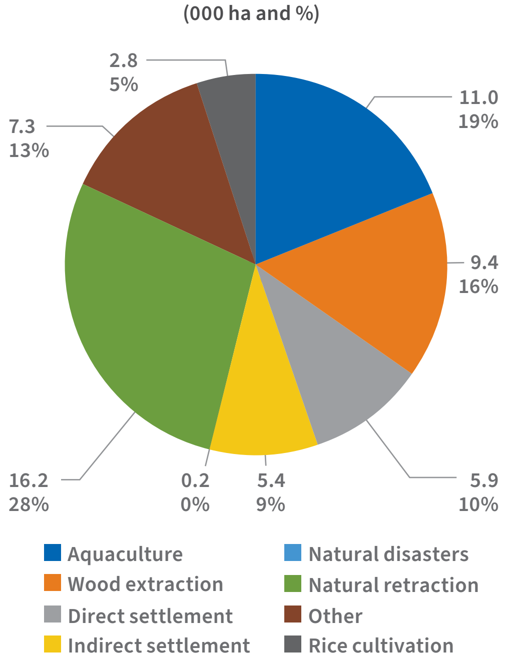
Drivers of mangrove loss and gain

The main driver of mangrove loss between 2000 and 2020 in North and Central America was natural retraction (including that arising from the impacts of climate change), accounting for 28 percent, followed by aquaculture (19 percent) and wood extraction (16 percent) (**Figure 21**). Mangroves face multifaceted threats in the region.

Aquaculture, rice cultivation and indirect settlement emerged as important drivers of mangrove loss in the region in 2010–2020 (**Figure 22**). In contrast, wood extraction, which was a significant driver in 2000–2010, ceased to be a factor in 2010–2020, and the importance of direct settlement also declined.

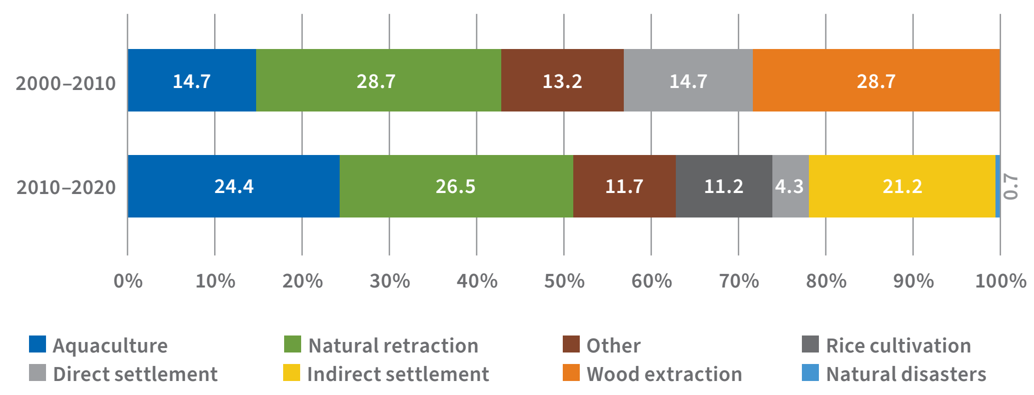
No sample plots showing mangrove gain in the region due to restoration were observed in either measurement period; thus, all gains in mangrove area between 2000 and 2020 were attributed to natural expansion (**Table 10**).

Figure 21. *Proportion of mangrove loss in South and Southeast Asia in 2000–2020, by driver*



Source: Authors' own elaboration.

Figure 22. *Relative importance of drivers of mangrove loss in North and Central America, 2000–2010 and 2010–2020 and 2010–2020*



Source: Authors' own elaboration.

Table 10. *Drivers of mangrove gain in North and Central America, 2000–2020*

REGION	NATURAL EXPANSION	RESTORATION	TOTAL
	000 ha (% of total)		
North and Central America	52.3 (100)	0	**52.3 (100)**

OCEANIA

Mangrove status and trends

The mangrove area in Oceania in 2020 is estimated at 1.46 million ha, which was 9.9 percent of the global mangrove area in that year.

There was minimal change in the area of mangroves lost between the two measurement periods, but the gain in mangrove area decreased from 7.28 thousand ha in the first measurement period to 2.84 thousand ha in the second (**Table 11**). The overall net change in mangrove area was minimal in 2000–2010, but there was a net loss of mangroves in the second period of about 3 thousand ha, or 0.02 percent of the region's total mangrove area.

Table 11. *Mangrove area losses and gains in Oceania, 2000–2010 and 2010–2020*

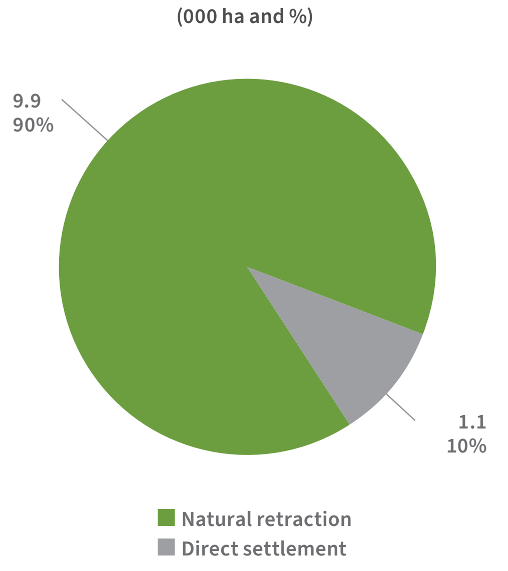
REGION	LOSS (000 ha)		GAIN (000 ha)		ANNUAL NET CHANGE (%)	
	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
North and Central America	−6.58	−5.80	7.28	2.84	0.00	−0.02

Drivers of mangrove loss and gain

According to the assessment, mangrove loss in Oceania was caused by only two drivers over the two decades. The main one was natural retraction, which caused 90 percent of mangrove loss between 2000 and 2020, and the other was direct settlement (10 percent) (**Figure 23**). Thus, it appears that mangroves are not under serious direct pressure from resource extraction and agricultural conversion in Oceania but are susceptible to coastal erosion exacerbated by climate change and to urban development, including for tourism.

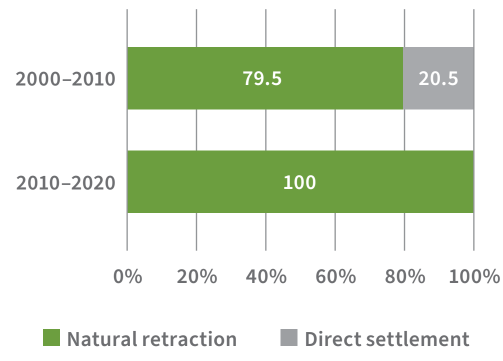
Direct settlement contributed to less than one-third of mangrove loss in Oceania in 2000–2010, but all loss in 2010–2020 was assessed as due to natural retraction (**Figure 24**).

Figure 23. *Proportion of mangrove loss in Oceania in 2000–2020, by driver*



Source: Authors' own elaboration.

Figure 24. *Relative importance of drivers of mangrove loss in Oceania, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

No sample plots showing mangrove gain due to restoration were observed in Oceania in either measurement period; thus, all mangrove area gains between 2000 and 2020 were attributed to natural expansion (**Table 12**).

Table 12. *Drivers of mangrove gain in Oceania, 2000–2020*

REGION	NATURAL EXPANSION	RESTORATION	TOTAL
	000 ha (% of total)		
Oceania	3.96 (100)	0	**3.96 (100)**

SOUTH AMERICA

Mangrove status and trends

The mangrove area in South America in 2020 is estimated at 2.14 million ha, which was 14.5 percent of the global mangrove area in that year.

Mangrove area loss increased by almost 50 percent between the two measurement periods but, conversely, the gain in mangrove area was lower in the second period. Thus, there was a net increase in mangrove area between 2000 and 2010 and a net loss between 2010 and 2020 (**Table 13**). There was minimal net change in mangrove area between 2000 and 2020.

Table 13. *Losses and gains in mangrove area in South America, 2000–2010 and 2010–2020*

REGION	LOSS (000 ha)		GAIN (000 ha)		ANNUAL NET CHANGE (%)	
	2000–2010	2010–2020	2000–2010	2010–2020	2000–2010	2010–2020
South America	−36.1	−53.3	50.8	40.5	0.07	−0.06

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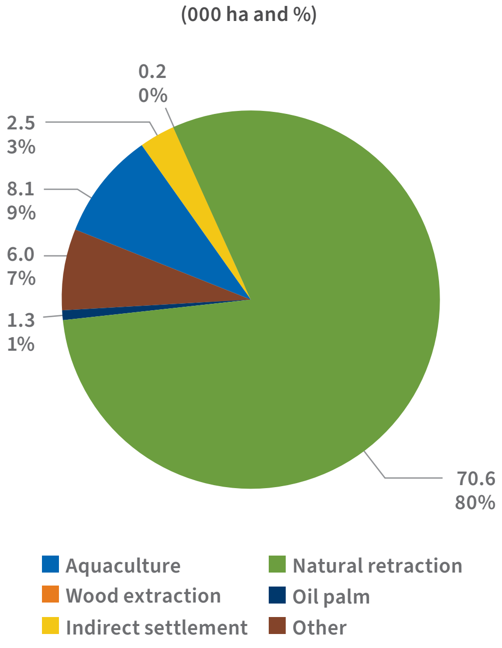
Drivers of mangrove loss and gain

The main driver of mangrove loss in South America over the two decades was natural retraction, accounting for about 80 percent of gross loss, followed by aquaculture (9 percent) and "other" (7 percent) (**Figure 25**).

Although natural retraction was the dominant driver of mangrove loss in both measurement periods, **Figure 26** shows that the drivers of change diversified in the period 2010–2020, with aquaculture, oil-palm plantations, other conversion and indirect settlement all making significant contributions.

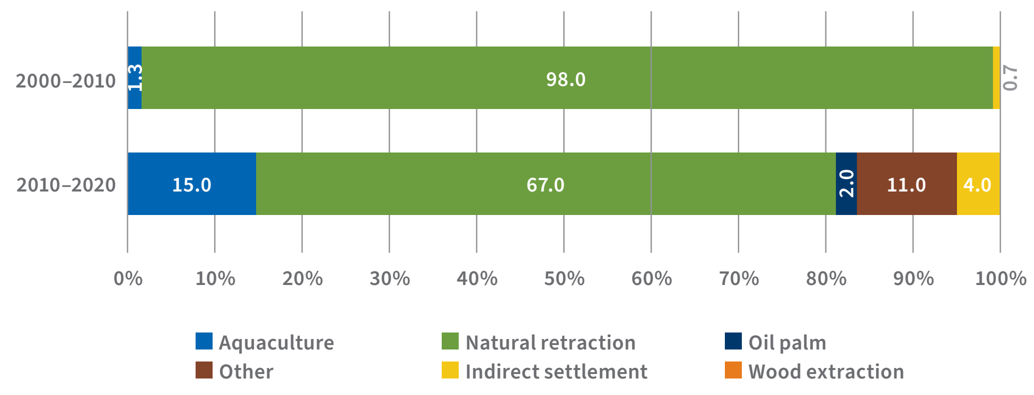
Most of the gain in mangrove area in the region over the study period was due to natural expansion, with only 6 percent attributable to restoration (**Table 14**).

Figure 25. *Proportion of mangrove loss in South America in 2000–2020, by driver*



Source: Authors' own elaboration.

Figure 26. *Relative importance of drivers of mangrove loss in South America, 2000–2010 and 2010–2020*



Source: Authors' own elaboration.

Table 14. *Drivers of mangrove gain in South America, 2000–2020*

REGION	NATURAL EXPANSION	RESTORATION	TOTAL
	000 ha (% of total)		
South America	76.7 (94)	4.82 (6)	**81.5 (100)**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5 / DISCUSSION

INTEGRATION OF LOCAL EXPERTISE AND KNOWLEDGE

The State of the World's Mangroves 2022 (Leal and Spalding, eds., 2022) recognized the important potential role of local people in addressing data deficiencies and knowledge gaps concerning mangrove conservation and restoration.

The present study used a hybrid methodology involving remote sensing, existing global mangrove maps and the expertise of local interpreters. Forty-eight experts from 26 countries participated in collecting data from 20 900 samples.

The involvement of local experts added value to the analysis by making it possible to distinguish between land cover and land use and by enabling deeper examination of specific deforestation drivers (e.g. oil-palm plantations, aquaculture and rice cultivation). The classification of drivers of change in mangrove area is much more difficult if it relies solely on remote sensing, given the similarity in spectral signatures that different land-cover classes can present (e.g. aquaculture and coastal waters; Goldberg *et al*., 2020).

MANGROVE AREA COMPARISONS

This study uses the concepts of land use and land-use change. Therefore, our estimates of mangrove area are not directly comparable with those of land-cover products such as global mangrove maps produced using automatic and semi-automatic classification of land cover in optical or radar satellite imagery. Nevertheless, a comparison of the results obtained in the present study with existing land-cover data can provide insights into the status and dynamics of the mangroves.

A number of recent studies assessed the extent of mangrove area (e.g. Giri *et al*., 2011; Bunting *et al*., 2018, 2022; Zanaga *et al*., 2021; Vancutsem *et al*., 2021). All were based almost entirely on the automatic or semi-automatic classification of remote sensing data. Although these layers can be used to derive area figures through pixel counting, estimates produced in this way are known to be biased (Dong *et al*., 2022; Moody and Woodcock, 1994; Ozdogan and Woodcock, 2006; Czaplewski and Catts, 1992). **Table 15** presents a comparison of our results with

Table 15. *Mangrove area estimates for 2020, by region or subregion, according to three studies*

REGION/SUBREGION	BUNTING *et al.* (2022) (000 ha)	FAO (2020) (000 ha)	PRESENT STUDY (000 ha)
Africa	**2,934**	**3,240**	**2,819**
Eastern and Southern Africa	792	936	726
Western and Central Africa	2,143	2,304	2,093
Asia	**5,828**	**5,545**	**6,511**
East Asia	23	32	15
South and Southeast Asia	5,777	5,330	6,476
Western and Central Asia	29	184	21
North and Central America	**2,283**	**2,552**	**1,846**
Oceania	**1,652**	**1,255**	**1,461**
South America	**2,038**	**2,124**	**2,140**
Total	**14,735**	**14,717**	**14,777**

those produced using FRA 2020 reported data (FAO, 2020) and the most recent Global Mangrove Watch data (Bunting *et al*., 2022), which have known map commission and omission errors. Although the estimates of global mangrove area in 2020 in Bunting *et al.* (2022), FAO (2020) and this study are very similar, there are significant differences at the regional level.

COMPARING ESTIMATES OF MANGROVE AREA CHANGE

Goldberg *et al.* (2020), Murray *et al.* (2022) and Bunting *et al.* (2022) all generated estimates of mangrove area change. Goldberg *et al.* (2020) and Murray *et al.* (2022) did not make their full original dataset available publicly, or they used different geographical subdivisions, so it was only possible to compare the results of the present study with global estimates of those sources. Due to differing analysis timeframes, we transformed the various estimates into rates of annual change to enable comparisons. **Table 16** (mangrove area loss) and **Table 17** (mangrove area gain) show that the estimates are highly variable. Goldberg *et al.* (2020) reported mangrove loss only; therefore, that study is not represented in **Table 17**.

Although the continuing net loss of mangroves is concerning, the results of this and other studies (e.g. Leal and Spalding, eds., 2022) highlight the dynamic nature of mangroves, with coastal ecosystems transitioning from one form to another as environmental conditions change. Forty-eight percent of the area of mangroves lost between 2000 and 2020 was offset by the re-establishment of mangroves in deforested areas or the colonization of new areas (i.e. those that did not previously support mangroves). Mangrove gain from natural regeneration exceeded mangrove loss due to natural retraction over the 20-year period, attesting to the resilience of mangroves and the persistence of mangrove communities in the face of changing environmental conditions (Alongi, 2015). If suitable habitats exist and propagules are available, mangroves can often recover on their own from natural and anthropogenic disturbances.

Table 16. *Estimates of global mangrove area loss, four global studies*

ANNUAL MANGROVE LOSS (000 ha)			
Bunting *et al.* (2022), 1996–2020	**Goldberg *et al.* (2020), 2000–2016**	**Murray *et al.* (2022), 1999–2019**	**Present study, 2000–2020**
38.9	21.0	27.8	33.8

Table 17. *Estimates of global mangrove area gain, three global studies*

ANNUAL MANGROVE GAIN (000 ha)		
Bunting *et al.* (2022), 1996–2020	**Murray *et al.* (2022), 1999–2019**	**Present study, 2000–2020**
17.1	9.14	19.6

DRIVERS OF MANGROVE LOSS AND GAIN

According to the present study, the conversion of mangroves for the production of agricultural commodities (i.e. aquaculture, oil-palm plantations and rice cultivation) accounted for at least 43.3 percent of global mangrove loss between 2000 and 2020. Goldberg *et al.* (2020) reported a similar result, finding that shrimp farming, oil-palm plantations and rice cultivation accounted for 47 percent of mangrove loss between 2000 and 2016.

The relative importance of the drivers of mangrove deforestation shifted noticeably between the two decadal periods examined in the present study. The area of mangroves cleared was 51 percent lower

in 2010–2020 than in 2000–2010 for aquaculture; 80 percent lower for rice cultivation; 87 percent lower for direct settlement; and 73 percent lower for unsustainable wood extraction. In many of the subregions examined, the drivers of mangrove deforestation diversified between the two periods of analysis, with natural disasters, indirect settlement and other types of agriculture increasing in significance.

Overall, the net rate of global mangrove area loss declined from −0.12 percent per year in 2000–2010 to −0.07 percent per year in 2010–2020, equivalent to a 44 percent drop in the area lost in 2010–2020 compared with the preceding decade. In large part this was due to economic development in key mangrove countries, restoration, greater recognition of the multiple benefits of mangroves, and increased protection of mangroves – with up to 42 percent of remaining mangrove areas now under legal protection globally (Leal and Spalding, eds., 2022).

Aquaculture was the predominant anthropogenic driver of mangrove loss globally in 2010–2020, accounting for 21 percent. Nevertheless, this was a drop from 31 percent in 2000–2010, due entirely to a reduction in the importance of this driver in South and Southeast Asia. Mangrove conversion for aquaculture increased sharply in 2010–2020 in North and Central America, South America and Western and Central Africa, indicating that this driver might need to be better managed in those regions to ensure an appropriate balance between conservation, local livelihoods and economic outcomes.

The conversion of mangroves for aquaculture, oil-palm plantations and rice cultivation continues to threaten mangroves in South and Southeast Asia, where these land uses were responsible for 61 percent of mangrove loss in 2000–2020. Although conversion for aquaculture declined significantly between 2000–2010 and 2010–2020, conversion to oil-palm plantations increased sharply. The overall rate of net loss of mangroves declined significantly in 2010–2020 compared with the previous decade, due to growing awareness of the importance of mangroves for climate-change mitigation and adaptation, biodiversity conservation, fisheries, and livelihoods. Other positive factors in South

and Southeast Asia in recent years include efforts by governments and communities to restore mangroves, improved regulation of the use and conversion of mangroves, and an increase in the area of mangroves under protection (Spalding, Kainuma and Collins, 2010).

The results of the present study show the growing importance of natural retraction – in part a likely consequence of the impacts of climate change – as a driver of mangrove loss. However, climate change can affect mangroves in various ways, including through sea-level rise; increases in atmospheric carbon dioxide; rises in temperature; changes in rainfall; and the predicted increase in the frequency and severity of extreme weather (CMEP, 2017). Such impacts will likely affect different regions in different ways. Alongi (2015) predicted that mangrove forests would experience either little change or some positive impact in areas where precipitation is forecast to increase, such as in Southeast Asia and along the western and central coasts of Africa. On the other hand, mangroves would likely decline in the Pacific and Caribbean islands – where there is little upland space to colonize – as sea levels rise. Alongi (2015) also predicted that mangroves along arid coastlines would decline in area, structure or functionality as precipitation decreased. In a study of subtropical wetlands in Florida, Coldren *et al.* (2018) found that global warming might accelerate mangrove expansion in some areas.

The climate-change-driven loss of mangroves further exposes vulnerable communities, including in Small Island Developing States, to disasters such as storm surges, floods and tsunamis – against which healthy mangroves provide a certain level of protection – resulting in a negative feedback loop. The area of mangroves lost to natural disasters increased threefold between the periods of 2000–2010 and 2010–2020, and this trend is expected to worsen in coming years.

Globally, we found that the area of mangroves gained through natural expansion greatly exceeded

the area lost due to natural retraction. It is not possible to explain this phenomenon on the basis of the current study – it might be expected that natural retraction would outpace natural expansion given the increasing impacts of climate change, but the opposite trend was observed. This finding shows the difficulty of predicting the effect of climate change on mangrove communities given the complex interplay between local biophysical conditions and the consequences of global warming. It also demonstrates the resilience of mangroves in responding to environmental change and in colonizing suitable habitats. In some of our sample plots, for example, we observed a significant natural expansion of mangroves on sediment depositions created by the discharge of mine tailings.

The drivers of mangrove deforestation shifted noticeably in Western and Central Africa – the subregion with the highest rate of mangrove loss in 2010–2020 – between the two measurement periods. In coming years, mangroves will continue to be threatened in the subregion by aquaculture development, conversion to other forms of agriculture, natural retraction, and indirect settlement, with large areas of mangroves mangroves unprotected (69 percent of the total resource in the subregion; Leal and Spalding, eds., 2022). Future efforts to restore, conserve and sustainably use mangroves will need to manage these emerging and diversifying threats through integrated, cross-sectoral approaches.

6 / CONCLUSION

In the study reported here, FAO developed and validated an easy, repeatable methodology that integrates remote sensing with the expertise of local interpreters. An FAO team and 48 interpreters from 26 countries successfully collected data on mangrove area in 2020, change in mangrove area between 2000 and 2020, and the drivers of change over the two decades. This is the first global study of mangrove area to provide information on land use rather than land cover, which was only possible because of the involvement of local experts

The sampling-based methodology developed and validated in this study offers opportunities for intensification at the national and subnational levels to assess changes and trends in mangroves with sufficient resolution to enable informed strategic planning for mangrove management and restoration. FAO is exploring the possibility of integrating the methodology with existing national forest inventories in several countries, which would also support national and international reporting on mangroves. The findings of this study have important implications for future work in conserving, restoring and sustainably managing mangroves, including the following:

1. In Southeast Asia, the subregion with the largest extent of mangroves worldwide, efforts to address land-use drivers of mangrove loss should continue, directing agricultural development to avoid deforesting remaining mangrove forests.
2. In Western and Central Africa, where a high rate of mangrove loss persisted over the two measurement periods, conversion to aquaculture and other forms of agriculture needs to be addressed by promoting sustainable use and livelihood support.
3. Mangrove restoration should be given priority in global, regional and national restoration initiatives in view of their crucial benefits for livelihoods, coastal resilience and biodiversity conservation.
4. Mangrove restoration, sustainable use and conservation should be further emphasized in nationally determined contributions and in climate-change mitigation strategies in general, given the importance of mangroves as carbon sinks and the co-benefits of adaptation and disaster risk reduction.
5. Given the ability of mangroves to naturally colonize suitable habitats and the high rate of failure of mangrove restoration efforts that have relied largely on replanting, mangrove restoration should focus on creating conducive biophysical and social conditions for the re-establishment and sustained growth of healthy mangrove forests.
6. The contributions of climate-change impacts to the retraction of mangroves should be monitored carefully because they further expose coastal communities to disasters.

REFERENCES

Alongi, D.M. 2015. The impact of climate change on mangrove forests. *Current Climate Change Reports*, 1: 30–39. https://doi.org/10.1007/s40641-015-0002-x

ASC. 2019. ASC Shrimp Standard Version 1.1. Aquaculture Stewardship Council (ASC). www.asc-aqua.org/wp-content/uploads/2019/03/ASC-Shrimp-Standard_v1.1_Final.pdf

Baloloy, A.B., Blanco, A.C., Rhommel, R., Ana, C.S. & Nadaoka, K. 2020. Development and application of a new mangrove vegetation index (MVI) for rapid and accurate mangrove mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, 166: 95–117. https://doi.org/10.1016/j.isprsjprs.2020.06.001

Ball, M.C. 1988. Ecophysiology of mangroves. *Trees*, 2: 129–142.

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J. & Lovelock, C.E. 2016. The cost and feasibility of marine coastal restoration. *Ecological Applications*, 26(4): 1055–1074. https://doi.org/10.1890/15-1077

Bryan-Brown, D.N., Connolly, R.M., Richards, D.R., Adame, F., Friess, D.A. & Brown, C.J. 2020. Global trends in mangrove forest fragmentation. *Scientific Reports*, 10(1): 7117. https://doi.org/10.1038/s41598-020-63880-1

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., Tadono, T., Worthington, T.A. *et al.* 2022. Global mangrove extent change 1996–2020: Global Mangrove Watch version 3.0. *Remote Sensing*, 14(15): 3657. https://doi.org/10.3390/rs14153657

Bunting, P., Rosenqvist, A., Lucas, R., Rebelo, L.-M., Hilarides, L., Thomas, N., Hardy, A. *et al.* 2018. The Global Mangrove Watch – a new 2010 global baseline of mangrove extent. *Remote Sensing*, 10(10): 1669. https://doi.org/10.3390/rs10101669

Carugati, L., Gatto, B., Rastelli, E., Lo Martire, M., Coral, C., Greco, S. & Danovaro, R. 2018. Impact of mangrove forests degradation on biodiversity and ecosystem functioning. *Scientific Reports*, 8(1): 13298. https://doi.org/10.1038/s41598-018-31683-0

Coldren, G.A., Langley, J.A., Feller, I.C. & Chapman, S.K. 2018. Warming accelerates mangrove expansion and surface elevation gain in a subtropical wetland. *Journal of Ecology*, 107(1): 79–90. https://doi.org/10.1111/1365-2745.13049

CMEP. 2017. *Caribbean Marine Climate Change Report Card 2017*. P. Buckley, B. Townhill, U. Trotz, K. Nichols, P.A. Murray, C. Clarke Samuels, A. Gordon & M. Taylor, eds. Commonwealth Marine Economies Programme (CMEP). 12 p.

Czaplewski, R.L. & Catts, G.P. 1992. Calibration of remotely sensed proportion or area estimates for misclassification error. *Remote Sensing of Environment*, 39(1): 29–43. https://doi.org/10.1016/0034-4257(92)90138-A

Dasgupta, S., Islam, M.S., Huq, M., Huque, K.Z. & Hasib M.R. 2019. Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh. *PLoS ONE*, 14(3): e0214079. https://doi.org/10.1371/journal.pone.0214079

Dong, Q., Chen, X., Chen, J., Yin, D., Zhang, C., Xu, F., Rao, Y. *et al.* 2022. Bias of area counted from sub-pixel map: origin and correction. *Science of Remote Sensing*, 6: 100069. https://doi.org/10.1016/j.srs.2022.100069

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K., eds. 2006. *2006 IPCC guidelines for national greenhouse gas inventories*. Hayama, Japan, Institute for Global Environmental Strategies.

European Commission Joint Research Centre. Undated. Tracking long-term (1990–2021) deforestation and degradation in tropical moist forests. In: *Forest Resources and Carbon Emissions (IFORCE).* [Cited 20 March 2023]. https://forobs.jrc.ec.europa.eu/TMF/index.php

FAO. 1988. Definition of aquaculture. Seventh Session of the Indo-Pacific Fisheries Council Working Party of Experts on Aquaculture, p.1–3. Bangkok.

FAO. 2007. *The world's mangroves 1980–2005.* Rome.

FAO. 2010. *Global ecological zones for FAO forest reporting: 2010 update.* Forest Resources Assessment Working Paper No. 179. Rome.

FAO. 2018. *Terms and definitions – FRA 2020.* Forest Resources Assessment Working Paper 188. Rome. https://www.fao.org/3/I8661EN/i8661en.pdf

FAO. 2020. *Global Forest Resources Assessment 2020.* Main report. Rome. https://doi.org/10.4060/ca9825en

FAO. 2022. *FRA 2020 Remote Sensing Survey.* FAO Forestry Paper No. 186. Rome. https://doi.org/10.4060/cb9970en

FAO/NACA/UNEP/World Bank/WWF. 2006. *International Principles for Responsible Shrimp Farming.* Bangkok, FAO, Network of Aquaculture Centres in Asia-Pacific (NACA), United Nations Environment Programme (UNEP), World Bank and Worldwide Fund for Nature (WWF). 20 p.

FAO/UNEP. 1981a *Los Recursos Forestales de la America Tropical Proyecto de Evaluación de los Recursos Forestales Tropicales*, Rome, 343 pp

FAO/UNEP. 1981b *Tropical Forest Resources Assessment Project, Forest Resources of Tropical Africa. Part II: Country Briefs.* Rome, 586 p

FAO/UNEP. 1981c *Tropical Forest Resources Assessment Project, Forest Resources of Tropical Asia Rome*, 475 pp

Feka, N.Z. & Ajonina, G.N. 2011. Drivers causing decline of mangrove in West-Central Africa: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 217–230.

Forbes, K. & Broadhead, J. 2007. *The role of coastal forests in the mitigation of tsunami impacts.* RAP Publication 1/2007. Bangkok, FAO.

Friess, D.A., Rogers, K., Lovelock, C.E., Krauss, K.W., Hamilton, S.E., Lee, S.Y., Lucas, R. *et al.* 2019. The state of the world's mangrove forests: past, present, and future. *Annual Review of Environment and Resources*, 44(1): 89–115. https://doi.org/10.1146/annurev-environ-101718-033302

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. & Duke, N. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data: status and distributions of global mangroves. *Global Ecology and Biogeography*, 20(1): 154–159. https://doi.org/10.1111/j.1466-8238.2010.00584.x

Goldberg, L., Lagomasino, D., Thomas, N. & Fatoyinbo, T. 2020. Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10): 5844–5855. https://doi.org/10.1111/gcb.15275

Hamilton, S.E. & Casey, D. 2016. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21): CGMFC-21. *Global Ecology and Biogeography*, 25(6): 729–738. https://doi.org/10.1111/geb.12449

Hogarth, P.J. 2015. *The biology of mangroves and seagrasses.* Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198716549.001.0001

Hutchison, J., Spalding, M. & Ermgassen, P. 2014. *The role of mangroves in fisheries enhancement.* The Nature Conservancy and Wetlands International. 54 p.

Juncosa, A.M. 1982. *Embryo and seedling development in Rhizophoraceae*. Durham, USA, Duke University.

Kodikara, K.A.S., Mukherjee, N., Jayatissa, L.P., Dahdouh-Guebas, F. & Koedam, N. 2017. Have mangrove restoration projects worked? An in-depth study in Sri Lanka: evaluation of mangrove restoration in Sri Lanka. *Restoration*

Ecology, 25(5): 705–716. https://doi.org/10.1111/rec.12492

Lewis, R.R. 2009. Methods and criteria for successful mangrove forest restoration. In: G.M.E. Perillo, E. Wolanski, D.R. Cahoon, M.M. Brinson, eds. *Coastal wetlands: An integrated ecosystem approach.* Elsevier.

Leal, M. & Spalding, M.D., eds. 2022. *The State of the World's Mangroves 2022*. Global Mangrove Alliance.

McNally, C.G., Uchida, E. & Gold, A.J. 2011. The effect of a protected area on the tradeoffs between short-run and long-run benefits from mangrove ecosystems. *Proceedings of the National Academy of Sciences*, 108(34): 13945–13950. https://doi.org/10.1073/pnas.1101825108

McSherry, M., Davis R.P., Andradi-Brown, D.A., Ahmadia, G.N., Van Kempen, M. & Wingard Brian, S. 2023. Integrated mangrove aquaculture: The sustainable choice for mangroves and aquaculture? *Front. For. Glob. Change* 6:1094306. https://doi.org/10.3389/ffgc.2023.1094306

Moody, A. & Woodcock, C.E. 1994. Scale-dependent errors in the estimation of land-cover proportions – implications for global land-cover datasets. *Photogrammetric Engineering Remote Sensing*, 60: 585–594.

Murray, N.J., Worthington, T.A., Bunting, P., Duce, S., Hagger, V., Lovelock, C.E., Lucas, R. *et al.* 2022. High-resolution mapping of losses and gains of Earth's tidal wetlands. *Science*, 376(6594): 744–749. https://doi.org/10.1126/science.abm9583

Ozdogan, M. & Woodcock, C.E. 2006. Resolution dependent errors in remote sensing of cultivated areas. *Remote Sensing of Environment*, 103(2): 203–217. https://doi.org/10.1016/j.rse.2006.04.004

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C., Farnsworth, E.J. *et al.* 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE*, 4: e10095.

Primavera, J.H. & Esteban, J.M.A. 2008. A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. *Wetlands Ecology and Management*, 16(5): 345–358. https://doi.org/10.1007/s11273-008-9101-y

Richards, D.R. & Friess, D.A. 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proceedings of the National Academy of Sciences*, 113(2): 344–349. https://doi.org/10.1073/pnas.1510272113

Saenger, P., Hegerl, E.J. & Davie, J.D.S. 1983. *Global status of mangrove ecosystems.* Commission on Ecology Papers No. 3. Gland, Switzerland, International Union for Conservation of Nature.

Sandker, M., Carrillo, O., Leng, C., Lee, D., d'Annunzio, R. & Fox, J. 2021. The importance of high-quality data for REDD+ monitoring and reporting. *Forests*, 12(1): 99. https://doi.org/10.3390/f12010099

Saunders, M.I., Doropoulos, C., Bayraktarov, E., Babcock, R.C., Gorman, D., Eger, A.M., Vozzo, M.L. *et al.* 2020. Bright spots in coastal marine ecosystem restoration. *Current Biology*, 30(24): R1500–R1510. https://doi.org/10.1016/j.cub.2020.10.056

Spalding, M., Blasco, F., Field, C., International Society for Mangrove Ecosystems, World Conservation Monitoring Centre & International Tropical Timber Organization, eds. 1997. *World mangrove atlas.* Okinawa, Japan, International Society for Mangrove Ecosystems.

Spalding, M., Kainuma, M. & Collins, L. 2010. *World atlas of mangroves.* London, Washington, DC, Earthscan.

Spalding, M., McIvor, A., Tonneijck, F.H., Tol, S. & van Eijk, P. 2014. *Mangroves for coastal defence: Guidelines for coastal managers & policy makers.* Wetlands International and The Nature Conservancy. 42 p.

Spurrier, L., Breda, A. van, Martin, S., Bartlett, R. & Newman, K. 2019. Nature-based solutions for water-related disasters. *Unasylva*, 251: 67–74.

Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A. & Simard, M. 2017. Distribution and drivers of global mangrove forest change, 1996–2010. *PLOS ONE*, 12(6): e0179302. https://doi.org/10.1371/journal.pone.0179302

Tomlinson, P.B. 1986. *The botany of mangroves.* Cambridge, UK, Cambridge University Press.

Tomlinson, P.B. 2016. *The botany of mangroves*. Second edition. Cambridge University Press. https://doi.org/10.1017/CBO9781139946575

Vancutsem, C., Achard, F., Pekel, J.-F., Vieilledent, G., Carboni, S., Simonetti, D., Gallego, J., Aragão, L.E.O.C. & Nasi, R. 2021. Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science Advances*, 7(10): eabe1603. https://doi.org/10.1126/sciadv.abe1603

Worthington, T. & Spalding, M. 2018. *Mangrove restoration potential: A global map highlighting a critical opportunity.* Apollo – University of Cambridge Repository. https://doi.org/10.17863/CAM.39153

Zanaga, D., Van De Kerchove, R., De Keersmaecker, W., Souverijns, N., Brockmann, C.N., Quast, R., Wevers, J. ***et al.*** 2021. ESA WorldCover 10 m 2020 v100. Zenodo. [Cited 24 March 2023]. https://zenodo.org/record/5571936

ANNEX 1
LIST OF TRUE MANGROVE SPECIES

Table A1.1. *List of true mangrove species*

	SPECIES
1	*Acrostichum aureum*
2	*Acrostichum speciosum*
3	*Aegialitis annulata*
4	*Aegialitis rotundifolia*
5	*Aegiceras corniculatum*
6	*Avicennia alba*
7	*Avicennia bicolor*
8	*Avicennia germinans*
9	*Avicennia integra*
10	*Avicennia marina*
11	*Avicennia officinalis*
12	*Avicennia rumphiana*
13	*Avicennia schaueriana*
14	*Bruguiera cylindrica*
15	*Bruguiera exaristata*
16	*Bruguiera gymnorhiza*
17	*Bruguiera hainesii*
18	*Bruguiera parviflora*
19	*Bruguiera sexangula*
20	*Camptostemon schultzii*
21	*Camptostemon philippinensis*
22	*Ceriops australis*
23	*Ceriops decandra*
24	*Ceriops tagal*
25	*Excoecaria agallocha*
26	*Kandelia candel*
27	*Kandelia obovata*
28	*Laguncularia racemosa*
29	*Lumnitzera littorea*
30	*Lumnitzera racemosa*
31	*Nypa fruticans*

	SPECIES
32	*Osbornia octodonta*
33	*Pelliciera rhizophorae*
34	*Rhizophora apiculata*
35	*Rhizophora harrisonii*
36	*Rhizophora lamarckii*
37	*Rhizophora mangle*
38	*Rhizophora mucronata*
39	*Rhizophora racemosa*
40	*Rhizophora samoensis*
41	*Rhizophora stylosa*
42	*Scyphiphora hydrophylacea*
43	*Sonneratia alba*
44	*Sonneratia apetala*
45	*Sonneratia caseolaris*
46	*Sonneratia x gulngai*
47	*Sonneratia x hainanensis*
48	*Sonneratia ovata*
49	*Xylocarpus granatum*
50	*Xylocarpus moluccensis*

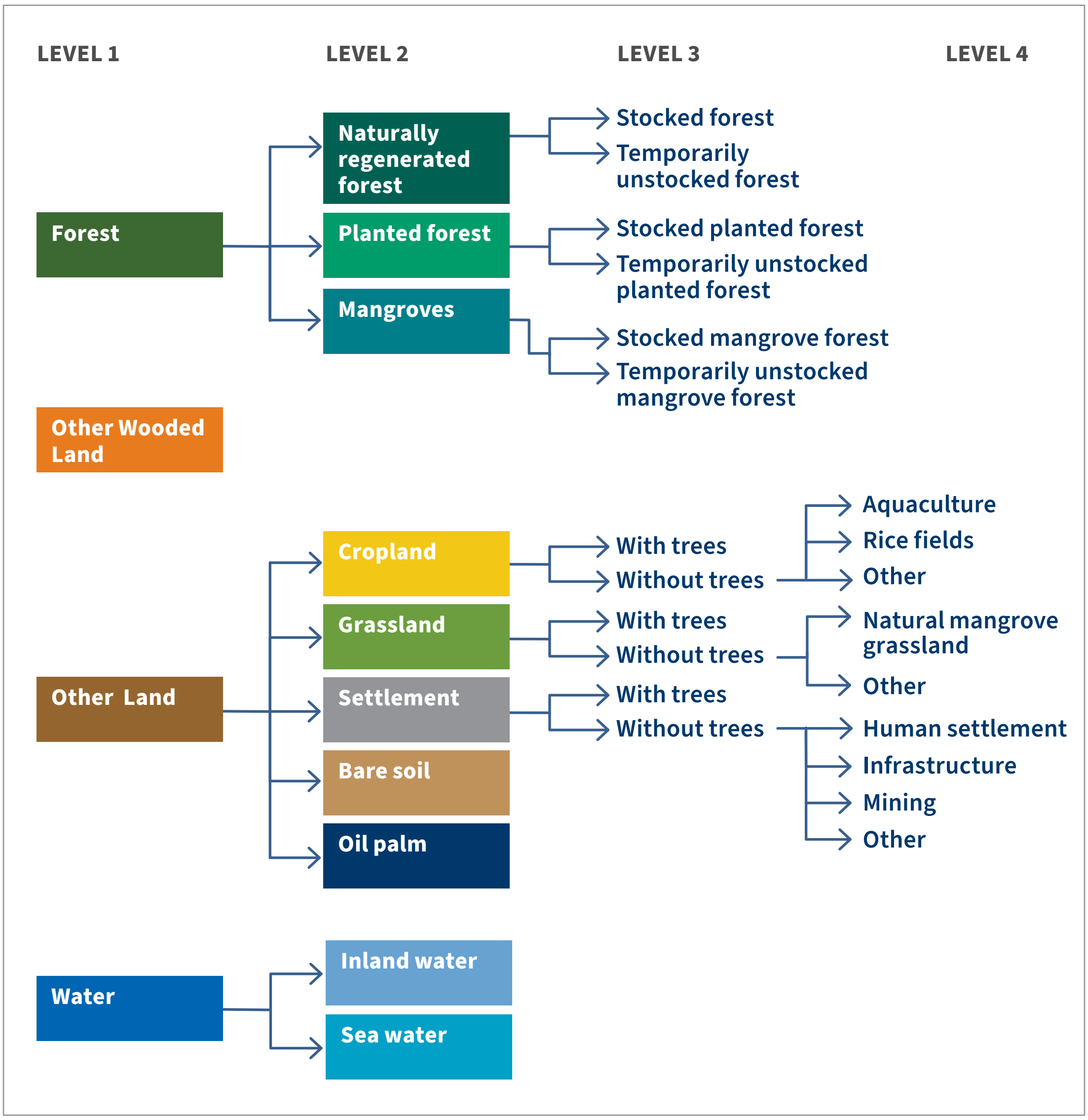
ANNEX 2
CLASSIFICATION SCHEME

TERMS AND DEFINITIONS

The terms and definitions used in this mangrove assessment are structured according to those used in FAO (2018).

Some of the terms and definitions used in the land-use classification categories (**Figure A2.1**) explained below are based on definitions in the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (Eggleston *et al.*, eds., 2006), in which Volume 4 provides guidance for preparing annual greenhouse-gas inventories in the agriculture, forestry and other land-use sectors.

Figure A2.1. *Centroid and hexagon current land use, 2020*



DEFINITIONS FOR CENTROID AND HEXAGON CURRENT LAND USE, 2020

Some of the terms and definitions used in the land-use classification.

Level 1

Forest

Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. Does not include land that is predominantly under agricultural or urban land use. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 m *in situ*. The definition encompasses forest roads, firebreaks and other small open areas inside the forest. It also includes windbreaks, shelterbelts and corridors of trees but it does not include trees used for livestock breeding or crops under the trees. The definition includes abandoned shifting cultivation land with a regeneration of trees that have reached, or are expected to reach, a canopy cover of 10 percent and a height of 5 m.

Please refer to FAO (2018) for other explanatory notes.

Other wooded land

Land not classified as forest, spanning more than 0.5 ha, with trees higher than 5 m and a canopy cover of 5–10 percent, or trees able to reach these thresholds in situ; or land with a combined cover of shrubs, bushes and trees above 10 percent. Does not include land that is predominantly under agricultural or urban land use.

Other land

All land not classified as forest or other wooded land. Includes agricultural land, meadows, pastures, built-up areas, barren land, land under permanent ice, etc. Also includes all areas considered as "other land with tree cover".

Level 2

Under "forest":

Naturally regenerated forest

Forest predominantly composed of trees established through natural regeneration.

Explanatory notes:

- Includes forests for which it is not possible to distinguish whether they were planted or naturally regenerated.
- Includes forests with a mix of naturally regenerated native tree species and planted/seeded trees, and where the naturally regenerated trees are expected to constitute the major part of the growing stock at stand maturity.
- Includes coppice from trees originally established through natural regeneration.
- Includes naturally regenerated trees of introduced species.

Planted forest

Forest predominantly composed of trees established through planting and/or deliberate seeding.

Explanatory notes:

- In this context, "predominantly" means that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity.
- Includes coppice from trees that were originally planted or seeded.

This category includes planted forest that is intensively managed and meets ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing.

Explanatory notes:

- Specifically includes short-rotation plantations for wood, fibre and energy.
- Specifically excludes forests planted for protection or ecosystem restoration.
- Specifically excludes forests established through planting or seeding which at stand maturity resemble or will resemble naturally regenerating forest.

Mangrove

Forest predominantly composed of true mangrove species (listed in **Annex 1**) established through natural regeneration or through planting and/or deliberate seeding. Includes mangrove species shorter than 5 m in height.

Under "other land":

Cropland

Includes arable and tillable land, rice fields, and agroforestry systems. Includes all annual and perennial crops as well as temporary fallow land (i.e. land set at rest for one or several years before being cultivated again). Annual crops include cereals, oilseeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g. agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut and bananas.

Grassland

Includes all pasture lands and all natural grasslands, as well as agricultural and silvopastoral systems. The term grassland in the remote sensing survey is closely linked to livestock breeding, independently of whether tree cover is high *in situ*. If the land use is for raising livestock, the land must be categorized as grassland regardless of whether there is a high density of trees, bushes or a mixture of shrubs with trees.

Settlement

Includes all developed land, including transportation infrastructure and human settlements of any size. Includes trees in urban settings such as in parks and gardens. Also includes mining areas, which are not considered bare soil because the soil was exposed by human activities.

Bare soil

Includes all bare soil for natural site conditions – rocks, sand (beaches or desert) and snow-covered mountain tops.

Oil palm

Includes all oil-palm (*Elaeis* spp.) plantations for commercial agriculture in the production of palm oil.

Level 3

Temporarily unstocked

This subcategory for natural, planted and mangrove forests comprises forest areas that are temporarily unstocked or with trees shorter than 1.3 m that have not yet reached but are expected to reach a canopy cover of at least 10 percent and a tree height of at least 5 m.

Explanatory notes:

- Includes forest areas that are temporarily unstocked due to clearcutting as part of forest management practice or due to disasters and which are expected to be regenerated within five years. In exceptional cases, local conditions may justify a longer time frame.
- Includes areas converted from other land use and with trees shorter than 1.3 m.
- Includes failed plantations.

Other land with tree cover (subcategory of the level-2 categories cropland, grassland and settlement)

Land classified as "other land", spanning more than 0.5 ha with a canopy cover of more than 10 percent of trees able to reach a height of 5 m at maturity.

Explanatory notes:

- Land use is the key criterion for distinguishing between forest and other land with tree cover.
- Specifically includes palms (coconut, dates, etc.), tree orchards (fruit, nuts, olive, etc.), agroforestry and trees in urban settings.
- Includes groups of trees and scattered trees (e.g. trees outside forest) in agricultural landscapes, parks, gardens and around buildings, provided that area, height and canopy-cover criteria are met.
- Includes tree stands in agricultural production systems, such as fruit tree plantations/orchards.

In these cases, the height threshold can be lower than 5 m.

- Includes agroforestry systems when crops are grown under tree cover and tree plantations established mainly for purposes other than wood.
- Excludes scattered trees with a canopy cover of less than 10 percent, small groups of trees covering less than 0.5 ha, and tree lines less than 20 m wide (the latter are included under "forest").

Level 4

Aquaculture

Aquaculture or farming in water is the aquatic equivalent of agriculture or farming on land. Defined broadly, agriculture includes farming both animals (animal husbandry) and plants (agronomy, horticulture and forestry in part). Similarly, aquaculture covers the farming of both animals (e.g. crustaceans, finfish and molluscs) and plants (e.g. seaweeds and freshwater macrophytes). Although agriculture is based predominantly on the use of freshwater, aquaculture occurs in both inland (freshwater) and coastal (brackish water, seawater) areas.

Rice fields

Any cultivation of rice (*Oryza sativa*), submerged or not. Includes rice-cum-fish cultures, which are mixes of rice cultivation and fish harvesting in the same ponds.

Natural mangrove grasslands

Natural grasses that grow in mangrove habitats, which comprise mangrove associate species (not true mangroves).

Human settlement

A human settlement of any size.

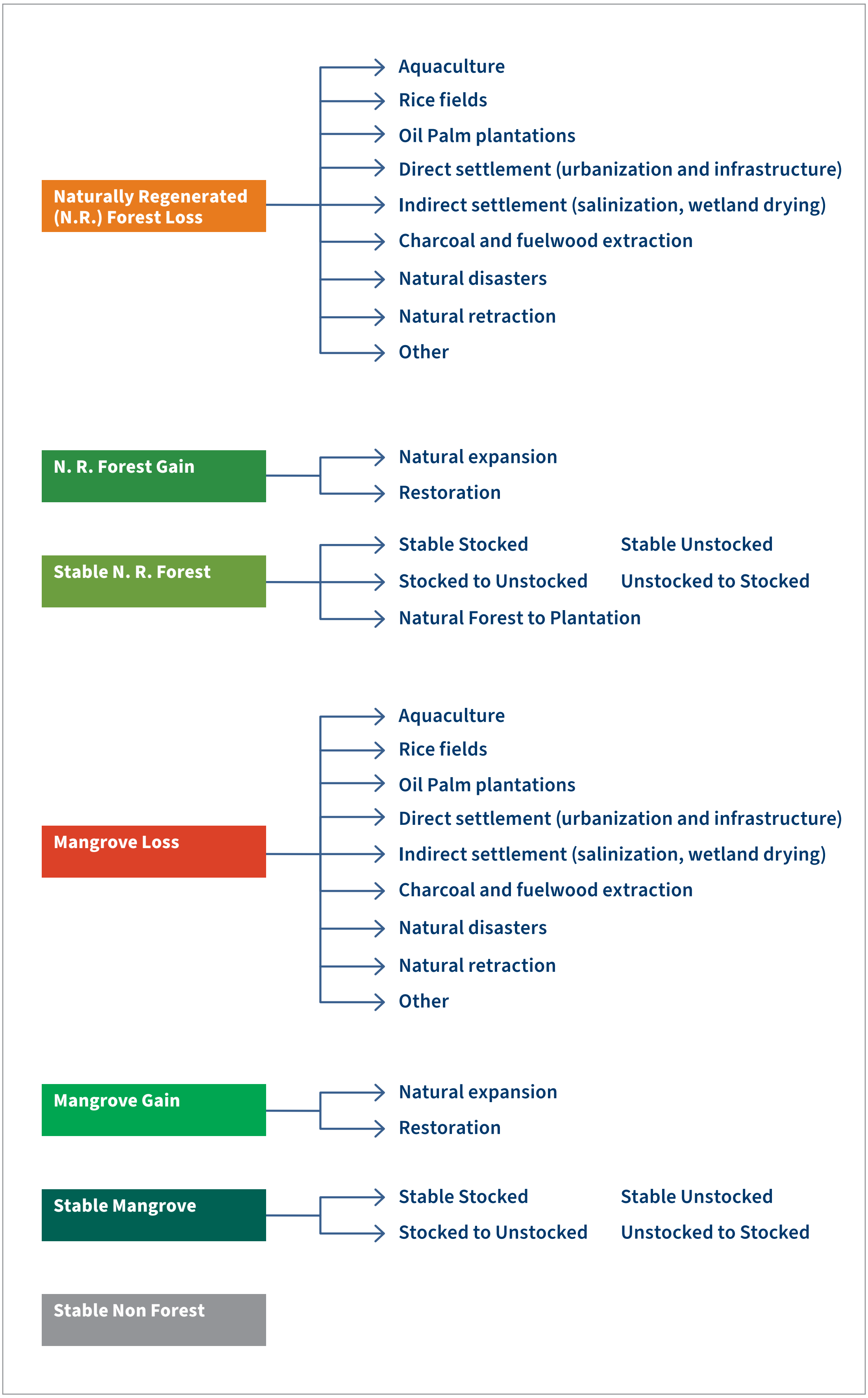
Infrastructure

Any transportation infrastructure, such as railways and highways.

Mining

Any area designated for the extraction of valuable minerals or other geologic materials from the Earth.

Figure A2.2. *Centroid and hexagon changes, 2000–2010 and 2010–2020*



DEFINITIONS FOR CENTROID AND HEXAGON CHANGES, 2000–2010 AND 2010–2020

Level 1

Figure A2.2 shows the various subcategories of level-1 categories.

Forest loss

Indicates any land-use change from a forest use to any other non-forest use (other land, water or – in very rare cases – other wooded lands).

Forest gain

Indicates any land-use change from non-forest use to forest use. Can be a new forest plantation established on a previous barren area, or natural forest expansion.

Stable natural forest

Refers to areas in which the forest land use remains in place over the study period. Includes temporarily unstocked areas because of forest management or natural causes. Also includes planted forest.

Stable mangrove

Refers to areas in which the mangrove vegetation and forest land use remain in place over the study period.

Stable non-forest

Refers to areas in which the other wooded land or other land use (cropland, settlement, grassland, etc.) remains in place over the study period.

Level 2

Loss to aquaculture

Change in land use from forest to any type of aquaculture.

Loss to rice fields

Change in land use from forest to any type of rice field.

Loss to oil-palm plantations

Change in land use from forest to any type of oil-palm plantation.

Loss to direct settlement (urbanization and infrastructure)

Forest loss to urbanization and other types of infrastructure, such as roads and mining activities.

Loss to indirect settlement (salinization, wetland drying)

Forest loss because of pedologic, microclimatic or hydrologic changes of the area indirectly generated by human actions (e.g. construction of a dam upstream).

Loss to charcoal and fuelwood extraction

Forest loss because of any type of wood extraction. Includes wood extraction for timber, fuelwood or charcoal production. Wood extraction for fuelwood and charcoal can be a gradual process, starting with the loss of a few trees at a time, which, if continuous, will lead to ecosystem degradation. Only when the ecosystem is degraded and the trees can no longer reach the forest threshold, with visible forest loss in the imagery, will it be classified as forest loss.

Loss to natural disasters

In case of particularly severe disasters such as floods, storm surges, tsunamis or landslides, the pedologic, microclimatic and hydrologic conditions of the area may change irrevocably and no longer allow the growth of mangrove vegetation.

Loss to natural retraction

For mangroves, natural changes or movements in riverbeds and sediment inputs or sea-level rise that leads to the local extinction of the mangrove ecosystem.

Loss to others

Any other type of land-use change from forest to non-forest not included in the previous categories.

Gain – natural expansion

Regarding naturally regenerated forest, includes areas designated for a land-use change from non-forest to forest through the natural regrowth of trees, without the direct human action of replanting trees. Regarding mangroves, natural changes or movements in riverbeds and sediment inputs may lead to the local colonization of new areas by mangrove vegetation.

Gain – restoration

Change in land use from non-forest to forest because of direct human action. Includes reforestation and afforestation projects, through both direct planting/seeding and hydrologic restoration and the control of disturbances that result in the natural regeneration of mangroves. Also includes protected areas ensured by new regulations, where the forest is naturally regrowing because laws ban human disturbance.

Stable forest subcategories

Changes between stocked and unstocked are tied to the definition of "temporarily unstocked", which is mainly found in forests under management for timber production. A temporarily unstocked area contains trees shorter than 1.3 m that have not yet reached but are expected to reach a canopy cover of at least 10 percent and a tree height of at least 5 m.

In all these forest areas where trees are replanted after extraction, despite temporary tree-cover loss after clearcutting, the cleared area is still considered a forest land use.

Two other cases of forest land use may be considered "temporarily unstocked", as follows:

- In many boreal forests, management practices allow silvicultural cutting and then abandonment of the land for natural regeneration. If there is no evidence of land-use change, these areas should still be considered to be under a forest land use.
- In cases of disasters such as wildfires, insect outbreaks and windstorms, where the forest is expected to be left to regenerate naturally, the areas should still be considered to be under a forest land use.

Stable stocked

A forest area where the threshold values for categorization as forest (i.e. canopy cover of at least 10 percent and tree height of at least 5 m) are always met within the study period.

Stable unstocked

A forest area where the thresholds for categorization as forest (i.e. canopy cover of at least 10 percent and tree height of at least 5 m) are not reached in the period of study but the potential exists for them to be reached in the near future.

Stocked to unstocked

A forest area where the thresholds for categorization as forest (i.e. canopy cover of at least 10 percent and tree height of at least 5 m) were met in the beginning of the study period (e.g. 2000, for the period 2000–2010) but were temporarily not met at the end of the period (e.g. 2010, for the period 2000–2010), for one of the reasons listed for "temporarily unstocked".

Unstocked to stocked

A forest area where the thresholds for categorization as forest (i.e. canopy cover of at least 10 percent and tree height of at least 5 m) were not met at the beginning of the measurement period (e.g. 2000, for the period 2000–2010) for one of the reasons listed for "temporarily unstocked" but were met at the end of the period (e.g. 2010, for the period 2000–2010).

Natural forest to forest plantation

A forest area where the natural forest has been converted to a forest plantation (e.g. eucalypt, rubberwood or poplar) but the land use remains forest (so there is no loss or gain).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FAO Forestry Division - Natural Resources and Sustainable Production
https://www.fao.org/forestry/en/
www.fao.org/in-action/forest-landscape-restoration-mechanism/en/
www.fao.org/forest-resources-assessment/background/en/

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