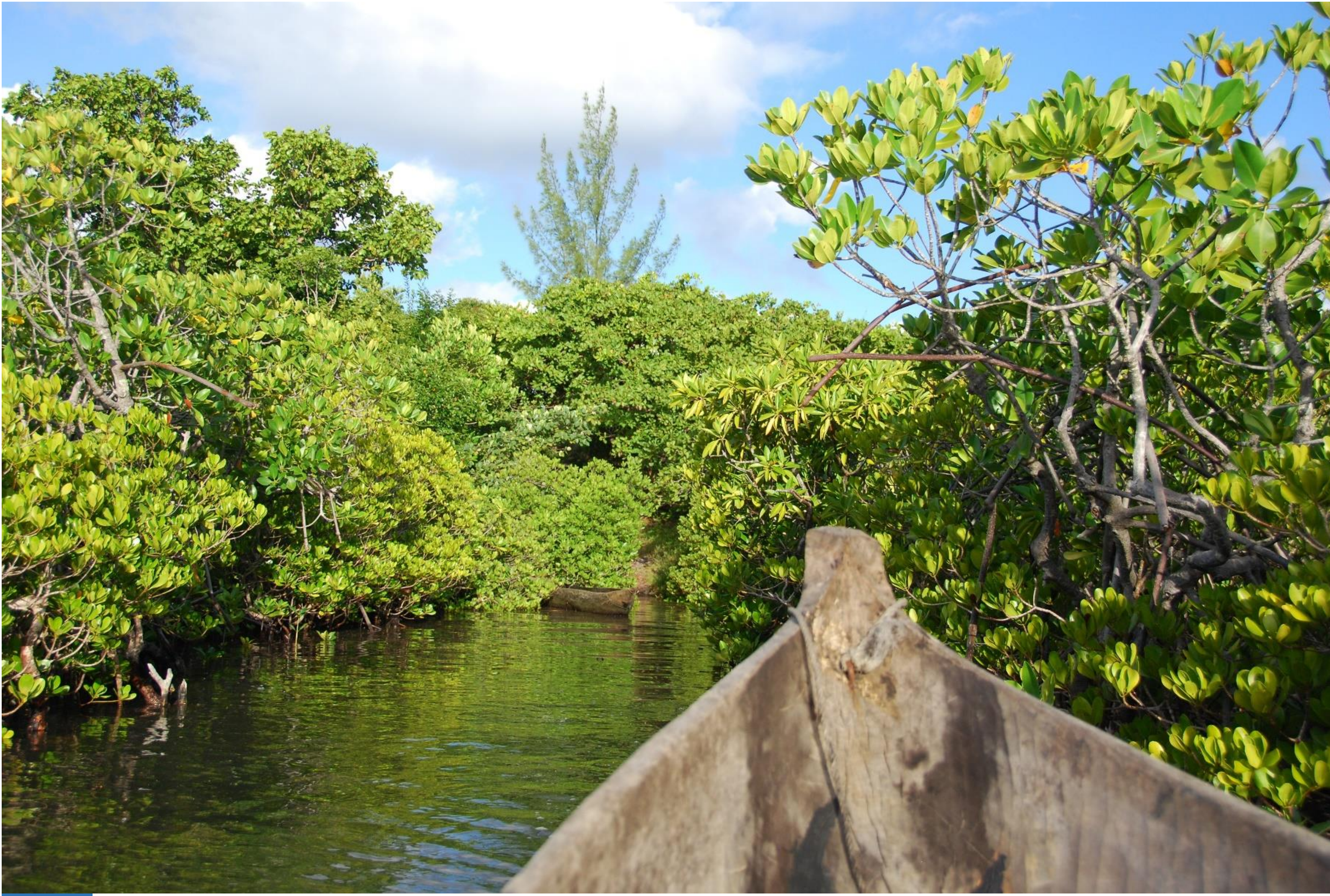

Scoping Paper

OPTIONS FOR ANALYSING MANGROVE ECOSYSTEM SERVICES AND BIODIVERSITY IN MYANMAR

UN-REDD PROGRAMME

Food and Agriculture Organization of the United Nations

UNDP

UN environment programme

October 2022

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme assists developing countries to prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).

Since its inception in 2008, UN-REDD, the UN interagency flagship programme on forests and climate, has, with support of Norway and other donors, contributed to slowing deforestation, promoted as a guiding principle the informed and meaningful involvement of all stakeholders, including indigenous peoples, local communities and women, established firm social and environmental safeguards, and contributed to the sustainable development of its 65 partner countries.

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is a global Centre of excellence on biodiversity. The Centre operates as a collaboration between the United Nations Environment Programme and the UK-registered charity WCMC. Together we are confronting the global crisis facing nature.

This report was prepared for the UN-REDD project 'Integrating mangroves sustainable management, restoration and conservation into REDD+ implementation in Myanmar. This work was funded by the UN REDD Programme and the Norwegian Agency for Development Cooperation (NORAD).

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Front cover: Mangrove en pirogue (Ariane Citron on AdobeStock)
Back cover: The strong prop roots of mangroves, Kangy river, Myanmar (efesenko, on AdobeStock)

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ACRONYMS & ABBREVIATIONS

ASEAN – Association of Southeast Asian Nations
CCDC – Continuous Change Detection and Classification algorithm
CDE – Centre for Development and Environment
CF – Community Forest
CPAs – Community Protected Areas
EAOs – Ethnic Armed Organisations
EX-ACT – Ex Ante Carbon balance Tool
FAO – Food and Agriculture Organisation
FFI – Flora and Fauna International
FREL – Forest Reference Emissions Level
GBIF – Global Biodiversity Information Facility
GEF – Global Environment Facility
GGE – Google Earth Engine
GHG – Greenhouse Gas Emissions
GIS – Geographic Information Systems
GMW – Global Mangroves Watch
INFORM – A collaboration of the Inter-Agency Standing Committee Reference Group on Risk, Early Warning and Preparedness and the European Commission
InVEST – Software models by Natural Capital Project
IPCC – Intergovernmental Panel for Climate Change
IUCN – International Union for the Conservation of Nature
KBA – Key Biodiversity Areas
LULC – Land-use and Land-use Change
MCCSAP – Myanmar Climate Change Strategy and Action Plan
MIMU – Myanmar Information Management Unit
MOALI – Ministry of Agriculture, Livestock, and Irrigation
MoNREC – Ministry of Natural Resources and Environmental Conservation
MRRP – Myanmar Reforestation and Rehabilitation Programme
MUDRA – Myanmar Unified platform for Disaster Risk Application
NASA-SEDAC – Socioeconomic Data and Application Centre
NBSAP – National Biodiversity Strategy and Action Plan
NDC – Nationally Determined Contribution
NDVI – Normalised Difference Vegetation Index
NFI – National Forest Inventory
NFMP – National Forest Master Plan
NRS – National REDD+ Strategy
NUG – National Unity Government

PaMs – Policies and Measures
PAs – Protected Areas
PFE – Permanent Forest Estate
PPF – Protected Public Forest
REDD+ – Reduce emissions from forest degradation and deforestation
RF – Reserved Forest
ROAM – Restoration Opportunities Assessment Methodology (ROAM)
SAC – State Administration Council
SEPAL – System for Earth Observations, Data Access, Processing and Analysis for Land Monitoring
SERVIR – A global network of leading regional knowledge centres, and a consortium of partners, dedicated to environmental management through the integration of Earth observations and geospatial technologies
SOC – Soil Organic Carbon
TESSA – toolkit interactive user manual for guidance, methods for measuring and evaluating ecosystem services and identifying priority sites.
UNDP – United Nations Development Programme
UNESCO – United Nations Educational, Scientific and Cultural Organization
WCS – World Conservation Society
WDPA – World Database on Protected Areas
WRI – World Resources Institute

I

BACKGROUND & PURPOSE

The socio-economic and environmental benefits that can be obtained from the sustainable use, conservation and restoration of mangroves have been extensively demonstrated. Mangrove forests provide ecosystem services and sources of income to local coastal communities and beyond. These include protection from extreme coastal weather, fuelwood provisioning, and tourism attractions, as well as contributing globally to carbon sequestration and storage. Mangroves also play an important role in the conservation of biodiversity, acting as a breeding ground and nursery for many fish and other fauna species. Mangrove forests and their associated resources are also important to socio-economic development, being sources of highly valued commercial products, fisheries resources and as sites for eco-tourism in Myanmar (Myint 2019).

To realise and protect these benefits, decisions-makers need trusted information on the spatial distribution of biodiversity, ecosystem services and human impacts to identify how and where they overlap and to prioritise actions accordingly. Within Myanmar, there is a lack of comprehensive and accessible information on the biodiversity and ecosystem goods and services provided by mangroves. Furthermore, despite significant decreases in mangrove extent, much of what is known about the drivers of deforestation and degradation is based on case studies and outdated statistics (Enters 2017).

This scoping report has been prepared by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), under the auspices of the UN-REDD project 'Integrating mangroves sustainable management, restoration and conservation into REDD+ Implementation in Myanmar'. The aim of this scoping report is to identify the priorities, data sources and options for proposed analyses that can support the integration of mangroves sustainable management, restoration, and conservation into REDD+ implementation in Myanmar.

This report draws on past and ongoing research and initiatives to identify important benefits provided by mangroves within Myanmar, as well as data needs and limitations to include them in analyses. The proposed analyses are based on a) available data and tools, and b) an initial assessment of priorities for informing future REDD+ planning and implementation in mangrove areas. These priorities will also be refined through discussions with project partners and stakeholders, and consideration of the resources and time available.

II

OVERVIEW: MANGROVES IN MYANMAR

2.1 Status and trends of mangroves in Myanmar

Myanmar contains an estimated 4% of the world's mangroves and 8.8% of the mangroves found in Southeast Asia (Estoque *et al*. 2018; Spalding *et al*. 2010; Zöckler & Aung 2019). Mangroves are found in all coastal regions of the country and are distributed across the coastline. Large concentrations of mangroves are found across the southernmost parts of the Ayeyarwady Delta, as well as in the Rakhine and Tanintharyi regions (Zöckler *et al*. 2013).

Approximately 34% of mangroves are found in areas legally defined as "Forest Land", also referred to as Permanent Forest Estates (PFE), and thus benefit from some level of legal protection in Myanmar. These areas comprise: "Reserved Forests" (RF) - priority areas for commercial timber production; "Protected Public Forests" (PPF) - usually lower timber priority, mainly for use by local communities and for ecosystem service provision; and Protected Areas (PA) – areas to preserve diverse ecosystems, species richness and habitats. Some 3% of Myanmar's mangroves are located in Protected Areas (CDE Myanmar, based on Bunting et al. (2018) 2016 mangrove extent).

Much of Myanmar's forests, including mangroves, remain as "Unclassified Forests", which are areas outside of those legally defined "Forest Lands" (see Table 1 below). The Forest Department of the Ministry of Natural Resources and Environmental Conservation (MoNREC[1]) is responsible for managing all "Forest Lands", though some forest areas are managed by ethic armed organisations (EAOs), such as the Karen National Union, or were under "mixed administration" by the Union authorities and EAOs in the past (Jolliffe 2016; REDD+ Myanmar 2019). In addition, "Unclassified Forests" (i.e. outside of "Forest Lands" or PFEs) are mostly under the management of the Department of Agricultural Land Management and Statistics (DALMS) within the Ministry of Agriculture, Livestock, and Irrigation (MoALI), and other land-managing departments and ministries, through the 2012 Vacant, Fallow and Virgin Lands Management Law. Those "Unclassified Forest" areas have ambiguous tenure and are more vulnerable to informal extraction and land use change (World Bank 2020). The Forest Department has the goal include much of the "Unclassified Forest" into the Forest Lands/PFE by increasing the area of RF/PPFs to 30% of total land area and

[1] When referring to general mandates, as well as policies, laws and regulations from the past, this paper will use the name of relevant ministries and departments at the time of the document's release. For documents authored after February 2021, where possible this paper will distinguish between the State Administration Council (SAC) and the National Unity Government (NUG).

PAs to 10% by 2030 (*30-year* National *Forestry Master Plan* (2001-02 to 2030-31)). Nevertheless, the Forest Department faces many challenges in realizing these goals.

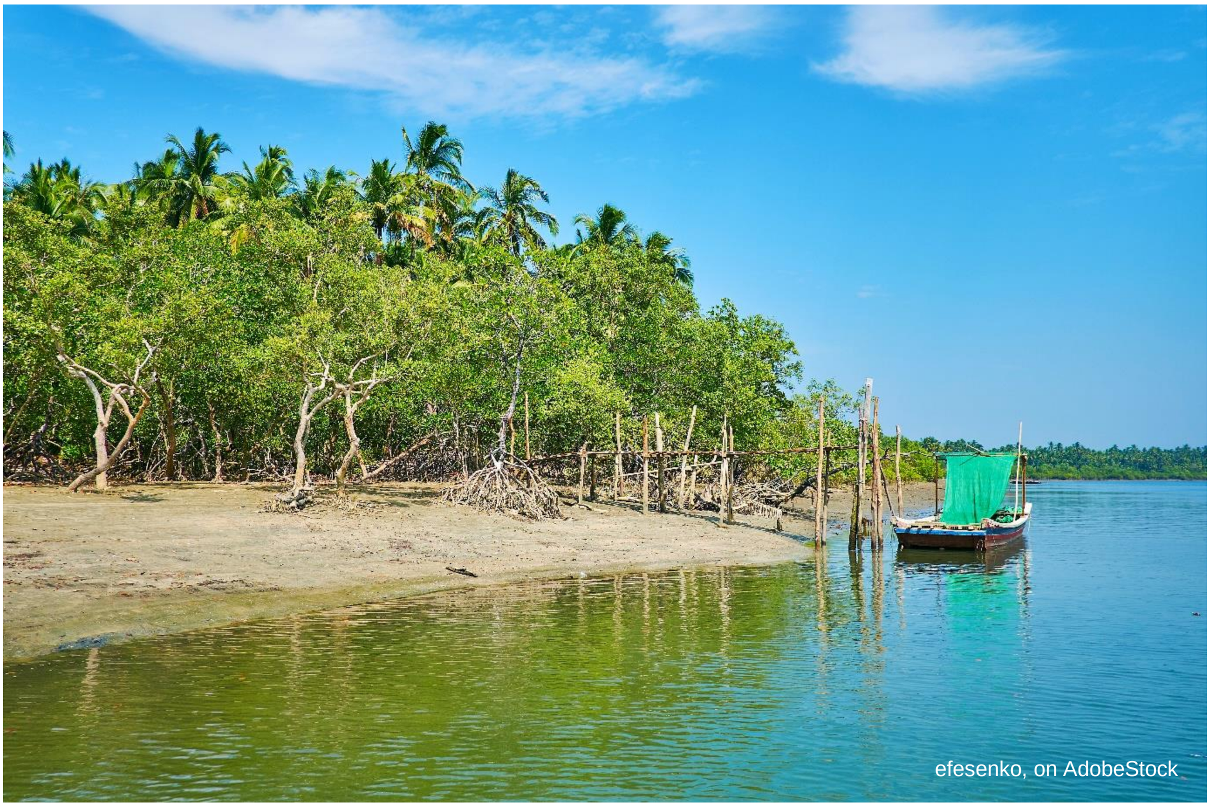
Table 1. Myanmar mangrove extent by state/region. Analysis by CDE Myanmar based on mangrove extent from Bunting et al. (2018) and draft PFE data from CDE Myanmar.

State/Region	Mangrove extent in 2016 (ha)			
	Forest Land/PFE		Unclassified Forest	Total
	RF & PPF	PA		
Mon	1	-	3,657	**3,657**
Ayeyarwady	77,163	12,150	26,334	**115,648**
Rakhine	21,667	-	118,030	**139,697**
Tanintharyi	59,822	296	176,899	**237,017**
Yangon	146	-	272	**418**
Total	**158,799**	**12,446**	**325,192**	**496,437**

Table 2. Estimations of mangrove area in 1996, 2007 and 2016 and annual deforestation rates across states/regions in Myanmar. Estimates from analysis using data from Bunting et al. 2018 and PFE draft data from CDE Myanmar (2021).

State/ Region	Forest Land/PFE				Unclassified Forest			
	1996 (ha)	2007 (ha)	2016 (ha)	1996-2016 net change) (%/year)	1996 (ha)	2007 (ha)	2016 (ha)	1996-2016 net change (%/year)
Mon	1	1	1	-0.59	4,516	3,373	3,657	-1.06
Ayeyarwady	92,995	89,161	89,314	-0.20	29,287	25,870	26,334	-0.53
Bago	-	-	-	-	212	-	-	-
Rakhine	23,161	21,837	21,667	-0.33	149,084	122,694	118,030	-1.17
Tanintharyi	61,018	60,438	60,118	-0.07	178,906	177,749	176,899	-0.06
Yangon	132	145	146	0.49	483	316	272	-2.87
Total	**177,307**	**171,582**	**171,245**	**-0.17**	**362,489**	**330,001**	**325,192**	**-0.54**

There has been a lack of formal communication or coordination mechanisms between the Forest Department and MOALI to date. An objective of the Forest Department has been to review “Forest Land” in order to remove areas defined as “Forest Land” that have been permanently converted to other land use as well as integrating areas of high-quality forest that are not yet legally defined as “Forest Land”. As yet there has not been an appropriate institutional basis for this dialogue, and the Forest Department has had little authority to add new areas to the legally defined “Forest Land”. However, the Biodiversity and Conservation of Protected Areas Law, passed in May 2018, has the potential to accelerate the establishment of community protected areas (CPAs), particularly in areas outside of the legally defined “Forest Land”.



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2.1.1 Links with national commitments and policies

The importance of mangroves in Myanmar is highlighted by their growing presence in new policies and laws, including the National Biodiversity Strategy and Action Plan (NBSAP) 2015-2020, the 2021 Nationally Determined Contribution (NDC), the 2016 Myanmar Reforestation and Rehabilitation Programme (MRRP), and the 2018 draft National REDD+ Strategy (NRS) and its Policies and Measures (PaMs). Key targets include: placing at least 10% of mangroves under protection[2], including for sustainable use and management (NBSAP 2015-2020); establishing 4,634 ha of mangrove plantations (government established) by 2027 (MoNREC 2021); prioritising the conservation of important mangrove areas; and increasing the resilience of mangroves and coastal communities that are at risk of flooding (MoNREC 2021).

In particular, the 2021 NDC[3] notes the importance of mangroves for their diverse co-benefits for climate change mitigation, climate change adaptation and biodiversity

[2] Depending on the estimate of mangrove cover used, e.g. approx. 27,000 ha (based on 2012 estimated mangrove cover for the three main mangrove regions, see table 1).

[3] The same NDC was submitted to the UNFCCC by the State Administration Council (SAC) and the National Unity Government (NUG); with the SAC version displayed on the UNFCCC website. This is the version referred to in this paper.

conservation. It states that a National Coastal Resources Management Committee (NCRMC) has been established to oversee the development of a coastal disaster defence and Green Belt through mangrove restoration and rehabilitation, as well as expanding forestry areas and increasing protected areas to enhance nature-based solutions to climate change (MoNREC 2021). The draft NRS has four objectives, each relevant to mangroves: reducing deforestation and related carbon emissions by 30% by 2030, enhancing forest carbon stocks by 90 million tonnes of CO_2e by 2030, reducing degradation on existing over exploited forests and preventing future forest degradation, conserving forest carbon stocks, particularly in PAs (REDD+ Myanmar 2019). In addition, the NRS has a broad goal of contributing to climate resilience and sustainable development, through "transformational change in the land-use and forestry sector'', which aligns with a range of national policies on forestry, climate change, environment, sustainable development, human rights, and gender equality (REDD+ Myanmar, 2019).

Although the 2021 NDC submitted by the State Administration Council is now available on the UNFCCC website, SAC representatives were denied entry to COP26. It is difficult to determine yet how the SAC and the National Unity Government (NUG) will approach commitments and targets as set out in documents like the NDC and the NBSAP. However, the political crisis in Myanmar does increase the likelihood that implementation of these policies will be stalled or interrupted.

2.1.2 Threats to Mangroves in Myanmar

Mangroves have been shown to sustain more than 70 direct human activities globally, providing both market and non-market goods, from fuel-wood collection to fisheries (Spaninks and Van Beukering 1997), and different groups of people use and benefit from mangroves in different ways. Despite this, their full value is often neglected in favour of directly marketable products, such as aquaculture and rice (Giri *et al.* 2008) which places great pressure on mangrove systems. Therefore, there is a considerable threat to their continued existence. Protection and inaccessibility can reduce mangrove deforestation and degradation rates. Results from CDE analysis in Table 2 demonstrate that in most cases, deforestation rates are higher in unclassified forest lands than mangrove classed under Forest Lands/PFE.

Myanmar is a global hotspot of mangrove deforestation with high human population pressures in many coastal areas (Zöckler *et al*. 2013). Between 1996 and 2016, 63%[4] of mangroves were estimated to be temporarily or permanently lost, with total net

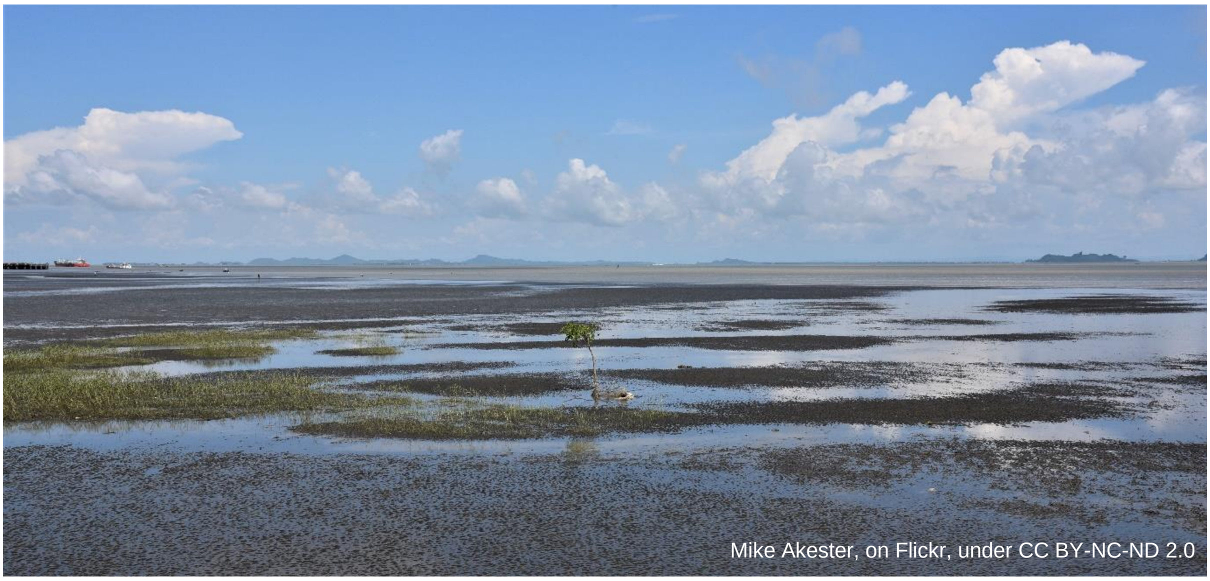
[4] This estimate is significantly higher than some other studies. For example, Global Mangrove Watch (GMW) estimates that between 1996 and 2016, 8% of mangrove forests were lost in Myanmar. Differences between the two sources may be due to the resolution the data is analysed (the Alban *et al.* (2020) study was analysed at 30m spatial resolution), the type of data (e.g. Landsat images, PALSAR, SRTM and vegetation indexes) and level of ground-truthing. Estimates made using only Landsat data may have lower levels of accuracy. Alban *et al.* (2020) estimated more than double the mangrove coverage in 1996 than GMW (13,233 km^2 vs 5,384.76 km^2) and higher net area losses between 1996 and 2016 were estimated.

mangrove cover declining by 52%, predominantly in Rakhine and Ayeyarwady (Alban *et al.* 2020). This was largely driven by conversion to rice paddies, oil palm and rubber tree plantations as well as aquaculture for shrimp farming, and additional losses due to cyclone Nargis in 2008 (Alban *et al.* 2020; Estoque *et al.* 2018; Zöckler *et al.* 2013).

The Ayeyarwady Delta is responsible for approximately 35% of Myanmar's rice production (Webb *et al.* 2014). Oil palm expansion is often associated with by large-scale agribusiness concessions, particularly in Tanintharyi, to meet domestic and industrial demands for palm oil (Richards and Friess 2015). Similarly, in recent years, previous governments had been promoting industrial agriculture in the country, with an emphasis on rubber (e.g. Agriculture Development Strategy and Investment Plan (2018-19 – 2022-23, National Export Strategy 2015-2020) (MOALI 2018). Between 2005-2016, there was a 288% increase in the surface area of planted rubber, replacing mangrove in some areas (Vagneron *et al*. 2017).

Although not currently a major driving force of mangrove deforestation, aquaculture expansion is expected to continue due to increased demand and accessibility to international markets (Webb *et al.* 2014; Belton *et al.* 2015; Karim *et al.* 2020). Conversion to aquaculture also degrades nearby mangroves as a result of altered hydrology, pollution and eutrophication (Friess *et al.* 2019). Sustainable forms of aquaculture which do not destroy mangroves are being encouraged, though they are still not the norm (Win 2004; MoNREC *et al.* 2016; IUCN 2021). The Myanmar draft National REDD+ Strategy aims to promote sustainable commodity supply chains, including developing training courses on environmentally responsible production, such as mangrove-friendly aquaculture (REDD+ Myanmar 2019).

Coastal industrial and infrastructure development also threaten mangroves through direct impacts (deforestation for development) and degradation (increased access to intact mangroves and pollution). These developments could also reduce connectivity between mangrove patches with detrimental effects for biodiversity, local communities (Zöckler *et al.* 2013), and particularly for vulnerable groups such as women and biodiversity (IUCN 2021).



Weak law enforcement is also an issue, with encroachment and conversion of mangroves in protected areas occurring. This has been particularly noted in Wunbaik Reserved Mangrove Forest in Rakhine State, where 40% of mangroves have been converted to shrimp farms and rice paddies, and degradation has occurred through wood cutting and bark peeling (Alban *et al*. 2020). The political crisis precipitated by the military coup in 2021 may increase the threats posed to mangroves, as well as other forests and natural ecosystems. Recent reports indicate that increased illegal logging has been taking place in the country since the coup (e.g. Conflict and Environment Observatory, 2021). Myanmar's Wunbaik mangrove forest, one of the largest in Myanmar, has been subject to increased logging since the military coup according to local residents (BNI 2021). Analysis also suggests that deforestation has been linked to the violence against Rohingya communities, with a 12% reduction in forests in Rakhine state (Aung 2021).

Whilst direct and indirect human activities and pressures pose the greatest threats to mangrove ecosystems currently through deforestation and degradation, increasing climate change and associated extreme weather events (such as tropical cyclones) may pose greater risks in the future (MoNREC 2019). Climate change and extreme weather events imposes increasing threats to ecosystems and local communities, especially marginalised and vulnerable groups, such as women, children, ethnic minority groups and migrants. For example, women feel they need to be better prepared for these disasters as the responsibility for caring for vulnerable family members falls primarily to them. Furthermore, although women actively participate in farming and agriculture, their contributions in these sectors are not well recognised, resulting in them often being excluded from government run climate change adaptation training for fishers and farmers. As a result, women lack the information and resources need to adapt to climate change (UNEP 2016).

2.1.3 Mangrove restoration and conservation in Myanmar

Despite the large overall losses, restoration efforts have facilitated mangrove gains in some areas (Alb*an et al*. 2020). Community-based mangrove restoration programmes, among other approaches, have been promoted by both government agencies and non-government organisations in the past. They were identified as a priority action for mangrove restoration as early as the 1995 Forest Policy, as well as subsequent documents such as in Myanmar's first NDC, reinforcing the role of local communities in forest management (Alban *et al.* 2020), while community-based and ecosystem-based adaptation and disaster risk reduction, and gender-inclusive production systems and agroforestry are discussed in Myanmar's updated NDC of 2021. However, there are currently few community forests in mangroves, limiting their effectiveness as a measure for mangrove restoration and conservation. Although community forestry has been scaling up recently, many community forestry user groups (CFUGs) are considered to be inactive, and progress below that required to meet the target of the National Forest Master Plan (NFMP) of 919,000 ha by 2030/2031 (World Bank 2019).[5] According to pre-2021 data, over 140 community forests in Myanmar are located in mangrove areas, covering 15,000 ha[6] (Table 3).

Table 3. Community forest areas by state/region in Myanmar and the number of which are in mangrove areas. Based on the draft Myanmar CF database (2020). Data provided by CDE Myanmar.

State/Region	CF area (ha)	Number of CFs in Mangrove areas
Mon	485	15
Ayeyarwady	7534	60
Rakhine	2583	36
Tanintharyi	4043	33
Yangon	314	7
Total	**14959**	**151**

Programs such as the Myanmar Reforestation and Rehabilitation Programme (MRRP) aim to restore forest cover using a multi-stakeholder approach. This includes mangroves in priority areas, such as the mangroves of northern Rakhine State and the Ayeyarwady Delta (Constable *et al.* 2019). Previous rehabilitation programmes by the Forestry Department have also improved mangrove conditions in the Ayeyarwady delta. Furthermore, activities promoting the socio-economic development of rural poor

[5] According to data compiled by Voices for Mekong Forests, as of 2018, community forests had been established on 221,169 ha, or about 24% of the 2001 target (https://www.frontiermyanmar.net/en/the-right-to-community-forest-in-tanintharyi-region/) (Htoon 2019)

[6] This value is from a pre-2021 coup draft of the national community forestry database. This database was in a draft format and incomplete for some areas (esp. for western Rakhine).

communities and the establishment of plantations by UNDP programmes have facilitated the rehabilitation of mangrove forest in various locations (Zöckler *et al.* 2013). Mangroves also regenerate passively and can rapidly recolonise open or abandoned aquaculture mudflats where conditions are appropriate (Friess *et al.* 2012).

Outside of restoration, the conservation of remaining intact mangroves is crucial to preserve the benefits mangroves provide to local communities and to meet conservation and climate change mitigation and adaptation goals. However, only 3% of mangroves are currently within protected areas. Myanmar's protected area law is strictly "no use", although this is often not enforced. However, following the 2018 Conservation of Biodiversity and Protected Areas Law, protected areas have buffer zones where local communities' socio-economic and ecotourism development can occur and community protected areas are recognised (Conservation of Biodiversity and Protected Areas Law No. 12/2018). UNESCO Biosphere Reserves and Ramsar sites including community-based protected areas and forest management have been suggested as some of the best approaches to preserve mangroves whilst involving local communities (Zöckler and Aung 2019). Protecting mangroves and reducing deforestation rates is more efficient and cost-effective than reforesting or restoring degraded mangroves, as these processes can take years, be expensive and have varying levels of success (Friess *et al.* 2019; Su *et al.* 2021).

Mangroves for the Future is an initiative which aims to build the resilience of coastal ecosystem-dependent communities in Asia. Furthermore, the MFF initiative aims to promote sustainable management and rehabilitation of coastal ecosystems in South and Southeast Asia, including in Myanmar, and since its inception to 2019, has overseen more than 380 grant projects implemented by local civil society organisations across the region. MFF also recognises the contribution of both men and women in conservation and socioeconomic development of coastal areas[7].

[7] For example, see: http://www.mangrovesforthefuture.org/news-and-media/news/asia-region/2018-2/asias-largest-coastal-resource-management-programme-sets-sights-on-further-growth/; http://www.mangrovesforthefuture.org/knowledge-hub/mff-knowledge-networks/gender-coastal-resource-management/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III

DATA, PLATFORMS AND PROPOSED ANALYSES

3.1 Mangrove extent, loss and degradation

3.1.1 Data availability

Mangrove extent datasets are increasingly available at global scales with both high temporal and spatial resolution. However, these datasets are often binary (presence/absence) and do not provide detail on mangrove typology (Worthington *et al.* 2020). Regional and national datasets on extent are also available, and expected to be improved in the future, including through analysis supported by this UN-REDD project. Yancho *et al.* (2020) conducted a review and comparison of relevant Myanmar mangrove datasets. As part of the output for this analysis, extent, change and condition (degradation) data layers will be produced by FAO, with more detail provided below and in Annexes 1 and 2).

Table 4. Relevant datasets that detail the extent of mangroves, global to national scales

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
Global	Global Mangrove Watch – Mangrove extent	Bunting *et al.* (2018)	Vector	1996, 2007, 2008, 2009, 2012, 2015, 2016	Link	Link
	Global biophysical typology of Mangroves	Worthington *et al.* (2020)	Vector (GMW extents)	1996, 2007, 2008, 2009, 2012, 2015, 2016	Link	Link
	Global distribution of mangroves	Giri *et al.* (2011)	30m	2000	Link	Link
	Global mangrove distribution and estimates of biomass	Simard *et al.* (2019)	30m	2000	Link	Link
	Global Mangrove Forest Cover Loss since 2000	Hamilton and Casey (2016)	30m	2000-2012	Link	Link

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
	Tropical Moist Forest dataset	Vancutsem *et al.* (2021)	30m	1990-present	Link	Link
	World Atlas of Mangroves	Spalding *et al.* (2010)	Vector	1999-2003	Link	Link
Regional	SERVIR Mekong Annual Land Cover (including mangrove class)	SERVIR	30m	1987-2018	Selection of publica-tions	Link
	Mangroves in the Bay of Bengal	WCS	Polygon	2005	No information available	No informa-tion available
	Tanintharyi Region Mangrove Forest dataset	Stephani (2016) (University of Bayreuth & FFI)	30m	2014	Not available	Link
	National coastal habitat map	No information available	No information available	No informa-tion available	No information available	http://www.myanmarnaturalcapital.org/en/data-repository (link invalid)
	Myanmar National Land Cover	SERVIR, MoNREC	No information available	No informa-tion available	No information available	https://landcovermapping.org/en/myanmar-national-portal/ (data appears unavail-able)
	Mangrove extent and change in Ayeyarwady and Tanintharyi regions	FAO	30m	2016 and 2021	Link to PowerPoint slides	Assets available on GEE (Asset links in Annex 1)
	Mangrove and Pond Aquaculture Conversion	Clark Labs	15m and 30m (for risk and vulnerability data)	1990, 2014, 2018	Link	Link
	Mangrove distribution and change in Tanintharyi	(Gaw *et al.* 2018) (National University of	Polygon	1998, 2000, 2005,	Link	No informat-ion available

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
		Singapore, FFI)		2009, 2014		
	Forest Types in Tanintharyi (incl. Mangroves)	(Connette *et al.* 2016)	30m	2016	Link	Link

The state of mangroves and impacts of human pressures are often reported in terms of deforestation metrics, however these alone are weak metrics of mangrove conditions. Degradation within remaining mangroves reduces their ability to provide key ecosystem services and resources as well as habitat for flora and fauna (Friess *et al.* 2019). Degradation is more difficult to measure than changes to mangrove extent, and there are fewer datasets available to measure and monitor ongoing mangrove degradation, particularly at the national and sub-national level in Myanmar. Forest gain was also identified in the FREL as an area for data improvements in future updates, due to difficulties distinguishing between afforestation and growing cycles of plantations. Other suggested improvements include better detailed land use maps and activity data refined by administration boundaries (MoNREC 2018).

Some papers and assessments of mangrove losses and drivers include Richards and Friess (2016), Friess *et al*. (2019), the Myanmar UN-REDD Programme deforestation drivers assessment (Enters 2017) and Oo *et al.* (2020).

Table 5. Relevant datasets that map condition and the drivers of mangrove loss and degradation, global to national scales

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
Global	Freshwater and sediment impacts on mangrove condition (global river-ocean outlets)	Maynard *et al*. (2019)	Uses Global Mangrove Watch extent	1996-2016	Link	Methods described in paper
	Global trends in mangrove forest fragmentation	Bryan-Brown *et al.* (2020)	30m	2000-2012	Link	Dryad repository not yet available
	Drivers of mangrove extent change	Goldberg *et al*. (2020)	30m	2000-2016	Link	Link

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
	Drivers of mangrove extent change	Bhargava *et al*. (upcoming)	30m	Not yet available.	Link	Not yet available
	Distribution and drivers of global mangrove forest change, 1996–2010	Thomas *et al.* (2017)	30m	1996-2010	Link	Not available for download
	Accessibility to cities	Weiss *et al.* (2018)	1km	2015	Link	Link
	Human Pressures Index	Geldmann, Joppa and Burgess (2014)	10km		Link	Link
	Night-time lights	Li *et al.* (2020)	1km	1992-2018	Link	Link
	Marine Pollution Index	(Halpern *et al.* 2015)	1km	2013	Link	Link
	Global Human Modification	Kennedy *et al.* (2019)	1km	2016	Link	Link
Regional	Mekong Infrastructure tracker (including deforestation app)	Stimson	30m for deforestation app (Data from Hansen *et al.* 2013)	2001-present	Link	Link
Regional	SERVIR Mekong Annual Land Cover (including mangrove class)	SERVIR	30m	1987-2018	Selection of publications	Link
Regional	Deforestation in the Ayeyarwady Delta	Webb *et al.* (2014)	30m	1978, 1989, 2000, 2011	Link	On request
National	Condition of mangroves in Ayeyarwady and Tanintharyi (level of maturity and canopy coverage) (tbc)	FAO (In development)	30m	2016 and 2021	In development	In development

3.1.2 Data platforms

Various platforms exist which aid the mapping and monitoring of mangrove extent, degradation, and restoration. Some examples include:

SEPAL (System for Earth Observations, Data Access, Processing & Analysis for Land Monitoring)

SEPAL is a cloud computing platform for geographical data processing. It enables users to quickly process large amount of data without high network bandwidth requirements or the need to invest in high-performance computing infrastructure. It facilities access to remote sensing data sources through a direct-access-interface to earth observation data repositories (such as Google Earth Engine) and includes a set of open-source software tools, capable of efficient data processing and completely customizable. Some of these tools can be used for mapping mangrove extent and monitoring changes (e.g. creation of satellite mosaics of optical and radar data, retrieving and analysis of time series, classification, change detection, etc.).

Link: SEPAL

Collect Earth

Developed by FAO and a part of the open-source suite of tools called Open Foris, it can be downloaded as software or accessed online through Collect Earth Online. The tool allows the user to visually interpret satellite imagery (e.g. Landsat and Sentinel-2) to document the biophysical properties of a landscape. The tool can be used by groups of participants which comprise a variety of stakeholders during 'mapathon' events. The tool includes Collect and Collect Mobile for designing surveys and collecting data in the field. The tool can be used for several purposes, including monitoring forest and landscape restoration, providing data for REDD+ measuring and conducting national forest inventories (Reytar *et al.* 2021). Collect Earth and the Open Foris suite of tools can provide a mechanism to bring together stakeholders from a variety of backgrounds to map and monitor changes to mangroves extent and condition.

Link: Collect Earth

Google Earth Engine

Google Earth Engine (GEE) is cloud computing platform allowing users to analyse high resolution datasets and satellite images. This platform has been used in a number of mangrove analyses from local to global scales. Examples include EcoMap, a GEE-based portal which maps and predicts global mangrove loss and degradation (Goldberg *et al*. 2018) and analysis by Sanderman *et al.* (2018) to map mangrove soil carbon globally. The tool is free to access and use, however, skills in GIS and javascript/python script writing are required. A tutorial on mapping and monitoring mangroves using Google Earth Engine has been developed by SERVIR and can be accessed here.

Link: Google Earth Engine

The Google Earth Engine Mangrove Mapping Methodology (GEEMMM)

A mangrove mapping tool developed in GEE by Yancho *et al.* (2020). This approach aims to be intuitive, accessible and replicable. A description of the tool and links to GEE scripts can be found here. Use of the tool requires a GEE account and some knowledge of using the platform but is catered towards non-specialist audiences and decision makers. The tool can be applied anywhere mangroves are found to map and monitor their distribution.

Link: GitHub repository (includes links to GEE scripts)

3.1.3 Proposed and ongoing analyses

Extent, loss and condition

Analysis supported by FAO as part of the project will map the extent, condition, and carbon stocks of mangroves in Myanmar (for two regions):

- *Mangrove extent for 2016 and 2021 (Ayeyarwady and Tanintharyi regions)*

Mangrove extent maps are being created from global and national datasets, and time series analysis (optical Landsat-8 and radar Sentinel-1 data). A binary presence and absence map has been developed based on where global and national datasets agree on probable presence and absence, including the Global Mangrove Watch of 2016 (Bunting *et al*. 2018), the Global Mangrove Forest Distribution of 2000 (Giri *et al.* 2013), the Global Mangrove Distribution of 2000 (Simard *et al.* 2019) and the LULC map of Myanmar 2015 (MoNREC and FAO 2016). This mask was then used as training data to map the probability of mangrove presence using analysis of time series of Landsat-8 and Sentinel-1, and the MERIT Digital Elevation Model, with the Continuous Change Detection and Classification (CCDC) algorithm (Zhu and Woodcock 2014). The classification of this probability map into mangrove extension maps is then further improved by increasing the training dataset over 'uncertain' areas, through visual interpretation of very high-resolution imagery by national experts, resulting in mangrove extent more in line with the national dataset than global products. Annex 1 provides more detail on the data used and methodological approach.

- *Mangrove condition (Ayeyarwady and Tanintharyi regions)*

The mangrove extent maps of Ayeyarwady and Tanintharyi regions are being classified in different levels of maturity (young and mature mangroves) and percentage of canopy cover. Data from the National Forest Inventory (NFI) are being used to support the visual interpretation of very high-resolution satellite data by national experts in Collect Earth. Basal area has been demonstrated to be the best parameter to differentiate young from mature mangroves. Maps of mangrove degradation are expected to be created by comparison of the classification maps targeting the 1st of January of the years 2016 and 2021. See Annex 2 for more detail on the methodology and data used.

- *Mangrove cover change (Ayeyarwady and Tanintharyi regions)*

Mangrove cover change maps for the period between 1st of January 2016 and 1st of January 2021 for Ayeyarwady and Tanintharyi regions are being created from the comparison of the above mangrove extent maps. These result in mangrove annual loss rates of 0.95% and 0.35% for Ayeyarwady and Tanintharyi regions respectively. See Annex 2 for more information.

- *Mangrove carbon stocks (Ayeyarwady and Tanintharyi regions)*

No specific remote sensing methodology will be used to estimate carbon stock in these two regions (e.g. lidar-based). Carbon stocks will be estimated combining the mangrove extent map of 2016, and possibly 2021, with NFI data (e.g. basal area) and other estimates of carbon stocks in mangroves.

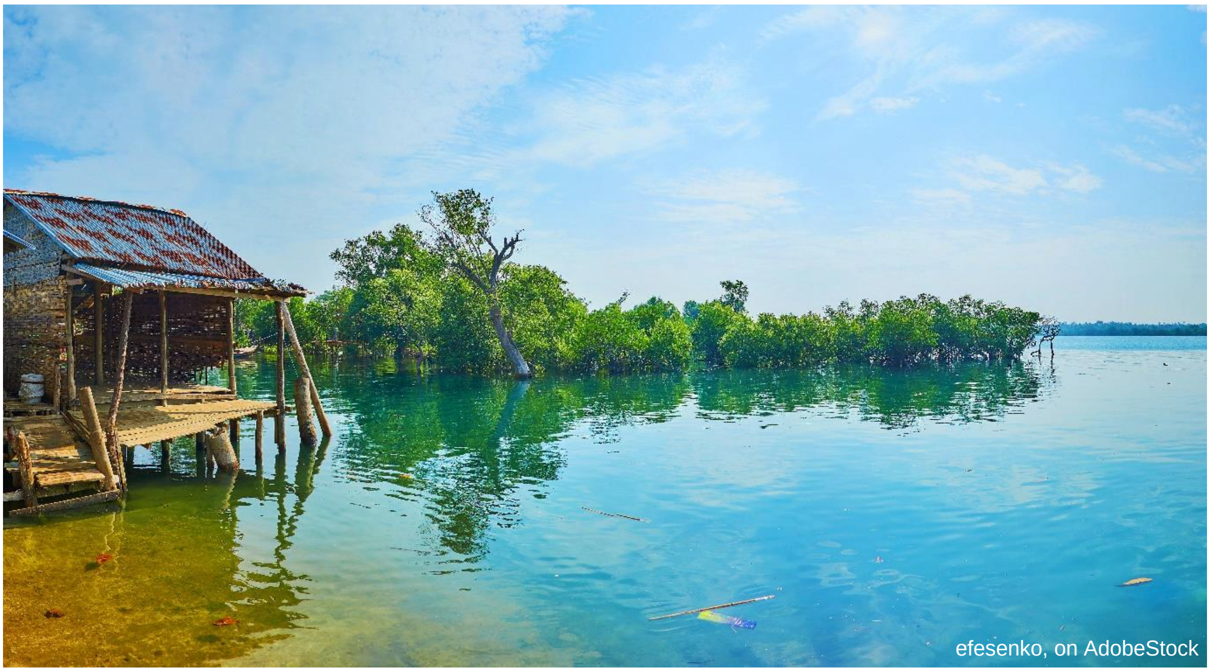
Mangrove pressures / mangroves at risk

Using the above information on mangrove extent and condition in combination with datasets such as the global Human Footprint index, settlements, and infrastructure, it may be possible to determine spatial patterns of the pressures placed upon mangroves and their vulnerability, such as:

- *Distribution of human pressures on mangroves*
- *Mangrove areas at risk of human pressures/drivers of deforestation & degradation*

3.2 Role of mangroves for ecosystem services, including for socio-economic development

Healthy mangrove forests in Myanmar provide a range of ecosystem services that contribute to people’s livelihoods, health and wellbeing as well as providing wider environmental and climatic benefits (Getzner and Islam 2020). Mangroves play a significant role in the socio-economic development and daily lives of coastal communities in Myanmar, providing food, fuel, income, and coastal protection. Many local coastal communities pursue subsistence livelihoods (Zöckler *et al.* 2013; Feurer *et al.* 2018), where mangroves provide food (through fishing and other food products including honey, algae and fruit), timber and fuelwood. Timber from mangroves are used as raw materials in house and boat construction, as well as fishing stakes by coastal fishers (Win 2004). Mangroves also provide several aesthetic and cultural services including ecotourism, education and local indigenous traditions (Camacho *et al*. 2020). However, the provision of ecosystem services and benefits from mangroves is not evenly distributed and different societal groups, including ethnic groups, women and others, may value and use mangroves in different ways. Although not always specific to mangroves, some research in Myanmar also shows how men and women differ in how they interact with and use forest ecosystems, and how benefits can vary. For example, men and women may both use forest resources often but in gendered ways, with some tasks seen as acceptable for men (e.g. management, logging) and others for women (collecting fruit, replanting, etc). Women's rights to own and access forests and land are more likely to be ignored, with similar inequalities present within ethnic groups, many of which are considered forest dependent. In addition, there is a lack of gender disaggregated data as well as research on differentiation of rights, roles and benefits (IUCN 2017; Naujoks *et al.* 2020; REDD+ Myanmar n.d.).



efesenko, on AdobeStock

As well as direct benefits, mangrove forests protect coastal areas from floods and storms, and coastal erosion, reducing economic losses and saving lives. Therefore, mangroves also offer significant potential for climate change adaptation, protecting coastal communities from rising sea levels, more intense and frequent storms and heavy rain events. They can also improve food and livelihood security, which are threatened by climate change (Costanza *et al*. 2021; IUCN 2021).

Furthermore, maintaining healthy mangroves makes an important contribution to climate change mitigation. Mangroves lock up vast quantities of carbon in their biomass and associated soils, it is estimated they store 3 to 4 times more carbon than tropical forests per hectare (Donato *et al*. 2011). Hamilton and Friess (2018) estimated that mangrove forests in Myanmar stored approximately 119 million tonnes of carbon, with the majority in their associated soils. Although national data for estimates of the GHG emissions reduction and removal potential for Myanmar's mangroves is currently lacking, mangroves could make a significant contribution to Myanmar's capacity to meet climate change mitigation targets.

Deforestation and degradation of mangroves undermines their use as long-term resources and their potential ecosystem service provisioning. Estoque *et al.* (2018) estimated that mangrove deforestation in Myanmar between 2000 and 2014 resulted in a net loss of US$ 2.397 billion per year, particularly through impacts on fisheries nursery populations and coastal protection.

Table 6. Summary of key mangrove ecosystem services in Myanmar and the wider tropics

Category	Ecosystem service	Description
Provisioning Services	Fisheries/aquatic products	Mangroves are rich in fishery resources, act as nurseries and spawning grounds for fish, molluscs and crustaceans (Aung *et al*. 2016). There are more than 3,000 fish species found in mangrove ecosystems, providing a source of food and income for local people through fisheries. The most important shrimp species in Myanmar, the white (banana) shrimp, is dependent on mangrove forests for shelter during its juvenile stage (Win 2004). Mud crabs, which breed at the roots of mangroves, are an important resource for local communities, both as a source of income and food (Feurer *et al.* 2018).
	Harvested wood products (including fuel)	Mangrove forests are a valuable source of timber and wood fuel, including charcoal, for local people. Products are used for fuel as well as raw building materials (e.g. for boat and house building building). Kanazo (*Heritiera formes*) is a prime timber species used in house and boat construction and favoured for charcoal making. This species is now rare in Myanmar (Win 2004).
Regulating Services	Carbon storage and sequestration	Mangroves are amongst the most carbon-rich forests in the world. The carbon storage potential of mangroves is estimated to be 3-4 times higher than that of tropical upland forests (Donato *et al*. 2011). They sequester and store large volumes of carbon into their biomass and, in particular, their associated soil sediments. Hamilton and Friess (2018) estimated that mangrove forests in

		Myanmar stored approximately 119 million tonnes in their biomass and associated soils.
	Coastal protection and flood defence	Myanmar is very susceptible to extreme weather events including tropical storms and cyclones. Mangroves are a vital resource for coastal protection, acting as storm barriers for local people. In Myanmar, studies showed that mangrove forests played a crucial in protecting settlements from Cyclone Nargis (Thant *et al.* 2009). Conserving and restoring coastal mangroves can provide a cost-effective alternative to grey infrastructure in protecting coastal areas from coastal inundation and inland areas from flooding and erosion.
Supporting services	Habitat for wildlife/ biodiversity conservation	Above water, mangroves provide homes for lizards, snakes and birds such as the mangrove pitta (*Pitta megarhyncha*) in their branches. Their roots provide protective nurseries for fish, crustaceans and marine mammals.
	Delta building/sediment retention	Mangroves can actively contribute to sediment accumulation on tidal flats, trapping sediment in their aerial root and trunk structure. This has been termed as their 'land-building' role. Mangroves sediment trapping ability also decreases the degradation of coastal watersheds and further erosion upstream (Aung *et al.* 2016; BMZ *et al.* 2020).
	Nutrient cycling/water filtration	Mangroves filter water, improving the quality of water for local people and wildlife. They trap pollutants and excess sediment, preventing it from entering the ocean and other nearby ecosystems (Aung *et al.* 2016; IUCN 2021).
Cultural Services	Recreation and ecotourism	Mangrove-related recreation and tourism, such as boat tours, kayaking and fishing provide income for local people. Tourism to coastal areas had been increasing recently, with tourism being one of the fastest growing industries in Myanmar, particularly in coastal areas (MoNREC *et al.* 2016; Spalding and Parrett 2019).
	Maintaining traditional knowledge, practices and cultural heritage	Mangrove ecosystem resources are crucial to the preservation of traditional practices and knowledge in food sources, building materials and traditional medicines such as plants which are used to treat stomach ache, fever, injuries and snake bites (Feurer *et al.* 2018; Firdaus *et al.* 2019; Wahyudin and de Soysa 2020).
	Spiritual and religious	Mangroves provide a 'sense of peace' and spiritual connection to nature. Mangrove forests may also contain sites significant to religious worship (Thiagarajah *et al.* 2015; Feurer, Gritten and Than, 2018).
	Scientific research and education	Mangroves provide opportunities for scientific research and education including educational guided tours for schools and interested members of the public (Thiagarajah *et al*. 2015).

3.2.1 Data availability

Several spatial layers for ecosystem services are available, from global to local scales. However, these tend to focus on carbon storage provided by mangroves, with few relating to ecosystem service provisioning to local communities. Ecosystem service layers developed at the national level are not common and data on soil organic carbon in the soil sediments of mangroves in Myanmar are currently very limited (MoNREC 2018).

National data including socio-economic, administrative boundaries and demographic data (e.g. MIMU, WorldPop), distance to infrastructure, settlements and cities (e.g. Mekong Infrastructure Tracker; Weiss *et al*. 2018), and disaster databases such as MUDRA or vulnerability indices (e.g. INFORM) could be used to inform ecosystem service analysis at local, sub-national and national scales, and some have data disaggregated by demographic group/location. Qualitative data and case studies on the role of mangroves and their ecosystem goods and services for local communities, differentiated by stakeholder group and gender, may provide useful supplementary information.

Table 7. Relevant datasets for mapping ecosystem services provided by mangroves, global to national scales

Extent	Eco-system service	Description	Author(s)	Resolu-tion	Year (s)	Link to paper	Link to data
Global	Carbon storage	Global estimate of biomass and carbon	Tang *et al*. 2018	30m	2000	Link	Request from author
		Global mangrove soil carbon	Sanderman (2017)	30m	2000	Link	Link
		Global patterns in mangrove soil carbon stocks and losses	Atwood *et al*. (2017)	30m	2014	Link	Link
		Global controls on carbon storage in mangrove soils	Rovai *et al*. (2018)	25km	Unclear	Link	On request
		Annual assessment of total carbon stocks and losses from mangrove deforestation	Hamilton and Friess (2018)	30m	2000-2012	Link	Link

Extent	Eco-system service	Description	Author(s)	Resolu-tion	Year (s)	Link to paper	Link to data
		Mangrove and tidal marsh soil carbon stocks	Ocean Wealth (Combining Simard *et al.* 2019 for AGB and Sanderman *et al.* 2018 for soil carbon)	30m			
		Potential coastal wetland carbon sequestration potential	Ocean Wealth				
	Tourism	Mangrove tourism	Spalding and Parret (2019)	Unclear	Up to 2015	Link	Link, request from authors
	Flood protection	Global flood protection benefits of mangroves	Loasada *et al*. (2020)	20km	2010	Link	Link
		Mangroves and value of flood risk protection	Menendez *et al*. (2020)	30m	Unclear	Link	Link
	Fisheries	Fishers who rely on mangroves	zu Ermgassen *et al.* (2020)	1km		Link	Request
	Habitat quality	Mangrove habitat dollar value	Ocean Wealth				Available to view
	Typology	Global biophysical typology of Mangroves	Worthing-ton *et al.* (2020)	Vector (GMW extents)	1996, 2007, 2008, 2009, 2012, 2015, 2016	Link	Link

Extent	Eco-system service	Description	Author(s)	Resolu-tion	Year (s)	Link to paper	Link to data
Regional	Hazards ecosys-tem services can address/ which impact ecosys-tem services	Climate change adaption platform (AP-PLAT) Climate Impact Viewer	Ministry of Environ-ment, Govern-ment of Japan	Raster	Periods: Current to end of 21st Century	Link to platform details	Link
National	Carbon storage	Myanmar mangrove estimated carbon storage – at least two regions	FAO	30m	In progress	In pro-gress	In progress
	Coastal protection and other	Assessing ecosystem service provision (coastal vulnerability) to support conservation and development planning	Mandle *et al.* (2017)	Point	Based on Global Mangrove Watch extents and a map for the Tanintharyi region provided by MoNREC in 2015.	Link	Request from authors

3.2.2 Data platforms

Several platforms exist which host data, largely global in extent, on ecosystem services and socioeconomic indicators associated with mangrove habitats. Some examples include:

Nature Map

The Nature Map explorer platform includes spatial layers of habitat types, species richness, biomass carbon, human pressures and areas of significance for biodiversity conservation. Nature Map aims to provide global maps on biodiversity and ecosystem services which based on the best scientific data. These maps can be used to support the design and planning of policies which aim to reduce biodiversity loss and net greenhouse gas emissions. Furthermore, the maps can be used as a decision support tool in identifying areas for conservation and restoration intervention and implementation. The data are available to explore via the Nature Map explorer platform and will also be freely accessible via UN Biodiversity Lab.

Link: Nature Map

UN Biodiversity Lab

The platform houses around 400 datasets covering biodiversity, ecosystem services and other environmental and sustainable development parameters, including data relevant to mangrove analysis such as mangrove forests, biomass carbon density, mangrove soil carbon, distribution of saltmarshes, annual fishing hours, human development index, NDVI, areas of global significance for biodiversity conservation and carbon storage and human population layers (WorldPop). Many of these datasets are also present on the NatureMap platform. Users can also create secure workspaces to incorporate national data alongside global data.

Link: UN Biodiversity Lab

EarthMap

Developed by the FAO, the tool provides a simple interface for a user to display and interact with datasets. Furthermore, the tool allows the user to query the data and produce statistics and simple analysis via Google Earth Engine without needing to use code. Users can select regions and countries or upload their own areas of interest for analysis.

Link: EarthMap

Global Mangrove Alliance

The platform provides users with news and updates on mangroves around the world with information on initiatives, restoration projects, new and relevant papers and reports. The platform includes a knowledge hub with tools and resources as well as the Global Mangrove Watch where users can view and download mangrove spatial datasets including extent, habitat change and blue carbon.

Link: Global Mangrove Alliance

Ocean Wealth

The Ocean Wealth includes a mapping portal, allowing the user to explore datasets including recreation and tourism, and coastal protection as well as learn more about their methodologies.

Link: Ocean Wealth

NASA Socioeconomic Data and Applications Centre (SEDAC)

The SEDAC platform allows users to download spatial data, often at the global scale, including population, built up areas and degree of urbanisation. Furthermore, data available covers themes including marine and coastal regions, infrastructure, conservation and hazards.

Link: NASA SEDAC

Myanmar Information Management Unit (MIMU)

This initiative tracks available data on over 270 indicators across 13 sectors. Data is gathered at the lowest administrative levels at which it is available. Data covers demography, economy, environment, health, nutrition, peacebuilding and agriculture, some of which is disaggregated by rural/urban, gender, township, etc).

Link: MIMU

3.2.3 Tools for modelling ecosystem services

Below is a selection of relevant tools which can be used to map and model ecosystem services provided by habitats such as mangroves. Furthermore, these can be used to assess the impacts of deforestation and degradation on the provisioning of ecosystem services provided by them. Different tools require differing levels of inputs and GIS skills.

InVEST

InVEST is a free suit of software models developed by the Natural Capital Project for mapping and valuing a range of ecosystem services. These include the services relevant to mangroves, such as blue carbon, coastal vulnerability and recreation.

Coastal vulnerability model

The InVEST coastal vulnerability model produces a qualitative estimate of exposure in the form of a vulnerability index. This index differentiates areas with relatively high or low exposure to erosion and inundation during storms.

Model inputs include digital elevation and bathymetry rasters as well as polygons representing the locations of natural habitats (e.g. mangroves, seagrass, coral reefs etc.) and a raster layer representing the distribution of coastal populations.

The outputs of the model can be used to better understand the contribution of different model variables to coastal exposure and highlight the protective services offered by natural habitats such as mangroves. The resulting spatial layers can be used in planning to identify areas most at risk and where natural habitats are contributing most to coastal protection. The model outputs several GIS files including a coastal exposure index layer, habitat role and population as well as intermediary layers including wind and wave layers and geomorphology to understand the final outputs.

Blue carbon model

The InVEST Blue Carbon model predicts the amount of carbon stored and sequestered over a coastal zone at particular points in time due to changes in land cover. The value of carbon stored or sequestered can also be estimated by the model using a market price or societal value of carbon. The results of the model can be used to identify where within a landscape the degradation or deforestation of coastal ecosystems such as mangroves should be avoided, and where restoration should be prioritised to enhance carbon storage and sequestration.

InVEST Visitation (Recreation and Tourism) model

Mangrove recreation and tourism increasingly contributes to the livelihoods and incomes of local communities. The InVEST model predicts the spread of person-days of recreation, based on the locations of natural habitats and other features such as roads and airports. Where empirical data on recreation is not available, the tool uses geotagged photos from the website *flickr* to parameterise the model. However, in areas where flickr is less commonly used, tourism hotspots may not be picked up, or they may be rated lower. The tool can be used to predict how changes to natural features will change visitation rates.

Model inputs include areas of interest (e.g. coastal states or regions), spread of natural habitats (e.g. mangroves), built features (e.g. roads), and human uses (e.g. industrial activities) amongst others. Scenarios can be analysed by altering one or some of the input variables (e.g. the area of mangroves or existence of roads).

Outputs include maps of current patterns of recreational use and maps of future patterns under different scenarios.

TESSA Toolkit

The TESSA Toolkit is an interactive user manual (best opened through Adobe Acrobat) which can be downloaded to be used online or offline in the field. The tool provides decision trees, guidance and methods for measuring and evaluate ecosystem services and identify priority sites. The tool aims to generate data which can be used to guide decisions aimed at safeguarding ecosystem services and covers six ecosystem services: global climate regulation, water-related services, harvested wild goods, cultivated goods, nature-based recreation and cultural services. The tool provides a low-cost approach and the user is not required to have advanced skills. The toolkit has been tested extensively across different contexts, countries and across habitats including wetlands.

Ex Ante Carbon balance Tool (EX-ACT)

Developed by FAO, this tool provides a non-spatial method for understanding the greenhouse gas (GHG) impact of land use changes and mangrove degradation. The tool allows the user to input areas of mangrove and other coastal habitats and changes to their condition over a specified timeline. The tool calculates a GHG balance by comparing emissions to a baseline scenario. The tool uses default IPCC Tier 1 emissions and removal factors which can be updated with Tier 2 values (those sourced from the literature or through field studies) to calculate GHG emissions and removals.

3.2.4 Proposed analyses

Carbon storage

Carbon storage in mangroves will be assessed by FAO and a layer produced.

- *Distribution of estimated carbon stocks in Myanmar's mangroves (two regions)*

Coastal protection

An analysis may be carried out showing where mangroves (potentially alongside other habitats such as coral reefs and seagrass) currently contribute to coastal protection. Analysis could be done using the Coastal Vulnerability InVEST model, with inputs including coastal populations. The coastal population data can be disaggregated by demographic where data is available. This can include gender and age groups.

- *Modelled protection services provided by coastal ecosystems*

Tourism

This analysis could help to determine where mangrove habitats are potentially contributing to nature-based tourism in coastal areas.

This could be done using existing global analysis (Spalding and Parrett 2019) and clipping data to areas of interest. The InVEST Recreation model is another option; inputs include mangroves presence/absence, distance to cities, roads and features such as airports (where available). In the absence of spatial data on mangrove tourism, the model would use data from flickr (between 2005 and 2017) to estimate visitation rates. However, it is noted that flickr may not be as useful a data source for tourism in Myanmar as other platforms; for example, domestic and regional tourists may be more likely to share photos using Facebook or Instagram (which may be difficult/impossible to link to the InVEST model)[8].

[8] It is also not possible to specify that the model uses photos tagged as mangrove. Instead, an area of interest must be supplied and all photos located in the area will be used, therefore areas considered to have high levels of tourism may not be for mangrove specifically.

Other sources of data on ecotourism in mangroves could be explored, such as national tourism statistics or assessments of ecotourism potential (including potential roles/benefits for different stakeholder group), and a workflow jointly developed with stakeholders, if tourism is prioritised as a mangrove ecosystem service.

- *Modelled/estimated tourism services provided by mangroves*

Potential economic/cost-benefits case study

A recent global study by Su, Friess and Gasparatos (2021) estimated the per hectare value or restored and natural mangroves for a number of ecosystem services including carbon storage and sequestration, fisheries, coastal protection, timber production and education and research.

In Myanmar, Estoque *et al.* (2018) estimated the coastal protection services provided by mangroves to be US$1,369 ha^{-1} $year^{-1}$ based on avoided expenditures from reclamation and replenishment. Other services valued included fuelwood, non-timber and non-fish products, regulation of water flow and water quality, recreational and cultural services. Maintenance of fisheries nursery populations and habitat was estimated to have the highest per hectare value, at US$ 9,112.45 per hectare per year. These values were estimated using a benefit transfer approach and could be applied to mangrove extents. It should be noted that values should vary by mangrove condition, age and spatial context (e.g. proximity to local populations), as well as how ecosystems are accessed and used by different groups (e.g. men, women, ethnic groups, migrants, etc). However, data limitations mean that this may not be possible to achieve this level of detail within the scope of the study.

The potential to collect and integrate additional economic or cost-benefit data about the value of mangroves (e.g. to communities, to specific groups, for global significance) into the analyses planned for this activity is also under consideration. Recognising that the Covid-19 and security situation in Myanmar may affect this work, this additional task is currently ‘’to be confirmed’’. If conditions allow, in the second phase of the project, we will aim to collect targeted data and perspectives on mangrove ecosystem services and their values, e.g. market values for fisheries and other products, values for different stakeholder groups (including by gender), and/or other additional existing economic information.

The potential to include economic assessments on ecosystem services losses and gains using a benefit transfer approach could also be scoped. Values for relevant services may be sourced from the literature where available, or from the local data collection described above. These can be applied to maps of mangrove extents and varied by condition (e.g. degraded, restored, natural, etc.) where possible, in order to map the value of mangroves more accurately, and applied to resulting ecosystem service losses and gains. It may not be possible to do so for all identified services, based on data availability. However, services such as carbon storage and sequestration may be relatively straightforward (e.g. by applying the social cost of carbon).

Another option may be to consider including information on the benefits and costs of mangrove reforestation and rehabilitation, and/or conservation and sustainable management, depending on the availability of nationally specific data; further investigation of existing case studies on cost-benefit ratios would also be needed, e.g. to produce a synthesis or review of currently available data on costs and benefits. If available, data showing the potential costs and benefits of mangrove management options according to different stakeholder groups (e.g. by income level, livelihood groups, gender, etc) would be a useful element of such a review.

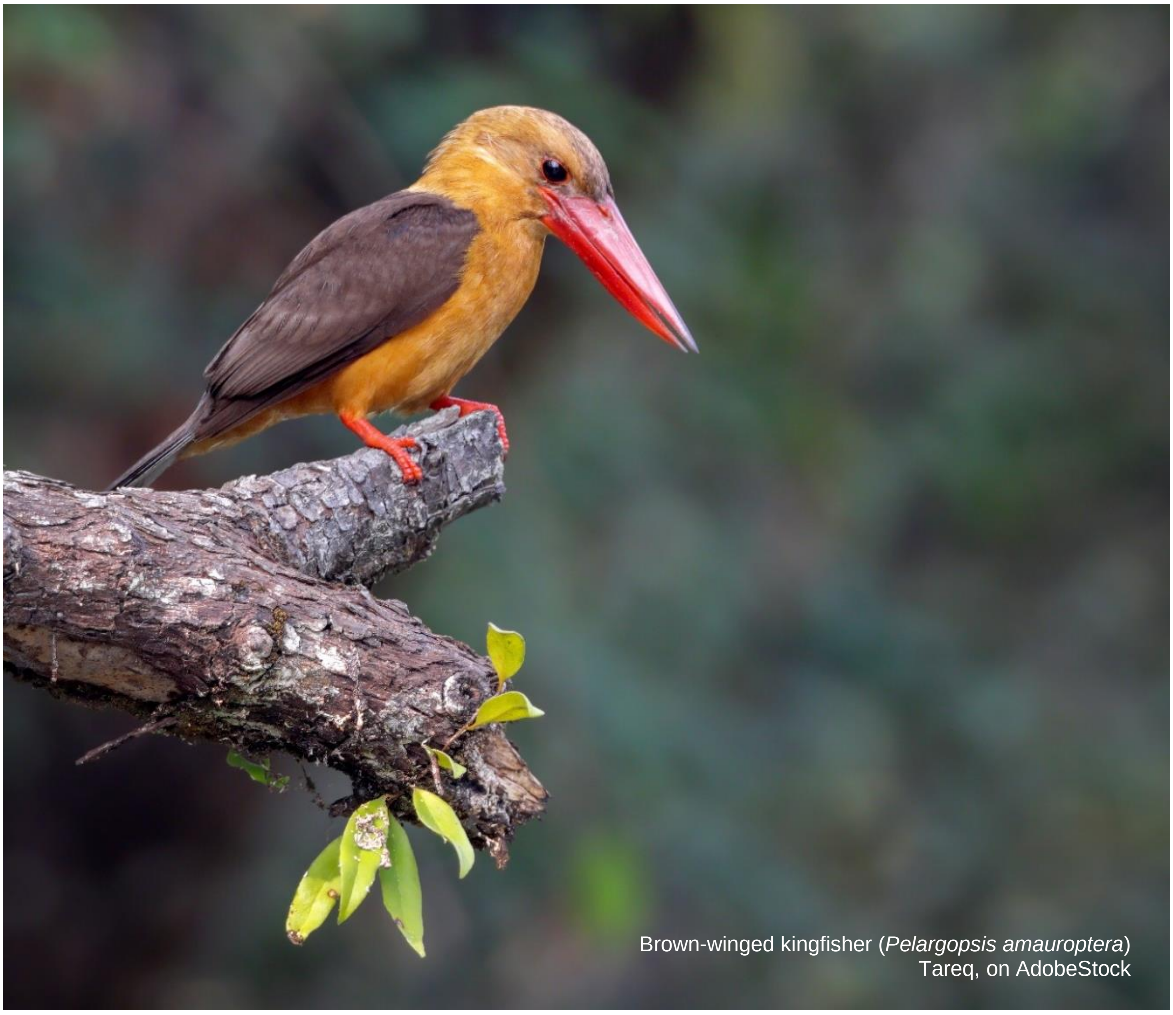
3.3 Biodiversity

Mangroves provide significant benefits to biodiversity and the wider environment. They provide habitat, breeding grounds and nurseries for a variety of species, from the fishing cat (*Prionailurus viverrinus*) to the lemon shark (*Negaprion brevirostris*). The mangroves of Myanmar contain high levels of biodiversity, with many of the species considered threatened.

There are 34 known species of mangrove trees in Myanmar (Aye *et al.* 2019), Over 230 bird species have also been recorded in mangrove forests in Myanmar, including the lesser adjutant stork (*Leptoptilos javanicus*), mangrove pitta (*Pitta megarhyncha*), and the brown-winged kingfisher (*Pelargopsis amauroptera*), all considered as flagship species in these habitats (Zöckler and Aung 2019). Furthermore, over 20,000 individual migratory waterbirds have been counted spending the winter in the mangroves of southern Tanintharyi (Zöckler and Aung 2019). Large fauna including marine turtles, crocodiles, hog deer, wild pigs, jackals, sambar deer, wild cats and elephants have been found to inhabit Myanmar's mangrove forests (Win 2004). Insects are also present, including several bee species, noting that the honey they produce is highly valued in the country (Zöckler and Aung 2019)

Biodiversity is recognised in Myanmar at many levels, with environmental policies and strategies being developed by the government since the 1990s. The 1995 National Forest Policy highlights the need to protect soils, water catchments, ecosystems and biodiversity. It recognises the need for sustainable forest management and aims for 30% of land areas to be reserved for forests, and 5% for protected areas (MoNREC 2016). The 2015 NBSAP reinforces the need for biodiversity conservation and outlines key priorities for action in line with the Aichi targets, including improved understanding by the different sectors of society (decision makers, private sector, media and local communities) of the value of biodiversity; incorporating biodiversity conservation into land use plans; and protection and sustainable management of mangrove forests and wetland areas (Forest Department Ministry of Environmental Conservation and Forestry 2015).

The 2018 Biodiversity and Protected Areas Law, which succeeded the 1994 Protection of Wildlife and Conservation of Protected Areas Law, also highlights the role of local communities in protected areas and in achieving biodiversity conservation (Myanmar UN-REDD Programme 2019). The Myanmar Climate Change Strategy and Action Plan (MCCSAP) 2016–2030 acknowledges the impacts of current and future climate change on biodiversity, and highlights the need to "(…) manage its natural resources to enhance the resilience of its biodiversity and ecosystem services that support social and economic development and to deliver carbon sequestration" (MoNREC 2016).


Brown-winged kingfisher (*Pelargopsis amauroptera*)
Tareq, on AdobeStock

3.3.1 Data availability

Data on biodiversity comes in many forms. It can be related to individual species, such as the IUCN Red List, or related to important areas for biodiversity as a whole, such as key biodiversity areas. There is a good selection of global datasets on biodiversity which can be used for national scale analyses, but there is a lack of specific national scale data.

Table 8. Relevant biodiversity spatial datasets, global to national scales

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
Global	Mangrove biodiversity importance (Based on IUCN Red List Data including species ranges and dependencies on mangroves)	Mangrove biodiversity and people project	1km	1996 and 2016		Internal UNEP-WCMC layer
	IUCN species range data	IUCN (2021)	Polygon	2021		Link
	Key Biodiversity Areas	BirdLife International	Polygon	2021		Request here
	Global Biodiversity Information Facility (GBIF) data on species occurrence	GBIF	Point	1600-present		Link
	Marine Key Biodiversity Areas	WCS	Polygon	2012		
	Marine Key biodiversity areas that are important for turtles	WCS	Polygon	2012		
	Global Safety Net: Rare Species Sites	Dinerstein *et al.* (2020)	Polygon	NA	Link	Link
	Global Safety Net: Intact Wilderness Areas	Dinerstein *et al.* (2020)	Polygon	NA	Link	Link
	Global Safety Net: High Biodiversity Areas	Dinerstein *et al.* (2020)	Polygon	NA	Link	Link
	Modelled mangrove commercial finfish enhancement	Ocean Wealth	Raster	Not available	Not available	Available to view
	Modelled mangrove commercial	Ocean Wealth	Raster	Not available	Not available	Available to view

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
	invertebrate enhancement					
National	World Database on Protected Areas	UNEP-WCMC and IUCN (2021)	Polygon	Ongoing	NA	Link
	National Red List of ecosystems assessment – Highest category of risk per cell	Murray *et al.* (2020)	Raster		Link	On request
	Myanmar Marine Biodiversity Atlas	WCS			Link	Currently unavailable
	Myanmar Conservation Corridors	WCS	Polygon	2015		On request
	Shark distribution	WCS	Polygon	No informa-tion available	No informa-tion available	No information available

3.3.2 Data platforms

Several platforms are available which host biodiversity data relevant to mangrove habitats. Some platforms allow users to download data, whilst others visualise data for users to view and query. Some examples include:

IUCN Red List of Threatened Species

The IUCN Red List is the most comprehensive source of species extinction risk globally. There are currently over 138, 000 species assessed and included on the IUCN Red List. As well as assessing species' extinction risk, the IUCN Red List also provides information on habitat preferences and the global range of each species. This enables range data for species of mangroves and species associated with mangroves to be downloaded in the form of polygons or points. This requires the user to create an account.

ASEAN Biodiversity Dashboard

ASEAN Biodiversity Dashboard layers include species occurrences, zoonosis outbreaks, habitat building species and protected areas and heritage parks. Layers can be viewed but are not available for download directly from the platform, and links to data sources are available (e.g. to GBIF for species occurrence data).

3.3.3 Proposed analyses

Biodiversity layers could be produced to demonstrate the importance of mangroves to biodiversity, their role in supporting species movement and connectivity and the extent to which key biodiversity areas overlap with protected areas.

Mangrove biodiversity importance

The project could produce a map showing estimated mangrove biodiversity importance using data developed for the UNEP Mangroves and People project, including mangrove associated species identified through the IUCN Red List. Biodiversity significance was calculated by weighting each pixel where mangrove-associated species occur, based on the number of overlapping species ranges and the proportion of the global distribution the pixel represents. Therefore, pixels with rare species receive a higher rating, reflecting the significance of the pixel for mangrove associated species. The IUCN Red List range data used here provides information on where the species range extends, rather than their actual area of habitat. However, for this analysis the range data were refined by landcover to produce the area of habitat. This is still not perfect though and ground surveys are needed to confirm the presence/absence of species. This analysis was based on only the taxonomic groups which have been comprehensively assessed, including birds, mammals, amphibians, mangrove plants and selected groups of reptiles and fish, meaning information on species from other groups is missing. These species are used as a proxy to represent biodiversity, it is not a comprehensive analysis of all species present.

- *Map showing mangrove biodiversity importance based on mangrove wildlife species*

Mangrove connectivity

This map would show which patches of mangrove are important for the connectivity of mangrove species. This could either be done for generic species (e.g. short, medium and long dispersers), or a specific species or group of species where dispersal information is known. This analysis may not be possible due to the presence of other tree types which animals can move through within mangrove forests. The inclusion of this layer will depend on feedback from stakeholders and experts on its feasibility.

- *Map showing mangrove areas important for connectivity of wildlife species*

Key Biodiversity Areas (KBAs)

This layer would utilise global KBA data for Myanmar (and/or updated Threatened Ecosystems of Myanmar/ new KBAs data for Myanmar), and could be combined with current protected areas in the country. Furthermore, BirdLife international could be consulted, e.g. produce an irreplaceability score (Baisero *et al.* 2021).

- *Map showing areas of mangrove that fall within KBAs*

Protected Areas (PAs)

This layer can be generated using existing WDPA (and/or national if available) data.

- *Map showing areas of mangrove that fall within PAs*

Other biodiversity data

Other options for mapping or analysing biodiversity are dependent on access to ground survey and/or other national or local datasets, e.g. survey data for particular sites and/or species, and/or recent analyses on conservation priorities. This needs to be explored with Myanmar civil society organisations.

Another option here is to produce a map using combining several biodiversity-related layers to look at the distribution and any potential overlap in *mangrove areas with significance for biodiversity conservation* (which could then be fed into multi-criteria analysis, as described below).

3.4 Restoration potential and priorities

3.4.1 Data availability

Maps of mangrove degradation vary in terms of scale, accuracy, coverage and resolution and may be developed from a range of data sources including in situ data from field observations, expert opinion and remote sensing. Remote sensed data is increasingly used, as these overcome some limitations associated with field observation data such as being labour intensive, costly and limited to local scales. The high temporal and spatial coverage of remote sensed data allows mapping of mangrove degradation to occur at greater scales, and over longer periods of time (time-series analysis).

Understanding where mangrove deforestation and degradation has occurred can inform analysis on restoration potential, in combination with other factors. Analysis carried out using the Restoration Opportunities Assessment Methodology (ROAM) in Myanmar identified key opportunity areas forest landscape restoration, including mangroves. Criteria included watersheds with forest cover in 1990 and at least 15% canopy cover loss between 1990-2015, Key Biodiversity Areas, and areas near roads or populated places (Constable *et al.* 2019).

Table 9. Relevant datasets mapping mangrove degradation and restoration potential, global to national scales

Extent	Description	Author(s)	Resolution	Year(s)	Link to paper	Link to data
Global	Tropical Moist Forest dataset	Vancutsem *et al*. (2021)	30m	1990-present	Link	Link
	Global forest change	Hansen *et al.* (2013)	30m	2001-present	Link	
	Mangrove degradation and restoration potential	Worthington and Spalding (2018)	25m	2016	Link	Link (to request access)
	Global biophysical typology of Mangroves	Worthington *et al.* (2020)	Vector (GMW extents)	1996, 2007, 2008, 2009, 2012, 2015, 2016	Link	Link
National	IUCN ROAM for Myanmar – Mangrove degradation	Constable *et al*. (2019)	90m	1990-2015	Link	Request from IUCN
	IUCN ROAM for Myanmar – Restoration opportunity areas and prioritised forest landscape restoration areas (Rakhine, Ayeyarwady, Bago)	Constable *et al*. (2019)	90m	1990-2015	Link (table 2)	Request from IUCN
	Myanmar mangrove condition layer	FAO	30m	2016 and 2021	In develop-ment	In develop-ment
	Mangrove extent and degradation in Rakhine State, Myanmar	Lee *et al.* (2021)	30m	2017	Link	GEE Random Forest Script (Need to request output layers)
	Threatened ecosystems of Myanmar	Murray *et al*. (2020)	Unknown	2020	Link	Request from IUCN

3.4.2 Proposed analyses

Multicriteria analysis based on the ROAM methodology can be used to identify priority areas for restoration (potentially weighted depending on variables used). This analysis has already been carried out at the national level in Myanmar (including mangrove habitats) (Constable *et al.* 2019). This data may be used to inform analysis outputs or may be updated using the new FAO data on mangrove extent and condition. Inputs with stakeholders may be used to inform whether other parameters/values can be added to the existing data. Input variables could include distance to roads and towns, population sizes, recent deforestation/degradation, potential ecosystem service provisioning and importance for biodiversity conservation (using a combination of the layers described above). Input variables may be finalised through stakeholder consultation, ensuring participation of all key stakeholder groups.

- *Map of priority areas for mangroves restoration with potential multiple benefits for carbon, biodiversity and ecosystem services provision*

3.5 Limitations and gaps in knowledge and data

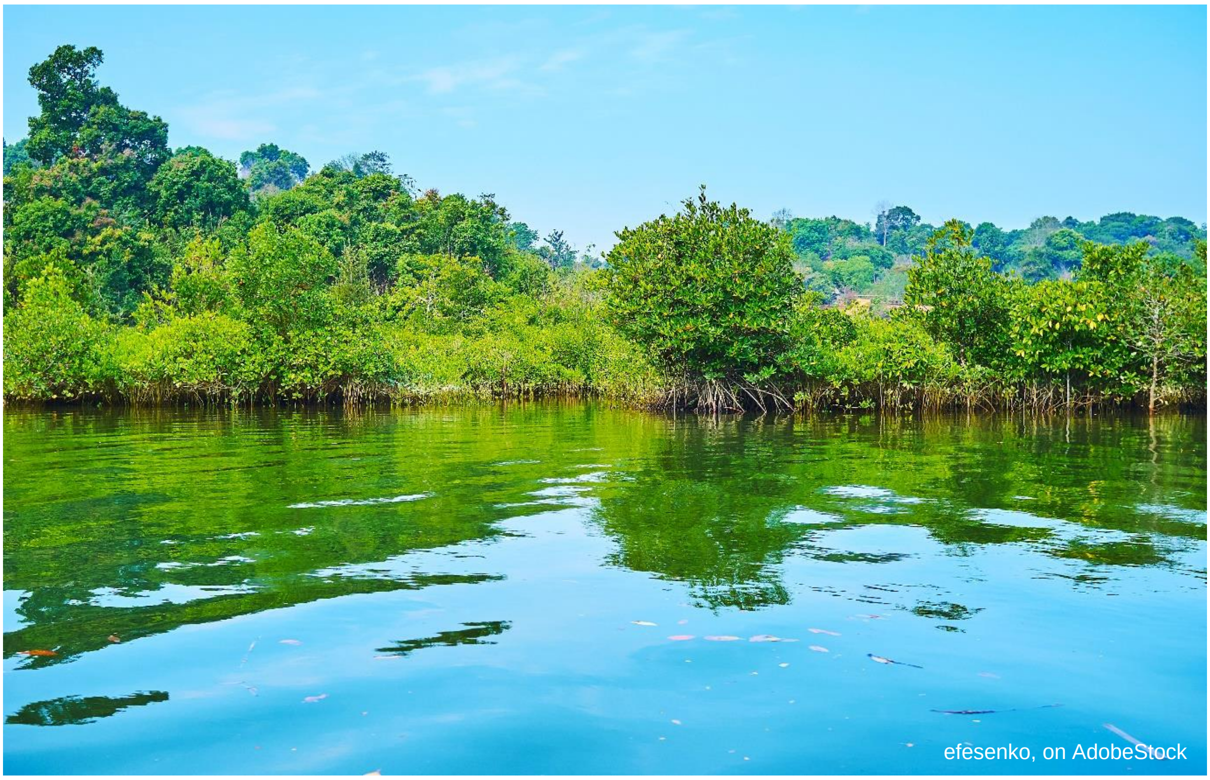
There are limitations and gaps in our understanding of the ecosystem services provided by mangroves (Himes-Cornell *et al.* 2018), which can prevent decision makers from making informed choices based on their true value, contributing to their deforestation and degradation. In particular, the provisioning of ecosystem services by mangroves under different conditions (e.g. intact, degraded, restored, mixed-species) and by stands of different ages are poorly understood. Furthermore, mangroves vary in their structure, height and species, which in turn influence their ecosystem service provisioning (Worthington *et al.* 2020). Improving estimates of ecosystem services provided by mangroves of different typologies, and in relation to different groups of users, will better enable ecosystem service and natural capital assessments and tailored management of coastal ecosystems. For example, gender disaggregated data and analyses of differentiated gender roles in forest use and management, especially in mangroves, is limited in Myanmar. Ecosystem undervaluing poses an obstacle to effective decision-making and land-use planning (Emerton 2006). For example, specific national estimates of carbon emission and removal factors for mangrove areas are not available yet in Myanmar. In particular, their FREL, submitted in 2018, estimated that SOC estimates for mangroves may not be available until 2022/2023 (MoNREC 2018). Establishing these will improve estimates of carbon currently stored in mangrove biomass and soils and prioritising areas for protection and restoration.

More robust data on mangrove extent and loss is needed; repeated analysis using remote sensing and ground truthing can improve monitoring data from local to global scales. There are considerable differences in the extent and rate of deforestation in mangroves in Myanmar estimated by different studies. Estoque *et al.* (2018) estimated that mangroves in Myanmar were lost at a rate of approximately 2.2% per year between 2000 and 2014, Webb *et al.* (2014) estimated a loss rate of approximately 1% per year between 2000 and 2013, and data from Hamilton and Casey (2016) estimates annual loss rates ranging from 0.2% in Tanintharyi to 2.65% in Rakhine State between 2000 and 2012.

Improving understanding of the extent and drivers of mangrove degradation is needed to better understand trends and impacts on ecosystem service provisioning, biodiversity and local communities, including the role and impact of different users, and to develop initiatives to address these drivers. Despite mangroves still standing, their ability to provide vital resources and protection could be severely impacted by degradation.

Many mangrove extent, restoration opportunity and ecosystem service layers are global. These have constraints for informing analysis at the national or subnational level, including low resolution and the inability to use country-specific data (IUCN and WRI 2014). Improving these datasets at a national or subnational level with higher resolution and local training data will increase the accuracy of future assessments. Due to difficulties in mapping, there is an under-representation of ecosystem services beyond carbon storage available, such as fisheries production, harvested timber and non-timber products. Developing spatial assessments of these services and including where possible the way these services are accessed by different stakeholder groups, can more accurately highlight areas contributing to the livelihoods and wellbeing of local communities.

Data on the status of biodiversity and coastal habitats in Myanmar and particularly on mangrove-dependant species is lacking. Biodiversity data produced at global scale poses challenges in using it for analysis at national or local scales. For example, IUCN Red List species range data displays the general area of occurrence, rather than the actual area of habitat for the species. This can, to some extent, be overcome by refining the ranges based on landcover data but this still is not perfect. Ground surveys are needed to confirm the presence/absence of species. There is also a taxonomic bias in this dataset towards birds, mammals and amphibians, with species from other groups lacking information. Improving these datasets, as well as more detailed national surveys on species of interest could result in better assessments of conservation priorities and outcomes.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IV

PROPOSED TUTORIALS

As part of this activity under the Myanmar Mangroves project, a series of tutorials will be produced for distribution among potential users in Myanmar; these tutorials are designed to help people working on mangrove and other forest conservation and management to carry out selected GIS analyses. These tutorials will draw on existing and updated tutorials produced by the UN-REDD Programme. The final list of tutorials for translation and dissemination will be based on discussion with project partners and stakeholders and consideration of available resources.

4.1.1 Relevant existing tutorials

Relevant existing QGIS tutorials could be updated and shared for capacity building purposes. These may need to be updated to reflect the latest version of QGIS being used, such as:

- Introduction to QGIS 2.18
- Mapping areas of importance for multiple benefits of REDD+ using QGIS 2.18
- Extracting and processing IUCN Red List species data using a vector/raster method
- Building spatial workflows to identify potential areas for undertaking a REDD+ intervention using the Graphical Modeler

4.1.2 Potential new tutorials

A limited number of tutorials on the analyses to be undertaken by the project could also be developed, to build capacity for similar assessments to be undertaken in different areas, or to update existing analysis as new data becomes available. These will use open-source GIS mapping software, mainly QGIS. Final selection of tutorials will be based on stakeholder engagement to understand needs.

Mangroves under pressure/ mangroves at risk

The tutorial would describe the datasets and methodological steps used to map human pressures on existing mangrove habitat, the outputs of this assessment may help identify drivers of mangrove degradation and loss spatially. Furthermore, the data can be used to identify intact mangroves which may be at risk of loss and encroachment.

Mapping coastal vulnerability/protection provided by mangroves

It is possible to develop a tutorial on using the InVEST Coastal Vulnerability model to map areas which are of high importance for coastal protection (in terms of wave exposure and affected coastal populations). The tutorial would include sourcing the relevant data, parametrising the model and using the model's spatial outputs to identify priority areas for protection/restoration of mangroves.

Multicriteria analysis for identifying mangrove areas providing multiple benefits

This tutorial would be based on the ROAM methodology and multi-criteria analysis, for identifying areas with priority for conservation and/or restoration of mangroves, based on their potential contribution to local livelihoods, biodiversity conservation and climate. This would include identifying relevant datasets, such as coastal populations, distances to villages/roads, ecosystem service provisioning and species range data. The output would be a map highlighting areas which are hotspots for contributing multiple benefits and which may be relevant for conservation or restoration.

The Continuous Change Detection and Classification (CCDC) algorithm

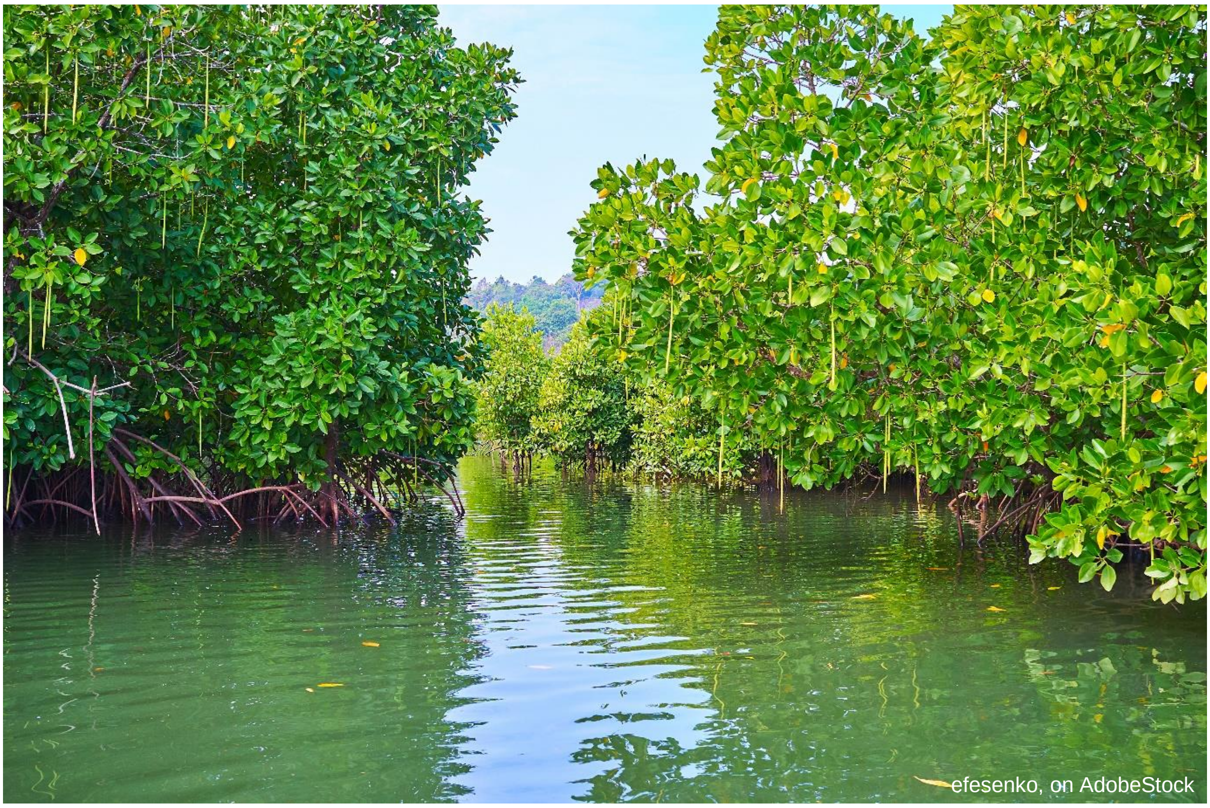
Two training and exercise sessions were carried out with FAO support in late 2020 on the with the purpose of creating a land cover map for 2020 and a land cover change map between 2015 and 2020 which identifies forest degradation, with a special focus on mangroves in the Ayeyarwady region of Myanmar. The training focused on the creation of a time series of Landsat-8 images and the application of the Continuous Change Detection and Classification (CCDC) algorithm using SEPAL and Google Earth Engine. The materials could be used as part of a package of tutorials.

V

DISSEMINATION OF OUTPUTS

The analyses to be carried out under this activity is intended to feed into two main aspects of the project: a) informing future planning and implementation of REDD+ actions in mangrove areas, and b) supporting communications and advocacy around the importance of mangroves, primarily for communities and a civil society audience.

The maps and layers produced under this activity may therefore be useful in the development of subsequent outputs, such as: maps showing areas of importance (e.g. in terms of ecosystems and/or biodiversity) in particular geographical areas or communities relevant to the project; spatial plans related to prioritising particular action in mangrove areas, such as conservation or restoration; and communications materials, such as brochures, reports and story-maps. The final format of such outputs is dependent on which project activities move forward and discussions with project partners.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Annex 1 – Mangrove extent analysis

Mangrove extent maps have been created from global and national datasets and satellite data time series analysis for the Ayeyarwady and Tanintharyi regions.

Firstly, a mangrove and non-mangrove mask was created from the combination of the following global and national mangrove dataset, and the MERIT Digital Elevation Model: the Global Mangrove Watch of 2016 (Bunting *et al.* 2018), the Global Mangrove Forest Distribution of 2000 (Giri *et al.* 2013), the Global Mangrove Distribution of 2000 (Simard *et al.* 2019) and the land use land cover map of Myanmar 2015 (MONREC and FAO 2016). Mangrove and non-mangrove area were mapped where all these datasets agree on the (probable) presence of mangroves and on the (probable) absence of mangrove respectively. A training data set was obtained for later classification using a stratified random sampling over the mangrove and non-mangrove masks (2500 samples of non-mangrove and 500 samples of mangrove forest).

Secondly, mangrove presence probability maps targeting the 1st of January of 2016 and the 1st of January of 2021 were created from time series that combine optical Landsat-8 and radar Sentinel-1 data for the period from 2013 to 2021, and MERIT DEM. To extract the information from the time series for the target dates, the Continuous Change Detection and Classification (CCDC) algorithm (Zhu and Woodcock 2014) was applied, which simultaneously map land cover and land cover changes. CCDC models the time series as a Fourier series, considering the temporal dynamics (seasonality and trend), important for dynamics ecosystems as mangroves, and abrupt changes (deforestation and forest degradation events). This information was classified in a probably map applying a random forest classifier using the mangrove and non-mangrove training dataset.

Finally, mangrove extent maps for the same dates were obtained from the classification of the probably map. To improve this mangrove extent map, and remove misclassified areas, a random forest stratified sampling over 'uncertain' areas (250 points overlapping the non-mangrove mask and 50 overlapping the mangrove mask) were validated by national experts using high resolution satellite data in Collect Earth. These validated points were ingested in the training dataset to repeat the classification.

Detailed information can be found here: https://docs.google.com/presentation/d/13e1eanQ8GdYZFFx6Q_GHOlF7t6HahjR1/edit#slide=id.p1. See also Table A below.

Table A: Mangrove extent data produced by FAO. Data can be used in, and downloaded from, Google Earth Engine. Links to GEE assets are provided in the table.

Region	Map	Year	GEE Asset
Ayeyarwady	Mangrove extension	2016	projects/ee-mangrovemyanmar/assets/mangrove_mmr_ayeyarwadi_no_masked_new_2016_mean
	Mangrove extension	2021	projects/ee-mangrovemyanmar/assets/mangrove_mmr_ayeyarwadi_no_masked_new_2021_mean
	Mangrove change	2016-2021	projects/ee-mangrovemyanmar/assets/mangrove_change_class_ayeyarwady
Tanintharyi	Mangrove extension	2016	projects/ee-mangrovemyanmar/assets/mangrove_mmr_tanintharyi_no_masked_new_2016
	Mangrove extension	2021	projects/ee-mangrovemyanmar/assets/mangrove_mmr_tanintharyi_no_masked_new_2021
	Mangrove change	2016-2021	projects/ee-mangrovemyanmar/assets/mangrove_change_class_tanintharyi

Annex 2 – Mangrove change analysis

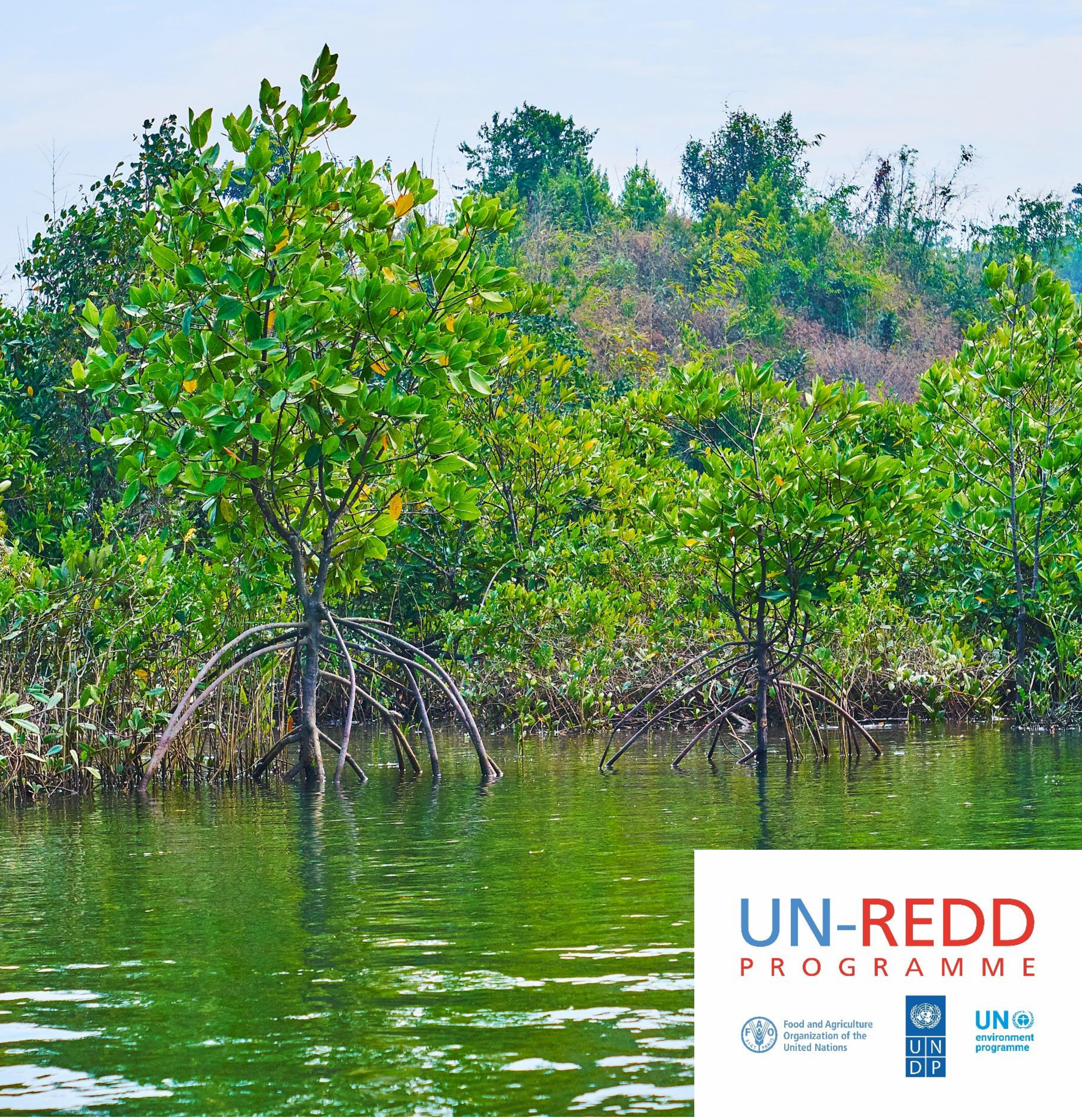
A mangrove change analysis for two regions has been developed through support provided by the UN-REDD project ‘Integrating mangroves sustainable management, restoration and conservation into REDD+ Implementation in Myanmar’. This annex describes the methodology in more detail.

The mangrove extent maps of Ayeyarwady and Tanintharyi regions have been classified into different land cover classes and mangrove conditions (young and mature mangroves) and percentage of canopy cover. As with the extent analysis (see Annex 1), CCDC was applied to time series of Landsat-8 and Sentinel-1 for the period from 2013 to 2021 to map land cover targeting the 1st of January of the years 2016 and 2021.

The training dataset for this classification was composed of plots centred at the location of the field plots collected by the National Forest Inventory (NFI) field testing during 2019 and first quarter of 2020, carried out in these regions (278 plots in Ayeyarwady and 573 in Tanintharyi). National experts classified these plots in Collect Earth for two time periods (2016 and 2021) in land cover, mangrove types and mangrove canopy cover classes; degradation (or regeneration) presence, with its possible causes, was also recorded.

The classification was supported by the following information integrated in Collect Earth: 1) the NFI data (including forest type, canopy cover, height, basal area, human activities) and 2) satellite data of different types (high resolution imagery available in Google Earth and Bing maps, Sentinel-2 and PLANET for the study times, and time series of vegetation indices). A smile random forest classifier was applied using the information of the spectral bands and vegetation indices of the CCDC models.

It will be studied further as to whether the degraded mangrove can be distinguished from non-degraded mangrove.



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