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Mangroves of the Red Sea and Gulf of Aden

EN

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Abstract
Mangroves of the Red Sea and Gulf of Aden is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine eco-regions of Gulf of Aden, Northern and Central Red Sea, and Southern Red Sea, and extends across Saudi Arabia, Egypt, Sudan, Yemen, Eritrea, Djibouti and Somalia. The biota is characterized by two species of true mangroves namely; *Avicennia marina* and *Rhizophora mucronata.* Both are classified by IUCN as Least Concern. The Red Sea and Gulf of Aden mangroves are threatened by cattle grazing, oil and solid wastes pollution, coastal development, heat waves and sea-level rise. Aridity and drought nature of this province, along with low nutrient inputs, are expected to exacerbate the adverse impacts of climate change on mangroves.

The mapped extent in 2020 was 189.2 Km^2, representing 0.1 % of the global mangrove extent. However, there is uncertainty about mapped extent in 1970 based on available studies. Although the net area of mangroves has decreased by 21.7% since 1996, it has only decreased by 4.0% since 2010. This improvement may be the result of increased conservation efforts to restore mangroves in various Red Sea and Gulf of Aden countries. Under a high sea-level rise scenario (IPCC RCP8.5) ≈-67.1% of the Red Sea and Gulf of Aden mangroves would be submerged by 2060. Moreover, 1.7% of the province's mangrove ecosystem is undergoing degradation, with the potential to increase to 5.2% within a 50-year period, based on a vegetation index decay analysis. Overall, the Red Sea and Gulf of Aden mangrove ecosystem is assessed as **Endangered (EN).**

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Keywords:
Mangroves; Red List of ecosystems; ecosystem collapse; threats.

Ecosystem classification:
MFT1.2 Intertidal forests and shrublands
Assessment's distribution:
Red Sea and Gulf of Aden province
Summary of the assessment

Criterion	A	B	C	D	E	Overall
Subcriterion 1	**NT**	**LC**	**DD**	**DD**	**NE**	
Subcriterion 2	**NT**	**LC**	**EN**	**LC**	**NE**	**EN**
Subcriterion 3	**DD**	**LC**	**DD**	**DD**	**NE**	

EN= Endangered, NT= NearThreatened, LC= Least Concern, DD= Data Deficient, NE=Not Evaluated

Mangroves of the Red Sea and Gulf of Aden

EN

1. Ecosystem Classification

IUCN Global Ecosystem Typology (version 2.1, Keith *et al.* 2022):

Transitional Marine-Freshwater-Terrestrial realm

MFT1 Brackish tidal biome

MFT1.2 Intertidal forests and shrublands

MFT1.2_4_MP_18 Mangroves of the Red Sea and Gulf of Aden

IUCN Habitats Classification Scheme (version 3.1, IUCN 2012):

1 Forest

1.7 Forest – Subtropical/tropical mangrove vegetation above high tide level* *below water level*[1]

12 Marine Intertidal

12.7 Mangrove Submerged Roots

2. Ecosystem Description

Spatial distribution

The Mangroves of the Red Sea and Gulf of Aden province includes intertidal forests and shrub lands of the marine eco-regions of the Gulf of Aden, Northern and Central Red Sea, and Southern Red Sea (Spalding *et al*., 2007). The Red Sea connects the continents of Africa and Asia and extends across coastlines in Egypt, Sudan, Eritrea, and Saudi Arabia, while the Gulf of Aden, which connects the Red Sea and the Indian Ocean, shares borders with Yemen, Djibouti and Somalia (Figure 1). Although the borders of the Red Sea and Gulf of Aden province pass through Yemen, this assessment includes the entire Yemeni mangroves, including the Al Maharah Governorate with approximately 0.01 km^2 of mangroves (Nagi *et al.*, 2012). Mangroves in Eritrea and Saudi Arabia contribute 41% and 35 %, of the total mangrove cover in the province, respectively.

In 2020, the estimated extent of mangroves in this province was 189.2 km^2, representing about 0.1% of the global mangrove area, with net area change of -21.7 % from 1996 to 2020, and of – 4.0 % from 2010 to 2020 (Bunting *et al.*, 2022). The decline in the rate of mangrove loss estimated from 2010 to 2020 could be associated with adoption of afforestation and restoration projects and establishment of protected areas that began in the 1990s (Almahasheer *et al*., 2016a, Friis and Burt, 2020).

[1] Note on the original classification scheme. This habitat should include mangrove vegetation below water level. Mangroves have spread into warm temperate regions to a limited extent and may occasionally occur in supratidal areas. However, the vast majority of the world's mangroves are found in tropical/subtropical intertidal areas.

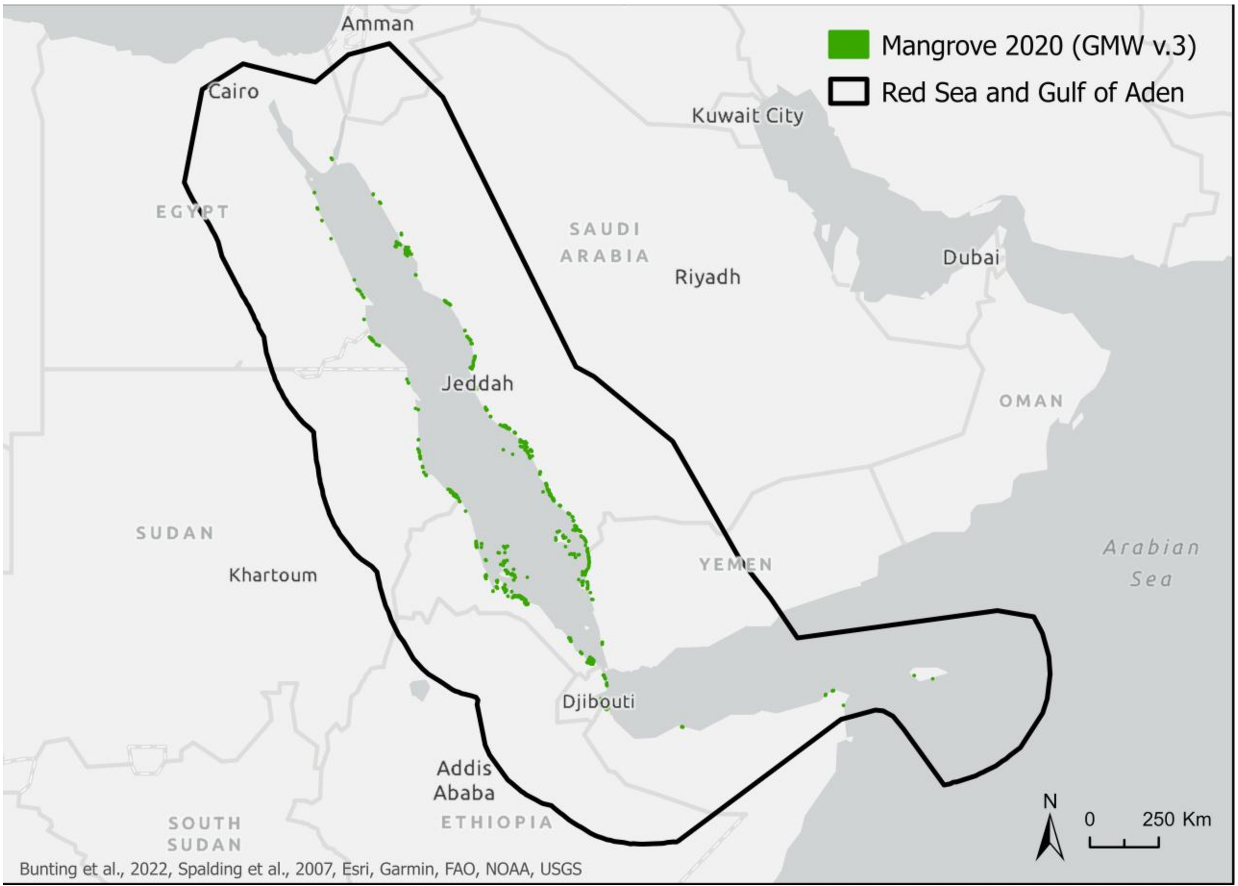

Figure 1. The distribution of mangroves of the Red Sea and Gulf of Aden province

Biotic components of the ecosystem (characteristic native biota)

The mangrove ecosystem of the Red Sea and Gulf of Aden is characterized by small scattered mangrove patches with low productivity due to aridity and other harsh environmental conditions in this province, including low rainfall, limited nutrients supply, and extreme temperature (Almahasheer *et al*. 2017). The Red Sea coast mangrove ecosystem is dominated by two plant species in the IUCN Red List of Threatened Species database (IUCN, 2022): *Avicennia marina* (Least Concern, LC) and *Rhizophora mucronata* (LC). *Avicennia* marina (Grey Mangrove) belongs to the Family Acanthaceae and grows as small to medium trees that dominate all intertidal zones. *Rhizophora mucronata* (family Rhizophoracea) is found mainly in lower to mid-intertidal regions. Both species are salt-tolerant and survive in extreme salinity levels up to 40 ppt (Robertson and Alongi 1992). Previous surveys reported the presence of *Bruguiera gymnorhiza* and *Ceriops tagal* in Djibouti and Eritrea (PERSGA, 2004; Khalil 2015); however, according to IUCN (2022) and Bunting *et al.* (2022) these species no longer occur. In Yemen, *Bruguiera gymnorhiza* is reported to be extinct (Duke *et al.*, 2010). In Somalia, although several mangrove species other than *Avicennia marina* and *Rhizophora mucronata* are identified (IUCN, 2022; Bunting *et al.*, 2022), only *Avicennia marina* and *Rhizophora mucronata* exist within this province (Mumuli *et al*. 2010; IUCN, 2022).

Avicennia marina is the dominant species in this province, and its growth varies based on plant location and associated environmental properties (Khalil, 2015). Along the fringe of the Red Sea, *Avicennia marina* grows to a maximum height of 4.95 m, compared to mangroves recorded in the central Red Sea, which are stunted with an average tree height of only 2.7 m. The annual node production is rather uniform among locations averaging 9.59 node y^{-1}, which results in a plastocron interval (the interval in between production of two consecutive nodes along a stem) of 38 days (Almahasheer *et al*., 2016b). A recent analysis has revealed that the maximum tree height of *Avicennia marina* and chlorophyll a concentration were correlated positively with nitrogen concentration in the leaves (Anton *et al*., 2020). According to the IUCN Red List of Threatened Species (IUCN, 2022), there are at least 170 species associated with mangroves of the Red Sea and Gulf of Aden province (see Appendix 1) within the taxa Actinopterygii (55 species), Aves (75 species), Chondrichthyes (10 species), Gastropoda (five species), Holothuroidea (three species), Liliopsida (four species), Magnoliopsida (two species), Mammalia (seven species), Reptilia (eight species), and Anthozoa (one species).

Avicennia marina scattered along shoreline of Central Red Sea showing dwarf mangroves (Photo credit: Hanan Almahasheer)

Avicennia marina and intertidal zone of the Central Red Sea (Photo credit: Hanan Almahasheer)

Rhizophora mucronata at Al-Gandal opposite Al-Hodeidah City, Yemen (Photo credit: Hisham Nagi)

Rhizophora mucronata, North of Kamaran Island in the Red Sea (Photo credit: Hisham Nagi)

Mangrove forests along the Egyptian Red Sea coast (Photo credit: Somaya Ghoraba)

Abiotic Components of the Ecosystem

The distribution of mangroves in the Red Sea and Gulf of Aden is influenced by harsh environmental conditions in this province. The low tidal range of the Red Sea, along with the arid conditions, including low freshwater supply and high water and air temperatures, result in high seawater salinity. Therefore, only two mangrove species adapted to hyper-saline conditions are present along the Red Sea coast (Pirri *et al*., 2023). Factors such as low rainfall, nutrient limitation and high temperature have lowered C_{org} sink capacity, increased soil respiration rates, and reduced growth rates of mangroves (Almahasheer, *et al.*, 2017). Low leaf nutrient concentrations and low carbon-to-nutrient stoichiometric ratios are characteristics of mangrove stands in the Central Red Sea, which indicate severe nutrient depletion, particularly of Phosphorous (P) and Iron (Fe), across stands and suggest the likelihood of nutrient limitation of Central Red Sea mangroves (Almahasheer *et al.*, 2016c). Nutrient limitation is attributed to lack of riverine nutrient input into the Red Sea, which has resulted in growth of dwarfed mangroves (Anton *et al.*, 2020; Perri *et al.*, 2023). Nutrient concentration is also suggested to be the main factor limiting the mangrove's response to high temperature and low fresh water supply, as well as the biogenic character of the carbonates-dominated Red Sea sediments (Almahasheer *et al.*, 2016b).

Key processes and interactions

Mangroves act as structural engineers possessing traits such as pneumatophores, salt excretion glands, vivipary, and propagule buoyancy that promote survival and recruitment in poorly aerated, saline, mobile, and tidally inundated substrata. The mangrove fauna plays a key role in mangrove ecological processes, with crabs being among the most abundant and important mangrove-associated invertebrates. In addition to their role as mangrove herbivores and detritivores, crab burrows oxygenate sediments, enhance groundwater penetration, and provide microhabitats for other invertebrates. Mangroves produce large amounts of organic matter, mainly leaves, plus flowers, twigs and bark, which are broken down physically by tidal and marine processes, or consumed by crabs, then decomposed further by smaller invertebrates, fungi and bacteria to produce mangrove detritus, which provides a protein- and nutrient-rich food source for other consumers in the mangrove and coastal food web.

Mangroves exhibit high efficiency in nitrogen use and nutrient resorption. The Nitrogen (N) and Phosphorous (P) stocks contained in the top 20 cm sediment layer was estimated to be 70 g P m^{-2}, while short-term N and P accumulation rates were 0.092 mg P cm^{-2} yr^{-1} (Saderne *et al.*, 2020). Although mangroves are considered to be major blue carbon sinks, mangroves of the Red Sea have limited capacity for carbon sequestration compared to other locations due to their low rate of productivity in the prevailing harsh environmental conditions (Almahasheer *et al*., 2017). Along the Egyptian Red Sea coast, soil organic carbon (SOC) density in mangrove stands has been shown to decline significantly with depth from 25.1 Kg C m^{-3} at depth 0–10 cm to 17.7 Kg C m^{-3} at depth 20–30 cm, Average carbon sequestration rates (CSR) of mangrove stands was estimated to be 6.1 g C m^{-2} yr^{-1}(Eid and Shaltout, 2016). A study of 10 mangrove sites within four locations along the Saudi coast of the Central Red Sea has shown that average SOC density and carbon stock in Red Sea mangroves was only 4 ± 0.3 mg C cm^{-3} and 43 ± 5 Mg C ha^{-1} (to a soil depth of 1 m), respectively; and average CSR was 15 g C m^{-2} yr^{-1}, indicating low SOC and CSR values for Red Sea mangroves (Almahasheer *et al*., 2017).

3. Ecosystem Threats and vulnerabilities

Main threatening process and pathways to degradation

Mangroves deforestation in the Red Sea and Gulf of Aden province arises from various factors, including conversion for aquaculture and expansion of shrimp and crab farms; urbanization associated with coastal development; over-harvesting for fuel wood, timber, and animal feeds; and oil pollution. Dumping of domestic solid wastes, including polyethylene bags, metal and plastic cans from residential communities along the coast is a cause of deterioration of the mangrove ecosystem. Large plastic objects are more frequently seen in mangroves than on beaches, because mangroves are sinks for marine plastic litter and trap anthropogenic debris before it is dispersed into the marine environment. In a study conducted in Saudi Arabia, a total of 1254 litter items have been recorded in the Red Sea, resulting in a density of 0.66 ± 0.18 items m^{-2} (mean ± SE) along transects. Litter densities in the surveyed stations ranged from 0.02 ± 0.01 items m^{-2} in a newly planted mangrove forest with sparse trees 9 km away from Yanbu City to 3.7 ± 1.8 items m^{-2} in a 30 years old natural forest on the Yanbu City shoreline (Martin *et al.*, 2019).

Camel grazing and cutting for fodder are causes of mangroves degradation, particularly in Yemen, Djibouti and Sudan (PERSGA, 2004; Witsen, 2012), leading to great losses of living mangrove foliage (Nagi and Abubakr, 2013). Moreover, construction of dams in Sudan and Yemen to meet increasing demand for freshwater along the Red Sea coast has led to sand deposition and reduction in water flow into mangrove forests, thus creating hyper-saline conditions, which reduces mangrove growth (Mandura, 1997; Aljahdali *et al*., 2021). Sand infilling was also responsible for mortality of *Rhizophora mucronata* trees in Djibouti (Witsen, 2012).

Climate change is a growing threat to mangroves in the form of frequently occurring drought and heatwaves along the Red Sea coast that have profound impacts on mangrove ecosystems. The location of mangrove forests within intertidal areas renders them vulnerable to the consequences of sea-level rise due to climate change (Blankespoor *et al*., 2014, Moustafa *et al.*, 2023). Generally, increased heatwave seasons cause seawater heating and increase salinization, which inhibits mangrove growth. In contrast, in this province, mangroves are not likely to be impacted by salinization as they are well-adapted to harsh environments, including extreme salinity and temperature and limited nutrient (Perri *et al*., 2023).

Sea-level rise threatens mangroves of the Red Sea and Gulf of Aden due to their vulnerability to inundation stress, sediment erosion, and drowning, as well as their restricted location within estuaries and rapid coastal developments, which hinders their landward migration (Nadim *et al.*, 2008; Ward *et al.*, 2016). According to Blankespoor *et al.* (2014) an increase of 1 m in sea-level could lead to the loss of 96% of the region's coastal wetlands, including mangroves. According to Schuerch *et al.* (2018) in a model accounting for sediment capture, the loss of mangroves in this province will be of 67.1% by 2060 (see Criteria C2 for further information). Moreover, coastal development and other human impacts on mangroves, such as overgrazing and deforestation, may exacerbate climate change-related risks.

Camel grazing on mangroves in Sudan (Photo credit: Awatif Abdelgadir)

Harsh environmental conditions (e.g. drought) limit mangroves' growth in Sudan (Photo credit: Awatif Abdelgadir)

Threat Classification

IUCN Threat Classification (version 3.3) (IUCN-CMP, 2022) relevant to mangroves of the Red Sea and Gulf of Aden province:

1. Residential & commercial development

1.1 Housing & urban areas

1.2 Commercial & industrial areas

1.3 Tourism & recreation areas

2. Agriculture & aquaculture

2.3 Livestock farming & ranching

2.3.1 Nomadic grazing
2.3.4 Scale Unknown/Unrecorded
2.4 Marine & freshwater aquaculture
2.4.1 Subsistence/artisanal aquaculture
2.4.2 Industrial aquaculture

3. Energy production & mining
3.1 Oil & gas drilling
3.2 Mining & quarrying
3.3 Renewable energy

4. Transportation & service corridors
4.1 Roads & railroads

5. Biological resource use
5.3 Logging & wood harvesting
5.4 Fishing & harvesting aquatic resources

6. Human intrusions & disturbance
6.1 Recreational activities
6.2 War, civil unrest & military exercises

7. Natural system modifications
7.2 Dams & water management/use

9. Pollution
9.1 Domestic & urban waste water
9.1.1 Sewage
9.1.2 Run-off
9.2 Industrial & military effluents
9.2.1 Oil spills
9.2.2 Seepage from mining
9.3 Agricultural & forestry effluents
9.3.2 Soil erosion, sedimentation
9.3.3 Herbicides & pesticides
9.4 Garbage & solid waste

11. Climate change & severe weather
11.1 Habitat shifting & alteration
11.2 Droughts
11.5 Other impacts (sea-level rise)

Definition of the collapsed state of the ecosystem

Mangroves, acting as structural engineers, possess specialized traits that facilitate high nitrogen use efficiency and nutrient resorption, influencing critical processes and functions within their ecosystem. Ecosystem collapse is recognized when the tree cover of diagnostic true mangrove species declines to zero, indicating complete loss (100%). Mangrove ecosystems exhibit remarkable dynamism, with species distributions adapting to local shifts in sediment distribution, tidal patterns, and variations in local inundation and salinity gradients. Disruptive processes can trigger shifts in this dynamism, potentially leading to ecosystem collapse. Ecosystem collapse may manifest through the following mechanisms: a) restricted recruitment and survival of diagnostic true mangroves due to climate change and sea-level rise); b) alterations in ecological processes such as, rainfall, nutrient inputs, waves, and tidal currents that destabilize and erode sediment, hindering mangrove recruitment and growth; c) shifts in water flow and tidal flushing, increase salinity stress and nutrient loading, thereby impacting overall survival; d) habitat conversion (e.g. coastal developments and urbanization).

For assessing the risk of collapse under Criteria A and B, mangroves are assumed to collapse when their mapped distribution declines to zero. For assessment of Criterion C, sea-level rise was selected as the indicator for ecosystem degradation as this ecoregion has been identified as one of the most severely vulnerable regions to the prospective impacts of sea-level rise. Vegetation indices estimated from the global mangrove degradation map were used to assess the disruption of biotic degradation Criterion D.

4. Ecosystem Assessment

Criterion A: Reduction in Geographic Distribution

Subcriterion A1 measures the trend in ecosystem extent during the last 50-year time window. Unfortunately, there is currently no common regional dataset that provides information for the entire target area in 1970 to extrapolate the trend between 1970 and 2020. Accordingly, we compiled reliable published sources (see appendix 3) that contain information on mangrove area estimates close to 1970 (both before and after) for each country within the province. These estimates were then used to interpolate the mangrove area in 1970 in each country. By summing up these estimates, we calculated the total mangrove area in the province. We only considered the percentage of each country's total mangrove area located within the province and the estimated values for 1970 should be considered only indicative (see appendix 3 for further details of the methods and limitations). For 2020 estimates, we used the most recent version of the Global Mangrove Watch (GMW v3.0) spatial dataset. The mangrove area in the province (and in the corresponding countries) was corrected for both omission and commission errors, utilizing the equations in Bunting *et al.* (2022).

The analysis of the Red Sea and Gulf of Aden mangroves of subcriterion A1 was assessed using two data sources to the estimate mangrove area in 1970; Almahasheer *et al.* (2015) and FAO (2007) time series (Annex 3). Significant differences between the sources resulted in both low and high estimates. The lower estimate based on Almahasheer *et al.* (2015) for 1970 and Bunting *et al.,* (2022) for 2020 shows that the Red Sea and Gulf of Aden mangroves gained approximately 22.2 % of its mangrove area over the last 50 years (1970-2020). This gaining trend was obvious across most countries within this province, with gaining rates observed across Egypt, Yemen and Sudan of ~ 85 %, 84% and 81 % respectively. The higher estimate based on FAO (2007) time series shows that mangroves area declined by approximately 39.1% from 1970 to 2020, where all countries observed reduction in mangrove area, except Eritrea, Yemen, and Sudan. These countries showed mangrove expansion by 62%, 61% and 15% respectively. Unlike the first analysis, reductions were observed in Saudi Arabia and Egypt. Yemen and Sudan observed remarkable increase in mangrove area between1970-2020; however, this trend diverges depending on the data source, with high estimated areas reported for these countries in Bunting *et al.* (2022) compared to other sources such as Almahasheer *et al.* (2015) or FAO (2007). For example for Yemen mangrove area in 2000, Almahasheer *et al.* (2015) reported 8.9 km^2, FAO (2007) estimated 9 Km^2, while Bunting *et al.* (2022) reported 20.6 km^2 for 1996. For Sudan mangrove areas: Almahasheer *et al.* (2015) and FAO (2007) reported 4.5 Km^2 and 5 Km^2 in 2000 respectively vs. Bunting *et al.* (2022) 14.2 Km^2 in 1996. This discrepancy highlights the importance of considering multiple sources when assessing trends in mangrove area over time.

Overall, the results from various temporal analyses indicate that the changes in mangrove extent between 1970 and 2020 were within 22.2% and – 39.1%. These results would place the Red Sea and Gulf of Aden mangrove ecosystem between the Least Concern (LC) and Vulnerable (VU) threat categories. But given the large differences between the differences sources the ecosystem is assessed as **Near Threatened (NT)** under subcriterion A1, with a plausible **range between Least Concern and Vulnerable (LC-VU).**

	Area 2020* (Km^2)		**Area 1970* (Km^2)**	**Net area Change (Km^2)**	**% Net Area Change**	**Rate of change (%/year)**
Mangroves of the Red Sea and Gulf of Aden	189.2	**Lower estimate**	154.8	34.4	22.2	0.4
		Higher estimate	311.3	-122.7	-39.1	-0.8

** Details on the methods and references used to estimate the mangrove area in 1970 are listed in appendix 3. Total mangrove area in 2020 is based on the Global Mangrove Watch Version 3 (GMW v3.0) dataset.*

Subcriterion A2 measures the change in ecosystem extent in any 50-year period, including from the present to the future: The Red Sea and Gulf of Aden province mangroves show a net area change of -21.7% (1996-2020) based on the Global Mangrove Watch time series (Bunting *et al.,* 2022). This value reflects the offset between areas gained (0.11%/year) and lost (1.02 %/year). The largest decrease in mangrove area in this time series occurred between 1996 and 2010. Applying a linear regression to the area estimations between 1996 and 2020, we obtained a rate of change of -0.9%/year. Assuming this trend continues in the future, it is predicted that the extent of mangroves in the Red Sea and Gulf of Aden province will change by - 46.5 % from 1996 to 2046, and by -58.1% from 2020 to 2070, but by -67.2% from 1996 to 2070 (Figure 2). However, by analyzing the trend of the time series between 1996 and 2020 it was observed that rates of change after 2010 significantly changed with net area change estimated of only – 4.0% from 2010 to 2020 and annual rate of decline of -0.4%/year. Assuming this rate continues in the future, it is predicted that the extent of mangroves in this province will change by -19.4 % from 2010 to 2060 and by -23.2 % from 2010 to 2070 (Figure 2). As the results from the two temporal analyses produced predicted changes in mangrove extent between – 19.4% and – 67.2% over 50 years, the Red Sea and Gulf of Aden mangrove ecosystem qualifies between plausible range (Near Threatened - Endangered) (NT-EN). Considering investigated data that show an enhancement of rate of decline after 2010 and literature that refers to several conservation programs started in mid-1990s, including establishment of protected areas and restoration and afforestation projects (Khalil, 2015, Almahasheer *et al*. 2016a, Friis and Burt, 2020, Moustafa *et al.* 2023), a status of Near Threatened or Vulnerable is more likely than Endangered status. Therefore, Red Sea and Gulf of Aden mangroves assessed as **Near Threatened (NT)** under subcriterion A2.

Subcriterion A3 measures changes in mangrove area since 1750. Unfortunately, there are no reliable data on the mangrove extent for the entire province during this period, and therefore the Red Sea and Gulf of Aden mangrove ecosystem is classified as **Data Deficient (DD)** for this subcriterion.

Overall, the ecosystem is assessed as **Near Threatened (NT)** under criterion A.

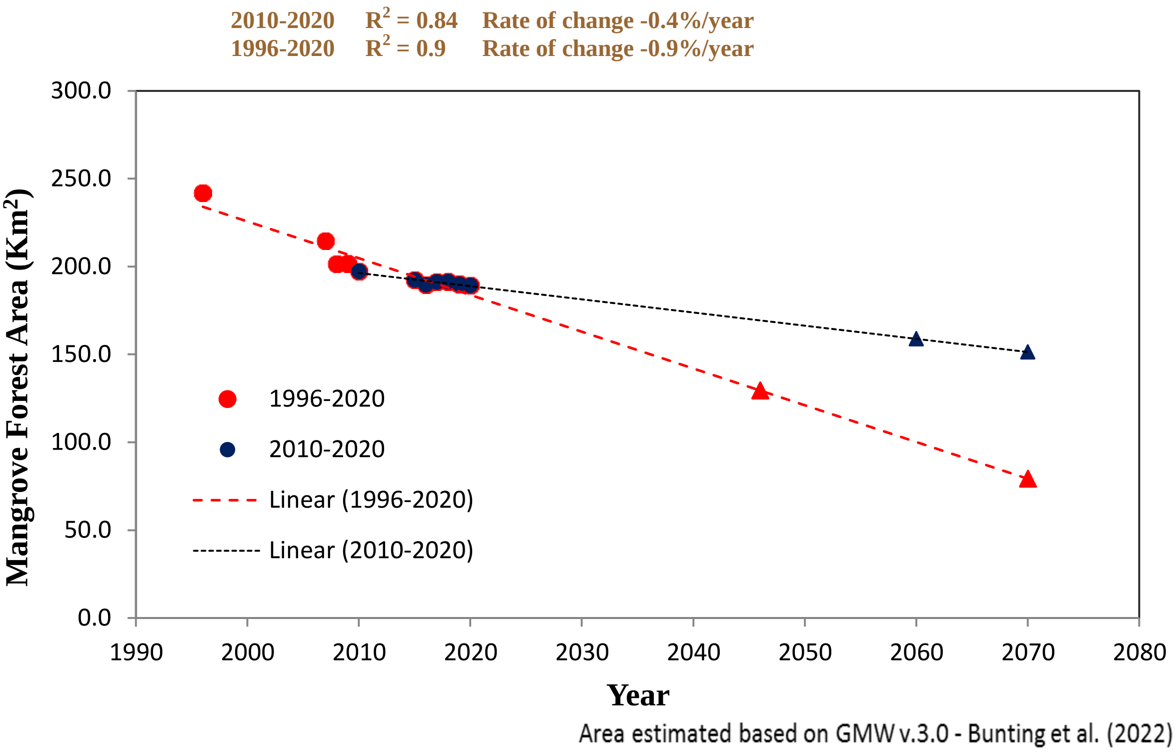

Figure 2. Projected extent of the Red Sea and Gulf of Aden mangrove ecosystem to 2070. Circles represent the province's mangrove area between 1996 and 2020 based on the GMW v3.0 dataset and equations in Bunting *et al.*, (2022). The red dotted line represents the linear regression from 1996 to 2070, and red triangles show the Red Sea and Gulf of Aden predicted mangrove area for 2046 and 2070 (R^2 = 0.9). The blue dotted line represents linear regression from 2010 to 2070 and blue triangles show the Red Sea and Gulf of Aden province predicted mangrove area for 2060 and 2070 (R^2 = 0.84). It is important to note that an exponential model (proportional rate of decline) did not give a better fit to the data.

Criterion B: Restricted Geographic Distribution

Province	Extent of Occurrence EOO (Km^2)	Area of Occupancy (AOO) ≥ 1%	Criterion B
The Red Sea and Gulf of Aden	1455130.0	53	**LC**

Criterion B measures the risk of ecosystem collapse associated with restricted geographical distribution, based on standard metrics (Extent of Occurrence EOO, Area of Occupancy AOO, and Threat-defined locations). These parameters were calculated based on the 2020 Red Sea and Gulf of Aden province mangrove extent (GMW v.3). For 2020, AOO and EOO were measured as 53 grid cells 10 x 10 km and

1455130.0 km^2, respectively (Figure 3). From total number of 296 cells, excluding from the AOO those grid cells that contain patches of mangrove forest that account for less than 1% of the grid cell area, (< 1 Km^2), the AOO is measured as **53, 10 x 10 km grid cells** (Figure 3, red grids). Therefore, Red Sea and Gulf of Aden mangroves assessed as **Least Concern** (**LC**) under subcriteria B1 and B2.

Considering the very high number of threat-defined-locations, there is no evidence of plausible catastrophic threats leading to potential disappearance of mangroves across their extent. As a result, the Red Sea and Gulf of Aden mangrove ecosystem is assessed as **Least Concern (LC)** under criterion B3.

Overall, the ecosystem is assessed as **Least Concern (LC)** under criterion B.

Figure 3. The Red Sea and Gulf of Aden mangrove Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) in 2020. Estimates based on 2020 GMW v3.0 spatial layer (Bunting *et al.*, 2022). The red 10 x 10 km grids (n=53.) are more than 1% covered by the ecosystem, and the black grids <1% (n= 243).

Criterion C: Environmental Degradation

Criterion C measures the environmental degradation of abiotic variables necessary to support the ecosystem.

Subcriterion C1 measures environmental degradation over the past 50 years: There are no reliable data to evaluate this subcriterion for the entire province, and therefore the Red Sea and Gulf of Aden mangrove ecosystem is classified as **Data Deficient (DD)** for subcriterion C1.

Subcriterion C2 measures environmental degradation in the future, or over any 50-year period, including from the present. In this context, the impact of future sea-level rise (SLR) on mangrove ecosystems was assessed by adopting the methodology presented by Schuerch *et al.* (2018). The published model was designed to calculate both absolute and relative change in the extent of wetland ecosystems under various regional SLR scenarios (i.e medium: RCP 4.5 and high: RCP 8.5), with consideration for sediment accretion. Therefore, Schuerch *et al*. (2018) model was applied to the Red Sea and Gulf of Aden mangrove ecosystem boundary, with spatial extent based on Giri *et al.* (2011) and assuming mangrove landward migration was not possible.

According to the results, under an extreme sea-level rise scenario of a 1.1 meter rise by 2100, the projected submerged area is ~ -67.1% by 2060, which is above 50% but below the 80% risk threshold (Figure 4). Therefore, considering that no mangrove recruitment can occur in a submerged system (100% relative severity), but that -67.1% of the ecosystem extent will be affected by SLR, the Red Sea and Gulf of Aden mangrove ecosystem is assessed as **Endangered (EN)** for subcriterion C2.

Subcriterion C3 measures change in abiotic variables since 1750. There is a lack of reliable historic data on environmental degradation covering the entire province, and therefore the Red Sea and Gulf of Aden province is classified as **Data Deficient (DD)** for this subcriterion.

Overall, the ecosystem is assessed as **Endangered (EN)** under criterion C.

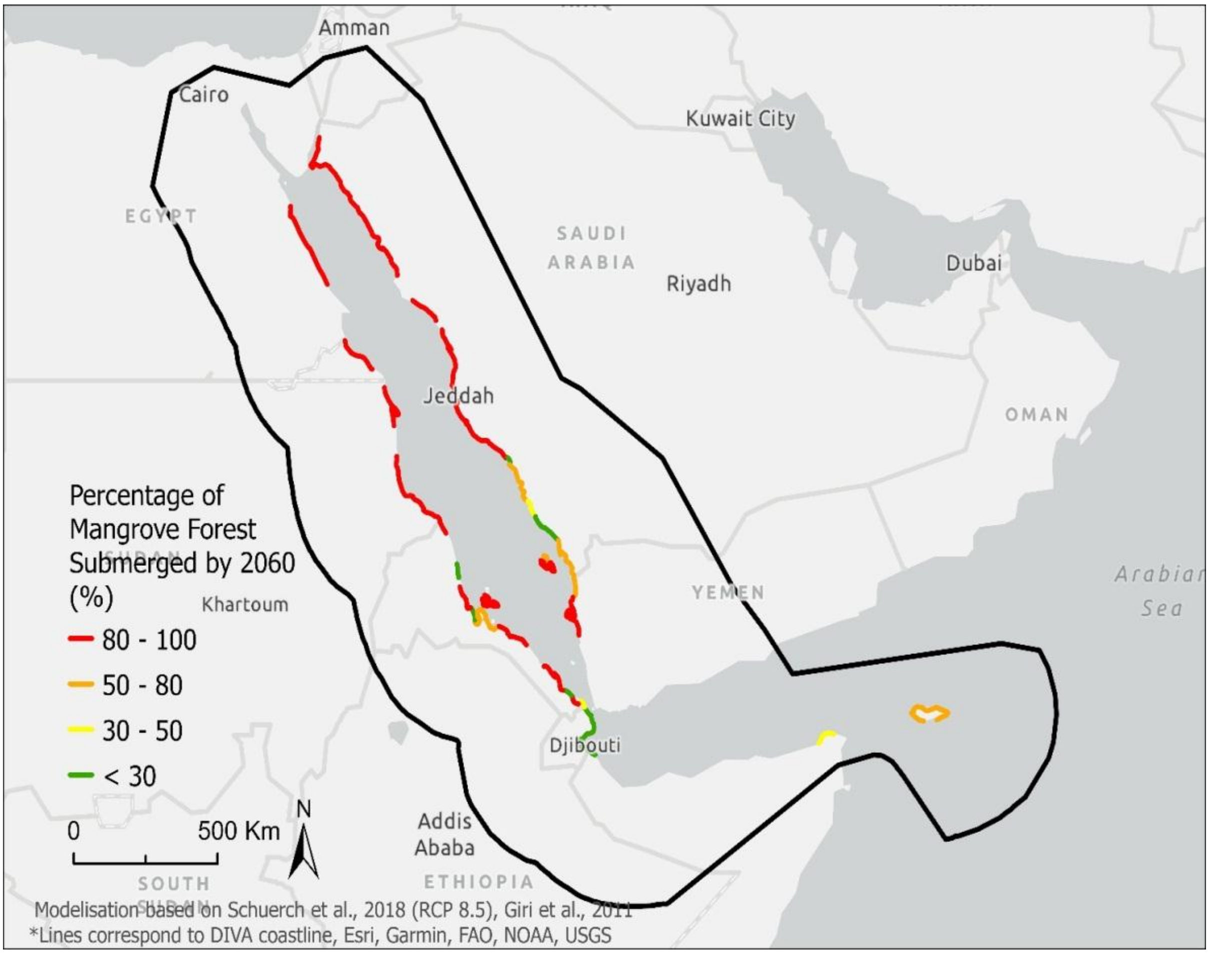

Figure 4. Predicted percentage of the Red Sea and Gulf of Aden mangrove forest submerged by 2060 under the IPCC RCP 8.5 scenario (1.1 m SLR by 2100). Predictions are based on the model of Schuerch *et al.*, 2018 with adjusted parameters: assuming no accommodation space available, constant sediment supply over time and no delta subsidence. The baseline corresponds to the spatial extent of mangroves in 2010 (Giri *et al.*, 2011). Colour lines represent the Dynamic Interactive Assessment Model (DIVA coastline), and do not reflect spatial distribution of mangroves.

Criterion D: Disruption of biotic processes or interactions

The global mangrove degradation map developed by Worthington and Spalding (2018) was used to assess the level of biotic degradation in the Red Sea and Gulf of Aden province. This map is based on degradation metrics calculated from vegetation indices (NDVI, EVI, SAVI, NDMI) using Landsat time series (≈2000 and 2017). These indices represent vegetation greenness and moisture condition.

Mangrove degradation was calculated at a pixel scale (30 m resolution), on areas intersecting with the 2017 mangrove extent map. Mangrove pixels were classified as degraded if two conditions were met: 1) at least 10 out of 12 degradation indices showed a decrease of more than 40% compared to the previous period; and 2) all twelve indices did not recover to within 20% of their pre-2000 value (detailed methods and data are available at: (maps.oceanwealth.org/mangrove-restoration/). The decay in vegetation indices has been used to identify mangrove degradation and abrupt changes, including mangrove die-back events, clear-cutting, and logging; as well as to track mangrove regeneration (Lovelock *et al.*, 2017; Santana, 2018; Murray *et al.*, 2020; Aljahdali *et al.*, 2021; Lee *et al.*, 2021). However, it is important to consider that changes observed in the vegetation indices can also be influenced by data artifacts (Akbar *et al.*, 2020). Therefore, a relative severity level of more than 50%, but less than 80%, was assumed.

The results from this analysis show that over a period of 17 years (~2000 to 2017), 1.76% of the Red Sea and Gulf of Aden mangrove area is classified as degraded, resulting in an average annual rate of degradation of 0.1%. Assuming this trend remains constant, +5.19% of the Red Sea and Gulf of Aden mangrove area will be classified as degraded over a 50-year period. As less than 50 % of the ecosystem will meet the category threshold for criterion D, the Red Sea and Gulf of Aden mangrove province is assessed as **Least Concern** (**LC)** under subcriterion D2b.

No data were found to assess the disruption of biotic processes and degradation over the past 50 years (subcriterion D1) or since 1750 (subcriterion D3). Thus, both subcriteria are classified as **Data Deficient (DD).**

Overall, the Red Sea and Gulf of Aden ecosystem remains **Least Concern (LC)** under criterion D.

Criterion E: Quantitative Risk

No model was used to quantitatively assess the risk of ecosystem collapse for this ecosystem; hence criterion E was **Not Evaluated (NE)**.

5. Summary of the Assessment

CRITERION			
A. Reduction in Geographic Distribution	**A1** Past 50 years	**A2** Future or any 50y period	**A3** Historical (1750)
	NT	NT	DD
B. Restricted Geo. Distribution	**B1** Extent of Occurrence	**B2** Area of Occupancy	**B3** # Threat-defined Locations < 5
	LC	LC	LC
C. Environmental Degradation	**C1** Past 50 years (1970)	**C2** Future or any 50y period	**C3** Historical (1750)
	DD	EN	DD
D. Disruption of biotic processes	**D1** Past 50 years (1970)	**D2** Future or Any 50y period	**D3** Historical (1750)
	DD	LC	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	EN		

EN= Endangered, LC= Least Concern, NT= Near Threatened, and DD= Data Deficient, NE= Not Evaluated

Overall, the status of the Red Sea and Gulf of Aden mangrove ecosystem is assessed as **Endangered (EN).**

6. References

Akbar, M R, Arisanto P A A, Sukirno B A, Merdeka P H, Priadhi M M, and Zallesa S. (2020) 'Mangrove vegetation health index analysis by implementing NDVI (normalized difference vegetation index) classification method on sentinel-2 image data case study: Segara Anakan, Kabupaten Cilacap', *IOP Conference Series: Earth and Environmental Science*, 584(1), p. 012069. https://doi.org/10.1088/1755-1315/584/1/012069.

Aljahdali, M. O., Munawar, S., & Khan, W. R. (2021). Monitoring Mangrove Forest Degradation and Regeneration: Landsat Time Series Analysis of Moisture and Vegetation Indices at Rabigh Lagoon, Red Sea. *Forests*, *12*(1), 52. https://doi.org/10.3390/f12010052

Almahasheer, H., Serrano, O., Duarte, C.M., Arias-Ortiz, A., Masque, P. and Irigoien, X. (2017). Low carbon sink capacity of Red Sea mangroves. *Scientific reports*, *7*(1), p.9700.

Almahasheer, H., Aljowair, A., Duarte, C.M., Irigoien, X.. (2016a). Decadal stability of Red Sea mangroves. *Estuarine, Coastal and Shelf Science*.169, 164–172

Almahasheer, H., Duarte, C.M. and Irigoien, X., (2016b). Phenology and Growth dynamics of *Avicennia marina* in the Central Red Sea. *Scientific reports*, *6*(1), p.37785.

Almahasheer, H., Duarte, C.M. and Irigoien, X., (2016c). Nutrient limitation in central Red Sea mangroves. *Frontiers in Marine Science*, *3*, p.271.

Almahasheer, H., Aljowair, A., Duarte, C. M., Irigoien, X. (2015): Mangrove cover in the Red Sea (1972-2013). *PANGAEA*. https://doi.org/10.1594/PANGAEA.855896

Anton, A., Almahasheer, H., Delgado, A., Garcias-Bonet, N., Carrillo-de-Albornoz, P., Marbà, N., Hendriks, I.E., Krause-Jensen, D., Saderne, V., Baldry, K. and Duarte, C.M., (2020). Stunted mangrove trees in the oligotrophic central Red Sea relate to nitrogen limitation. *Frontiers in Marine Science*, *7*, p.597.

Blankespoor, B., S. Dasgupta, and B. Laplante. (2014). Sea level rise and coastal wetlands. *Ambio* 43:996evel r

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M.D., Murray, N. J., & Rebelo, L.-M. (2022). Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. *Remote Sensing*, *14*(15), 3657. https://doi.org/10.3390/rs14153657

Duke, N., Kathiresan, K., Salmo III, S.G., Fernando, E.S., Peras, J.R., Sukardjo, S. and Miyagi,T.(2010). *Bruguiera gymnorhiza*. The IUCN Red List of Threatened Species (2010): e.T178803A7610926. http://dx.doi.org/10.2305/IUCN.UK.2010-2.RLTS.T178803A7610926.en

Eid, E. M., & Shaltout, K. H. (2016). Distribution of Soil Organic Carbon in the Mangrove Avicennia marina (Forssk.) Vierh. along the Egyptian Red Sea Coast. *Regional Studies in Marine Science*, 3, 76-82. https://doi.org/10.1016/j.rsma.2015.05.006

FAO (2007). The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf

Friess, D. A., & Webb, E. L. (2014). Variability in mangrove change estimates and implications for the assessment of ecosystem service provision: Variability in mangrove ecosystem loss. *Global Ecology and Biogeography*, *23*(7), 715–725. https://doi.org/10.1111/geb.12140

Friis, G. and Burt, J.A. (2020). Evolution of mangrove research in an extreme environment: Historical trends and future opportunities in Arabia. Ocean and Coastal Management. 195. https://doi.org/10.1016/j.ocecoaman.2020.105288

Giri, C. Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr. 20*(54–159).

IUCN (2012). IUCN Habitats classification scheme (3.1). [Dataset]. https://www.iucnredlist.org/resources/habitat-classification-scheme.

IUCN (2022). The IUCN Red List of Threatened Species. (Version 2022-2) [Data set]. https://www.iucnredlist.org

IUCN-CMP (2022). Unified Classification of Direct Threats (3.3) [Dataset]. https://www.iucnredlist.org/resources/threat-classification-scheme.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., & Kingsford, R. T. (Eds.) (2020). IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. *IUCN, International Union for Conservation of Nature*. https://doi.org/10.2305/IUCN.CH.2020.13.en

Khalil, A. (2015). Mangroves of the Red Sea. In: The Red Sea: the formation, morphology, oceanography, and environment of a young ocean basin. Editors: Najeeb M.A. Rasul and Ian C.F. Stewart. *Springer*. Pp 585-597. https://doi.org/ 10.1007/978-3-662-45201-1_33

Lee, C. K. F., Duncan, C., Nicholson, E., Fatoyinbo, T. E., Lagomasino, D., Thomas, N., Worthington, T. A., & Murray, N. J. (2021). Mapping the Extent of Mangrove Ecosystem Degradation by Integrating an Ecological Conceptual Model with Satellite Data. *Remote Sensing*, *13*(11), 2047. https://doi.org/10.3390/rs13112047

Lovelock, C. E., Feller, I. C., Reef, R., Hickey, S., & Ball, M. C. (2017). Mangrove dieback during fluctuating sea levels. *Scientific Reports*, *7*(1), 1680. https://doi.org/10.1038/s41598-017-01927-6

Mandura, A.S (1997). A mangrove stand under sewage pollution stress: Red Sea. Mangroves Salt Marshes. 1, 255–262.

Martin, C., Almahasheer, H. and Duarte, C.M. (2019). Mangrove forests as traps for marine litter. *Environmental Pollution*, *247*, pp.499-508.

Moustafa, A.A., Abdelfatah, A., Arnous, M.O., Afifi, A.M., Guerriero, G. and Greed, D.R. (2023). Monitoring temporal changes in coastal mangroves to understand the impacts of climate change: Red Sea, Egypt. Journal of Coastal Conservation. 27(5). https://doi.org/ 10.1007/s11852-023-00970-y

Mumuli, S. O, Alim, M. and Oduori, G., (2010). Monitoring of Mangroves in Somalia (Puntland, Somaliland and South Central Somalia). *FAO-SWALIM. Project Report* No. L-19. Nairobi, Kenya.

Murray, N. J., Keith, D. A., Tizard, R., Duncan, A., Htut, W. T., Oo, A. H., Ya, K. Z., & Grantham, M. (2020). *Threatened ecosystems of Myanmar: An IUCN Red List of Ecosystems Assessment. Version 1*. Wildlife Conservation Society. https://doi.org/10.19121/2019.Report.37457

Nadim, F., Bagtzoglou,A. and Iranmahboob, J.(2008). Coastal management in the Persian Gulf region within the framework of the ROPME programme of action. Ocean and Coastal Management 51:556–565.

Nagi, H. M. and Abubakr, M. M. (2013) Threats status to mangrove ecosystem along the coastal zone of Yemen. *Journal of King AbdulAziz University – Marine Science*, 24(1), 101-117.

Nagi, H. M.; Khanbari, K. M. and Al-Sameh, A. (2012). Estimating Total Area of Mangrove Habitats in the Republic of Yemen Using Remote Sensing and GIS; Faculty of Science Bulletin, 24: 75-84.

Perri, S., Detto, M., Porporato, A. and Molini, A. (2023). Salinity-induced limits to mangrove canopy height. *Global Ecology and Biogeography*. https://doi.org/ 10.1111/geb.13720

PERSGA/GEF. (2004). Regional Action Plan for the Conservation of Mangroves in the Red Sea and Gulf of Aden. PERSGA, Jeddah, Saudi Arabia.

Robertson, A.I. and Alongi, D.M. (1992). Tropical Mangrove Ecosystems. Bioscience. 44(3). DOI: 10.2307/1312261

Saderne, V., Cusack, M., Serrano, O., Almahasheer, H., Krishnakumar, P.K., Rabaoui, L., Qurban, M.A. and Duarte, C.M. (2020). Role of vegetated coastal ecosystems as nitrogen and phosphorous filters and sinks in the coasts of Saudi Arabia *Environmental Research Letters: 15*(3), p.034058. https://doi.org/ 10.1088/1748-9326/ab76da

Santana, N.C. (2018). Fire Recurrence and Normalized Difference Vegetation Index (NDVI) Dynamics in Brazilian Savanna. *Fire*, *2*(1), 1. https://doi.org/10.3390/fire2010001

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M. L., Wolff, C., Lincke, D., McOwen, C. J., Pickering, M. D., Reef, R., Vafeidis, A. T., Hinkel, J., Nicholls, R. J., & Brown, S. (2018). Future response of global coastal wetlands to sea-level rise. *Nature*, *561*(7722), 231–234. https://doi.org/10.1038/s41586-018-0476-5

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., Jorge, M. A., Lombana, A., Lourie, S. A., Martin, K. D., McManus, E., Molnar, J., Recchia, C. A., & Robertson, J. (2007). Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. *BioScience*, *57*(7), 573–583. https://doi.org/10.1641/B570707

Ward, R. D., D. A. Friess, R. H. Day, and R. A. MacKenzie. (2016). Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability* 2(4):e01211. https://doi.org /doi:10.1002/ehs2.1211

Witsen, D. (2012). Mangrove Restoration and Management in Djibouti: Criteria and Conditions for Success. Virginia Polytechnic Institute and State University Master of Natural Resources Major: Natural Resources. *Virginia Polytechnic Institute and State University*. http://pdf.usaid.gov/pdf_docs/pnaed179.pdf.

Worthington, T.A., & Spalding, M. D. (2018). Mangrove Restoration Potential: A global map highlighting a critical opportunity. *Apollo - University of Cambridge Repository*. https://doi.org/10.17863/CAM.39153

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Appendices

1. List of Key Mangrove Species

List of plant species considered true mangroves according to Red List of Threatened Species (RLTS) spatial data (IUCN, 2022). We included species whose range maps intersected with the boundary of the marine provinces/ecoregions described in the distribution section. RLTS category, LC= Least Concern.

Class	Order	Family	Scientific name	RLTS category
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia marina*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Rhizophora mucronata*	LC

2. List of Associated Species

List of taxa associated with mangrove habitats in the Red List of Threatened Species (RLTS) database (IUCN, 2022). We included only species with entries for Habitat 1.7: "Forest - Subtropical/Tropical Mangrove Vegetation above high tide level" or Habitat 12.7 for "Marine Intertidal - Mangrove Submerged Roots", suitability recorded as suitable with any seasonality except passage, and presence recorded as "Extant" or "Possibly Extinct" and origin marked as "Native" or "Reintroduced". Common names are those shown in the RLTS, except common names between brackets, which are from other sources. We included species whose range maps intersected with the boundary of the marine provinces/ecoregions described in the Distribution section. RLTS category: CR= Critically Endangered, EN= Endangered, VU= Vulnerable, LC= Least Concern, NT= Near Threatened, and DD= Data Deficient.

Class	Order	Family	Scientific name	RLTS category	Common name
Actinopterygii	Perciformes	Sparidae	*Acanthopagrus berda*	LC	Picnic Seabream
Actinopterygii	Perciformes	Sparidae	*Acanthopagrus bifasciatus*	LC	Two-bar Seabream
Actinopterygii	Albuliformes	Albulidae	*Albula glossodonta*	VU	Shortjaw Bonefish
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron hispidus*	LC	White-spotted Puffer
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron immaculatus*	LC	Immaculate Puffer
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron stellatus*	LC	Stellate Puffer
Actinopterygii	Gobiiformes	Gobiidae	*Asterropteryx semipunctata*	LC	Star-finned Goby
Actinopterygii	Atheriniformes	Atherinidae	*Atherinomorus lacunosus*	LC	Hardyhead Silverside
Actinopterygii	Perciformes	Carangidae	*Atule mate*	LC	Yellowtail Scad
Actinopterygii	Gobiiformes	Eleotridae	*Butis butis*	LC	Crimson-tipped Gudgeon
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Chelonodontops patoca*	LC	Milkspotted Puffer
Actinopterygii	Elopiformes	Elopidae	*Elops machnata*	LC	(Tenpounder)
Actinopterygii	Ophidiiformes	Carapidae	*Encheliophis homei*	LC	Silver Pearlfish
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus coioides*	LC	Orange-spotted Grouper
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus tauvina*	DD	Greasy Grouper
Actinopterygii	Perciformes	Leiognathidae	*Eubleekeria splendens*	LC	Splendid Ponyfish
Actinopterygii	Perciformes	Leiognathidae	*Gazza minuta*	LC	Toothed Ponyfish
Actinopterygii	Perciformes	Gerreidae	*Gerres filamentosus*	LC	Whipfin Mojarra
Actinopterygii	Syngnathiformes	Syngnathidae	*Hippichthys cyanospilos*	LC	Bluespeckled Pipefish
Actinopterygii	Syngnathiformes	Syngnathidae	*Hippichthys spicifer*	LC	Bellybarred Pipefish
Actinopterygii	Gobiiformes	Gobiidae	*Istigobius ornatus*	LC	Ornate Goby

Class	Order	Family	Scientific name	RLTS category	Common name
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Lagocephalus guentheri*	LC	Diamondback Puffer
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Lagocephalus lunaris*	LC	Lunartail Puffer
Actinopterygii	Perciformes	Leiognathidae	*Leiognathus equulus*	LC	Common Ponyfish
Actinopterygii	Perciformes	Lethrinidae	*Lethrinus harak*	LC	Thumbprint Emperor
Actinopterygii	Perciformes	Lethrinidae	*Lethrinus nebulosus*	LC	Spangled Emperor
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus argentimaculatus*	LC	Mangrove Red Snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus ehrenbergii*	LC	Blackspot Snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus fulviflamma*	LC	Dory Snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus fulvus*	LC	Blacktail Snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus johnii*	LC	John's Snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus sebae*	LC	Red Emperor Snapper
Actinopterygii	Elopiformes	Megalopidae	*Megalops cyprinoides*	DD	Indo-Pacific Tarpon
Actinopterygii	Perciformes	Monodactylidae	*Monodactylus argenteus*	LC	Silver Moony
Actinopterygii	Gobiiformes	Gobiidae	*Mugilogobius mertoni*	LC	Merton's Mangrove Goby
Actinopterygii	Perciformes	Labridae	*Novaculichthys macrolepidotus*	LC	Green-banner wrasse
Actinopterygii	Perciformes	Mullidae	*Parupeneus barberinus*	LC	Dash-and-dot goatfish
Actinopterygii	Perciformes	Mullidae	*Parupeneus forsskali*	LC	Dash-and-dot Goatfish
Actinopterygii	Clupeiformes	Pristigasteridae	*Pellona ditchela*	LC	Indian Pellona
Actinopterygii	Gobiiformes	Gobiidae	*Periophthalmus argentilineatus*	LC	Barred Mudskipper
Actinopterygii	Gobiiformes	Gobiidae	*Periophthalmus kalolo*	LC	Kalolo Mudskipper
Actinopterygii	Mugiliformes	Mugilidae	*Planiliza subviridis*	LC	Greenback Mullet
Actinopterygii	Perciformes	Ephippidae	*Platax orbicularis*	LC	Orbiculate Batfish
Actinopterygii	Perciformes	Haemulidae	*Plectorhinchus gibbosus*	LC	Brown Sweetlips
Actinopterygii	Perciformes	Haemulidae	*Plectorhinchus pictus*	LC	Trout Sweetlips
Actinopterygii	Perciformes	Haemulidae	*Plectorhinchus plagiodesmus*	LC	Barred Rubberlip
Actinopterygii	Mugiliformes	Mugilidae	*Planiliza subviridis*	LC	Greenback Mullet
Actinopterygii	Siluriformes	Ariidae	*Plicofollis dussumieri*	LC	Blacktip Sea Catfish
Actinopterygii	Gobiiformes	Gobiidae	*Psammogobius biocellatus*	LC	Sleepy Goby
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Pseudorhombus arsius*	LC	Largetooth Flounder
Actinopterygii	Clupeiformes	Clupeidae	*Sardinella albella*	LC	White Sardinella
Actinopterygii	Clupeiformes	Clupeidae	*Sardinella melanura*	LC	Blacktip Sardinella
Actinopterygii	Clupeiformes	Engraulidae	*Thryssa baelama*	LC	Baelama Anchovy
Actinopterygii	Anguilliformes	Muraenidae	*Uropterygius concolor*	LC	Brown Moray Eel
Anthozoa	Scleractinia	Siderastreidae	*Siderastrea savignyana*	LC	(African pillow coral)
Aves	Accipitriformes	Accipitridae	*Accipiter minullus*	LC	Little Sparrowhawk
Aves	Accipitriformes	Accipitridae	*Accipiter toussenelii*	LC	Red-chested Goshawk
Aves	Charadriiformes	Scolopacidae	*Actitis hypoleucos*	LC	Common Sandpiper
Aves	Coraciiformes	Alcedinidae	*Alcedo atthis*	LC	Common Kingfisher
Aves	Psittaciformes	Psittacidae	*Alexandrinus krameri*	LC	Rose-ringed Parakeet
Aves	Gruiformes	Rallidae	*Amaurornis phoenicurus*	LC	White-breasted Waterhen
Aves	Suliformes	Anhingidae	*Anhinga rufa*	LC	African Darter
Aves	Passeriformes	Cisticolidae	*Apalis flavocincta*	LC	Brown-tailed Apalis
Aves	Caprimulgiformes	Apodidae	*Apus affinis*	LC	Little Swift
Aves	Caprimulgiformes	Apodidae	*Apus caffer*	LC	White-rumped Swift

Class	Order	Family	Scientific name	RLTS category	Common name
Aves	Pelecaniformes	Ardeidae	*Ardea brachyrhyncha*	LC	Yellow-billed Egret
Aves	Pelecaniformes	Ardeidae	*Ardea cinerea*	LC	Grey Heron
Aves	Charadriiformes	Scolopacidae	*Actitis hypoleucos*	LC	Common Sandpiper
Aves	Pelecaniformes	Ardeidae	*Ardea goliath*	LC	Goliath Heron
Aves	Pelecaniformes	Ardeidae	*Ardea purpurea*	LC	Purple Heron
Aves	Pelecaniformes	Threskiornithidae	*Bostrychia hagedash*	LC	Hadada Ibis
Aves	Charadriiformes	Burhinidae	*Burhinus senegalensis*	LC	Senegal Thick-knee
Aves	Pelecaniformes	Ardeidae	*Butorides striata*	LC	Green-backed Heron
Aves	Pelecaniformes	Ardeidae	*Calherodius leuconotus*	LC	White-backed Night-heron
Aves	Passeriformes	Cisticolidae	*Camaroptera brachyura*	LC	Bleating Camaroptera
Aves	Passeriformes	Hirundinidae	*Cecropis abyssinica*	LC	Lesser Striped Swallow
Aves	Coraciiformes	Alcedinidae	*Ceryle rudis*	LC	Pied Kingfisher
Aves	Charadriiformes	Charadriidae	*Charadrius dubius*	LC	Little Ringed Plover
Aves	Charadriiformes	Charadriidae	*Charadrius mongolus*	LC	Lesser Sandplover
Aves	Ciconiiformes	Ciconiidae	*Ciconia microscelis*	LC	African Woollyneck
Aves	Passeriformes	Nectariniidae	*Cinnyris cupreus*	LC	Copper Sunbird
Aves	Passeriformes	Nectariniidae	*Cinnyris pulchellus*	LC	Beautiful Sunbird
Aves	Passeriformes	Nectariniidae	*Cinnyris venustus*	LC	Variable Sunbird
Aves	Accipitriformes	Accipitridae	*Clanga clanga*	VU	Greater Spotted Eagle
Aves	Columbiformes	Columbidae	*Columba arquatrix*	LC	African Olive-pigeon
Aves	Coraciiformes	Alcedinidae	*Corythornis cristatus*	LC	Malachite Kingfisher
Aves	Passeriformes	Nectariniidae	*Cyanomitra olivacea*	LC	Olive Sunbird
Aves	Piciformes	Picidae	*Dendropicos fuscescens*	LC	Cardinal Woodpecker
Aves	Piciformes	Picidae	*Dendropicos goertae*	LC	Grey Woodpecker
Aves	Passeriformes	Malaconotidae	*Dryoscopus gambensis*	LC	Northern Puffback
Aves	Pelecaniformes	Ardeidae	*Egretta ardesiaca*	LC	Black Heron
Aves	Pelecaniformes	Ardeidae	*Egretta garzetta*	LC	Little Egret
Aves	Pelecaniformes	Ardeidae	*Egretta gularis*	LC	Western Reef-egret
Aves	Coraciiformes	Coraciidae	*Eurystomus glaucurus*	LC	Broad-billed Roller
Aves	Coraciiformes	Alcedinidae	*Halcyon smyrnensis*	LC	White-breasted Kingfisher
Aves	Accipitriformes	Accipitridae	*Haliaeetus vocifer*	LC	African Fish-eagle
Aves	Passeriformes	Acrocephalidae	*Hippolais languida*	LC	Upcher's Warbler
Aves	Pelecaniformes	Ardeidae	*Ixobrychus minutus*	LC	Common Little Bittern
Aves	Pelecaniformes	Ardeidae	*Ixobrychus sturmii*	LC	Dwarf Bittern
Aves	Charadriiformes	Laridae	*Larus hemprichii*	LC	Sooty Gull
Aves	Coraciiformes	Alcedinidae	*Megaceryle maxima*	LC	Giant Kingfisher
Aves	Coraciiformes	Meropidae	*Merops albicollis*	LC	White-throated Bee-eater
Aves	Coraciiformes	Meropidae	*Merops nubicus*	LC	Northern Carmine Bee-eater
Aves	Coraciiformes	Meropidae	*Merops persicus*	LC	Blue-cheeked Bee-eater
Aves	Coraciiformes	Meropidae	*Merops superciliosus*	LC	Olive Bee-eater
Aves	Suliformes	Phalacrocoracidae	*Microcarbo africanus*	LC	Long-tailed Cormorant
Aves	Charadriiformes	Scolopacidae	*Numenius arquata*	NT	Eurasian Curlew
Aves	Charadriiformes	Scolopacidae	*Numenius phaeopus*	LC	Whimbrel
Aves	Pelecaniformes	Ardeidae	*Nycticorax nycticorax*	LC	Black-crowned Night-heron
Aves	Passeriformes	Oriolidae	*Oriolus larvatus*	LC	Eastern Black-headed Oriole
Aves	Strigiformes	Strigidae	*Otus senegalensis*	LC	African Scops-owl

Class	Order	Family	Scientific name	RLTS category	Common name
Aves	Accipitriformes	Pandionidae	*Pandion haliaetus*	LC	Osprey
Aves	Passeriformes	Paridae	*Parus major*	LC	Great Tit
Aves	Pelecaniformes	Pelecanidae	*Pelecanus rufescens*	LC	Pink-backed Pelican
Aves	Passeriformes	Phylloscopidae	*Phylloscopus collybita*	LC	Common Chiffchaff
Aves	Passeriformes	Phylloscopidae	*Phylloscopus tristis*	LC	Siberian Chiffchaff
Aves	Passeriformes	Phylloscopidae	*Phylloscopus trochilus*	LC	Willow Warbler
Aves	Pelecaniformes	Threskiornithidae	*Platalea leucorodia*	LC	Eurasian Spoonbill
Aves	Passeriformes	Platysteiridae	*Platysteira cyanea*	LC	Brown-throated Wattle-eye
Aves	Charadriiformes	Charadriidae	*Pluvialis fulva*	LC	Pacific Golden Plover
Aves	Gruiformes	Heliornithidae	*Podica senegalensis*	LC	African Finfoot
Aves	Passeriformes	Cisticolidae	*Prinia gracilis*	LC	Graceful Prinia
Aves	Passeriformes	Cisticolidae	*Prinia subflava*	LC	Tawny-flanked Prinia
Aves	Columbiformes	Columbidae	*Streptopelia semitorquata*	LC	Red-eyed Dove
Aves	Passeriformes	Sylviidae	*Sylvia atricapilla*	LC	Eurasian Blackcap
Aves	Passeriformes	Macrosphenidae	*Sylvietta brachyura*	LC	Northern Crombec
Aves	Passeriformes	Macrosphenidae	*Sylvietta leucopsis*	LC	Eastern Crombec
Aves	Pelecaniformes	Threskiornithidae	*Threskiornis aethiopicus*	LC	African Sacred Ibis
Aves	Coraciiformes	Alcedinidae	*Todiramphus chloris*	LC	Collared Kingfisher
Aves	Charadriiformes	Scolopacidae	*Tringa nebularia*	LC	Common Greenshank
Aves	Columbiformes	Columbidae	*Turtur afer*	LC	Blue-spotted Wood-dove
Aves	Charadriiformes	Scolopacidae	*Xenus cinereus*	LC	Terek Sandpiper
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Carcharhinus amblyrhynchoides*	VU	Graceful Shark
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Carcharhinus amboinensis*	VU	Pigeye Shark
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Carcharhinus melanopterus*	VU	Blacktip Reef Shark
Chondrichthyes	Myliobatiformes	Dasyatidae	*Himantura uarnak*	EN	Coach Whipray
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Negaprion acutidens*	EN	Sharptooth Lemon Shark
Chondrichthyes	Myliobatiformes	Dasyatidae	*Pastinachus ater*	VU	Broad Cowtail Ray
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis pristis*	CR	Largetooth Sawfish
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis zijsron*	CR	Green Sawfish
Chondrichthyes	Myliobatiformes	Dasyatidae	*Taeniura lymma*	LC	Bluespotted Lagoon Ray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Urogymnus granulatus*	VU	Mangrove Whipray
Gastropoda	Sorbeoconcha	Potamididae	*Cerithidea decollata*	LC	(truncated mangrove snail)
Gastropoda	Neogastropoda	Conidae	*Conus varius*	LC	(The freckled cone)
Gastropoda	Littorinimorpha	Littorinidae	*Littoraria undulata*	LC	(The robust shell)
Gastropoda	Ellobiida	Ellobiidae	*Pedipes affinis*	LC	NA
Gastropoda	Sorbeoconcha	Potamididae	*Pirenella conica*	LC	NA
Holothuroidea	Aspidochirotida	Holothuriidae	*Holothuria impatiens*	DD	Bottleneck Sea Cucumber
Holothuroidea	Aspidochirotida	Holothuriidae	*Holothuria parva*	DD	NA
Holothuroidea	Aspidochirotida	Holothuriidae	*Holothuria scabra*	EN	Golden Sandfish
Liliopsida	Alismatales	Hydrocharitaceae	*Enhalus acoroides*	LC	(Tape Seagrass)
Liliopsida	Alismatales	Cymodoceaceae	*Halodule uninervis*	LC	(Narrowleaf seagrass)
Liliopsida	Alismatales	Hydrocharitaceae	*Halophila ovalis*	LC	(Spoon seagrass)
Liliopsida	Alismatales	Cymodoceaceae	*Thalassodendron ciliatum*	LC	(Sickle-leaved cymodocea)
Magnoliopsida	Malvales	Malvaceae	*Thespesia populnea*	LC	Portia Tree
Magnoliopsida	Caryophyllales	Cactaceae	*Rhipsalis baccifera*	LC	Mistletoe Cactus
Mammalia	Carnivora	Mustelidae	*Aonyx capensis*	NT	African Clawless Otter

Class	Order	Family	Scientific name	RLTS category	Common name
Mammalia	Primates	Cercopithecidae	*Chlorocebus pygerythrus*	LC	Vervet Monkey
Mammalia	Sirenia	Dugongidae	*Dugong dugon*	VU	Dugong
Mammalia	Chiroptera	Pteropodidae	*Eidolon helvum*	NT	African Straw-coloured Fruit-bat
Mammalia	Rodentia	Muridae	*Rattus rattus*	LC	House Rat
Mammalia	Chiroptera	Pteropodidae	*Rousettus aegyptiacus*	LC	Egyptian Fruit Bat
Mammalia	Cetartiodactyla	Delphinidae	*Sousa plumbea*	EN	Indian Ocean Humpback Dolphin
Reptilia	Squamata	Viperidae	*Bitis arietans*	LC	Puff Adder
Reptilia	Crocodylia	Crocodylidae	*Crocodylus niloticus*	LC	Nile Crocodile
Reptilia	Squamata	Colubridae	*Crotaphopeltis hotamboeia*	LC	Red-lipped Snake
Reptilia	Testudines	Cheloniidae	*Eretmochelys imbricata*	CR	Hawksbill Turtle
Reptilia	Squamata	Gekkonidae	*Hemidactylus robustus*	LC	Red Sea Leaf-toed Gecko
Reptilia	Squamata	Sphaerodactylidae	*Pristurus obsti*	LC	(Mangrove semaphore gecko)
Reptilia	Testudines	Trionychidae	*Trionyx triunguis*	VU	African Softshell Turtle
Reptilia	Squamata	Varanidae	*Varanus niloticus*	LC	Nile Monitor

3. National Estimates for subcriterion A1

To estimate the Red Sea and Gulf of Aden mangrove ecosystem extent in 1970, we gathered reliable information on the mangrove area for each country within the province around this period (Table b). We then estimated the area of mangroves in 1970 for each country, assuming a linear relationship between mangrove extent and time. Finally, we summed up the country estimates to determine the total mangrove area in the Red Sea and Gulf of Aden province (Table a). We assumed that the percentage of mangrove extent by country within the province remained constant over time, as the percentages did not change between 1996 and 2020 (GMW v3.0 dataset). Two temporal analyses, Almahasheer *et al.* (2015) and FAO (2007) were used for estimating area of mangroves in 1970. It was found that trends diverge depending on data sources; Almahasheer *et al.* (2015) reported the least estimate for mangroves area compared to FAO (2007) in 1970. However, Bunting *et al* (2022) reported a higher estimate for 1996 compared to Almahasheer *et al.* (2015) and FAO (2007) for 2000. Indeed, using mangrove area estimates from different sources can lead to uncertainty (Friess and Webb, 2014)[2]. Results were represented by a plausible range between two categories to overcome uncertainty. There were no consistent regional statistics or global studies available for this time period. Thus, the estimates for 1970 should be considered only indicative.

[2] Friess, D. A. and Webb, E. L. (2014). Variability in mangrove change estimates and implications for the assessment of ecosystem service provision. *Global Ecology and Biogeography*, 23 (7). 715-725 doi:10.1111/geb.12140

Table a. Estimated mangrove area in Km^2 by country in 1970 and 2020. Estimates for 2020* mangrove area are based on the Global Mangrove Watch Version 3 (GMW v3.0) dataset. The references used to calculate mangrove area for each country in 1970 are listed below in Table b.

Year	Country total 2020*	Within province 2020*	Country total 1970**	Within province 1970 Least estimate**	Within province 1970 Highest estimate***
Djibouti	7.5	7.5	10	10***	10
Egypt	3.5	3.5	1.89	1.89	5
Eritrea	77.9	77.9	59.84	59.84	67.9
Saudi Arabia	76.0	66.5		42.02	186.1
Somalia	35.2	9.1	100.00	27.05***	27.05
Sudan	8.1	8.1	4.47	4.47	5
Yemen	16.6	16.6	9.00	9.00	10.3
The Red Sea and Gulf of Aden		**189.2**		**154.8**	**311.3**

Table b. List of selected studies considered to have reliable information on mangrove area for the period around 1970 in each country of the Red Sea and Gulf of Aden province.

Country	Year	Mangrove Area (ha)	Reference
Mangroves of the Asian Red Sea shore**	1972	5100	Almahasheer, Hanan; Aljowair, Abdulaziz; Duarte, Carlos Manuel; Irigoien, Xabier (2015): Mangrove cover in the Red Sea (1972-2013). *PANGAEA.* https://doi.org/10.1594/PANGAEA.855896
Mangroves of the African Red Sea shore**	1972	6900	Almahasheer, Hanan; Aljowair, Abdulaziz; Duarte, Carlos Manuel; Irigoien, Xabier (2015): Mangrove cover in the Red Sea (1972-2013). *PANGAEA.* https://doi.org/10.1594/PANGAEA.855896
Mangroves of the Red Sea countries (Egypt, Saudi Arabia, Sudan, Yemen, Eritrea)**	1972	12000	Almahasheer, Hanan; Aljowair, Abdulaziz; Duarte, Carlos Manuel; Irigoien, Xabier (2015): Mangrove cover in the Red Sea (1972-2013). *PANGAEA.* https://doi.org/10.1594/PANGAEA.855896
Djibouti***	1985	1000	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Saudi Arabia***	1980	21000	FAO (2007) The World's Mangroves 1980-2005. Asia. https://www.fao.org/3/a1427e/a1427e06.pdf
Saudi Arabia***	1990	20000	FAO (2007) The World's Mangroves 1980-2005. Asia. https://www.fao.org/3/a1427e/a1427e06.pdf
Saudi Arabia***	2000	20000	FAO (2007) The World's Mangroves 1980-2005. Asia. https://www.fao.org/3/a1427e/a1427e06.pdf
Saudi Arabia***	2005	20000	FAO (2007) The World's Mangroves 1980-2005. Asia. https://www.fao.org/3/a1427e/a1427e06.pdf
Saudi Arabia***	2004	3500	El-Juhany, L., 2009. Present status and degradation trends of mangrove forests on the southern Red Sea coast of Saudi Arabia. American-Eurasian J. Agric. Environ. Sci. 6, 328e340.
Somalia***	1975	10000	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Somalia***	1980	9500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Somalia***	1990	8600	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Somalia***	2000	7800	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Somalia***	2005	7300	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Egypt***	1980	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Egypt***	1990	500	FAO (2007) The world's mangroves 1980-2005. Africa.

			https://www.fao.org/3/a1427e/a1427e05.pdf
Egypt* **	2000	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Egypt* **	2005	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Sudan * **	1980	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Sudan * **	1990	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Sudan * **	2000	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Sudan * **	2005	500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Yemen * **	1980	1000	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Yemen * **	1990	9500	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Yemen * **	2000	9000	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf
Yemen * **	2005	9000	FAO (2007) The world's mangroves 1980-2005. Africa. https://www.fao.org/3/a1427e/a1427e05.pdf