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Mangroves of The Western India and Pakistan

VU

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Abstract

Mangroves of the Western India and Pakistan is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine ecoregions of Western India and Pakistan. According to global data the Western India and Pakistan mangrove province mapped extent in 2020 was 1625.3 km^2, representing 1.1% of the global mangrove area, while national and regional studies estimated it at 2,991 km^2. The biota is characterized by 20 species of true mangroves and 180 associated plant and animal species.

There are multiple threats to mangroves in this province: degradation leading to deforestation caused by over-harvesting of mangroves for timber, fuelwood and fodder for camels and cattle, or from direct grazing by livestock; conversion of mangroves for coastal industrial or urban development; coastal pollution; and in Gujarat mangrove conversion to salt pans. There are also increasing threats to mangroves from lack of freshwater and climate change in the form of higher temperatures, sea-level rise and more frequent and severe cyclonic storms.

Today, the Western India and Pakistan mangroves cover ≈ 30 – 60 % less than our broad estimation for 1970. However, the net area of mangroves has decreased by 10.9% since 1996, according to global data. National and regional studies indicate that mangrove areas in Western India and Pakistan have increased by 170% from 1990 to 2020, with a projected increase of 280% by 2040. Under a high sea-level rise scenario (IPCC RCP8.5) ≈-1.5% of the Western India and Pakistan mangroves would be submerged by 2060. Moreover, 3.4% of the province's mangrove ecosystem is undergoing degradation, with the potential to increase to 9.9% within a 50-year period, based on a vegetation index decay analysis. These results should be interpreted with caution, as they are based on global datasets (underestimated) and not on national or regional estimations of the actual extent of the mangrove ecosystem for 2020. Overall, the Western India and Pakistan mangrove ecosystem is assessed as **Vulnerable (VU).**

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

Ecosystem classification:
MFT1.2 Intertidal forests and shrublands

Assessment's distribution:
West India and Pakistan province

Summary of the assessment:

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

VU= Vulnerable, LC= Least Concern,
DD= Data Deficient, NE= Not Evaluated

Mangroves of The Western India and Pakistan

VU

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_21a Mangroves of the Western India and Pakistan

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

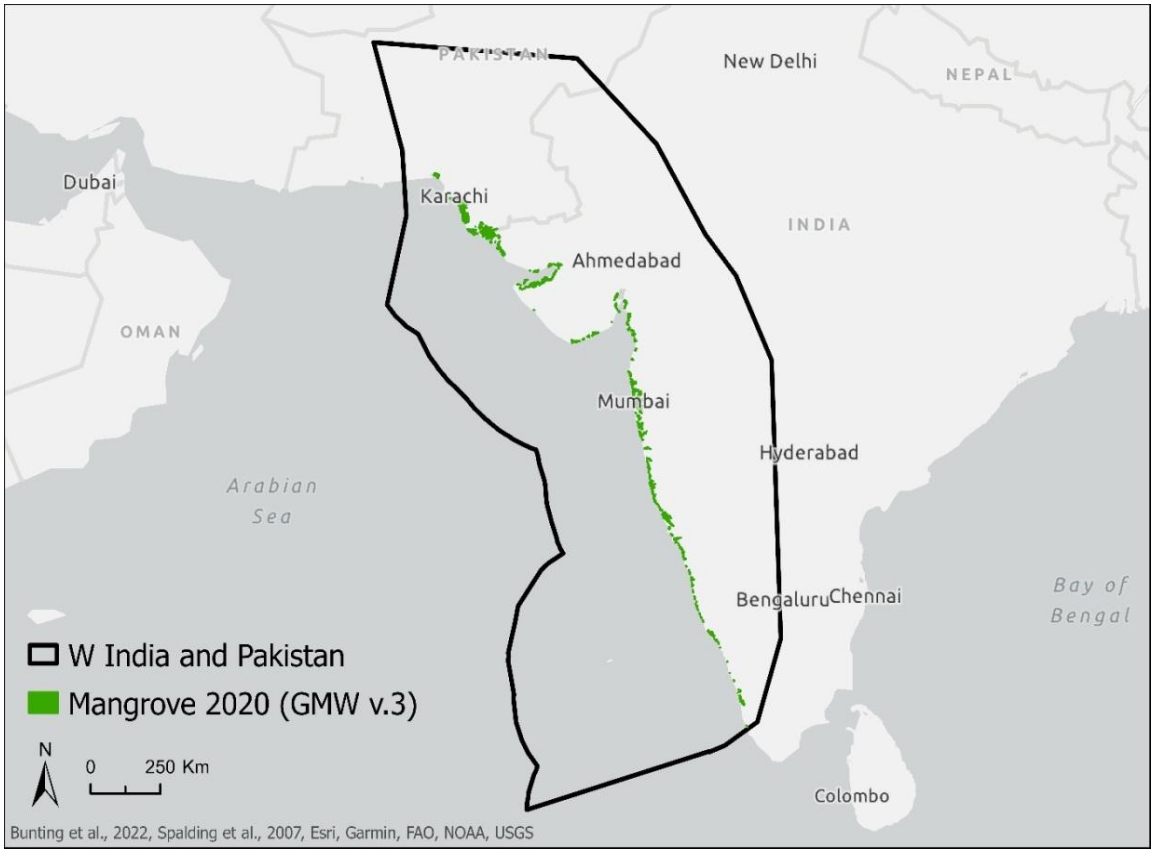


Figure 1. The mangroves of Western India and Pakistan.

[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.

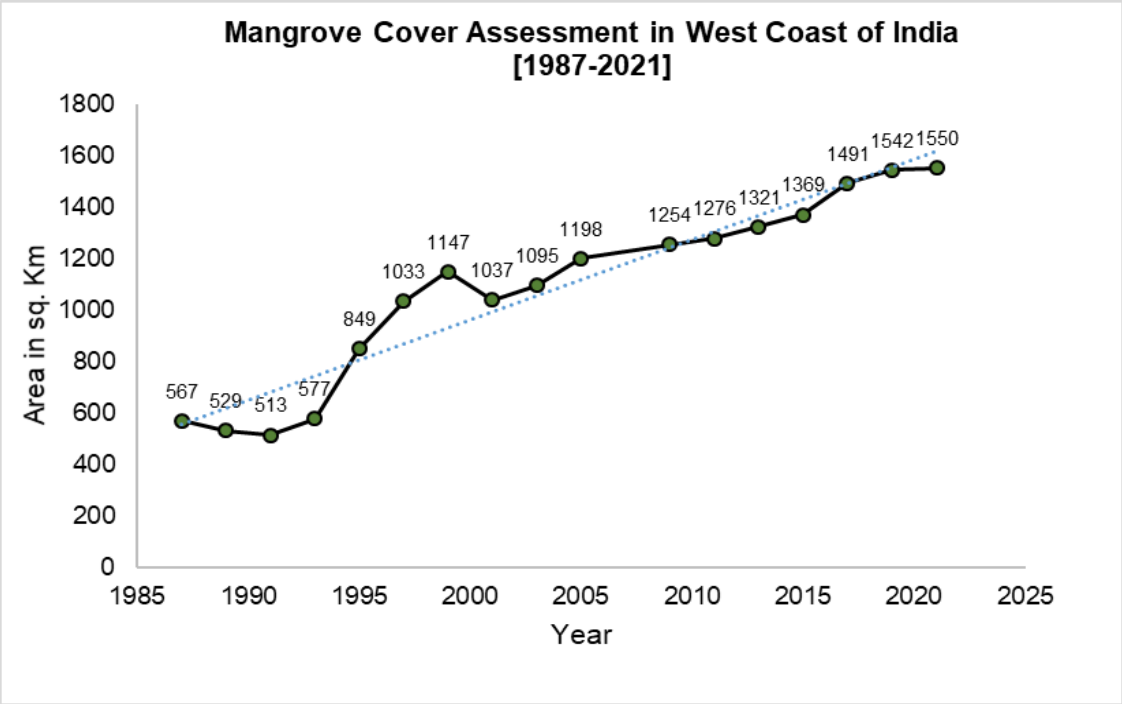
2. Ecosystem Description

Spatial distribution

The Mangroves of Western India and Pakistan include intertidal forests and shrublands of the marine ecoregions of Western India and Pakistan (Karachi coast and Indus Delta region) (Figure 1).The estimated extent of mangroves in this province is of 1,625.3 km^2 in 2020, representing about 1.1% of the global mangrove area. There has been a -10.9 % net area change since 1996 (Bunting *et al.*, 2022). Following a long history of mangrove loss due to overharvesting and conversion to other land uses, plus environmental change (especially in the Indus Delta), large-scale mangrove rehabilitation and afforestation programs from the 1990s have achieved significant increases in mangrove cover in both Western India and Pakistan.

West Coast of India

The estimated extent of mangroves on the west coast of India was 1,550 km^2 in 2021 (FSI, 2021), representing an increase of 983 km^2 compared to only 567 km^2 in 1987 (FSI, 1987-2021). The largest spatial increase was reported from Gujarat, followed by Maharashtra. In general, the data show a trend of long-term increase (see graph below), particularly in the category of sparse mangrove forests.



Source: Biannual State of Forest Report (1987-2021).

Indus Delta Pakistan

The total area of the Indus Delta is about 668,000 ha. Two recent studies in Pakistan have provided different estimates of the delta's mangrove cover. Gilani *et al.* (2021) estimated 140,922 ha in 2020 based on Landsat satellite imagery. The other study by the Sindh Forest Department in support of a large carbon credit project (Delta Blue Carbon 1) reported 198,465 ha in 2021 (Sindh Forest Department, 2022).

A mangrove-fringed creek typical of the habitat in the Indus Delta, Keti Bundar, Sindh Province (Photo credit: Don Macintosh)

Biotic components of the ecosystem (characteristic native biota)

The mangroves of the Western India and Pakistan province are biologically diverse with 20 recorded true mangrove plant species in eight families in the IUCN Red List of Threatened Species (IUCN, 2022). There are at least 180 plant and animal species associated with mangroves of the West India and Pakistan province within the taxa Mammalia (23 species), Aves (53 species), Reptilia (eight species), Actinopterygii (72 species), Chondrichthyes (13 species), Gastropoda (four species), Insecta (one species), Magnoliopsida (five species) and Polypodiopsida (one species). Two species are Critically Endangered (CR): *Pristis pristis* and *Pristis zijsron*; six species are Endangered (EN); 14 species are Vulnerable (VU) and three species are Near Threatened (NR) according to the IUCN Red List of Threatened Species (IUCN, 2022).

West Coast of India

Twenty-eight species of true mangroves have been recorded from the west coast of India belonging to 12 families and 17 genera (Raghavendra *et al.*, 2016). There are 55 mangrove associate species belonging to 29 families and 49 genera on the west coast of India (Kathiresan, 2019). However, except in a few locations, the mangroves are generally in a vulnerable condition (Kathiresan, 2010). As to their global status, 26 of the true mangrove species are of least concern (LC); one is near threatened (NT) (*Ceriops decandra*); and one is data deficient (DD) (*Excoecaria indica*) (Polidoro *et al.*, 2010). However, their status in India shows that three species are endangered (EN) (*Nypa fruticans, Excoecaria indica, Acanthus ebracteatus*); 11 are vulnerable (VU), and 13 are low risk (See Appendix 1) (Kathiresan, 2008). The largest diversity of true mangroves has been reported from the State of Maharashtra (22 species) and the lowest from Lakshadweep and Daman and Diu, with three and four species, respectively (Raghavendra *et al.*, 2016).

A total of 72 mammalian species, 359 species of birds, 388 fishes, 85 molluscs, 50 Hemiptera, 35 Coleoptera, 23Oodonata, 46 Hymenoptera, 172 Diptera, 51 Lepidoptera and 198 crustacean species are

reported from the west coast of India with many included in the IUCN Red List of Threatened Species (RLTS, 2022). Among the fish species, three species are assessed as Critically Endangered, six are Endangered, 13 are Vulnerable, and 18 are Near Threatened. Of the remainder, about 37% fishes (245 species) are Least Concern and so exploitable for fishery purpose. A majority of fishes (about 52%) are not assessed for their conservation status. The Endangered Leatherback turtle, Hawksbill turtle and Olive Ridley turtle use various nesting sites close to the mangroves (Chandra *et al.*, 2019).

The globally threatened Dalmatian pelican, Pallas fish-eagle, Greater Spotted eagle, Indian skimmer and the Near Threatened Spot-billed pelican, darter, Painted stork, Black-necked stork, Black- headed ibis, Lesser flamingo, Eurasian curlew, Black tailed godwit have been recorded. Of the threatened species of birds, the Black-headed ibis, darter, Painted stork and Black neck stork breed mainly in the mangroves, while the Lesser flamingo breeds mainly on mudflats near mangroves (GEER, 2002; Chandra *et al.*, 2019).

Indus Delta (Pakistan)

The Indus Delta mangrove ecosystem in Pakistan supports rich biodiversity; however, there are only four true mangrove species: *Avicennia marina, Rhizophora mucronata, Ceriops tagal* and *Aegiceras cornicullatum*. The dominant species is *Avicenna marina* due to its high salt tolerance, which is an indicator of stressed environments that are too extreme for other mangrove plant species.

Old Avicennia marina forest in Korangi-Pitti Creek near Karachi, Northwest Indus Delta (Photo credit: Don Macintosh)

The mangroves serve as habitat and breeding grounds for a wide range of flora and fauna, including various species of fishes, crabs, molluscs, and birds. The Bird diversity includes 100 species belonging to 28 families (Jabeen *et al.*, 2014; Khan *et al.*, 2022). The Egyptian vulture (*Neophron percnopterus*), Dalmatian pelican (*Pelicanus crispus*) and Black bellied tern (*Sterna acuticauda*) are Endangered; and the Eurasian curlew (*Numenius Arquata*) and Black tailed godwit (*Limosa limosa*) are Near Threatened. Of the mammals, the

Fishing cat (*Prionailurus viverrinus*) is Vulnerable and the Indian ocean humpback dolphin (*Sousa plumbea*) is Endangered. The Fish fauna contains 84 finfish species present in 60 genera and 29 families (Aamer *et al.*, 2018). There are also 10 species of crabs belonging to four families (Nazim *et al.*, 2010); 18 species of gastropods belonging to 15 families; and 12 bivalve species belonging to eight families (Nazim *et al.*, 2015).

Abiotic Component of the ecosystem

Mangrove distribution and biodiversity are influenced by interactions among landscape position, rainfall, hydrology, sea level, sediment dynamics, subsidence, storm-driven processes, and disturbance by pests and predators. Rainfall and sediment supply from rivers and currents promote mangrove establishment and persistence, while waves and large tidal currents destabilize and erode soft mangrove substrata, mediating local-scale dynamics in ecosystem distributions. High rainfall reduces salinity stress and increases nutrient loading from adjacent catchments, while tidal flushing also regulates salinity. There are significant differences in mangrove distribution and biodiversity across the Pakistan and Western India province, which are due largely to variation in the rainfall regime and the quantities of freshwater and sediments being carried to the coast by rivers.

West Coast India

India's west coast is a very narrow strip of land abutted by the mountains of the Western Ghats. Reduction in freshwater flow, reduced sediment flow because of dams upstream, marine and coastal pollution, siltation, sedimentation and excessive salinity are reported. Climate-wise, the eastern and southwestern coastal regions experience significant rainfall (1300-2850 mm annually), while the northwest coastal region experiences low rainfall (450-1000 mm annually). These soils have been created from inland alluvial materials, as well as e.g. coastal basalt deposits and severely weathered lateritic materials. which differ significantly in terms of texture, stratification and water permeability (Mandal *et al.*, 2023). Gujarat on the north west coast contains around 40% of the total area of coastal saline soils in India. The coastal saline soils are due to the periodic inundation of cultivable land by creeks/seawater during high tides, and the distribution of fine-textured soil with poor hydraulic conductivity.

Indus Delta (Pakistan)

As in Gujarat, which borders Sindh Province in Pakistan, the Indus Delta, mangroves are under the influence of low average annual rainfall (200 to 500 mm) and high salinities. The mangroves thrive on the clay and silty sediments transported to the delta by the Indus River, which branches out into 17 major creeks forming estuaries and a network of tributaries. The dense root systems of mangrove trees serve as natural filters, enhancing water quality by trapping sediment and absorbing excess nutrients (Osland *et al.*, 2018). The tides are semidiurnal with amplitude of up to 3 m.

The Indus mangrove ecosystem experiences fluctuations in salinity due to tidal influence and freshwater inputs from rivers. This creates a dynamic environment supporting a diverse range of species adapted to

varying salinity levels. However, during most of the year the salinity levels are high (range 37-44 ppt), which is considerably above the optimum salinity for growth of the mangrove tree species in the delta (Khan and Aziz, 2001).

Young Rhizophora mucronata trees planted to increase mangrove cover in the Indus Delta and benefit from carbon financing, Gharo, Sindh Province (Photo credit: Don Macintosh)

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. They exhibit high efficiency in nitrogen use and nutrient resorption. Mangroves produce large amounts of detritus (e.g., leaves, twigs, and bark), which is either buried in waterlogged sediments, consumed by crabs and gastropods, and then decomposed further by fungi and bacteria, creating protein-rich detritus that becomes available to other consumers in the mangrove and coastal food web. Mangrove ecosystems also play a crucial role in carbon sequestration and serve as major blue carbon sinks, incorporating organic matter into sediments and living biomass. The Indus Delta mangroves store an average of 163.8 tons of carbon per hectare, or a total of approximately 32,508,567 tons across the mangrove forest cover of 198,465 hectares (Sindh Forest Department, 2022).

3. Ecosystem Threats and vulnerabilities

Main threatening process and pathways to degradation

Mangrove degradation in the Western India and Pakistan province is caused by various factors, including land use change, over-harvesting of mangroves for timber, fuelwood and fodder for camels and cattle, as well as direct grazing by livestock. The impact of these activities can lead eventually to deforestation. Pollution stemming from domestic, municipal, industrial and agricultural wastes is also a threat to mangroves at the ecosystem level. The location of mangrove forests within intertidal areas also renders them vulnerable to sea-level rise because of climate change. Cyclones and tropical storms can damage mangrove

forests through direct defoliation and destruction of trees, as well as through the mass mortality of animal communities within the ecosystem.

West Coast, India

Mangrove degradation leading to deforestation on the west coast of India has many causes both general and more localized in impacts. The causes include industrialization, urbanization and pollution, over-exploitation of mangroves for fuelwood, grazing habitat and cattle fodder, developmental activities, aquaculture, agriculture expansion, natural calamities and coral reef degradation (Joshy *et al.*, 2022). The largest part of west coast of India has observed deforestation, reclamation, conversion and pollution (Kaladharan *et al.*, 2005). Gujarat state is the largest producer of salt in India and fulfils 80% of the total marine salt production of the country. Expansion of salt pans along India's west coast is also one of the major causes of decline of mangroves. The leasing of large areas of mangroves to industries for conversion to salt pans has resulted in high soil and water salinity levels that are reducing the natural regeneration of mangrove forests.

Although the occurrence of cyclones is highly unusual for the west coast of India, there has been a significant increase in the frequency, duration, and intensity of cyclonic storms over the Arabian Sea from 1982 to 2019 (Deshpande *et al.*, 2021). The Arabian Sea has experienced temperature changes reaching up to 1.2°C-1.4℃ over the past 20 years compared to the average global ocean surface warming of 0.8-0.9 °C. There has also been a significant increase in the frequency, duration, and intensity of cyclonic storms over the Arabian Sea between 1982 and 2019 (Deshpande *et al.*, 2021).

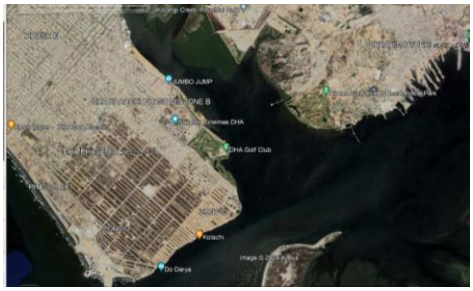
Indus delta (Pakistan)

There are multiple threats to the mangroves in the Indus delta which include land use change, deforestation, and pollution. Land clearing for industrialization, port construction and urbanization is the major threat near the metropolitan city of Karachi. This area contains the densest area of mangroves in the entire delta.

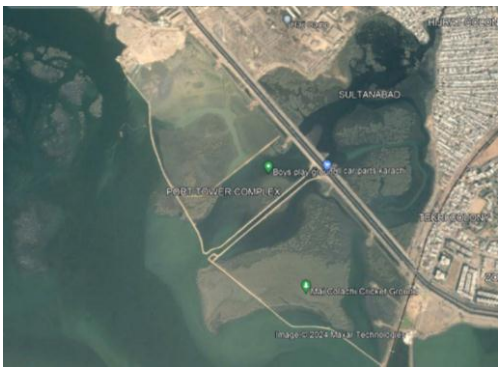
Pollution is another major concern which threats to the biodiversity in the mangroves near the Karachi coast which touches the Indus delta in the Northwestern part. There is approximately 600 million gallons per day of wastewater entering the marine environment all of which is untreated (Ahmed & Shaukat 2015). This wastewater contains toxic pollutants including heavy metals, dyes and oxygen demanding waste. The origin of the wastewater is domestic, industrial and livestock waste. The Cattle Colony, which is also known as Landhi Dairy Colony or Bhains Colony, in Karachi is the largest of its kind in the world. The colony houses about 400,000 cattle (mostly buffaloes) and is spread over an area of 6.5 km^2 (Ahmed, 2007). Levels of all types of pollutants are extremely high and exceed the legal limits (Shahzad *et. al*., 2009).

Industrial wastewater is also a significant source of environmental degradation and contains high amounts of toxic pollutants including the COD, BOD and heavy metals (Shahzad *et. al*., 2009). However, in the rest of the Indus Delta the reduced flow of fresh water, which is a result of the diversion of water upstream, is a major threat as it creates hyper salinity stress and reduced siltation rates (Saifullah, 2017). Due to these conditions, sea water intrusion and land erosion are major causes of concern (Aeman *et al.*, 2023).

Heavily polluted water and garbage draining into the mangrove-creek system near Karachi (Photo credit: Waqar Ahmed)



The Defence Housing Authority, Karachi: a) year 2000; and b) 2023 (Google Earth)



Sultanabad and Karachi Port Trust areas: a) year 2000; and b) 2023 (Google Earth)

Mangroves growing closer to human habitations in Kochi, Kerala (Photo credit: Sanaya Joshy)

Mangroves habitat affected by invasive species in Kochi, Kerala (Photo credit: Sanaya Joshy)

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 dwindles 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 adverse climatic conditions (e.g., low temperatures); b) alterations in rainfall, river inputs, waves, and tidal currents that destabilize and erode soft substrata, hindering recruitment and growth; c) shifts in rainfall patterns and tidal flushing altering salinity stress and nutrient loadings, impacting overall survival.

Threat Classification

IUCN Threat Classification (version 3.3, IUCN-CMP, 2022) relevant to mangroves of the Western India and Pakistan province:

1. Residential & commercial development
- 1.1 Housing & urban areas
- 1.2 Commercial & industrial areas
- 1.3 Tourism & recreation areas

2. Agriculture & aquaculture
- 2.1 Annual & perennial non-timber crops
  - 2.1.1 Shifting agriculture
  - 2.1.2 Small-holder farming
  - 2.1.3 Agro-industry farming
  - 2.1.4 Scale Unknown/Unrecorded
- 2.2 Wood & pulp plantations
  - 2.2.1 Small-holder plantations
  - 2.2.2 Agro-industry plantations
  - 2.2.3 Scale Unknown/Unrecorded
- 2.3 Livestock farming & ranching
  - 2.3.1 Nomadic grazing
  - 2.3.2 Small-holder grazing, ranching or farming
  - 2.3.3 Agro-industry grazing, ranching or farming
  - 2.3.4 Scale Unknown/Unrecorded
- 2.4 Marine & freshwater aquaculture
  - 2.4.1 Subsistence/artisanal aquaculture
  - 2.4.2 Industrial aquaculture
  - 2.4.3 Scale Unknown/Unrecorded

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
- 4.2 Utility & service lines
- 4.3 Shipping lanes
- 4.4 Flight paths

5. Biological resource use
- 5.2 Gathering terrestrial plants
  - 5.2.1 Intentional use (species being assessed is the target)
  - 5.2.2 Unintentional effects (species being assessed is not the target)
  - 5.2.3 Persecution/control
  - 5.2.4 Motivation Unknown/Unrecorded
- 5.3 Logging & wood harvesting

        - 5.3.1 Intentional use: subsistence/small scale (species being assessed is the target [harvest]
        - 5.3.2 Intentional use: large scale (species being assessed is the target) [harvest]
        - 5.3.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
        - 5.3.4 Unintentional effects: large scale (species being assessed is not the target) [harvest]
        - 5.3.5 Motivation Unknown/Unrecorded
    - 5.4 Fishing & harvesting aquatic resources
        - 5.4.1 Intentional use: subsistence/small scale (species being assessed is the target) [harvest]
        - 5.4.2 Intentional use: large scale (species being assessed is the target) [harvest]
        - 5.4.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
        - 5.4.4 Unintentional effects: large scale (species being assessed is not the target) [harvest]
        - 5.4.5 Persecution/control
        - 5.4.6 Motivation Unknown/Unrecorded

7. Natural system modifications

- 7.2 Dams & water management/use
    - 7.2.6 Abstraction of ground water (commercial use)
    - 7.2.7 Abstraction of ground water (agricultural use)

8. Invasive & other problematic species, genes & diseases

- 8.1 Invasive non-native/alien species/diseases

9. Pollution

- 9.1 Domestic & urban waste water
    - 9.1.1 Sewage
    - 9.1.2 Run-off
    - 9.1.3 Type Unknown/Unrecorded
- 9.3 Agricultural & forestry effluents
    - 9.3.1 Nutrient loads
    - 9.3.2 Soil erosion, sedimentation
- 9.4 Garbage & solid waste

10. Geological events

- 10.1 Volcanoes
    - 10.2 Earthquakes/tsunamis
    - 10.3 Avalanches/landslides

11. Climate change & severe weather

- 11.4 Storms & flooding
- 11.5 Other impacts (see-level rise)

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. However, country-level estimates of mangrove extent can be used 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) in West India (including the Indian states of

Goa, Guajarat, Karnataka, Kerata, Maharashtra) and the province of Sindh in Pakistan. These estimates were used to interpolate the mangrove area in 1970 in West India and Sindh Pakistan. By summing up these estimates, we calculated the total mangrove area in the province. However, the estimated values for 1970 should be considered only indicative (see appendix 3 for further details of the methods and limitations).

To assess the more recent changes in the mangrove area we used the Global Mangrove Watch (GMW v3.0) spatial dataset covering 1996 - 2020. To ensure accuracy, both omission and commission errors were corrected in the mangrove area estimates, using the equations in Bunting *et al.* (2022). Furthermore, we compared the GMW results for Western India with the corresponding data from the Indian State of Forests Report (ISFR) 2021. Similarly, for Sindh Province in Pakistan, we compared the GMW estimates with those documented by Gilani *et al.* (2024).

The analysis of sub-criterion A1 (see Annex 3) reveals a significant decline in mangrove area in the province of West India and Pakistan over the last 50 years (1970-2020). According to the GMW mangrove area estimates for 2020, there has been an approximate decline of ~-62.6%. However, if GMW data are excluded, and national sources such as ISFR (2021) and Gilani *et al.* (2024) are considered, the decline in mangrove area is lower at -31.2%. As the estimated change in geographical distribution is between higher than 30% but lower than 80%, the mangroves are assessed as **Vulnerable, with a plausible range between Vulnerable and Endangered (VU-EN) under sub-criterion A1**.

		Area 2020 (km^2)	Area 1970* (km^2)	Net area Change (km^2)	% Net Area Change	Rate of change (%/year)
Mangroves of the Western India and Pakistan	Lower estimate**	1625.3	4346.8	-2721.5	-62.6%	-1.3 %/Year
	Higher estimate***	2991.0	4346.8	-1355.8	-31.2%	-0.6%/Year

** Details on the methods and references used to estimate the mangrove area in 1970 are listed in appendix 3.*
*** Lower estimate for total mangrove area in 2020 is based on the Global Mangrove Watch Version 3 (GMW v3.0) dataset. ***Higher Estimate for total mangrove area in 2020 is based on ISFR (2021) and Gilani et al. (2024).*

Subcriterion A2 evaluates the change in ecosystem extent in any 50-year period, including from the present to the future. The mangroves of the Western India and Pakistan province exhibit a net area change of -10.9% (1996-2020), as per GMW dataset. This value reflects the offset between gained areas (+ 0.2%/year) and lost areas (-0.7%/year) resulting in an overall annual area change rate of -0.5%. The largest decrease in mangrove area within this period occurred between 1996 and 2009. Due to the absence of a linear trend in the time series (figure 2), linear regression cannot be applied to forecast the mangrove area in the next 50 years.

Furthermore, findings from regional studies (ISF, 2021 and Gilani *et al.* 2024) suggest an increasing trend in the mangrove area in the Western India and Pakistan province since the 1990s (annex 3, table b). Estimates

indicate a net area change of +170% between 1990 and 2020, with a corresponding rate of change of 5.7% per year. If this trend is extrapolated linearly into the future, the mangrove area in the province of Western India and Pakistan is expected to change by +280% between 1990 and 2040 and by +103.9% between 2020 and 2070. Given that these predicted changes in mangrove extent show increase in the Western India and Pakistan mangrove cover, the ecosystem is assessed as **Least Concern (LC)** 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 Western India and Pakistan mangrove ecosystem is classified as **Data Deficient (DD)** for this subcriterion.

Overall, the ecosystem is assessed as **Vulnerable (VU)** under criterion A.

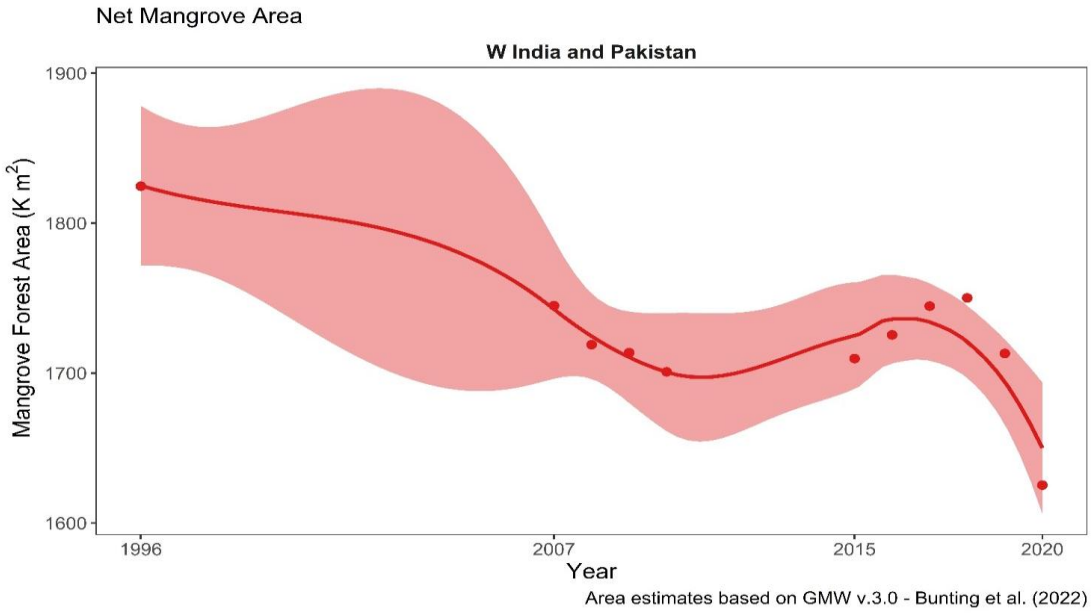


Figure 2. Western India and Pakistan mangrove ecosystem time series. Circles represent the province mangrove area between 1996 and 2020 based on the GMW v3.0 dataset and equations in Bunting *et al.*, (2022). The shaded area represents 95% confidence interval. It is important to note that neither the linear nor the exponential model (proportional rate of decline) give a good fit to the data (R^2 = 0.4).

Criterion B: Restricted Geographic Distribution

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 Western India and Pakistan province mangrove extent (GMW v.3).

For 2020, AOO and EOO were measured as 212 grid cells 10 x 10 km and 398153.0 km^2, respectively (Figure 3). Excluding from total of 427 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 **212, 10 x 10 km grid cells** (Figure 3, red grids).

Province	Extent of Occurrence EOO (km^2)	Area of Occupancy (AOO)≥1	Criterion B
The Western India and Pakistan	398153.0	212	**LC**

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 Western India and Pakistan mangrove ecosystem is assessed as **Least Concern (LC)** under criterion B.

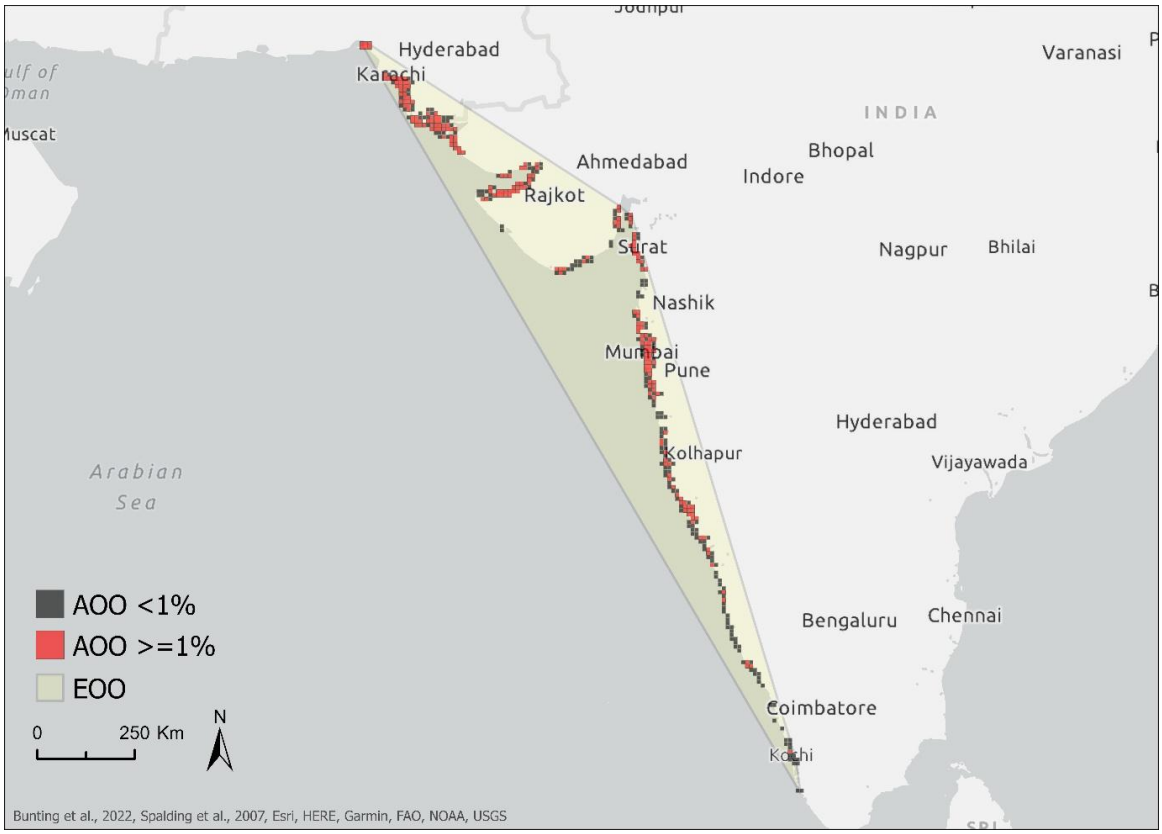


Figure 3. The Western India and Pakistan mangrove Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) in 2020. Estimates based on 2020 GMW v3.0 spatial layer (Bunting *et al.*, 2022). The red 10 x 10 km grids (n=212.) are more than 1% covered by the ecosystem, and the black grids <1% (n= 215).

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 Western India and Pakistan 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 Western India and Pakistan mangrove ecosystem boundary, using the spatial extent in 2010 (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 ~ -1.5% by 2060, which remains below the 30% risk threshold. Therefore, considering that no mangrove recruitment can occur in a submerged system (100% relative severity), but that -1.5% of the ecosystem extent will be affected by SLR, the Western India and Pakistan mangrove ecosystem is assessed as **Least Concern (LC)** 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 Western India and Pakistan province is classified as Data Deficient (DD) for this subcriterion. Nevertheless, it is important to note that these results should be interpreted with caution, as they are based on global datasets (underestimated) and not on national or regional estimations of the actual extent of the mangrove ecosystem for 2020.

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

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 Western India and Pakistan 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 (30m resolution), on areas intersecting with the 2017 mangrove extent map (GMW v2). 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, fire damage, 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), 3.4% of the Western India and Pakistan mangrove area is classified as degraded, resulting in an average annual rate of

degradation of 0.20%. Assuming this trend remains constant, +9.9% of the Western India and Pakistan mangrove area will be classified as degraded over a 50-year period. Since less than 30% of the ecosystem will meet the category thresholds for criterion D, the Western India and Pakistan 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 Western India and Pakistan ecosystem remains **Least Concern (LC)** under criterion D. Nevertheless, it is important to note that these results should be interpreted with caution, as they are based on global datasets (underestimated) and not on national or regional estimations of the actual extent of the mangrove ecosystem for 2020.

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 50 years period	**A3** Historical (1750)
	VU	**LC**	**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 50 years period	**C3** Historical (1750)
	DD	**LC**	**DD**
D. Disruption of biotic processes	**D1** Past 50 years (1970)	**D2** Future or Any 50 years period	**D3** Historical (1750)
	DD	**LC**	**DD**
E. Quantitative Risk analysis		**NE**	
OVERALL RISK CATEGORY		**VU**	

DD= Data deficient, LC= Least Concern, VU= Vulnerable, NE= Not Evaluated

Overall, the status of the Western India and Pakistan mangrove ecosystem is assessed as **Vulnerable (VU)**

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7. 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.

Class	Order	Family	Scientific name	RLTS category
Magnoliopsida	Lamiales	Acanthaceae	*Acanthus ilicifolius*	LC
Polypodiopsida	Polypodiales	Pteridaceae	*Acrostichum aureum*	LC
Magnoliopsida	Ericales	Primulaceae	*Aegiceras corniculatum*	LC
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia alba*	LC
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia marina*	LC
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia officinalis*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Bruguiera cylindrica*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Bruguiera gymnorhiza*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Bruguiera parviflora*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Bruguiera sexangula*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Ceriops tagal*	LC
Magnoliopsida	Malpighiales	Euphorbiaceae	*Excoecaria agallocha*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Kandelia candel*	LC
Magnoliopsida	Myrtales	Combretaceae	*Lumnitzera racemosa*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Rhizophora apiculata*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Rhizophora mucronata*	LC
Magnoliopsida	Myrtales	Lythraceae	*Sonneratia alba*	LC
Magnoliopsida	Myrtales	Lythraceae	*Sonneratia apetala*	LC
Magnoliopsida	Myrtales	Lythraceae	*Sonneratia caseolaris*	LC
Magnoliopsida	Sapindales	Meliaceae	*Xylocarpus granatum*	LC

2. List of Associated Species

List of taxa that are 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", and with suitability recorded as "Suitable", with "Major Importance" recorded as "Yes", and any value of seasonality except "Passage". The common names are those shown in the RLTS, except common names in brackets, which are from other sources.

Class	Order	Family	Scientific name	RLTS category	Common name
Actinopterygii	Anguilliformes	Muraenidae	*Uropterygius concolor*	LC	Brown moray eel
Actinopterygii	Anguilliformes	Ophichthidae	*Scolecenchelys macroptera*	LC	
Actinopterygii	Atheriniformes	Atherinidae	*Atherinomorus lacunosus*	LC	Hardyhead silverside
Actinopterygii	Aulopiformes	Synodontidae	*Saurida nebulosa*	LC	Clouded lizardfish
Actinopterygii	Beloniformes	Zenarchopteridae	*Zenarchopterus dispar*	LC	Feathered river-garfish
Actinopterygii	Beloniformes	Zenarchopteridae	*Zenarchopterus ectuntio*	LC	
Actinopterygii	Beloniformes	Zenarchopteridae	*Zenarchopterus gilli*	LC	Shortnose river garfish
Actinopterygii	Beloniformes	Zenarchopteridae	Zenarchopterus striga	LC	
Actinopterygii	Clupeiformes	Clupeidae	*Nematalosa nasus*	LC	Bloch's gizzard shad
Actinopterygii	Clupeiformes	Clupeidae	*Sardinella albella*	LC	White sardinella
Actinopterygii	Clupeiformes	Clupeidae	*Sardinella melanura*	LC	Blacktip sardinella
Actinopterygii	Clupeiformes	Engraulidae	*Coilia neglecta*	LC	Neglected grenadier anchovy
Actinopterygii	Clupeiformes	Engraulidae	*Thryssa mystax*	LC	Moustached thryssa
Actinopterygii	Elopiformes	Megalopidae	*Megalops cyprinoides*	DD	Indo-pacific tarpon
Actinopterygii	Gobiiformes	Eleotridae	*Bostrychus sinensis*	LC	Four-eyed sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Butis butis*	LC	Crimson-tipped gudgeon
Actinopterygii	Gobiiformes	Eleotridae	*Butis koilomatodon*	LC	Marblecheek sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Eleotris fusca*	LC	Brown spinecheek gudgeon
Actinopterygii	Gobiiformes	Eleotridae	*Ophiocara porocephala*	LC	Spangled gudgeon
Actinopterygii	Gobiiformes	Gobiidae	*Asterropteryx semipunctata*	LC	
Actinopterygii	Gobiiformes	Gobiidae	*Boleophthalmus boddarti*	LC	Boddart's goggle-eyed goby
Actinopterygii	Gobiiformes	Gobiidae	*Oligolepis acutipennis*	LC	Paintedfin goby
Actinopterygii	Gobiiformes	Gobiidae	*Oxyurichthys ophthalmonema*	LC	Eyebrow goby

Actinopterygii	Gobiiformes	Gobiidae	*Parachaeturichthys polynema*	LC	Lancet-tail goby
Actinopterygii	Gobiiformes	Gobiidae	*Psammogobius biocellatus*	LC	Sleepy goby
Actinopterygii	Gobiiformes	Gobiidae	*Taenioides cirratus*	DD	Whiskered eel goby
Actinopterygii	Gobiiformes	Gobiidae	*Trypauchen vagina*	LC	Burrowing goby
Actinopterygii	Mugiliformes	Mugilidae	*Planiliza subviridis*	LC	Greenback mullet
Actinopterygii	Ophidiiformes	Carapidae	*Encheliophis homei*	LC	Silver pearlfish
Actinopterygii	Perciformes	Ambassidae	*Ambassis nalua*	LC	Scalloped perchlet
Actinopterygii	Perciformes	Apogonidae	*Apogonichthyoides pharaonis*	LC	Pharaoh cardinalfish
Actinopterygii	Perciformes	Apogonidae	*Apogonichthyoides taeniatus*	LC	Two-belt cardinal
Actinopterygii	Perciformes	Apogonidae	*Fowleria variegata*	LC	Variegated cardinalfish
Actinopterygii	Perciformes	Apogonidae	*Yarica hyalosoma*	LC	Mangrove cardinalfish
Actinopterygii	Perciformes	Caesionidae	*Caesio cuning*	LC	Redbelly yellowtail fusilier
Actinopterygii	Perciformes	Carangidae	*Atule mate*	LC	Yellowtail scad
Actinopterygii	Perciformes	Ephippidae	*Platax orbicularis*	LC	Orbiculate batfish
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus coeruleopunctatus*	LC	Whitespotted grouper
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus coioides*	LC	Orange-spotted grouper
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus malabaricus*	LC	
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus miliaris*	LC	Netfin grouper
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus tauvina*	DD	Greasy grouper
Actinopterygii	Perciformes	Gerreidae	*Gerres erythrourus*	LC	Deep-bodied mojarra
Actinopterygii	Perciformes	Haemulidae	*Plectorhinchus gibbosus*	LC	Brown sweetlips
Actinopterygii	Perciformes	Haemulidae	*Plectorhinchus pictus*	LC	Trout sweetlips
Actinopterygii	Perciformes	Haemulidae	*Pomadasys argenteus*	LC	Silver javelin
Actinopterygii	Perciformes	Haemulidae	*Pomadasys kaakan*	LC	Javelin grunter
Actinopterygii	Perciformes	Leiognathidae	*Gazza minuta*	LC	Toothed ponyfish
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	Lethrinidae	*Lethrinus semicinctus*	LC	Black-spot emperor
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus fulviflamma*	LC	Dory snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus fulvus*	LC	Blacktail snapper
Actinopterygii	Perciformes	Mullidae	*Parupeneus barberinus*	LC	Dash-and-dot goatfish
Actinopterygii	Perciformes	Pomacentridae	*Dascyllus trimaculatus*	LC	Threespot damselfish
Actinopterygii	Perciformes	Pomacentridae	*Neopomacentrus*	DD	Freshwater

			taeniurus		damsel
Actinopterygii	Perciformes	Sciaenidae	*Johnius belangerii*	LC	Belanger's croaker
Actinopterygii	Perciformes	Sciaenidae	*Johnius borneensis*	LC	Hammer croaker
Actinopterygii	Perciformes	Sciaenidae	*Johnius carouna*	LC	Caroun croaker
Actinopterygii	Perciformes	Sciaenidae	*Nibea maculata*	LC	
Actinopterygii	Perciformes	Sciaenidae	*Otolithes cuvieri*	LC	
Actinopterygii	Perciformes	Sciaenidae	*Panna heterolepis*	LC	
Actinopterygii	Perciformes	Sciaenidae	*Pennahia anea*	LC	
Actinopterygii	Perciformes	Siganidae	*Siganus vermiculatus*	LC	Vermiculated spinefoot
Actinopterygii	Perciformes	Sparidae	*Acanthopagrus berda*	LC	Picnic seabream
Actinopterygii	Perciformes	Toxotidae	*Toxotes jaculatrix*	LC	Banded archerfish
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Pseudorhombus arsius*	LC	Largetooth flounder
Actinopterygii	Siluriformes	Bagridae	*Mystus gulio*	LC	
Actinopterygii	Syngnathiformes	Syngnathidae	*Hippichthys penicillus*	LC	Beady pipefish
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron reticularis*	LC	Reticulated pufferfish
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron stellatus*	LC	Stellate puffer
Aves	Accipitriformes	Accipitridae	*Clanga clanga*	VU	Greater spotted eagle
Aves	Charadriiformes	Charadriidae	*Charadrius mongolus*	LC	Lesser sandplover
Aves	Charadriiformes	Charadriidae	*Pluvialis fulva*	LC	Pacific golden plover
Aves	Charadriiformes	Laridae	*Larus hemprichii*	LC	Sooty gull
Aves	Charadriiformes	Scolopacidae	*Actitis hypoleucos*	LC	Common sandpiper
Aves	Charadriiformes	Scolopacidae	*Numenius arquata*	NT	Eurasian curlew
Aves	Charadriiformes	Scolopacidae	*Xenus cinereus*	LC	Terek sandpiper
Aves	Ciconiiformes	Ciconiidae	*Ciconia episcopus*	NT	Asian woollyneck
Aves	Ciconiiformes	Ciconiidae	*Ephippiorhynchus asiaticus*	NT	Black-necked stork
Aves	Ciconiiformes	Ciconiidae	*Leptoptilos javanicus*	VU	Lesser adjutant
Aves	Coraciiformes	Alcedinidae	*Alcedo atthis*	LC	Common kingfisher
Aves	Coraciiformes	Alcedinidae	*Alcedo meninting*	LC	Blue-eared kingfisher
Aves	Coraciiformes	Alcedinidae	*Ceryle rudis*	LC	Pied kingfisher
Aves	Coraciiformes	Alcedinidae	*Ceyx erithaca*	LC	Oriental dwarf-kingfisher
Aves	Coraciiformes	Alcedinidae	*Halcyon pileata*	VU	Black-capped kingfisher
Aves	Coraciiformes	Alcedinidae	*Todiramphus chloris*	LC	Collared kingfisher
Aves	Coraciiformes	Meropidae	*Merops persicus*	LC	Blue-cheeked bee-eater
Aves	Falconiformes	Falconidae	*Falco severus*	LC	Oriental hobby
Aves	Passeriformes	Aegithinidae	*Aegithina tiphia*	LC	Common iora
Aves	Passeriformes	Campephagidae	*Pericrocotus cinnamomeus*	LC	Small minivet
Aves	Passeriformes	Campephagidae	*Pericrocotus divaricatus*	LC	Ashy minivet
Aves	Passeriformes	Cisticolidae	*Prinia flaviventris*	LC	Yellow-bellied prinia
Aves	Passeriformes	Cisticolidae	*Prinia gracilis*	LC	Graceful prinia
Aves	Passeriformes	Cisticolidae	*Prinia hodgsonii*	LC	Grey-breasted

					prinia
Aves	Passeriformes	Cisticolidae	*Prinia inornata*	LC	Plain prinia
Aves	Passeriformes	Corvidae	*Corvus macrorhynchos*	LC	Large-billed crow
Aves	Passeriformes	Dicruridae	*Dicrurus paradiseus*	LC	Greater racquet-tailed drongo
Aves	Passeriformes	Monarchidae	*Terpsiphone paradisi*	LC	Indian paradise-flycatcher
Aves	Passeriformes	Muscicapidae	*Copsychus malabaricus*	LC	White-rumped shama
Aves	Passeriformes	Muscicapidae	*Cyornis rubeculoides*	LC	Blue-throated blue-flycatcher
Aves	Passeriformes	Oriolidae	*Oriolus chinensis*	LC	Black-naped oriole
Aves	Passeriformes	Oriolidae	*Oriolus xanthornus*	LC	Black-hooded oriole
Aves	Passeriformes	Paridae	*Parus major*	LC	Great tit
Aves	Passeriformes	Phylloscopidae	*Phylloscopus trochiloides*	LC	Greenish warbler
Aves	Passeriformes	Ploceidae	*Ploceus philippinus*	LC	Baya weaver
Aves	Passeriformes	Pycnonotidae	*Pycnonotus leucotis*	LC	White-eared bulbul
Aves	Passeriformes	Pycnonotidae	*Rubigula gularis*	LC	Flame-throated bulbul
Aves	Passeriformes	Sittidae	*Sitta frontalis*	LC	Velvet-fronted nuthatch
Aves	Passeriformes	Sturnidae	*Gracula indica*	LC	Southern hill myna
Aves	Pelecaniformes	Ardeidae	*Ardea purpurea*	LC	Purple heron
Aves	Pelecaniformes	Ardeidae	*Butorides striata*	LC	Green-backed heron
Aves	Pelecaniformes	Ardeidae	*Egretta garzetta*	LC	Little egret
Aves	Pelecaniformes	Ardeidae	*Egretta gularis*	LC	Western reef-egret
Aves	Pelecaniformes	Ardeidae	*Ixobrychus cinnamomeus*	LC	Cinnamon bittern
Aves	Pelecaniformes	Ardeidae	*Ixobrychus sinensis*	LC	Yellow bittern
Aves	Piciformes	Megalaimidae	*Psilopogon haemacephalus*	LC	Coppersmith barbet
Aves	Piciformes	Picidae	*Chrysocolaptes guttacristatus*	LC	Greater flameback
Aves	Piciformes	Picidae	*Dinopium javanense*	LC	Common flameback
Aves	Piciformes	Picidae	*Micropternus brachyurus*	LC	Rufous woodpecker
Aves	Piciformes	Picidae	*Picoides nanus*	LC	Indian pygmy woodpecker
Aves	Suliformes	Anhingidae	*Anhinga melanogaster*	NT	Oriental darter
Aves	Suliformes	Fregatidae	*Fregata ariel*	LC	Lesser frigatebird
Aves	Suliformes	Phalacrocoracidae	*Phalacrocorax fuscicollis*	LC	Indian cormorant
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	Carcharhiniformes	Carcharhinidae	*Negaprion acutidens*	EN	Sharptooth lemon shark
Chondrichthyes	Myliobatiformes	Dasyatidae	*Himantura uarnak*	EN	Coach whipray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Maculabatis*	EN	Whitespotted

			gerrardi		whipray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Pastinachus ater*	VU	Broad cowtail ray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Pateobatis bleekeri*	EN	Bleeker's whipray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Taeniura lymma*	LC	Bluespotted lagoon ray
Chondrichthyes	Orectolobiformes	Hemiscylliidae	*Chiloscyllium arabicum*	NT	Arabian carpetshark
Chondrichthyes	Rhinopristiformes	Pristidae	*Anoxypristis cuspidata*	EN	Narrow sawfish
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis pristis*	CR	Largetooth sawfish
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis zijsron*	CR	Green sawfish
Gastropoda	Ellobiida	Ellobiidae	*Ellobium aurisjudae*	LC	Judas ear cassidula
Gastropoda	Littorinimorpha	Clenchiellidae	*Clenchiella microscopica*	LC	
Gastropoda	Littorinimorpha	Littorinidae	*Littoraria undulata*	LC	
Gastropoda	Sorbeoconcha	Thiaridae	*Sermyla riqueti*	LC	
Insecta	Odonata	Coenagrionidae	*Ceriagrion cerinorubellum*	LC	
Magnoliopsida	Fabales	Fabaceae	*Cynometra iripa*	LC	
Magnoliopsida	Fabales	Fabaceae	*Dalbergia candenatensis*	LC	*Trắc một hột*
Magnoliopsida	Lamiales	Acanthaceae	*Acanthus ebracteatus*	LC	
Magnoliopsida	Lamiales	Bignoniaceae	*Dolichandrone spathacea*	LC	
Magnoliopsida	Myrtales	Lythraceae	*Pemphis acidula*	LC	
Mammalia	Carnivora	Felidae	*Panthera pardus*	VU	Leopard
Mammalia	Carnivora	Felidae	*Panthera tigris*	EN	Tiger
Mammalia	Carnivora	Felidae	*Prionailurus bengalensis*	LC	Mainland leopard cat
Mammalia	Carnivora	Felidae	*Prionailurus viverrinus*	VU	Fishing cat
Mammalia	Carnivora	Mustelidae	*Aonyx cinereus*	VU	Asian small-clawed otter
Mammalia	Carnivora	Mustelidae	*Lutra lutra*	NT	Eurasian otter
Mammalia	Carnivora	Mustelidae	*Lutrogale perspicillata*	VU	Smooth-coated otter
Mammalia	Carnivora	Viverridae	*Paradoxurus hermaphroditus*	LC	Common palm civet
Mammalia	Carnivora	Viverridae	*Viverricula indica*	LC	Small indian civet
Mammalia	Cetartiodactyla	Phocoenidae	*Neophocaena phocaenoides*	VU	Indo-pacific finless porpoise
Mammalia	Cetartiodactyla	Suidae	*Sus scrofa*	LC	Wild boar
Mammalia	Chiroptera	Hipposideridae	*Hipposideros ater*	LC	Dusky leaf-nosed bat
Mammalia	Chiroptera	Hipposideridae	*Hipposideros galeritus*	LC	Cantor's leaf-nosed bat
Mammalia	Chiroptera	Hipposideridae	*Hipposideros lankadiva*	LC	
Mammalia	Chiroptera	Hipposideridae	*Hipposideros speoris*	LC	
Mammalia	Chiroptera	Megadermatidae	*Lyroderma lyra*	LC	Greater false vampire
Mammalia	Chiroptera	Megadermatidae	*Megaderma spasma*	LC	Lesser false vampire
Mammalia	Chiroptera	Vespertilionidae	*Hesperoptenus tickelli*	LC	Tickell's bat
Mammalia	Chiroptera	Vespertilionidae	*Pipistrellus*	LC	Kelaart's

			ceylonicus		pipistrelle
Mammalia	Chiroptera	Vespertilionidae	*Pipistrellus coromandra*	LC	
Mammalia	Primates	Cercopithecidae	*Macaca mulatta*	LC	Rhesus monkey
Mammalia	Rodentia	Sciuridae	*Funambulus palmarum*	LC	Common palm squirrel
Mammalia	Sirenia	Dugongidae	*Dugong dugon*	VU	Dugong
Polypodiopsida	Polypodiales	Lindsaeaceae	*Lindsaea malabarica*	NT	
Reptilia	Squamata	Chamaeleonidae	*Chamaeleo zeylanicus*	LC	Asian chameleon
Reptilia	Squamata	Colubridae	*Chrysopelea ornata*	LC	Ornate flying snake
Reptilia	Squamata	Colubridae	*Coelognathus helenae*	LC	Trinket snake
Reptilia	Squamata	Colubridae	*Lycodon nympha*	LC	Vellore bridal snake
Reptilia	Squamata	Elapidae	*Ophiophagus hannah*	VU	King cobra
Reptilia	Squamata	Typhlopidae	*Indotyphlops braminus*	LC	Brahminy blind snake
Reptilia	Squamata	Viperidae	*Echis carinatus*	LC	
Reptilia	Squamata	Viperidae	*Trimeresurus gramineus*	LC	Common bamboo viper

3. National Estimates for subcriterion A1

To estimate the Western India and Pakistan 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 mangrove area 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 Western India and Pakistan 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). However, using mangrove area estimates from different sources can lead to uncertainty (Friess and Webb 2014)[2] and there were no regional statistics or global studies available for this time period. Thus, the estimates for 1970 should be considered only indicative.

Table a. Estimated mangrove area by country in 1970 and 2020. Estimates for 2020 mangrove area are based on the *Global Mangrove Watch Version 3 (GMW v3.0) dataset, ISF, 2021 and Gilani *et al.* 2024***. The references used to calculate mangrove area for each country in 1970**** are listed below in Table b.**

Year	Mangrove area within province (km^2)		
	2020		1970****
	Lower estimate (GMW v3.0)	Higher estimate (National/Regional statistics)	
West India	803.61*	1581.78**	991.21
Pakistan (Sindh province)	821.71*	1409.22***	3355.59
The Western India and Pakistan	**1625.3**	**2991.0**	**4346.8**

Table b. List of selected studies considered to have reliable information on mangrove area for the period around 1970 in each country of the Western India and Pakistan province. Some of the variation in these estimates for Sindh Province, Pakistan is due to differences in methodology, and in some early estimates creeks and mudflats may have been included together with mangrove forest.

Country/Region	Year	Mangrove Area (Ha)	Reference
W India	1963	116171.6	Sidhu, S.S. 1963. Studies on the Mangroves of India: I. East Godavari Region. Indian Forester, 89(5): 337-351. Sum of Bombay State (155520 Acres) + Saurashtra and Kutch (131540 Acres)
W India	1987	56700	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	1989	52900	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	1991	51300	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India

[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

Country/Region	Year	Mangrove Area (Ha)	Reference
W India	1993	57700	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	1995	84900	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	1997	103300	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	1999	114700	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2001	103600	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2003	110088.48	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2005	120092.8	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2009	125692.8	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2011	127491.36	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2013	131991.36	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2015	136687.04	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2017	148887.04	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2019	154187.04	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
W India	2021	154787.04	India State of Forest Report 2021 (2021) Ministry of Environment, Forest and Climate Change). Vol 17, 2019-20. Government of India, India
Sindh, Pakistan	1966	344870	Khan, S.A. (1966). The Working Plan of Coastal Forests of Sindh 1963-64 to 1983-84. Government of West Pakistan. Sindh Government Printing Press.
Sindh, Pakistan	1977	263000	Memon, A. (2005). Devastation of the Indus River Delta. In: Proceedings of the American Society of Civil Engineers World Water and Environmental Resources Congress 2005 “Impacts of Global Climate Change” May 15-19,

Country/Region	Year	Mangrove Area (Ha)	Reference
			2005, Anchorage, Alaska, USA. Vol 8: pp. 4618-4629.
Sindh, Pakistan	1983	243000	Mirza, M.I., Hasan, M.Z., Akhtar, S. and Ali, J. (1983). Identification and area estimation of mangrove vegetation on the Indus Delta using Landsat data. ESCAP Regional Workshop on Remote Sensing Applications for Vegetation Mapping. Colombo, Sri Lanka. Pp. 19-21.
Sindh, Pakistan	1983	281000	Amjad and Khan 1983.The State of Forestry in Pakistan. Pakistan Forest Institute, Peshawar, Pakistan (cited by IUCN, 2005).
Sindh, Pakistan	1984	235564	Qureshi, T. (2005). Mangrove of Pakistan - Status and Management. International Union for Conservation of Nature Pakistan. 110 pp.
Sindh, Pakistan	1985	280479	IUCN (2016). A Handbook on Pakistan's Coastal and Marine Resources. Mangroves for the Future (MFF) Pakistan, Karachi, Pakistan. 78pp.
Sindh, Pakistan	1990	158500	Memon, A. (2005). Devastation of the Indus River Delta. In: Proceedings of the American Society of Civil Engineers World Water and Environmental Resources Congress 2005 “Impacts of Global Climate Change” May 15-19, 2005, Anchorage, Alaska, USA. Vol 8: pp. 4618-4629.
Sindh, Pakistan	1990	160000	Kella, L. (1999). Protective role of Indus Delta mangroves with particular reference to cyclone mitigation. Proceedings of the National Seminar on Mangrove Ecosystem Dynamics of the Indus Delta. Pp. 86-90.
Sindh, Pakistan	1998	129000	Stedman-Edwards, P. (2000). Pakistan: Mangroves. Wood, A., Stedman-Edwards, P. and Mang, J. (eds.). The root causes of biodiversity loss. World Wildlife Fund and Earthscan Publications Ltd., London, UK.
Sindh, Pakistan	2003	82669.5	Qureshi, T. (2005). Mangrove of Pakistan - Status and Management. International Union for Conservation of Nature Pakistan. 110 pp.
Sindh, Pakistan	2003	86728	SUPARCO, (2009). Mapping Mangrove Forest Resources of Indus Delta Region Using Satellite Remote Sensing & GIS Techniques. GIS Application Division, SUPARCO, Karachi, Pakistan. (In: Wagan, R.A., 2018. Rehabilitation of Indus Delta Mangroves: A Success Story. In Dinshaw, R.C. (ed.): Proceedings of the National Workshop on Sustainable Forest Management Best Practices in Pakistan, Naran, 6-7 September 2018. Ministry of Climate Change, Islamabad, and International Union for Conservation of Nature Pakistan. Pp. 12-21.
Sindth (Sandspit + Indus Delta)	1990	45784	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690
Sindth (Sandspit + Indus Delta)	1995	54996	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690
Sindth (Sandspit + Indus Delta)	2000	78750	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690

Country/Region	Year	Mangrove Area (Ha)	Reference
Sindth (Sandspit + Indus Delta)	2005	81706	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690
Sindth (Sandspit + Indus Delta)	2010	105836	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690
Sindth (Sandspit + Indus Delta)	2015	121230	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690
Sindth (Sandspit + Indus Delta)	2020	140922	Gilani, H., Naz, H. I., Arshad, M., Nazim, K., Akram, U., Abrar, A., & Asif, M. (2024). Mangrove cover dataset of Pakistan on 5-year interval (1990-2020) at 30m spatial resolution (1.0) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.10732690