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Mangroves of the Warm Temperate Northwest Atlantic

CR

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Abstract

The 'Mangroves of the Warm Temperate Northwest Atlantic' province is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine ecoregions of Carolinian and Northern Gulf of Mexico. The biota is characterized by 3 species of mangroves: *Avicennia germinans, Laguncularia racemosa, and Rhizophora mangle*, and 1 mangrove associate *Conocarpus erectus,* though not all species are equally distributed throughout the province.

Mangroves in this province cross the USA and Mexico and are quite unique, as they exist at the latitudinal range limit of the mangrove ecosystem. The majority of mangroves in this province are located in Florida and Louisiana (USA), though substantial mangrove patches can be found in Texas (USA) and Tamaulipas (Mexico). Small mangrove patches are present in Mississippi and have recently been found in Georgia (USA) at a latitude of 30.74°N, making these some of the northernmost mangroves in the world. Mangroves in this province also experience a longitudinal aridity gradient, with more arid conditions experienced in the west (Tamaulipas, Mexico; Texas, USA) and wetter conditions in the east (Louisiana, Florida, USA).

Today, mangroves in the Warm Temperate Northwest Atlantic cover a minimum of 83.11 km^2, though due to challenges in measuring the extent of patchy mangroves at their latitudinal range limits, we expect the actual extent to be higher, and we consider the extent presented here to be a substantial underestimate. Based on global datasets, mangrove net area change in this province has been -11% since 1996, with mangrove loss caused by a combination of anthropogenic (land use change, pollution) and climatic (freezes, drought) drivers. If this trend continues, an overall change of -55% is projected over the next 50 years. Furthermore, under a high sea level rise scenario (IPCC RCP8.5) ≈83% of mangroves in the Warm Temperate Northwest Atlantic would be at risk of submergence by 2060. Moreover, ≈3% of the province's mangrove ecosystem is experiencing degradation, with the potential to increase to ≈8% within a 50-year period, based on a vegetation index decay analysis. Overall, mangroves in the Warm Temperate Northwest Atlantic province are assessed as **Critically Endangered (CR)**. However, this conclusion should be interpreted with caution, due to challenges to mapping mangroves at this latitudinal range limit, as well as limitations to the sea-level rise modelling approaches used in this study. Important data gaps found in this study highlight a strong need for continued focused mangrove research in this province.

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Keywords:
Mangroves; Red List of Ecosystems; threats; USA; Mexico; Tamaulipas; Texas; Louisiana; Florida

Ecosystem classification:
MFT1.2 Intertidal forests and shrublands

Assessment's distribution:
Warm Temperate Northwest Atlantic province

Summary of the assessment:

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

CR: Critically Endangered, EN: Endangered, LC: Least Concern, DD: Data Deficient, NE: Not Evaluated

Mangroves of The Warm Temperate Northwest Atlantic

CR

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_06 Mangroves of the Warm Temperate Northwest Atlantic

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

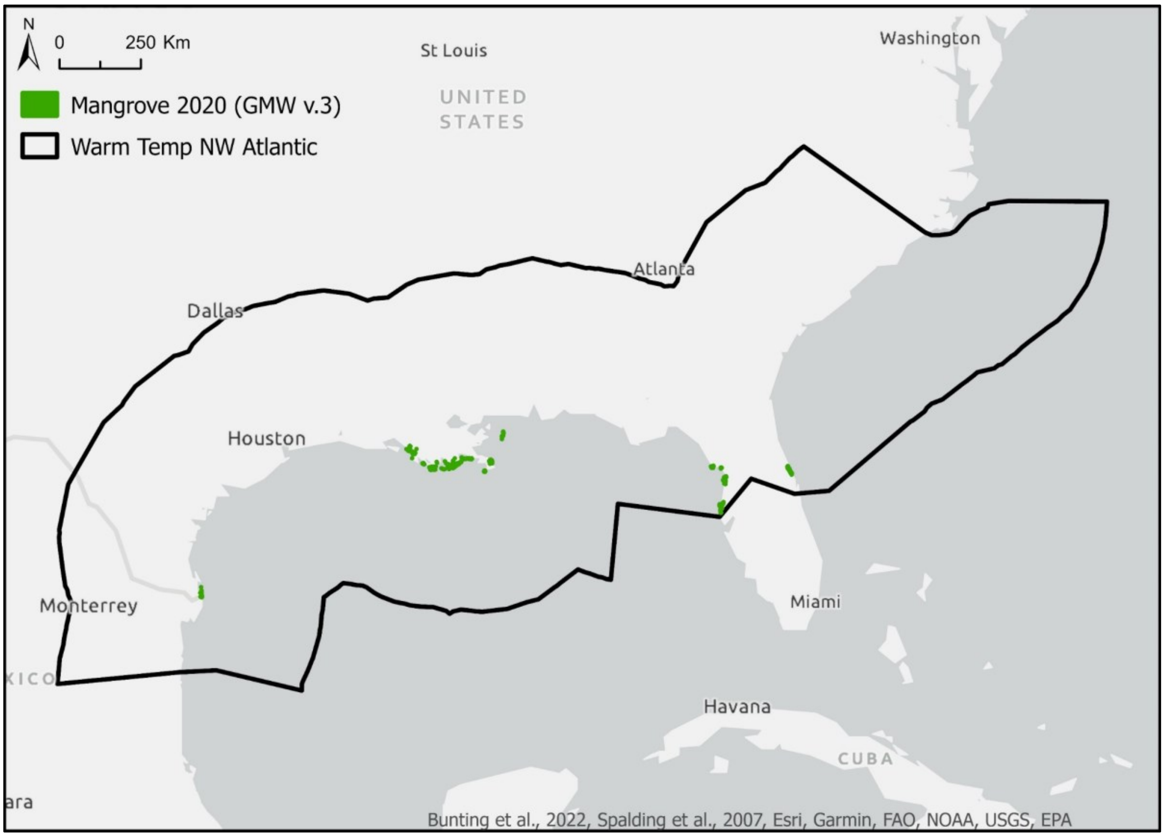

Figure 1. Mangroves of the Warm Temperate Northwest Atlantic for the year 2020. Mangrove extent data from Bunting *et al.* (2022); marine ecoregion province delimitation modified from Spalding *et al.* (2007). Note that this mangrove extent is based on global data and is considered by the authors to be a substantial underestimate.

[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 province 'Mangroves of the Warm Temperate Northwest Atlantic' is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine ecoregions of the Carolinian and Northern Gulf of Mexico (Figure 1), which extends across Mexico (Tamaulipas) and the United States (primarily Texas, Louisiana, and Florida). Northernmost parts of this province are at one of the latitudinal range limits of global mangrove distribution, characterised by mangroves of relatively short stature and generally patchy distribution, particularly at their northernmost limit, where mangroves may exist as individual trees or small forest patches. Individual mangrove shrubs have been reported on barrier islands off the coast of Mississippi, USA (Scheffel *et al.,* 2013; Macy *et al.,* 2019), and self-sustaining mangrove patches of *Avicennia germinans* have recently been found in southern Georgia, USA at an estimated latitude of 30.74 °N (Vervaeke *et al., in prep*). This is a similar latitude to mangroves in southern Japan (30.81°N; Ximenes *et al.,* 2023), making these some of the northernmost mangroves in the world.

Using global remote sensing datasets of mangrove coverage, the estimated extent of mangroves in this province was 83.1 km^2 in 2020, representing about 0.1% of the global mangrove area (Bunting *et al.,* 2022). However, an important caveat is that both Bunting *et al.* (2022) and other studies that have mapped mangroves in this province (e.g., Giri *et al.,* 2023), do not comprehensively map all mangroves in the Warm Temperate North Atlantic. In particular, important mangrove areas are present in Tamaulipas (Mexico), Texas, and northern Florida (USA) (e.g., Valderrama *et al.,* 2014; Armitage *et al.,* 2015; Snyder *et al.,* 2022; Bardou *et al.,* 2023) that are not currently mapped using these global data products. Mangroves in Tamaulipas, including in this province are estimated to cover 36.6 km^2 (Zamora-Tovar *et al.,* 2024) and form a discontinuous ecosystem along the coast (Zamora-Tovar, 2018).

Mapping at ecosystem range limits is challenging because land cover maps generally classify the dominant land cover. So, low-density, short-stature mangrove vegetation growing in a tidal marsh will likely be misclassified as tidal marsh in remote sensing analyses. Additionally, land cover maps often use a minimum mapping unit to limit the minimum parcel size. In Florida water management district land cover maps, for instance, the minimum mapping unit is 0.2 ha (e.g., SJRWMD, 2018). Thus, a wetland that includes a narrow mangrove fringe (less than 0.2 ha in size) along a tidal marsh would be classified accordingly. In northern Florida, for example, mangrove extents mapped at moderate resolutions missed 84% of the mangroves detected with higher-resolution imagery (Doughty *et al., accepted*). Finally, land cover maps often take several years to produce. Thus, land cover needs to be captured in real time, and expanding mangrove coverage is underestimated. For these three reasons (patchy distribution, small parcel size, and rapid change) mangrove expansion at higher latitudes is often underestimated in traditional land cover mapping. Considering these caveats, we estimate the actual extent of mangroves in this province to be substantially higher than that proposed by Bunting *et al.* (2022), similar to the conclusion of a prior study (Bardou *et al.,* 2023; Figure 2).

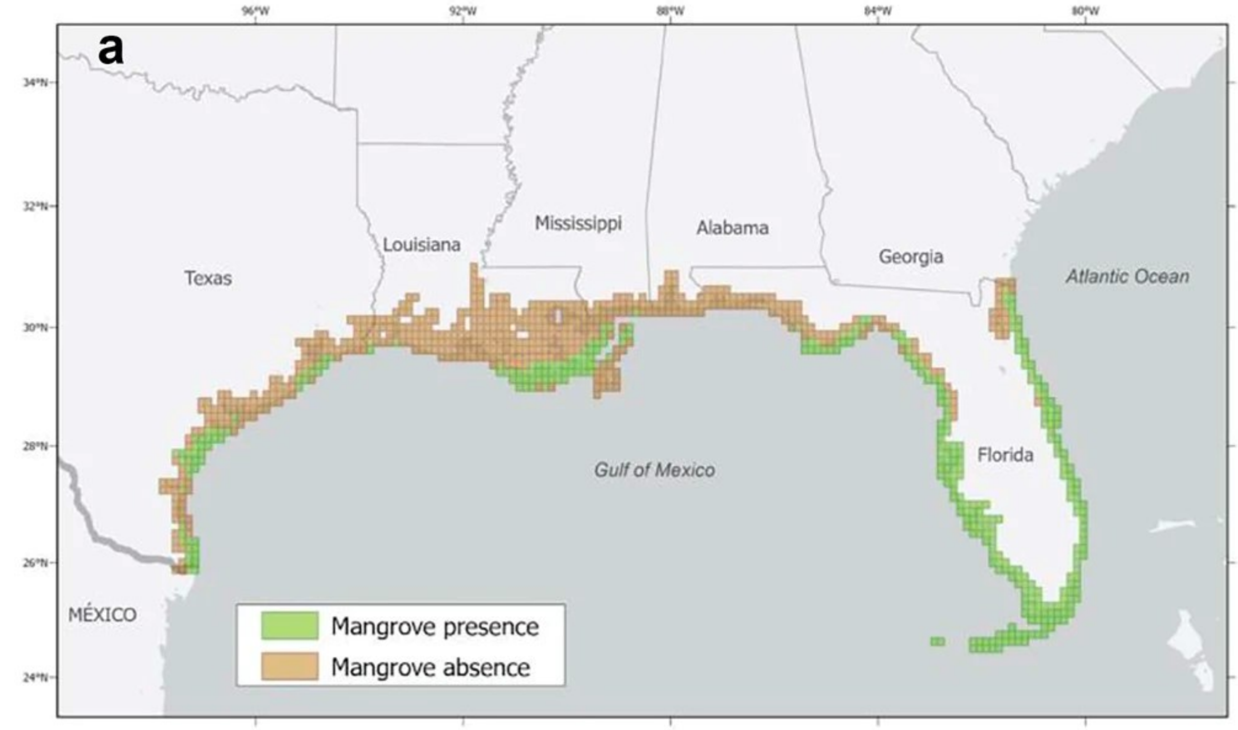

Figure 2. Expected mangrove distribution in the Warm Temperate Northwest Atlantic, estimated by expert judgement. Note that this covers mangroves in Texas, Louisiana, Mississippi, northwest Florida, and northeast Florida (USA) only and excludes recent mangroves found in Georgia (USA) as well as mangroves in Tamaulipas (Mexico). This map also includes mangroves in South Florida, which is outside the Warm Temperate Northwest Atlantic Province. Reproduced from Bardou *et al.* (2023).

Mangrove area change

Using global remote sensing datasets (with the abovementioned caveats), there has been a -11.2% net area change since 1996 (data from Bunting *et al.,* 2022). Other data sources support the observation of a net loss of mangrove forests in this province. Giri *et al.* (2023) mapped mangrove forest cover change for the conterminous United States between 1980 and 2020 (Figure 3). Note that this includes areas outside of the Warm Temperate Northwest Atlantic province; data from this study were not publicly available, so could not be analysed for this province only. This study shows that mangroves in Texas experienced a net gain in mangrove area (<10% increase) over this time period, while Louisiana experienced a net reduction in mangrove area (10−20%). Florida showed mixed mangrove area dynamics; the west coast of north Florida experienced small (<5%) gains in mangrove area over this time period, while the Atlantic coast of north Florida experienced a net loss (<10%) of mangrove area. However, other studies suggest a small increase in mangrove area between 1990 and 2014 (Dix *et al.,* 2021).

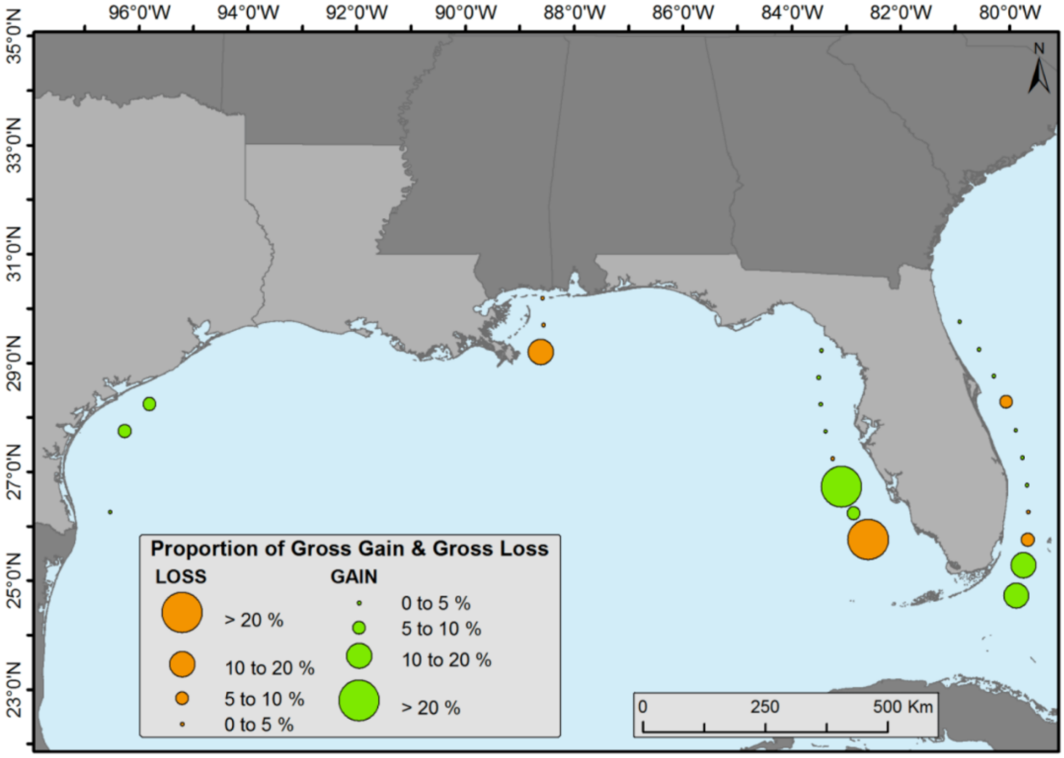

Figure 3. Proportion of mangrove forest cover change in the conterminous United States between 1980 and 2020, summed by 0.5° latitudinal intervals. Note that this covers mangroves in the United States only, and also includes mangroves in South Florida, which is outside the Warm Temperate Northwest Atlantic province. Reproduced from Giri *et al.* (2023).

Mangroves in Tamaulipas, Mexico are unlikely to contribute substantially to the overall losses observed in this province. Evidence suggests that mangroves here have increased in area by 16% from 1970 to 2005 (Valderrama *et al.,* 2014). Data from 2005 to 2020, available from the federal agency Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), show mangroves being mapped in Laguna Madre and the Rio Bravo Delta for the first time. However, increases between 2015 and 2020 may be due to changing definitions of mangrove land cover classes in the most recent assessment (Acosta-Veláquez *et al.,* 2023).

While mangroves show a general trend in reduction in areal extent globally (e.g., Bunting *et al.,* 2022) and in this province specifically (Giri *et al.,* 2023; *this study*), it should also be noted that mangroves are expanding into tidal marsh-dominated areas in many parts of the province. This has been observed particularly in Louisiana and the Atlantic coast of Florida (USA) and is linked in part to the decreasing frequency of extreme cold events (Cavanaugh *et al.,* 2014; Osland *et al.,* 2020a), though other biophysical limitations are also expected to control range expansion along these coastlines (Bardou *et al.,* 2020). However, such gains are likely to be missed by current mangrove mapping efforts using coarser resolution imagery (see above).

Biotic components of the ecosystem (characteristic native biota)

The mangroves of the Warm Temperate Northwest Atlantic province contain 3 recorded true mangrove plant species (IUCN, 2022; Appendix 1), 1 mangrove associate, and multiple associated plant species. The distribution of the 3 main mangrove plant species is indicated by Osland *et al.* (2018); *Avicennia germinans* is the most widespread species, found across the entire province, and *Rhizophora mangle* is present in Tamaulipas (Mexico), and the Gulf and Atlantic coasts of north Florida (USA). Some *R. Mangle* individuals can also be found in Texas (USA). *Laguncularia racemosa* is indicated to be present in southern Tamaulipas (Mexico) and the Gulf and Atlantic coasts of north Florida (USA). Tamaulipas shows a changing distribution of species; it contains all species of mangroves in the south, though only *A. germinans* is present in the northern half of the state close to the Mexico/USA border (Zamora-Tovar, 2018), with tree height and stem diameter decreasing further north (Zamora-Tovar & Fierro, *accepted*).

Conocarpus erectus is sometimes considered a true mangrove, though can be considered a mangrove associate (as it is in Florida) because it lacks many morphological features that characterise mangroves, and can be found inland (Tomlinson, 1986). The IUCN Red List of Species considers *C. erectus* a mangrove associate. This species can be found as far north as Levy and Volusia Counties in Florida (USA). The fern *Acrostichum danaeifolium* is also found in some parts of north and central Florida (USA).

While likely an underestimate, there are at least 100 animal species within the taxa Actinopterygii (34), Anthozoa (4), Aves (48), Chondrichthyes (2), Gastropoda (3), Insecta (1), Mammalia (6) and Reptilia (2) associated with mangrove habitats in the IUCN Red List of Threatened Species (IUCN, 2022). 90% have a Red List status of Least Concern, including the Bald eagle *Haliaeetus leucocephalus*, Mangrove cuckoo *Coccyzus minor*, Ocelot *Leopardus pardalis*, Collared peccary *Pecari tajacu,* and various mojarra species. Three species are considered Near Threatened (Bonefish *Albula vulpes*, Reddish egret *Egretta rufescens*, Jaguar *Panthera onca*), four species are considered Vulnerable (Atlantic goliath grouper *Epinephelus itajara*, Yellowmouth grouper *Mycteroperca interstitiali*s, Lemon shark *Negaprion brevirostris,* Diamondback Terrapin *Malaclemys terrapin*), one species is considered Endangered (Yellow-headed amazon *Amazona oratrix*) and one species is considered Critically Endangered (Smalltooth sawfish *Pristis pectinata*). The status of Scamp *Mycteroperca phenax* is listed as Data Deficient. See Appendix 2 for the full list of associated species.

Abiotic Components of the Ecosystem

Mangrove soils are generally nutrient-limited (particularly for nitrogen and phosphorus). Mangrove distribution is influenced by myriad interactions between landscape position, climate, hydrology, relative sea level, geomorphic processes, and natural disturbances such as storms and pests. Precipitation and allochthonous sediment input promote mangrove establishment once physiological thresholds related to tidal inundation and hydrodynamic forcing are overcome (Balke *et al.,* 2011; Friess *et al.,* 2012), and long-term persistence is determined in part by the balance between positive (sediment accretion, organic matter production, wrack accumulation, etc.) and negative (organic matter oxidation, sediment compaction, etc.) surface elevation change processes (Krauss *et al.,* 2014). High rainfall reduces salinity stress and increases nutrient loading from adjacent catchments, while tidal flushing also regulates salinity and nutrient cycling.

The geomorphic setting is a key control of mangrove structure (Rovai *et al.,* 2021) and ecosystem carbon storage (e.g., Rovai *et al.,* 2018). As per Worthington *et al.* (2020), most mangroves in this province are classified as deltaic, so will be primarily minerogenic systems that receive allochthonous sediment input. This is particularly the case for mangroves in Louisiana (USA). Mangroves in northeast Florida (USA) are considered lagoonal, and some mangrove areas in northwest Florida are considered fringing systems. Since this model is based on data from Global Mangrove Watch, it misses substantial mangrove areas in northern Florida and Texas (USA), and Tamaulipas (Mexico). However, observations suggest that many of these systems would be classified as fringing or lagoonal.

Mangroves at the poleward limit in the Warm Temperate Northwest Atlantic are highly sensitive to freezing and chilling, so mangrove ecosystem structure and function are strongly influenced by the duration and frequency of winter air temperature extremes (e.g., Osland *et al.,* 2020b; Martinez *et al.,* 2024; see also Section 3 below). Mangroves in this province also exist along an aridity gradient that varies from west (Tamaulipas, Texas; semi-arid) to east (Louisiana, Florida; humid), which may influence vegetation growth rates and morphology. Hypersaline conditions probably limit Mangrove distribution in Tamaulipas, Mexico (Osland *et al.,* 2018). Cyclones have had observable impacts on vegetation structure and distribution that can result in physical damage, sediment and nutrient deposition, erosion, or compaction of the substrate on an occasional but large-scale basis (e.g., Armitage *et al.,* 2020; Krauss & Osland, 2020; Kennedy *et al.* 2020).

Key processes and interactions

Mangroves, in areas where they are dominant, are foundational species. Mangrove vegetation species have evolved a number of species-specific traits and adaptations to survive in a physiologically stressful coastal environment. These include pneumatophores, salt excretion glands, viviparous reproduction, and propagule buoyancy (Tomlinson, 1986) that promote establishment and persistence in poorly aerated, saline, mobile, and tidally inundated substrates. Mangroves also serve as important blue carbon sinks, incorporating organic matter into sediments and living biomass above and below ground; mangroves produce large amounts of detrital material which is either buried in waterlogged sediments, consumed and cycled by crabs and gastropods, or more commonly decomposed by fungi and bacteria (Adame *et al.,* 2024).

3. Ecosystem Threats and vulnerabilities

Main threatening process and pathways to degradation

Mangrove deforestation and degradation in the Warm Temperate Northwest Atlantic are driven by a number of anthropogenic and natural processes.

Anthropogenic threats to mangroves

Large-scale direct land cover changes occurring in the Warm Temperate Northwest Atlantic include urban and port development (*IUCN Threat Classification 1.1-1.3,* see Section 4 below) and the creation of mosquito impoundments (*6.3*; *sensu* Middleton *et al.,* 2008; Giri *et al.,* 2023).

Pollution is a key threat to mangroves in this province, particularly oil spills in Louisiana and Texas, USA (*9.2.1*; Duke, 2016), often due to pipeline ruptures or ship collisions. For example, large areas of mangroves were affected by the Deepwater Horizon oil spill in the Gulf of Mexico (Mendelssohn *et al.,* 2012). Mangrove vegetation is sensitive to oil and oil dispersants and is affected due to chemical toxicity and the smothering of pneumatophores (Duke, 2016). In other locations, pollution sources include septic tank leaks (*9.1*) and agricultural runoff (*9.3*). Microplastics also commonly accumulate in mangrove soils (Maghsodian *et al.,* 2022), and this has been observed in this province (e.g., Shruti *et al.,* 2021; Culligan *et al.,* 2022), though the long-term impacts on mangroves are uncertain.

At smaller scales, mangroves in this province are affected by debris from falling space rockets and their collection near Boca Chicas (Texas, USA) and Cape Canaveral (Florida, USA; *6.2-6.3*); controlled vegetation burns in some locations such as Cape Canaveral (Florida, USA; *7.1.1*); and grazing by non-native species such as Nilgai antelope (Texas, USA) and feral pigs (Louisiana and Florida, USA; *8.1.2*).

Climatic controls on mangroves

With climate change, mangroves in the Warm Temperate Northwest Atlantic are expected to experience increases in air temperature, increases in cyclone frequency and intensity, a potential decrease in precipitation, and increases in sea level (Friess *et al.,* 2022). The major climatic driver controlling mangrove distribution at their global range limit is temperature, specifically the frequency, duration and magnitude of freeze events (*11.3*). Mangroves in this province are sensitive to extreme low temperatures, and it has been suggested that mangrove distribution in northeast Florida is controlled by a threshold of extreme low temperatures of -4 °C (Cavanaugh *et al.,* 2014). Mangroves are impacted by extremely low-temperature events due to disruptions in vascular water transport (Stuart *et al.,* 2006), though their overall sensitivity is affected by phenotype and local microclimatic conditions. While a reduction in freeze events due to climate change is generally expected to lead to an increase in mangrove area and a latitudinal increase in their range limit (e.g., Cavanaugh *et al.,* 2015), freeze events will cause localised mangrove loss so that future expansion is likely to occur in a stepwise fashion (Giri *et al.,* 2023).

Mangrove defoliation due to a freeze event in Texas, USA in 2021 (photo credit: A. Armitage).

Mangroves in this province have been observed to reduce the erosional impacts of cyclones (Pennings *et al.,* 2021), though cyclones themselves have had observable impacts on mangrove forest structure (*11.4;* Armitage *et al.,* 2020), including impacts on above- and below-ground biomass (e.g., Krauss & Osland, 2020; Kuhn *et al.,* 2021). This threat is projected to increase in the future due to climate change, particularly in this province (Mo *et al.,* 2023). While some mangrove species such as *Avicennia germinans* are relatively resilient to cyclone impacts due to epicormic resprouting (as observed in this province, e.g., Armitage *et al.,* 2020), this is determined in part by the return period of cyclone activity, which is projected to decrease substantially with climate change in the Gulf of Mexico (Xi *et al.,* 2023).

Taller mangroves damaged by a hurricane event in Texas. Shorter-stature mangroves were protected from wind damage as the associated storm surge submerged them (photo credit: A. Armitage).

Drought (11.2) and concomitant increases in soil salinization have been observed to affect mangroves in western, more arid parts of this province, or slightly south of the province, such as the hypersaline Laguna Madre and Laguna de San Andres in Tamaulipas (Mexico). Mangroves in this area are already experiencing water stress due to hypersaline soil and estuarine water conditions, so are expected to be the most sensitive to changing precipitation regimes now and into the future compared to other mangrove areas in this province (Osland *et al.,* 2018). However, drought impacts on vegetation may also occur in wetter parts of the province; large areas of marsh dieback have been observed in Louisiana (USA) due to localised drought and saltwater intrusion (Elsey-Quirk *et al.,* 2024), though the impact on associated mangrove communities is currently unknown.

Mangrove defoliation in Laguna de San Andres, Tamaulipas, Mexico, located on the same coastline south of the Warm Temperate Northwest Atlantic province. Defoliation is attributed to physiological stress caused by hypersaline conditions that occurred during a drought in 2023 (photo credit: L. Priego).

While it is currently challenging to attribute changes in mangrove extent to sea-level rise (classified in the IUCN Threat Classification as *11.5 Other Impacts*), it is expected to affect mangrove distribution now and into the future, especially in combination with natural and anthropogenically-induced subsidence in locations such as Louisiana (USA), which will increase the relative sea-level rise that mangroves experience. Coastal wetlands have the ability to modify their sediment surface elevations relative to the tidal frame through a range of internal and external processes (Krauss *et al.,* 2014), though mangrove-specific responses to sea-level rise in this province are complex. Some field observations suggest that mangroves in some locations in this province may have greater elevation capital than surrounding tidal marshes (McKee & Vervaeke, 2018). Modelling suggests that mangroves may be better able to keep pace with sea-level rise compared to tidal marshes due to autochthonous belowground biomass production, but that this may increase vulnerability to sea-level rise once the system collapses and this organic material decomposes (Morris *et al.,* 2023).

Elevation deficits (where wetlands cannot keep pace vertically with rates of late-Holocene sea-level rise) are variable across the province, with wetlands in Texas and west Louisiana (USA) experiencing positive elevation deficits and those on the Mississippi Delta and northwest Florida (USA) experiencing a negative elevation deficit (Saintilan *et al.,* 2022). Furthermore, a recent study of surface elevation dynamics across 253 monitoring locations in Louisiana (USA) showed that 87% of coastal wetland sites are not keeping pace with contemporary rates of sea-level rise (Li *et al.,* 2024). As such, large areas of coastal wetlands in this province are expected to be at risk from projected sea-level rise (e.g., White *et al.,* 2019; Reed *et al.,* 2020). Mangrove populations may show increased resilience in locations where they are able to migrate laterally upslope as sea levels rise, with this potential particularly high in Louisiana and parts of Florida (USA; Osland *et al.,* 2022), though shoreline transgression is currently outpacing rates of landward wetland migration in many locations in the United States, including parts of this province (Parkinson, 2024).

Definition of the collapsed state of the ecosystem

Mangrove forests exhibit remarkable dynamism, with vegetation 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. The Red List of Ecosystems recognizes collapse when the tree cover of diagnostic true mangrove species dwindles to zero, indicating complete loss (100%). 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 substrates, 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) relevant to mangroves of the Warm Temperate Northwest Atlantic province:

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

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

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

7. Natural system modifications
- 7.1 Fire & fire suppression
  - 7.1.1 Increase in fire frequency/intensity
- 7.2 Dams & water management/use
  - 7.2.1 Abstraction of surface water (domestic use)
  - 7.2.2 Abstraction of surface water (commercial use)
  - 7.2.3 Abstraction of surface water (agricultural use)

    - 7.2.4 Abstraction of surface water (unknown use)
    - 7.2.5 Abstraction of ground water (domestic use)
    - 7.2.6 Abstraction of ground water (commercial use)
    - 7.2.7 Abstraction of ground water (agricultural use)
    - 7.2.8 Abstraction of ground water (unknown use)
    - 7.2.9 Small dams
    - 7.2.10 Large dams
    - 7.2.11 Dams (size unknown)
- 7.3 Other ecosystem modifications

8. Invasive & other problematic species, genes & diseases

- 8.1 Invasive non-native/alien species/diseases
    - 8.1.2 Named species

9. Pollution

- 9.1 Domestic & urban waste water
    - 9.1.1 Sewage
    - 9.1.2 Run-off
    - 9.1.3 Type Unknown/Unrecorded
- 9.2 Industrial & military effluents
    - 9.2.1 Oil spills
    - 9.2.3 Type Unknown/Unrecorded
- 9.3 Agricultural & forestry effluents
    - 9.3.1 Nutrient loads
    - 9.3.3 Herbicides & pesticides
    - 9.3.4 Type Unknown/Unrecorded
- 9.4 Garbage & solid waste

11. Climate change & severe weather

- 11.2 Droughts
- 11.3 Temperature extremes
- 11.4 Storms & flooding
- 11.5 Other impacts

12. Other options

- 12.1 Other threat

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 are currently no country-level estimates, nor common regional dataset that provides information for the entire target area in 1970. Therefore, mangroves in the Warm Temperate Northwest Atlantic are classified as **Data Deficient (DD)** for this subcriterion.

Subcriterion A2 measures the change in mangrove extent in any 50-year period, including from the present to the future: To estimate mangrove area in the Warm Temperate Northwest Atlantic mangrove area from 1996 to 2020, 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). Mangroves in the Warm Temperate Northwest Atlantic province show a net area change of -11.2% (1996-2020) (Bunting *et al.,* 2022). This value reflects the offset between areas gained (+0.6 %/year) and lost (-1.1 %/year). The largest decrease in mangrove area in this time series occurred between 2007 and 2015. Applying a linear regression to the area estimations between 1996 and 2020 we obtained a rate of change of -0.5 %/year (Figure 4). Assuming this trend continues in the future, it is predicted that the extent of mangroves in the Warm Temperate Northwest Atlantic province will change by -38.3% from 1996 to 2046; by -60.1% from 1996 to 2070; but by -55.1% from 2020 to 2070. Given that these predicted changes in mangrove extent are above 50% but below the 80% risk threshold, mangroves in the Warm Temperate Northwest Atlantic are assessed as **Endangered (EN)** under subcriterion A2. However, we note that setting habitat loss baselines is challenging (e.g., Teo *et al.,* 2023). Similarly, linear projections assume similar drivers and linear magnitudes of loss into the future, though drivers and rates of loss may be temporally and spatially variable (e.g., DeFries *et al.,* 2007; Sloan & Pelletier, 2012).

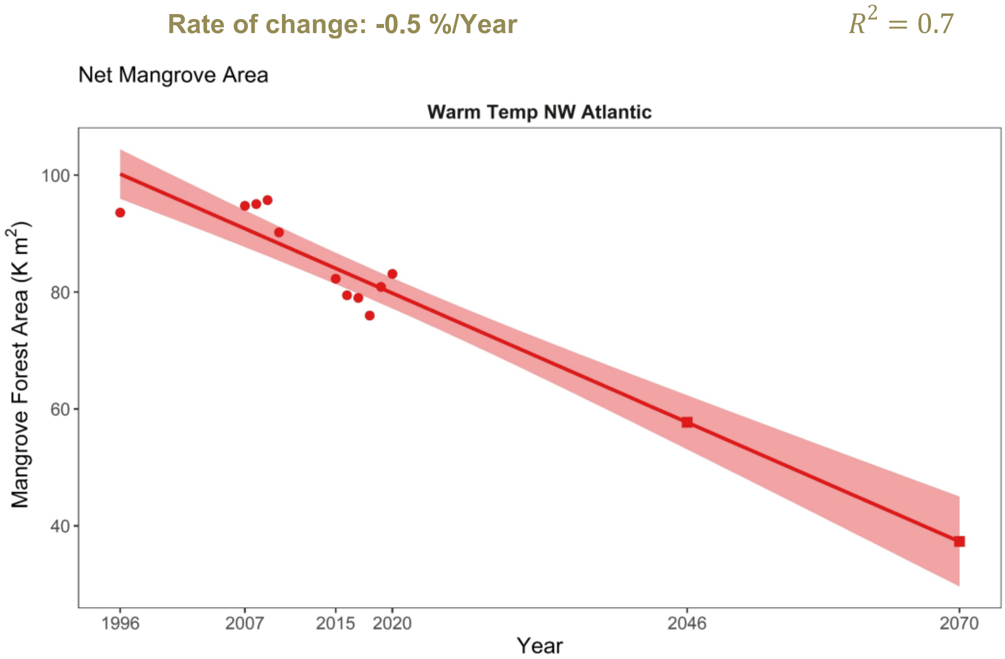

Figure 4. The Warm Temperate Northwest Atlantic province mangrove extent decline projected to 2070. Circles represent the province mangrove area between 1996 and 2020 based on the GMW v3.0 dataset and equations in Bunting *et al.* (2022). The solid line and shaded area are the linear regression and 95% confidence intervals. Squares show the Warm Temperate Northwest Atlantic province predicted mangrove area for 2046 and 2070. It is important to note that an exponential model (proportional rate of decline) did not give a better fit to the data ($R^2 = 0.6$).

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 mangroves in the Warm Temperate Northwest Atlantic are classified as **Data Deficient (DD)** for this subcriterion.

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

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 Warm Temp NW Atlantic province mangrove extent (GMW v.3).

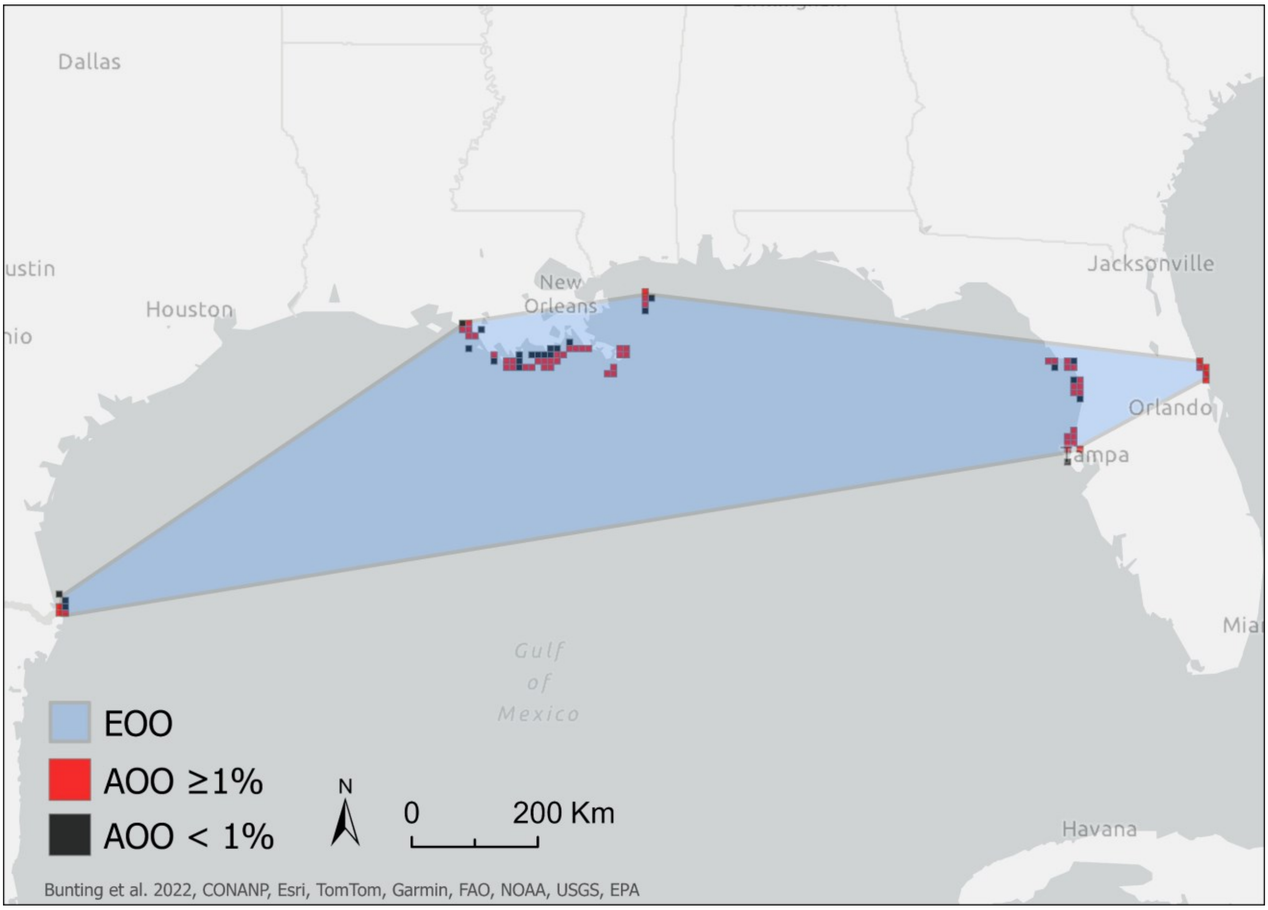

Figure 5. The Warm Temperate Northwest Atlantic Mangroves Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) in 2020. Estimates based on 2020 GMW v3.0 spatial layer (Bunting *et al.*, 2022). The red 10 x 10 km grids (n = 59) cover 99% of the ecosystem's accumulated area, and the black grids 0 - 1% (n = 24). Note that this mangrove analysis is based on global data and is considered by the authors to be a substantial underestimate (see discussion above).

For 2020, the AOO and EOO were measured as 83 grid cells (10 x 10 km) and 331284.0 km^2, respectively (Figure 5). Excluding from the AOO, those grid cells that collectively contain small patches covering less than 1% of the total mapped area of the ecosystem, the AOO was estimated as 59 (10 x 10 km) grid cells (Figure 5, red grids). As both the Extent of Occurrence (EOO) and the Area of Occupancy (AOO) exceed threat thresholds for sub-criteria B1 and B2, the ecosystem is considered **Least Concern (LC)** under these criteria.

Province	Extent of Occurrence EOO (Km^2)	Area of Occupancy (AOO)	Criterion B
The Warm Temperate Northwest Atlantic	331,284.0	59	**LC**

Given the absence of identifiable threats capable of precipitating the collapse of the entire ecosystem within a short time period, it is not plausible to determine the number of "threat-defined locations." Consequently, the ecosystem is evaluated as **Least Concern (LC)** under subcriterion B3.

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

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 mangroves in the Warm Temperate Northwest Atlantic are 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 the mangrove ecosystem was assessed by adopting the methodology presented by Schuerch *et al.* (2018). This published model calculates both absolute and relative change in the extent of wetland ecosystems under various regional SLR scenarios (medium: RCP 4.5, and high: RCP 8.5), with consideration of sediment accretion. The Schuerch *et al*. (2018) model was applied to mangroves within the Warm Temperate Northwest Atlantic province boundary, with spatial extent based on Giri *et al.* (2011) (considered underestimated), and assuming mangrove landward migration was not possible.

Under an extreme sea-level rise scenario of a 1.1 meter rise by 2100, this model projects a submerged area of ≈83% between 2010 and 2060, which is slightly above the 80% risk threshold. Therefore, considering that no mangrove recruitment can occur in a submerged system (100% relative severity), and that ≈ 83% of the ecosystem extent will be affected by SLR, mangroves in the Warm Temperate Northwest Atlantic are currently assessed as **Critically Endangered (CR)** for subcriterion C2. This broadly matches similar conclusions by other studies e.g., Buchanan *et al.* (2022), where substantial wetland area in the Gulf of Mexico is expected to be lost even under high rates of sediment supply, particularly in Louisiana and parts of Texas. The Mississippi Delta in Louisiana is particularly at risk from projected inundation; a recent study suggests that 87% of coastal wetland monitoring sites are currently not keeping pace with sea-level rise and that 75% of Louisiana's coastal wetlands are expected to be drowned by 2070 (Li *et al.,* 2024). Mangroves in this region may also be able to adapt through landward migration to higher elevation, however the evidence on the potential for landward migration of mangroves in this province is mixed; substantial landward migration space is available along many parts of the province, particularly in Louisiana and parts of Texas (Borchert *et al.,* 2018), though observations in the mid-Atlantic and southeast USA (including one site in this province) suggest that shoreline transgression currently outpaces rates at which wetlands can migrate landwards (Parkinson, 2024).

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 Warm Temperate Northwest Atlantic province is classified as **Data Deficient (DD)** for this subcriterion.

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

Criterion D: Disruption of biotic processes or interactions

A global mangrove degradation model developed by Worthington & Spalding (2018) was used to assess the level of biotic degradation in mangroves of the Warm Temperate Northwest Atlantic province. This model is based on degradation metrics calculated from various vegetation indices (NDVI, EVI, SAVI, NDMI) using a 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 (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 (e.g., Murray *et al.,* 2020; 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.

Results from this analysis show that over a period of 17 years (≈2000 to 2017), ≈3% of the Warm Temperate Northwest Atlantic mangrove area was classified as degraded, resulting in an average annual rate of degradation of ≈0.2%. Assuming this trend remains constant, ≈+8% of the Warm Temperate Northwest Atlantic 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 Warm Temperate Northwest Atlantic mangrove province is assessed as **Least Concern** (**LC)** under subcriterion D2b. However, the results obtained with this method should be interpreted with caution as mangrove areas are underestimated, due to challenges to mapping mangroves at this latitudinal range limit.

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 Warm Temperate Northwest Atlantic 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 50 years period	**A3** Historical (1750)
	DD	EN	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	CR	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	CR		

CR = Critically Endangered; EN = Endangered; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated.

Overall, the status of mangroves in the Warm Temperate Northwest Atlantic is assessed as **Critically Endangered (CR)**, with the caveat of substantial data gaps in mangrove distribution in this province and limitations of modelling their vulnerability to sea-level rise.

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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 described in the distribution section.

Class	Order	Family	Scientific name	RLTS category
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia germinans*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Rhizophora mangle*	LC
Magnoliopsida	Myrtales	Combretaceae	*Laguncularia racemosa*	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 presence recorded as "Extant", "Possibly Extant" or "Possibly Extinct", Origin recorded as "Native" or "Reintroduced" , with any value of Seasonality except "Passage", suitability recorded as "Suitable", and with "Major Importance" recorded as "Yes". 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	Albuliformes	Albulidae	*Albula vulpes*	NT	Bonefish
Actinopterygii	Anguilliformes	Muraenidae	*Gymnothorax funebris*	LC	Green moray
Actinopterygii	Anguilliformes	Ophichthidae	*Ahlia egmontis*	LC	Key worm eel
Actinopterygii	Beloniformes	Belonidae	*Strongylura notata*	LC	Redfin needlefish
Actinopterygii	Beloniformes	Belonidae	*Strongylura timucu*	LC	Timucu
Actinopterygii	Clupeiformes	Clupeidae	*Jenkinsia lamprotaenia*	LC	Dwarf round herring
Actinopterygii	Cyprinodontiformes	Fundulidae	*Fundulus similis*	LC	Longnose killifish
Actinopterygii	Cyprinodontiformes	Rivulidae	*Kryptolebias marmoratus*	LC	Mangrove rivulus
Actinopterygii	Elopiformes	Elopidae	*Elops saurus*	LC	Northern ladyfish
Actinopterygii	Gobiiformes	Eleotridae	*Dormitator maculatus*	LC	Fat sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Erotelis smaragdus*	LC	Emerald sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Gobiomorus dormitor*	LC	Bigmouth sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Guavina guavina*	LC	Guavina
Actinopterygii	Gobiiformes	Gobiidae	*Bathygobius curacao*	LC	Notchtongue goby

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Actinopterygii	Gobiiformes	Gobiidae	*Ctenogobius smaragdus*	LC	Emerald goby
Actinopterygii	Gobiiformes	Gobiidae	*Ctenogobius stigmaturus*	LC	Spottail goby
Actinopterygii	Gobiiformes	Gobiidae	*Lophogobius cyprinoides*	LC	Crested goby
Actinopterygii	Perciformes	Centropomidae	*Centropomus mexicanus*	LC	Largescale fat snook
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus itajara*	VU	Atlantic goliath grouper
Actinopterygii	Perciformes	Epinephelidae	*Mycteroperca acutirostris*	LC	Comb grouper
Actinopterygii	Perciformes	Epinephelidae	*Mycteroperca interstitialis*	VU	Yellowmouth grouper
Actinopterygii	Perciformes	Epinephelidae	*Mycteroperca phenax*	DD	Scamp
Actinopterygii	Perciformes	Gerreidae	*Diapterus auratus*	LC	Irish mojarra
Actinopterygii	Perciformes	Gerreidae	*Eucinostomus harengulus*	LC	Tidewater mojarra
Actinopterygii	Perciformes	Gerreidae	*Eucinostomus havana*	LC	Bigeye mojarra
Actinopterygii	Perciformes	Gerreidae	*Eugerres awlae*	LC	Maracaibo mojarra
Actinopterygii	Perciformes	Gerreidae	*Eugerres plumieri*	LC	Striped mojarra
Actinopterygii	Perciformes	Gerreidae	*Gerres cinereus*	LC	Yellow fin mojarra
Actinopterygii	Perciformes	Pomacentridae	*Stegastes leucostictus*	LC	Beaugregory
Actinopterygii	Perciformes	Sciaenidae	*Sciaenops ocellatus*	LC	Red drum
Actinopterygii	Perciformes	Serranidae	*Hypoplectrus unicolor*	LC	Butter hamlet
Actinopterygii	Perciformes	Sparidae	*Archosargus rhomboidalis*	LC	Sea bream
Actinopterygii	Perciformes	Sparidae	*Lagodon rhomboides*	LC	Pinfish
Actinopterygii	Pleuronectiformes	Bothidae	*Bothus lunatus*	LC	Plate fish
Anthozoa	Scleractinia	Faviidae	*Manicina areolata*	LC	Rose coral
Anthozoa	Scleractinia	Oculinidae	*Oculina diffusa*	LC	Diffuse ivory bush coral
Anthozoa	Scleractinia	Poritidae	*Porites furcata*	LC	Branched finger coral
Anthozoa	Scleractinia	Poritidae	*Porites porites*	LC	Finger coral
Aves	Accipitriformes	Accipitridae	*Buteo brachyurus*	LC	Short-tailed hawk
Aves	Accipitriformes	Accipitridae	*Buteogallus urubitinga*	LC	Great black hawk
Aves	Accipitriformes	Accipitridae	*Elanoides forficatus*	LC	Swallow-tailed kite

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Aves	Accipitriformes	Accipitridae	*Haliaeetus leucocephalus*	LC	Bald eagle
Aves	Anseriformes	Anatidae	*Nomonyx dominicus*	LC	Masked duck
Aves	Caprimulgiformes	Caprimulgidae	*Nyctidromus albicollis*	LC	Pauraque
Aves	Ciconiiformes	Ciconiidae	*Mycteria americana*	LC	Wood stork
Aves	Columbiformes	Columbidae	*Zenaida asiatica*	LC	White-winged dove
Aves	Coraciiformes	Alcedinidae	*Chloroceryle amazona*	LC	Amazon kingfisher
Aves	Coraciiformes	Alcedinidae	*Chloroceryle americana*	LC	Green kingfisher
Aves	Coraciiformes	Alcedinidae	*Megaceryle alcyon*	LC	Belted kingfisher
Aves	Coraciiformes	Alcedinidae	*Megaceryle torquata*	LC	Ringed kingfisher
Aves	Cuculiformes	Cuculidae	*Coccyzus minor*	LC	Mangrove cuckoo
Aves	Cuculiformes	Cuculidae	*Crotophaga ani*	LC	Smooth-billed ani
Aves	Falconiformes	Falconidae	*Micrastur semitorquatus*	LC	Collared forest-falcon
Aves	Galliformes	Cracidae	*Ortalis vetula*	LC	Plain chachalaca
Aves	Gruiformes	Aramidae	*Aramus guarauna*	LC	Limpkin
Aves	Gruiformes	Rallidae	*Rallus crepitans*	LC	Clapper rail
Aves	Passeriformes	Corvidae	*Aphelocoma californica*	LC	Western scrub-jay
Aves	Passeriformes	Furnariidae	*Sittasomus griseus*	LC	Western olivaceous woodcreeper
Aves	Passeriformes	Furnariidae	*Xiphorhynchus flavigaster*	LC	Ivory-billed woodcreeper
Aves	Passeriformes	Hirundinidae	*Stelgidopteryx serripennis*	LC	Northern rough-winged swallow
Aves	Passeriformes	Parulidae	*Geothlypis trichas*	LC	Common yellowthroat
Aves	Passeriformes	Parulidae	*Helmitheros vermivorum*	LC	Worm-eating warbler
Aves	Passeriformes	Parulidae	*Parkesia noveboracensis*	LC	Northern waterthrush
Aves	Passeriformes	Parulidae	*Protonotaria citrea*	LC	Prothonotary warbler
Aves	Passeriformes	Parulidae	*Setophaga discolor*	LC	Prairie warbler
Aves	Passeriformes	Parulidae	*Setophaga dominica*	LC	Yellow-throated warbler
Aves	Passeriformes	Parulidae	*Setophaga ruticilla*	LC	American redstart

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Aves	Passeriformes	Polioptilidae	*Polioptila caerulea*	LC	Blue-grey gnatcatcher
Aves	Passeriformes	Tyrannidae	*Myiarchus tyrannulus*	LC	Brown-crested flycatcher
Aves	Passeriformes	Tyrannidae	*Tyrannus dominicensis*	LC	Grey kingbird
Aves	Passeriformes	Vireonidae	*Vireo altiloquus*	LC	Black-whiskered vireo
Aves	Passeriformes	Vireonidae	*Vireo flavoviridis*	LC	Yellow-green vireo
Aves	Pelecaniformes	Ardeidae	*Ardea herodias*	LC	Great blue heron
Aves	Pelecaniformes	Ardeidae	*Butorides striata*	LC	Green-backed heron
Aves	Pelecaniformes	Ardeidae	*Cochlearius cochlearius*	LC	Boat-billed heron
Aves	Pelecaniformes	Ardeidae	*Egretta caerulea*	LC	Little blue heron
Aves	Pelecaniformes	Ardeidae	*Egretta rufescens*	NT	Reddish egret
Aves	Pelecaniformes	Ardeidae	*Egretta tricolor*	LC	Tricolored heron
Aves	Pelecaniformes	Ardeidae	*Ixobrychus exilis*	LC	Least bittern
Aves	Pelecaniformes	Threskiornithidae	*Eudocimus albus*	LC	White ibis
Aves	Piciformes	Picidae	*Campephilus guatemalensis*	LC	Pale-billed woodpecker
Aves	Piciformes	Picidae	*Colaptes auratus*	LC	Yellow-shafted flicker
Aves	Piciformes	Picidae	*Colaptes cafer*	LC	Red-shafted flicker
Aves	Piciformes	Picidae	*Dryobates scalaris*	LC	Ladder-backed woodpecker
Aves	Psittaciformes	Psittacidae	*Amazona oratrix*	EN	Yellow-headed amazon
Aves	Suliformes	Fregatidae	*Fregata magnificens*	LC	Magnificent frigatebird
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Negaprion brevirostris*	VU	Lemon shark
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis pectinata*	CR	Smalltooth sawfish
Gastropoda	Cycloneritida	Neritidae	*Vitta virginea*	LC	Virgin nerite
Gastropoda	Ellobiida	Ellobiidae	*Melampus coffeus*	LC	Coffee melampus
Gastropoda	Sorbeoconcha	Potamididae	*Cerithidea pliculosa*	LC	Horn shell
Insecta	Odonata	Libellulidae	*Erythrodiplax berenice*	LC	Seaside dragonlet
Magnoliopsida	Myrtales	Combretaceae	*Conocarpus erectus*	LC	Silver-leaved buttonwood
Mammalia	Carnivora	Felidae	*Leopardus pardalis*	LC	Ocelot
Mammalia	Carnivora	Felidae	*Panthera onca*	NT	Jaguar

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Mammalia	Carnivora	Procyonidae	*Procyon lotor*	LC	Northern raccoon
Mammalia	Cetartiodactyla	Cervidae	*Odocoileus hemionus*	LC	Mule deer
Mammalia	Cetartiodactyla	Tayassuidae	*Pecari tajacu*	LC	Collared peccary
Mammalia	Didelphimorphia	Didelphidae	*Didelphis virginiana*	LC	Virginia opossum
Polypodiopsida	Polypodiales	Pteridaceae	*Acrostichum danaeifolium*	LC	Na
Reptilia	Squamata	Iguanidae	*Ctenosaura acanthura*	LC	Veracruz spiny-tailed iguana
Reptilia	Testudines	Emydidae	Malaclemys Terrapin	VU	Diamondback Terrapin