Climatic and Ecological Value of the threatened mangroves of Chiriqui Province, Panama

Independent study commissioned by:

No to Puerto Baru Campaign

Prepared by:

Restor and Tropical Landscapes Climate Program

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Scope and purpose

This independent study was prepared by Restor and the Tropical Landscapes Climate Program and commissioned by the No to Puerto Baru Campaign. The content is intended for general information purposes only and has been developed using data from publicly available databases. While these datasets are robust, we recognize that each individual dataset possesses its own inherent limitations. However, by leveraging and integrating multiple data layers, we are able to construct a comprehensive picture of the general state and ecological value of the regional biodiversity. Please note that we have not conducted any ground assessments or on-site field surveys of these ecosystems, as such empirical verification would require significantly more resources than were available for this preliminary technical analysis.

1 Executive Summary

The mangrove ecosystems of Chiriquí Province, stretching across the districts of David, Alanje, and San Lorenzo, represent one of the most ecologically significant and intact coastal forests remaining in the Americas. This 79,686-hectare area is not merely a local resource but a global climate and biodiversity stronghold currently under imminent threat from the proposed Puerto Barú port development.

This report provides a scientific quantification of the ecological value and climate importance of this irreplaceable ecosystem:

- **A "Carbon Vault" for Panama**: These mangroves hold **14.6 million tonnes of carbon**, accounting for **24% of Panama's total blue carbon stock**. The potential release of this carbon (53.2 Mt CO2e) exceeds Panama's total annual national emissions by a factor of 3.6.
- **Irreplaceable Coastal Defense ($17M Savings)**: The natural barrier provided by these mangroves currently limits annual economic flood damage to $1M. Without this ecosystem, estimated **damages would skyrocket to $18M—a 1,700% increase in liability for the region**.
- **Global Biodiversity Stronghold**: The area supports more species of plants, mammals, and birds than 90% of the Earth, including **all 11 Panamanian mangrove tree species** and **7 critically endangered species**.
- **Rare Ecological Integrity**: While **over 82% of the world's forests are degraded**, this region has maintained exceptional stability with **less than 2% forest loss over the last 20 years**. It features "canopy giants" reaching **50.9 meters**, some of the tallest mangroves recorded globally - an ancient "climax community" that is essentially irreplaceable.
- **Extreme Fragility to Disturbance**: Analysis of historical events shows this ecosystem is highly susceptible to hydrological changes. Past instances show impeded tidal flow led to **total structural collapse and "ghost forest" formation in as little as 3-5 years**.

The proposed dredging of a 100m wide, 11m deep channel through this sensitive area poses a fundamental threat to regional environmental security. These data points will inform the next phase of our work: the #MissionPanama Communications Campaign - to mobilize public and institutional support to protect one of Central America's last great mangrove strongholds.

While this technical analysis primarily focuses on ecological metrics, we recognize that these ecosystems are the lifeblood of local communities. Extensive literature and anecdotal evidence consistently point to the profound positive effects of intact mangroves on local food security and income. We will bring these vital human stories to the forefront through our upcoming community-led storytelling series.

The deep-dive analysis conducted for this project has yielded a suite of high-resolution datasets that we believe hold transformative potential for the wider nature sector. If integrated into the Restor platform, these models could unlock critical performance-based financing for thousands of other mangrove projects globally. We are currently engaging our community to test the appetite for these data layers and refine their application for large-scale investment.

2 Introduction

2.1 Background and Scientific Framework

The mangrove ecosystems of Chiriquí Province, Panama, face a critical juncture with the proposed development of port facilities at Puerto Barú. These coastal forests, situated along the Gulf of Chiriquí, represent one of the most ecologically valuable and scientifically significant mangrove systems in Central America (Spalding *et al,* 2010).

Mangroves worldwide are recognized as critical ecosystems that bridge terrestrial and marine environments, providing irreplaceable services including coastal protection, carbon sequestration, water filtration, and nursery habitat for commercial fisheries. The mangroves of David, Alanje, and San Lorenzo are particularly significant due to their exceptional size, pristine condition, and strategic location protecting the coastline south of the city of David and its international airport.

This ecological assessment was commissioned by the No to Puerto Baru Campaign to provide scientific quantification of the ecological and climate value of the mangrove ecosystems potentially affected by the Puerto Barú port development. It complements the Lynker independent scientific review (Lynker, 2024) of the Environmental Impact Statement submitted by the developers of the Puerto Barú project. While that review evaluates the adequacy and accuracy of the developer's impact predictions and mitigation proposals, this study adds some additional analysis and a data deep-dive into the ecological and climatic values of the mangroves.

2.2 Study Area

The study area encompasses the extensive mangrove forests of the Chiriquí Province (Figure 1) in Western Panama, specifically within the districts of David, Alanje, and San Lorenzo along the Gulf of Chiriquí coastline (Figure 2). These mangroves are positioned directly adjacent to and protecting the city of David, the provincial capital and third-largest city in Panama (with a population of 130,000), as well as the Enrique Malek International Airport.

Figure 1: Provinces of Panama

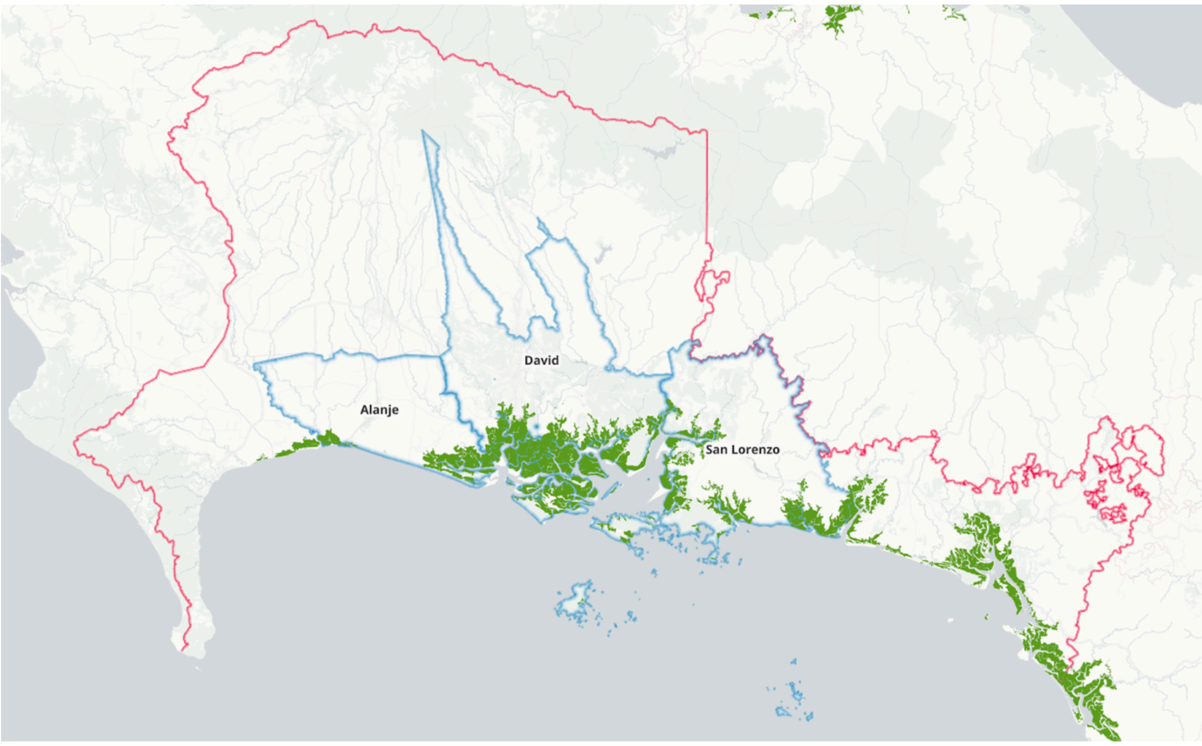

Figure 2: Mangroves of Chiriquí Province (and Alanje, David and San Lorenzo districts)

The mangrove belt extends along the coastal fringe, forming a continuous protective barrier between the Pacific Ocean and low-lying urban and agricultural areas. The width of this mangrove belt varies along its length, with measurements and specific dimensions detailed in the spatial analysis results.

2.3 Protected Area Designations

The study area overlaps with two key protected areas that reflect the recognized conservation value of these ecosystems (Figure 3).

2.3.1 La Playa de la Barqueta Agrícola

This protected area was designated in 1994 as an IUCN Category IV Wildlife Refuge with an area of 6,704 hectares. The Protected Planet data for this protected area is here.

2.3.2 Manglares de David, Alanje y San Lorenzo (proposed)

These mangrove forests are currently designated as protected areas by the Municipal Council of David (Concejo Municipal de David, 2007) with an area of 72,982 hectares. The limits are awaiting for approval at the national level by the Ministry of Environment in Panama (MiAmbiente, 2024).

Figure 3: Protected Areas in the study area

2.4 Proposed Port Development

The proposed port development of Puerto Barú is located just outside the Manglares de David protected area with the channel that accesses the port passing directly through the mangroves (Figure 4). The proposal states that this channel will be dredged to a depth of up to 11m deep and will be 100m wide. The dredged material will be disposed of in a site near the mouth of a Manglares de David estuary.

For the purposes of this study, both protected areas are combined together to form a single Area of Interest (AOI) that is used in all the analyses with a total area of 79,686 hectares. This AOI represents a single contiguous block of mangroves within the study area and is meaningful in terms of its ecological connectivity and unfragmented nature.

Figure 4: The AOI used in this study showing the proposed Puerto Barú Port Development, the Dredged Channel and the Dredging Material Disposal Site. The red triangle marks the location of the sudden mangrove die-back case study outlined in Figure 5.

2.5 Physical Characteristics

The mangroves of Chiriquí Province are a system governed by Panama's large tidal range and by intense seasonal storms. These factors drive the essential circulation, nutrient delivery, and salinity regulation required for mangrove survival. Historical remote sensing reveals that while the system is resilient to natural coastal accretion and erosion, it remains highly susceptible to hydrological disturbance; even brief periods of impeded tidal flow or root asphyxiation caused by sediment *ponding* can lead to rapid, widespread forest die-back.

As an example of the susceptibility of these mangroves to hydrological disturbance, Figure 5 shows a sequence of remotely sensed images within the AOI centered on 8°14'17.92" N, 82°21'53.38" W between 2018 and 2023. This sequence shows how impeded tidal flow caused by coastal accretion leads to the cessation of tidal flushing. Without tidal flushing, interstitial (soil) salinity can spike to levels far beyond the tolerance of even the hardiest species (often exceeding 90–100 parts per thousand). This then leads to rapid die-back of the crowns and structural collapse, leading to a ghost forest. In this particular case, it is not known what caused the coastal accretion.

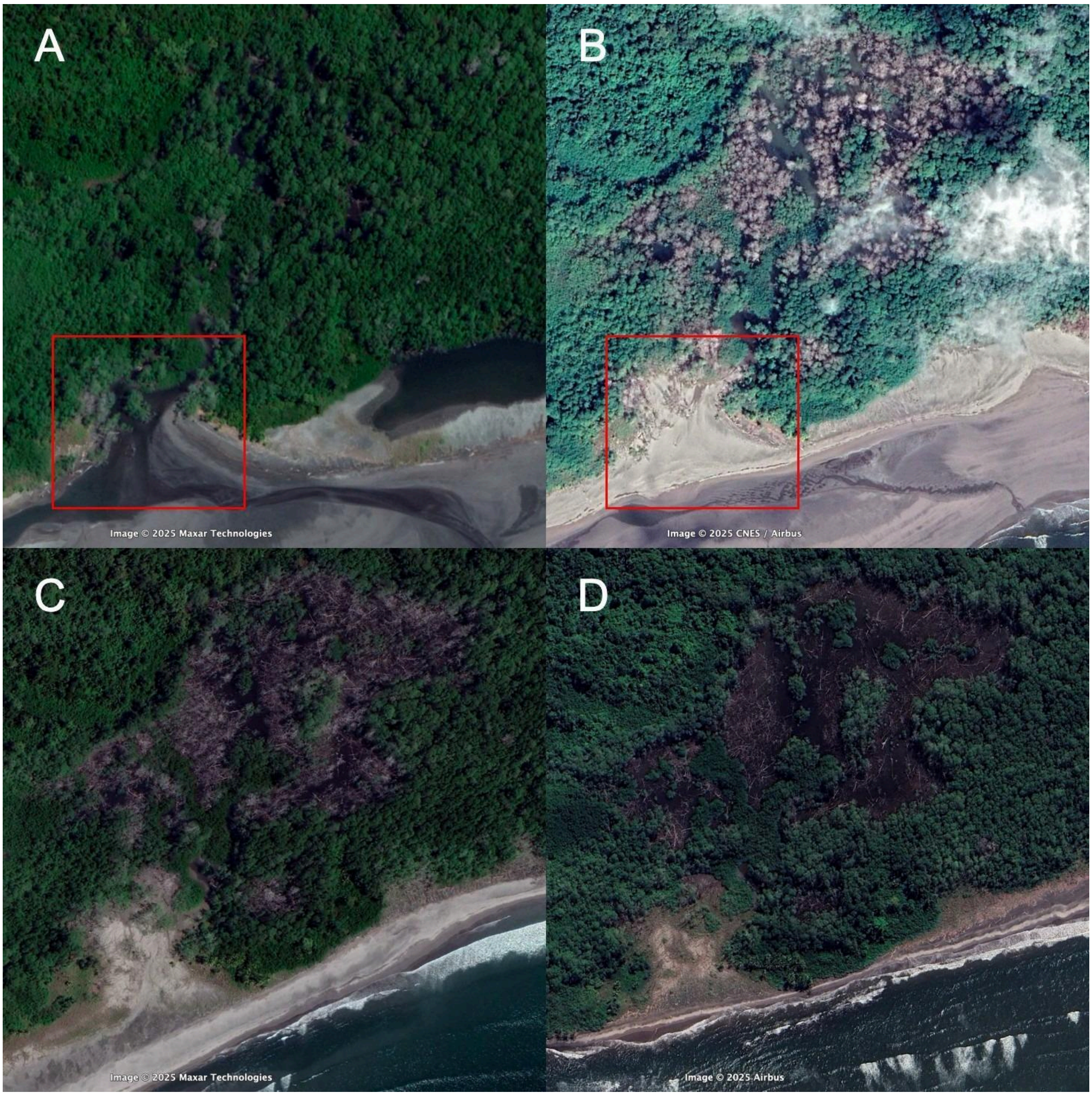

Figure 5: Sudden mangrove die-back due to coastal accretion between 2018 and 2023. The details are described in the text below.

In **A** (March 2018) there is a healthy forest that drains and flushes through the tidal channel (which is shown in red). In **B** (December 2018) the tidal flushing is impeded due to sedimentation and there is now chlorosis in the tree crowns. In **C** (February 2021) there is structural collapse of the trees. In **D** (June 2023) soil decomposition causes peat collapse and carbon release and a ghost forest forms.

The proposed port development threatens this delicate equilibrium through dredging and the modification of natural tidal channels (Lynker, 2025).

3 Scientific Analysis and Results

3.1 Total Mangrove Cover

Description of Metric: This analysis measures the spatial extent and distribution of mangrove forests. Quantifying total cover is the baseline for all ecosystem service valuations, as the scale of carbon sequestration, nursery habitat, and coastal protection is directly proportional to the contiguous area of the forest canopy.

- **Analysis:** The analysis utilized the official 2021 Panama Land Cover Map from MiAmbiente and 2007 Baseline and Diagnostic Study for the Mangrove Forests of the Gulf of Chiriquí to determine baseline extent (MiAmbiente, 2021a, CATHALAC, 2007).
- **Results:** The baseline metrics for the Chiriquí Province are summarized in Table 1.

	Area of Mangroves (hectares)	~% National Area
Republic of Panama	181,338 - 187,064[1]	
Chiriqui Province	38,622 - 50,133	25%

Table 1: Proportion of mangroves in Panama, Chiriqui Province.

- **Context:** The Chiriquí Province accounts for 25% of the total mangrove area in the Republic of Panama. The size and connectivity of this mangrove block is ecologically significant. Large, contiguous mangrove forests support more diverse biological communities, maintain more stable hydrological regimes, and demonstrate greater resilience to disturbance compared to fragmented patches (Lee *et al.*, 2014).

3.2 Canopy Height Distribution

Description of Metric: Canopy height measurements derived from remote sensing data provide insights into forest structure, age distribution, and growing conditions. Height is a key indicator of mangrove productivity and structural complexity.

- **Analysis:** The analysis utilized the canopy height model developed by Simard *et al.* (2019).
- **Results:** The spatial distribution of the maximum canopy heights within the AOI is illustrated in Figure 6. The maximum canopy height in the AOI was 50.9m and the average was 22.1m.

[1] MiAmbiente, 2021b, CATHALAC, 2007

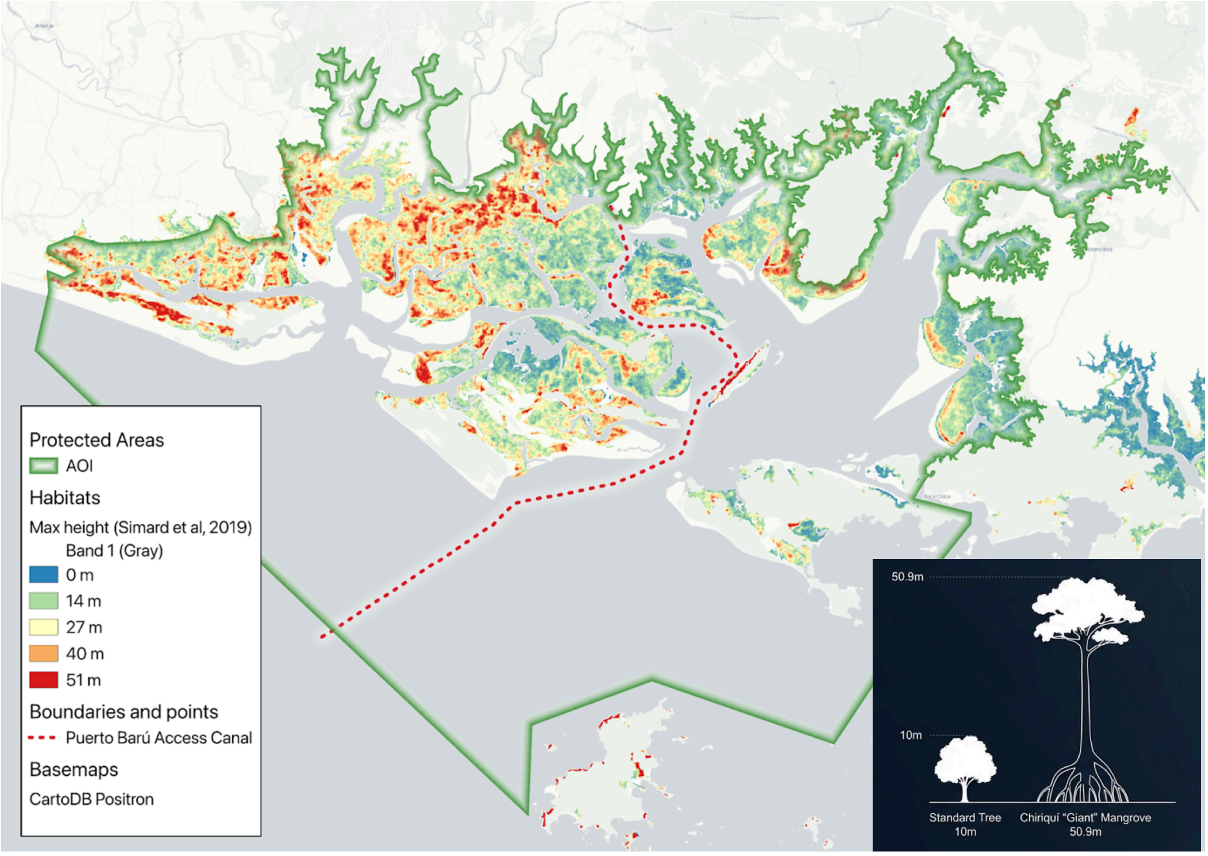

Figure 6: Spatial distribution of maximum canopy heights at 30m resolution (Simard et al, 2019)

- **Context:** Mangrove tree heights >45m are only found elsewhere in Gabon and the San Juan River (Colombia). Nationally, these are characteristic of a stable, late-successional old-growth ecosystem. These heights also indicate the AOI is an “Amazon of the Ocean” which has remained undisturbed by climatic or anthropogenic clearing for decades. Just as one cannot "restore" a 500-year-old rainforest, these 50m mangrove stands cannot be mitigated or replanted; their loss would be permanent.

3.3 Mangrove Canopy Species

Description of Metric: A list of the mangrove tree species that occur in the AOI can be valuable in understanding the ecological resilience of the ecosystem to environmental stressors. Different species of mangroves inhabit different zones within the forest and provide essential ecosystem services related to flood mitigation, fishery nurseries, biodiversity and carbon storage.

- **Analysis:** An analysis was performed between the AOI and the IUCN Red List of Threatened Species ranges on the IUCN Red List website (IUCN, 2025). This was supplemented by occurrence data from the Global Biodiversity Information Facility (GBIF).
- **Results:** Based on the intersection analysis, all 11 Panamanian mangrove tree species occur in the AOI. These are shown in Table 2 together with the source and the IUCN Category.

Scientific name	Common Name	Source	IUCN Threatened Category
Acrostichum danaeifolium		IUCN 2025	Least Concern
Avicennia bicolor		IUCN 2025	Vulnerable
Avicennia germinans	Black Mangrove	IUCN 2025	Least Concern
Conocarpus erectus	Silver-leaved Buttonwood	IUCN 2025	Least Concern
Laguncularia racemosa	White Mangrove	IUCN 2025	Least Concern
Mora oleifera		IUCN 2025	Vulnerable
Pelliciera rhizophorae		IUCN 2025	Vulnerable
Rhizophora mangle	Red Mangrove	GBIF 2026	Least Concern
Rhizophora racemosa		IUCN 2025	Least Concern
Rhizophora samoensis		IUCN 2025	Near Threatened
Tabebuia palustris		IUCN 2025	Vulnerable

Table 2: Mangrove species that occur in the AOI.

- **Context:** Panama lies at the centre of diversity for the western mangrove flora, supporting 11 mangrove tree species — the joint highest for the Americas alongside Colombia (Spalding *et al.*, 1997). All 11 species are present within the AOI, capturing the full complement of Panama's mangrove tree diversity in a single site.

3.4 Total Biomass and Blue Carbon Stocks

Description of Metric: This metric quantifies the Blue Carbon stored within the ecosystem, including Above-Ground Biomass, Below-Ground Biomass and Soil Organic Carbon. Measuring carbon density allows us to value the forest as a climate mitigation asset and calculate the potential emissions that would be released if the area were degraded.

3.4.1 Above-Ground Biomass (AGB)

Description of Metric: The AGB is all living organic matter located above the soil, including the trunks, branches, and leaves that store carbon through photosynthesis.

- **Analysis:** AGB estimates were calculated using the 30m resolution models produced by Simard *et al.* (2019) for the current value and the 500m models from Walker *et al.* (2022) for the potential value.

- **Results:** The spatial distribution of AGB within the AOI is illustrated in Figure 7. The AGB values follow a similar spatial distribution to the canopy heights as expected.

The maximum AGB density value in the AOI was 373 Mg C /ha [2] and the average was 111 Mg C /ha.

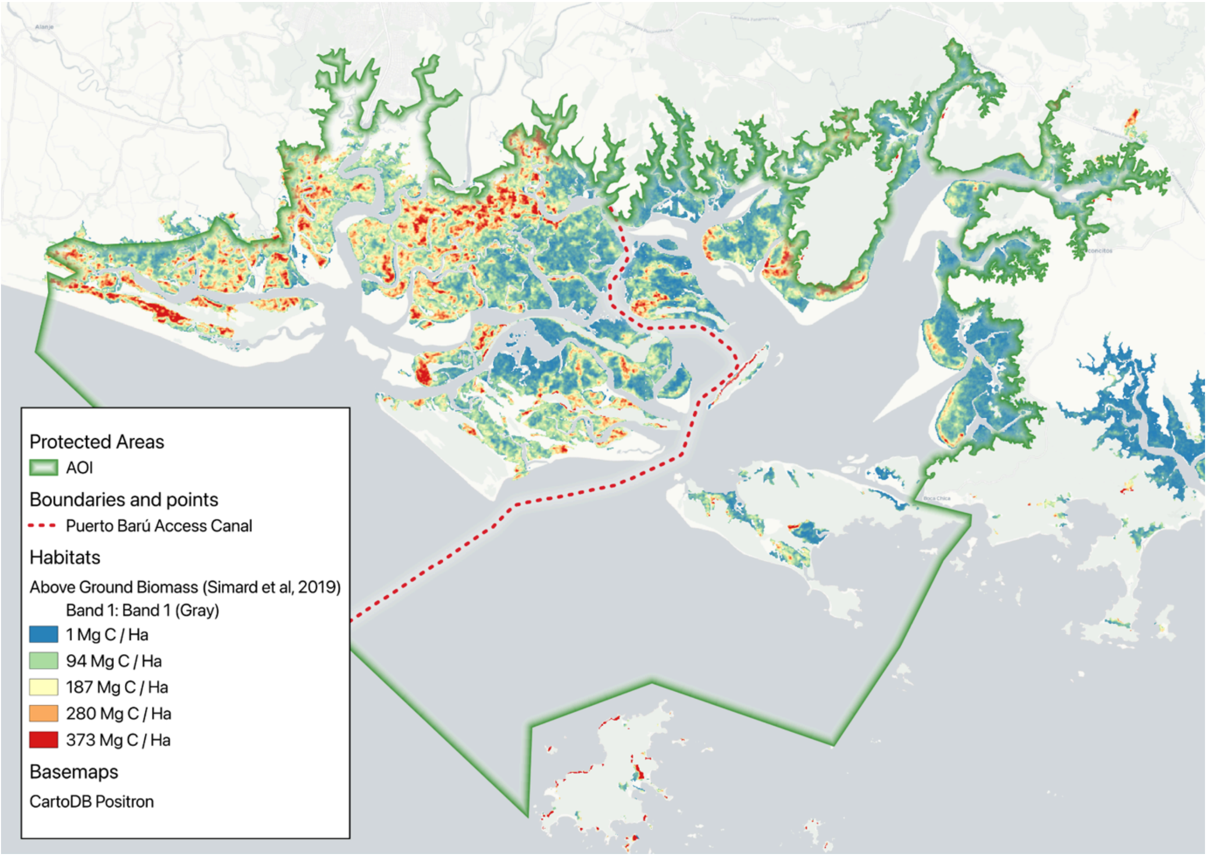

Figure 7: Spatial distribution of AGB at 30m resolution (Simard et al, 2019)

The total values for the AOI are given in Table 3.

	Current (Mt C) [3]	Potential (Mt C)
Total Above-Ground Biomass	2.3	4.53

Table 3: Total AGB in the AOI (Simard et al., 2019 and Walker et al., 2022).

- **Context:** The maximum AGB density value is more than double the global mangrove average of 184 Mg C /ha and places the David-Alanje-San Lorenzo complex among the most productive ecosystems in the Eastern Equatorial Pacific and not just in Panama.

[2] 1 Megagram (Mg) = 1 tonne
[3] 1 Megatonne (Mt) = 1,000,000 tonnes

3.4.2 Below-Ground Biomass (BGB)

Description of Metric: The BGB is the living root systems of the trees, which in mangroves are particularly extensive to provide stability in unstable, waterlogged soils.

- **Analysis:** BGB estimates were calculated using the 500m resolution models produced by Walker *et al.* (2022).
- **Results:** The spatial distribution of BGB is excluded from the mapping due to its lower resolution and its high degree of spatial correlation with AGB.

The maximum BGB density value in the AOI was 63 Mg C /ha, and the average was 36 Mg C /ha.
The total values for the AOI are given in Table 4.

	Current (Mt C)	Potential (Mt C)
Total Below-Ground Biomass	0.966	1.75

Table 4: Total BGB in the AOI (Walker et al., 2022).

- **Context**: The mangrove forests within the AOI store an average of 63 Mg C /ha in below-ground biomass, placing them within the typical range for Neotropical mangroves.

3.4.3 Soil Organic Carbon (SOC)

Description of Metric: The SOC is the carbon stored in the thick, anaerobic mud beneath the trees, which represents the largest carbon reservoir in mangrove ecosystems due to slow decomposition rates.

- **Analysis:** SOC estimates were calculated using the 500m resolution models produced by Walker *et al.* (2022).
- **Results:** The spatial distribution of SOC is excluded from the mapping due to its lower resolution and its high degree of spatial correlation with AGB.

The maximum SOC density value in the AOI was 620 Mg C /ha, and the average was 422 Mg C /ha.
The total values for the AOI are given in Table 5.

	Current (Mt C)	Potential (Mt C)
Total Soil Organic Carbon	11.2	11.3

Table 5: Total SOC in the AOI (Walker et al., 2022).

- **Context**: Mangrove soils are exceptional carbon reservoirs, storing organic carbon accumulated over centuries to millennia. The anaerobic conditions in waterlogged mangrove sediments slow decomposition rates, enabling long-term carbon sequestration. Typically, mangrove sediments store several times more carbon than terrestrial tropical forests on a per-hectare basis (Sheehan, 2019), making their conservation critical for climate change mitigation. If disturbed this carbon would be irrecoverable on a human timescale. If the soil is disturbed by dredging, the resulting "peat collapse" (as noted in Figure 5D) turns a millennial carbon sink into an immediate carbon bomb.

3.4.4 Total Ecosystem Carbon Stock (TECS)

Description of Metric: The TECS represents the total carbon reservoir protected by these mangrove ecosystems (or Blue Carbon).

- **Analysis:** The TECS is given by the equation TECS = AGB + BGB +SOC.
- **Results:** The total values for the AOI are given in Table 6.

	Current (Mt C)	Potential (Mt C)
Total Ecosystem Carbon Stock	14.5	17.6

Table 6: Total TECS in the AOI.

- **Context**: For Panama, the TECS for all mangrove forests is 58.9 Mt C (Walker *et al.*, 2022) so the AOI represents 24% of the total carbon stock in the mangroves of Panama.

The 14.5 Mt C identified within the AOI represents a massive climate stabilization reservoir. To put this in perspective, the potential release of this carbon as 53.2 Mt CO_2e exceeds the annual national emissions of Panama by a factor of 3.6 (ClimateChangeTracker, 2026). From a climate security standpoint, the David-Alanje-San Lorenzo complex functions as a carbon vault; its disturbance would incur a climate liability equivalent to adding 11.6 million cars to the road simultaneously.

3.5 Change in Mangrove Extent

Description of Metric: This metric tracks the gain or loss of forest cover over time and was analysed using two complementary remote sensing datasets, each with distinct strengths for detecting different types of forest change:

3.5.1 Global Mangrove Watch (GMW) Analysis

- **Analysis:** Mangrove loss/gain figures were calculated using the Global Mangrove Watch dataset (Bunting *et al.*, 2022). This utilizes Synthetic Aperture Radar imagery (SAR) from the Japanese Aerospace Exploration Agency to map mangrove extent from 1996 to 2020. SAR's ability to penetrate clouds makes it valuable for tropical regions with persistent cloud cover. The change data is not available for each year so only the overall change from 1996 to 2020 is calculated.
- **Results:** The spatial distribution of mangrove loss/gain is shown in Figure 8.

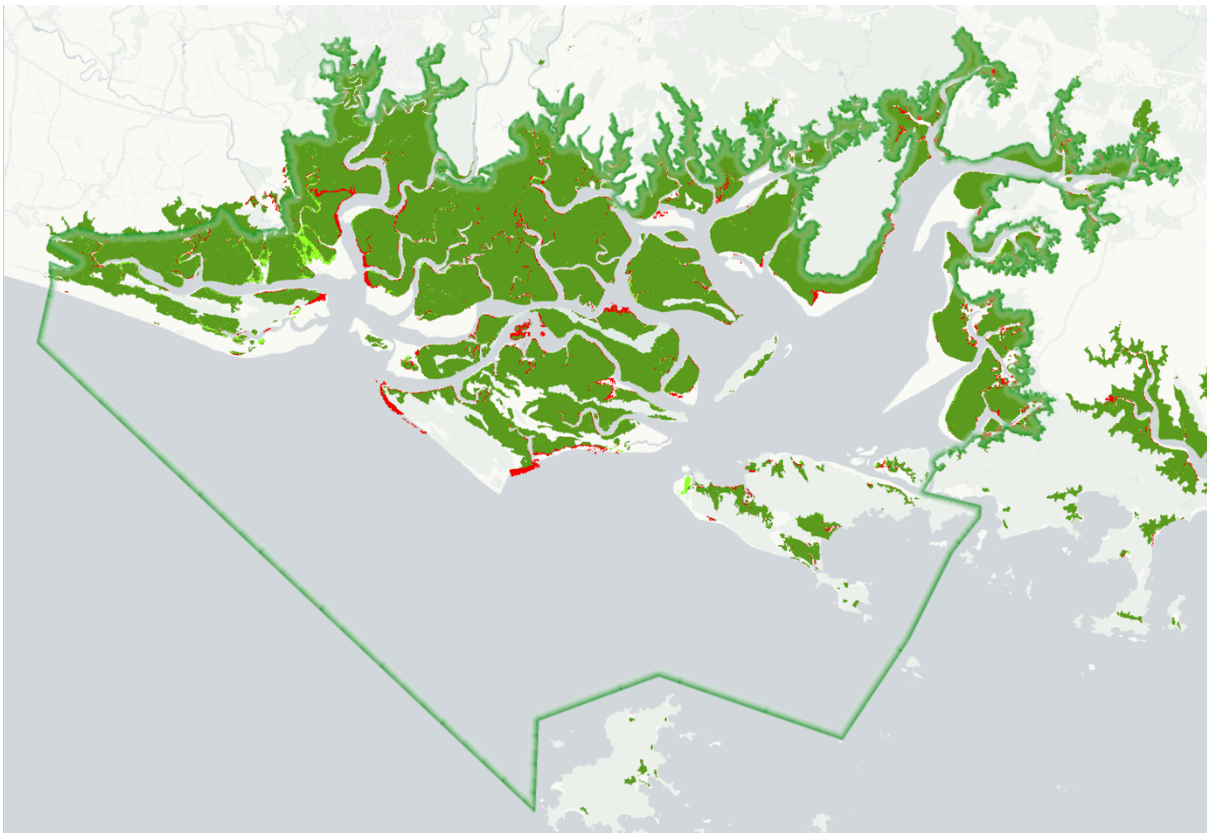

Figure 8: Tree cover loss/gain (red/green) from 1996 to 2020 for the AOI (Bunting et al., 2022).

Total loss from 1996 to 2020 was: **832 Hectares** (3.9% of the mangrove area).
Total gain from 1996 to 2020 was: **415 Hectares** (1.9% of the mangrove area).
=> The net loss from 1996 to 2020 was: **417 Hectares** (1.9% of the mangrove area).
The results show excellent detection of peripheral changes along forest edges with poorer detection of small interior changes (shown in Hansen) which is typical of radar-based approaches.

3.5.2 Hansen Forest Change Analysis

- **Analysis:** The Hansen Global Forest Change dataset uses Landsat optical imagery from 2001 to 2024 (Hansen *et al.,* 2013) to detect tree cover loss at 30-meter resolution. The data is available for every year between 2001 and 2024.
- **Results:** The spatial distribution of mangrove loss is shown in Figure 9.

Figure 9: Tree cover loss from 2001 to 2024 (Hansen et al., 2013). Dark red areas are more recent.

The annual tree cover loss data are shown in Figure 10.

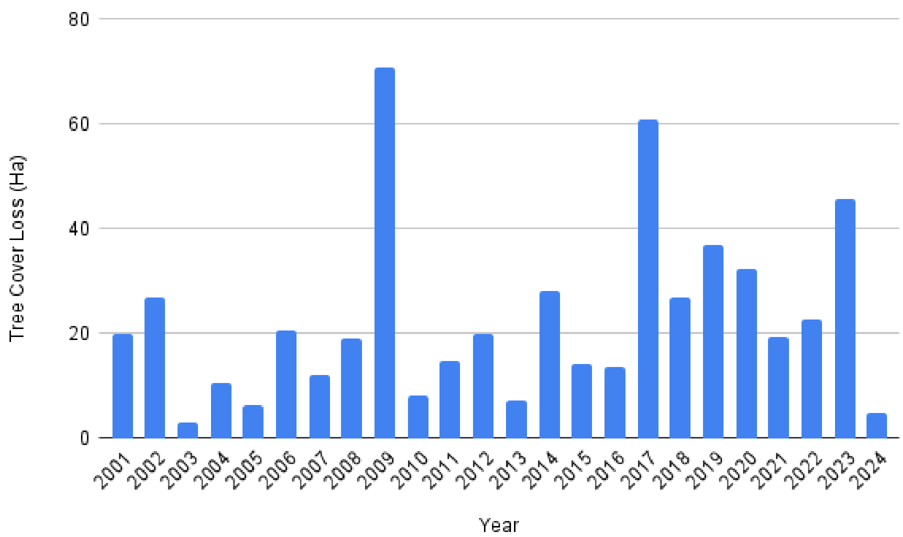

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Figure 10: Tree cover loss from 2001 to 2024 (hectares) for the AOI (Hansen et al., 2013)

This dataset excels at identifying changes in canopy cover and interior forest degradation, including the sudden die-back events documented in the study area. Landsat's spectral bands capture changes in vegetation health and canopy condition not detectable by radar.

Total loss from 2001 to 2024 was: **544 Hectares** (2.5% of the mangrove area)

3.5.3 Integrated Change Assessment

By integrating both datasets, a comprehensive picture emerges: the mangrove forests have experienced primarily natural edge dynamics (detected by GMW) and localized interior disturbance events attributable to storm-induced hydrological disruption (detected by Hansen). The overall pattern confirms limited anthropogenic disturbance and predominantly natural change processes. To put this into a global context, as much as 82% of global forests are now degraded to some extent (Watson *et al.*, 2018) so these intact forests are increasingly rare refugia that represent the highest tier of ecological integrity and conservation priority.

3.6 Biodiversity Value

3.6.1 Species Richness

Description of Metric: Species richness measures the total estimated number of plant, amphibian, bird and mammal species for an area. For plants, it is based on environmental modelling (Kreft and Jetz, 2007) to produce species richness at the 1-degree latitude/longitude level (approx. 12,100Km^2). For the other taxa it is based on the IUCN Red List of Threatened Species (Jenkins *et al.,* 2013 and Pimm *et al.,* 2014) to produce species richness maps at the 10Km2 level.

- **Analysis:** A spatial intersection analysis was conducted between the AOI and the species richness data to determine the maximum richness for the AOI and how that compares to global levels of richness.
- **Results:** The species richness metrics for the site and how they compare to global levels is shown in Table 7.

Taxa	AOI Richness	Global Percentile
Plants	2,626	96.8%
Mammals	133	94.6%
Birds	357	90.6%
Amphibians	18	76.6%

Table 7: Species richness values for plants, mammals, birds and amphibians in the AOI

- **Context:** The mangroves of the AOI exhibit exceptional biodiversity, particularly for plants and mammals, which rank in the 96th and 94th global percentiles respectively. While bird richness remains high at the 90th percentile, amphibians show a comparatively lower global standing at 76.6%. This AOI is also recognised globally for biodiversity value by being both an **Important Shark and Ray Area** (factsheet here) and also a **Key Biodiversity Area** (factsheet here).

3.6.2 List of critically endangered species

Description of Metric: The list of critically endangered species for an AOI provides a valuable communication tool in promoting the site's value to the wider public.

- **Analysis:** An analysis was performed between the AOI and the IUCN Red List of Threatened Species ranges on the IUCN Red List website (IUCN, 2025).
- **Results:** The Critically Endangered Species are shown in Table 8.

Taxa	Scientific Name	Common Name
Cartilaginous fishes	*Carcharhinus cerdale*	Pacific Smalltail Shark
Cartilaginous fishes	*Pristis pristis*	Largetooth Sawfish
Cartilaginous fishes	*Sphyrna corona*	Scalloped Bonnethead
Cartilaginous fishes	*Sphyrna lewini*	Scalloped Hammerhead
Cartilaginous fishes	*Sphyrna media*	Scoophead Shark
Cartilaginous fishes	*Sphyrna mokarran*	Great Hammerhead
Reptiles	*Eretmochelys imbricata*	Hawksbill Turtle

Table 9: Critically Endangered Species that occur in the AOI (IUCN, 2025)

- **Context:** The presence of these nine critically endangered species highlights these mangroves as a globally important area for marine and coastal survival, particularly for shark species. The area is part of the recognised **Panama Muertos Bay Important Shark and Ray Area**. For more information see the Factsheet here.

3.7 Coastal Risk and Resilience

The mangrove forests of Chiriquí act as an indispensable "green shield," providing irreplaceable coastal defense for the city of David, its international airport, and the surrounding agricultural hinterland.

Flood risk assessment and potential coastal impact analysis was done with two different datasets: the World Resources Institute (WRI) Aqueduct Flood Hazard Maps (WRI Aqueduct, 2020) and the Climate Risk Index tool (Ocean Risk and Resilience Action Alliance Inc., 2024). Key findings show:

- **Avoided Damage Valuation ($17M Annual Savings)**: Using the Climate Risk Index tool (2050, RCP4.5 scenario), we have quantified the protective value of this specific ecosystem. Currently, with the mangroves intact, annual economic flood damages are limited to $1M. Without this natural barrier, estimated damages would skyrocket to $18M—a 1,700% increase in liability.
- **Physical Protection & Inundation Risk**: The presence of these mangroves reduces potential flood depths from 2.7m to just 0.1m (see Figure 11). This protective function is particularly critical during Panama's intense seasonal storms, known as Cordonazos.
- **The Climate Change Multiplier**: As sea levels rise and storm intensity increases, the $17M in "avoided damages" is a conservative baseline. The WRI Aqueduct model confirms that under high-emission scenarios (RCP8.5), the proposed Puerto Barú site itself sits within a high-risk inundation zone.

Maintaining this 79,686-hectare protective belt is not just an environmental priority but a fundamental requirement for regional economic security.

3.7.1 WRI Aqueduct

- **Analysis:** Flood risk analysis was conducted using the WRI Aqueduct Flood Hazard Maps Version 2, which model coastal inundation under various climate scenarios and return periods.

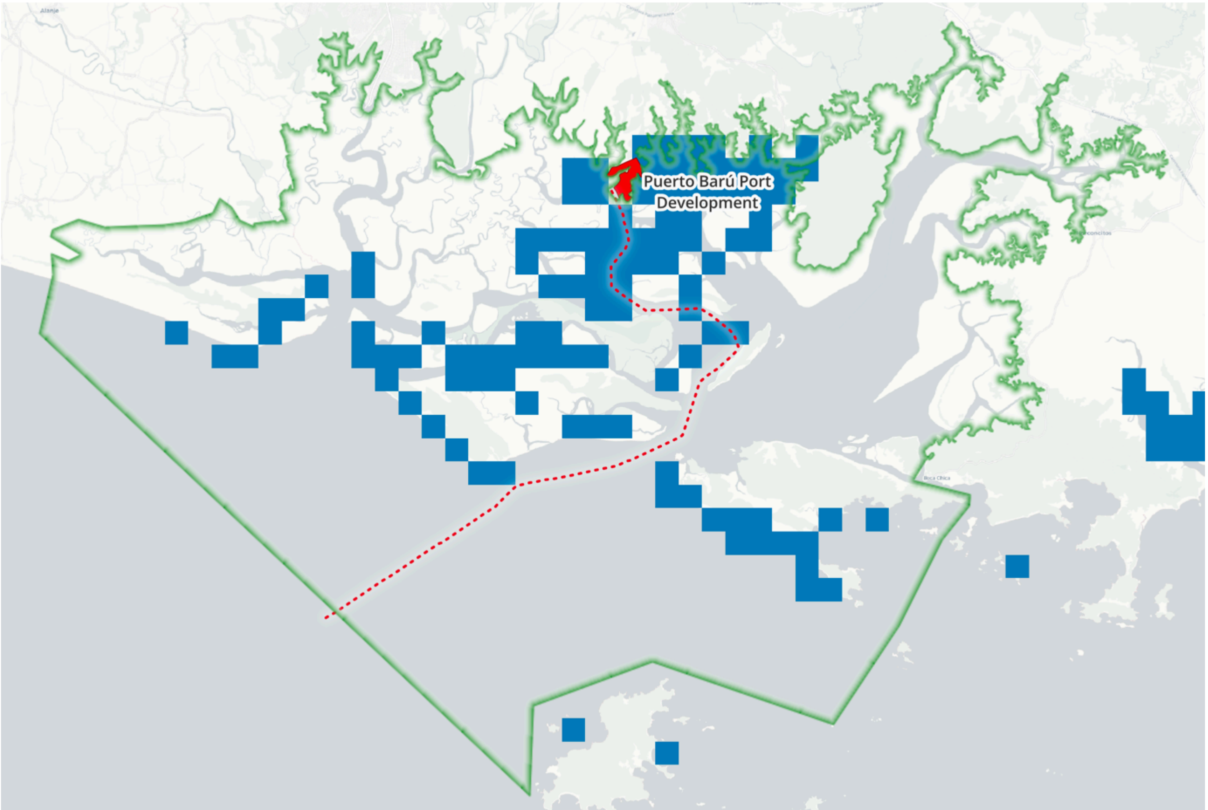

Figure 11: Areas of flooding predicted using the WRI Aqueduct dataset at 1Km resolution (2050, RCP8.5 and 1000 year return period) (World Resources Institute, 2020)

- **Context**: The areas of flooding predicted using the WRI Aqueduct dataset show that there is widespread flooding within the AOI under the RCP8.5 scenario in 2050 with a 1000 return period. This area of flooding includes part of the Puerto Barú Port Development itself.

3.7.2 Climate Risk Index tool

- **Analysis:** An analysis of the value of the mangroves and coral reefs in the AOI in terms of coastal protection and flood prevention was done using the Climate Risk Index tool (Ocean Risk and Resilience Action Alliance Inc., 2024).
- **Results:** Table 9 summarises the flood depth and likely population and economic impacts using the year 2050, RCP4.5 and a 1000-year return period.

Indicator	With Ecosystems	Without Ecosystems

Flood depth	0.1m	2.7m
Estimated economic damage	$1M	$18M
Estimated population impact	41	590

Table 10: Coastal Risk Index indicators for the AOI (Ocean Risk and Resilience Action Alliance Inc., 2024)

- **Context**: The Coastal Risk Index tool provides overall ratings for the climate risks associated with degradation of mangrove and coral reef ecosystems. For the AOI the population risk index, ecosystem benefit and damage risk index are all Low reflecting the fact that much of the hinterland (with urban areas and agricultural land) is at higher elevation and therefore less prone to flooding and flood damage. The overall ecosystem benefit is rated as Medium.

4 Conclusions

The mangrove ecosystems of Chiriquí Province represent an ecological and climate asset of exceptional value. This assessment has documented:

- **Exceptional Carbon Stocks:** Blue carbon storage several times greater than terrestrial tropical forests, representing substantial climate mitigation value
- **High Biodiversity Value:** Supporting diverse terrestrial and marine species including threatened sea turtles, sharks, rays and commercially important fisheries
- **Critical Coastal Protection:** Providing irreplaceable wave attenuation, storm surge reduction, and erosion control for the coast south of the city of David
- **Pristine Condition:** Long-term remote sensing analysis demonstrates minimal human disturbance and predominantly natural change dynamics
- **Unique Extent and Connectivity:** Representing one of the largest contiguous mangrove blocks on Panama's Pacific coast with irreplaceable ecological connectivity

A central conclusion of this assessment involves the precautionary principle. The Puerto Barú project proposes dredging a 100m wide, 11m deep channel and disposing of massive sediment volumes in the heart of this high-value ecosystem. Our analysis of historical die-back case studies shows that even minor impediments to tidal flow or sediment ponding can trigger rapid, irreversible forest mortality. Given that the long-term effects of sediment dumping in such a sensitive area are largely unknown yet potentially catastrophic for 24% of Panama's mangrove carbon and the agricultural hinterland, the risk profile suggests a fundamental threat to the regional environmental security. In the absence of scientific certainty that such impacts can be avoided, the precautionary principle should apply to this irreplaceable asset.

The methodologies developed for this Chiriquí analysis—specifically our high-resolution biomass and flood-risk modeling—serve as a powerful pilot. By standardizing these data sets, we see a clear pathway to scaling this 'deep dive' approach to other critical ecoregions, providing the transparent data that international carbon and resilience investors currently lack

5 References

5.1 Journal Articles & Books

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