Climate Variability as a Driver of Coastal Ecosystem Stressors in the Coral Triangle: A Case Study from the Derawan Islands, Indonesia

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Abstract

The Derawan Islands, located off the eastern coast of Kalimantan, are part of the Coral Triangle, a region recognized for its exceptional marine biodiversity. This area is influenced by both seasonal monsoonal cycles and interannual climate variability, including the El Niño–Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and freshwater discharge from the Berau River Estuary. Using 20 years (2003–2022) of satellite-derived data on turbidity (total suspended matter, TSM) and sea surface temperature (SST), this study explores the spatial and temporal dynamics of potential stressors to the coastal ecosystem in the Derawan region. Seasonal analysis reveals warmer SSTs during April–May, while turbidity and salinity fluctuate in response to freshwater discharge from the Berau River, modulated by monsoonal wind patterns. From May to August, increased turbidity from the river plume extends toward coral reef areas north of the estuary. Interannually, ENSO and IOD events drive prolonged SST anomalies and changes in precipitation, indirectly affecting freshwater input and turbidity levels. Notably, extreme El Niño events in 2010, 2016, and 2020 were associated with significant reductions in both TSM and rainfall. Conversely, negative IOD phases exhibit a strong negative correlation with turbidity, indicating increased turbidity during periods of intensified rainfall and freshwater influx. The co-occurrence of elevated SST and turbidity during La Niña events suggests the presence of compound stressors, which may pose heightened risks to marine ecosystems. Increased precipitation during La Niña can also enhance river discharge, promoting the expansion of low-salinity water plumes across coral habitats. This study identifies several climate-driven stressors that may impact the Derawan coastal ecosystem, though further in-situ validation is needed to assess their direct effects on local biodiversity.

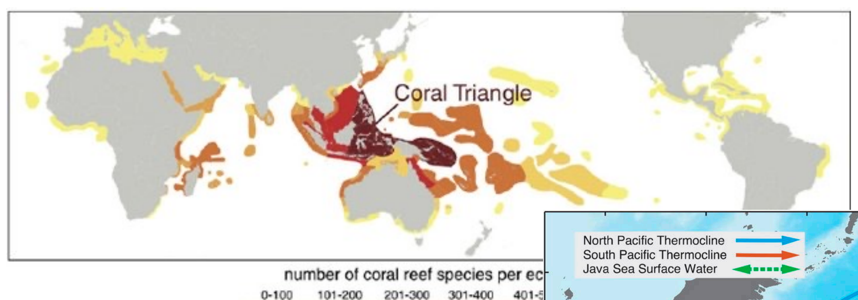
Introduction

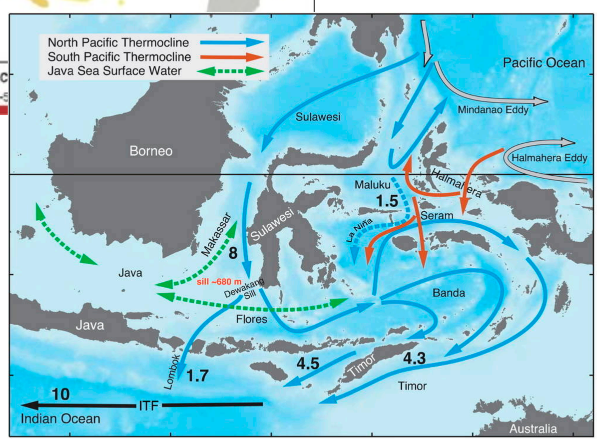
The Berau Coastal Shelf (BCS), located in East Kalimantan, lies within the Coral Triangle, the global center of marine biodiversity. It hosts coral reefs, seagrass meadows, mangroves, sea turtles, manta rays, and reef fish communities.

The BCS is shaped by a large river discharge, strong monsoonal winds, a mixed semi-diurnal tide, and the influence of the Indonesian Throughflow (ITF). This combination makes it a highly dynamic system where freshwater plumes, ocean currents, and climate variability interact.

Seasonal circulation controls how the Berau River plume spreads—northward during the southeast monsoon, southward during the northwest monsoon, and confined near the river mouth during transition periods. Rainfall peaks in April and November, with interannual variability linked to ENSO and the Indian Ocean Dipole (IOD).

These unique features make the BCS an ideal natural laboratory to study how climate variability and river inputs drive turbidity stressors that threaten coral reef and seagrass ecosystems in the Derawan Islands.





Foale, S., et. al., 2013

Site Location

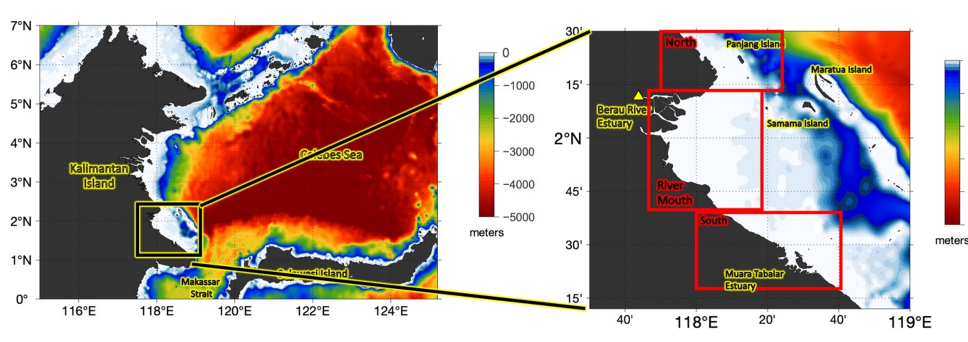


Figure 1. Berau Coastal Shelf regions

Ecosystems & species: coral reefs, seagrass meadows, mangroves, sea turtles, manta rays.

Geomorphology: flat reef platform (20–50 m depth) extending from the continental shelf.

Habitats:

•Seagrass around Derawan, Maratua, Samama, Panjang Islands.

•Mangroves at the Berau River mouth.

Hydrodynamics:

•Berau River discharge: 20–2000 m³/s (avg. 650 m³/s).

•Tides: mixed semi-diurnal, range 1 m (neap) – 2.5 m (spring).

•Influenced by Celebes Sea & Makassar Strait (depths up to 3000 m).

Analysis regions **(Figure 1): North, South, and River Mouth (red boxes).**

Data

Remote Sensing Data

•**Source**: Aqua MODIS Level-3 (4 km resolution)

•**Period**: 2003–2022 (monthly data)

•**Area**: 117.52° E – 119° E, 1.02° N – 2.5° N

•**Processing**:

- TSM derived from remote sensing reflectance (rrs: 488, 555, 645 nm)
- Algorithm: Zhang et al. (2010)
- Data: oceancolor.gsfc.nasa.gov

Met-Ocean Data

- Zonal & meridional wind components
- Precipitation
- Sea Surface Temperature (SST)
- Climate indices: DMI, ENSO
- DMI & ENSOSST

Results

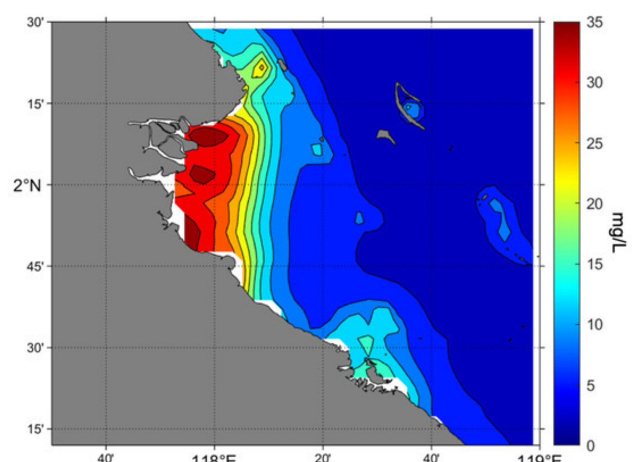


Figure 2. Mean Climatological TSM (mg/L) in Berau Coastal Shelf

- Highest TSM (25–35 mg/L) at the Berau River mouth.
- Turbidity plume extends northward, affecting coral reef habitats.
- Southern hotspot: elevated turbidity near the Muara Tabalar River estuary.
- Offshore waters: TSM values decrease gradually with distance from the coast.

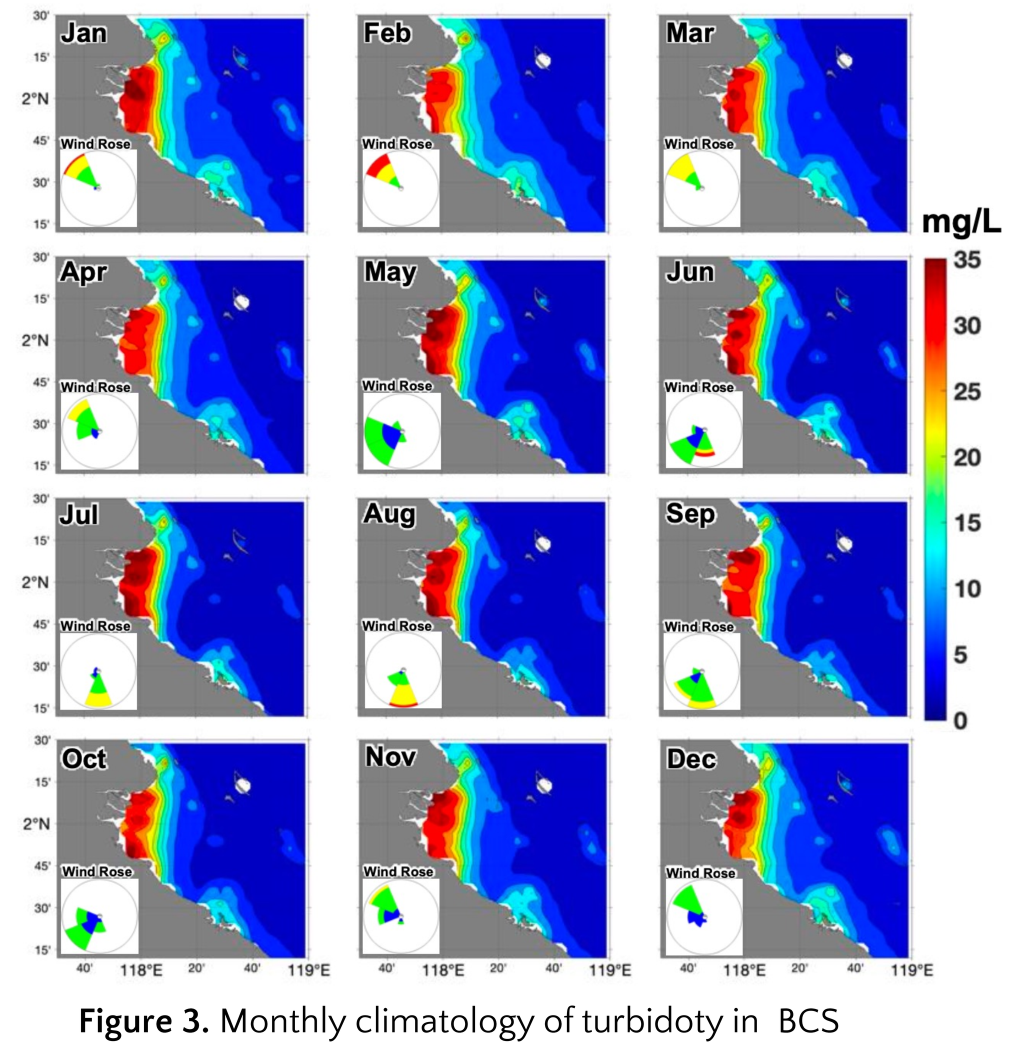


Figure 3. Monthly climatology of turbidoty in BCS

The distribution of TSM in the BCS is significantly influenced by monsoon winds. During the Southwest Monsoon (June–August), intensified winds disperse TSM northward, reaching the Berau Barrier Reef. In contrast, the Northeast Monsoon (December-February) drives southward TSM dispersion. During transition periods, TSM concentrations are lower and more localized near the river mouth due to weaker winds and currents.

Results

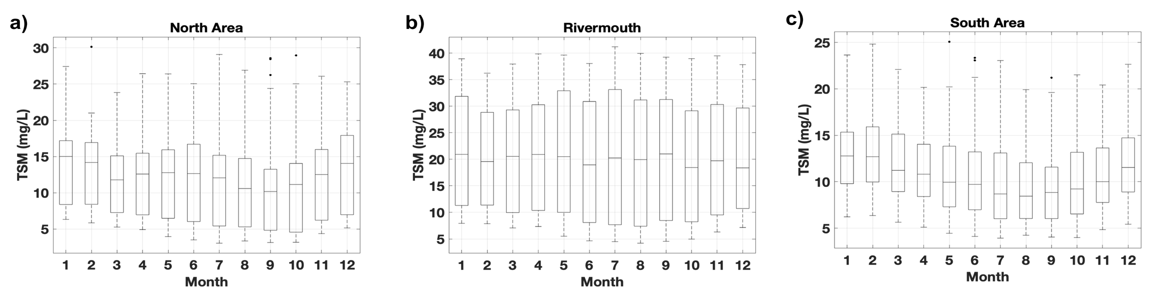


Figure 4. Monthly differences in average TSM (mg/L): average TSM in the (**a**) north, (**b**) river mouth, and (**c**) south areas.

Northern region: closer to main freshwater outlets → higher TSM variability.

Southern region: lower variability due to weaker freshwater influence.

Spectral analysis findings:

- South → dominant annual cycle, minor semi-annual signal.
- North → dominant semi-annual cycle, secondary annual signal.
- River mouth → multiple peaks (intra-seasonal to interannual), highest variability overall.

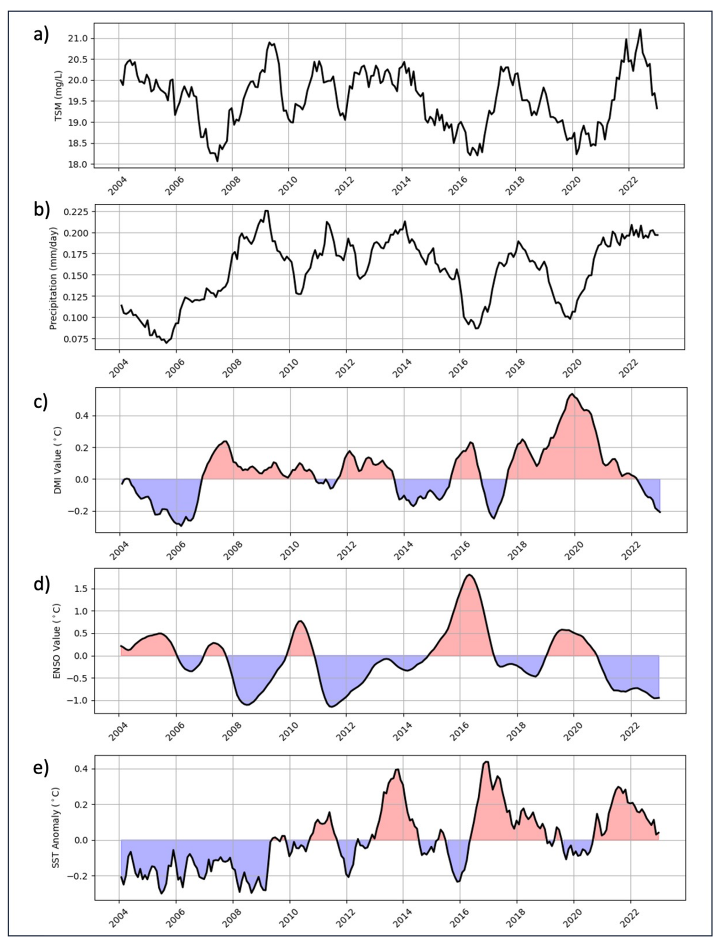


Figure 5. The variation for 15-month moving average of TSM in river mouth, (b) El Niño-Southern Oscillation Index (NINO 3.4), Dipole Mode Index and Precipitation.

TSM in the BCS is significantly influenced by regional phenomena like ENSO and IOD. During La Niña events, TSM and precipitation increase, while they decrease during El Niño events. Negative IOD events are also associated with increased turbidity and rainfall. Climate change is expected to intensify these phenomena, impacting the BCS ecosystem. Additionally, the Pacific Decadal Oscillation (PDO) may influence TSM on a decadal scale.

Conclusion

We analyzed 20 years of satellite data to track turbidity in the Derawan Islands, Coral Triangle. Turbidity is strongly influenced by seasonal winds, currents, and climate modes like IOD and ENSO. Episodes of high turbidity, often paired with warmer waters, can stress coral reefs, seagrass, and other habitats. With climate change likely to intensify IOD and ENSO events, the risk to these ecosystems is expected to increase.

Refferences

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