

German Remote Sensing Data Center (DFD)
Land Surface Dynamics

Monitoring Mangrove Loss from Pond Aquaculture Expansion in Asia Using Satellite Earth Observation

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Mangroves under Pressure



Figure 1: Mangrove forest in Vietnam

Mangrove forests (**Fig. 1**) are among the world's most valuable coastal ecosystems, providing biodiversity hotspots, natural shoreline protection, water filtration, and major blue carbon storage. Despite their ecological importance, they are under severe pressure from human-driven land conversion. One of the dominant drivers is pond-based aquaculture expansion, particularly shrimp and fish farming in low-lying tropical coastal zones. The construction of aquaculture ponds often requires large-scale clearing of mangrove forests, leading to habitat fragmentation, biodiversity loss, reduced coastal resilience, and carbon emissions. Across Asia, rapid aquaculture development in deltas and estuarine lowlands has intensified this pressure, making mangrove conversion a major land-use challenge for sustainable coastal management. This study combines long-term Earth observation datasets on aquaculture pond dynamics [1] and mangrove extent [2] to analyze the spatio-temporal relationship between pond activation and mangrove loss across Asia from 1996 to 2019.

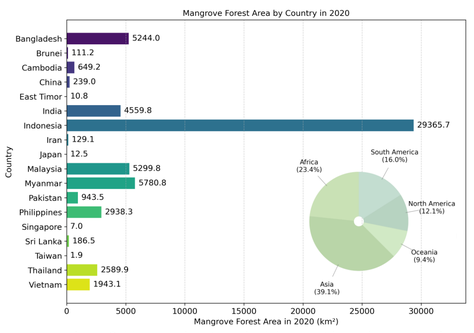


Figure 2: Mangrove forest area by Asian countries and proportional continental shares (pie chart). Source of mangrove extent data: Global Mangrove Watch [2].

Mangrove Loss in Asia

Asia contains approximately 40% of the global mangrove extent, with Indonesia alone accounting for nearly half of the region's total mangrove area (**Fig. 2**). Between 1996 and 2019, substantial mangrove losses were observed across major coastal countries, with the strongest absolute losses in Indonesia and Myanmar (**Fig. 3**). Spatial hotspot analysis reveals concentrated loss clusters in Indonesia, Myanmar, Vietnam, and Thailand, strongly overlapping with dense aquaculture pond development. The most severe conversion phase occurred during 1996–2007, followed by continued localized losses in subsequent years. These patterns highlight aquaculture expansion as a key driver of mangrove degradation across Asian coastal systems.

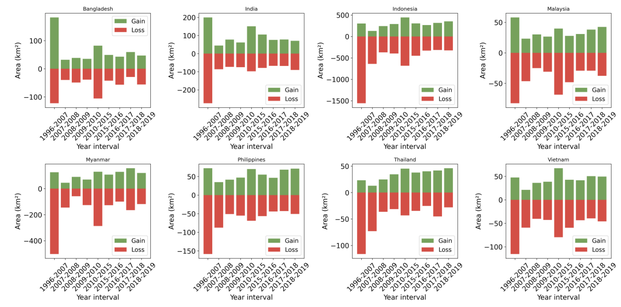


Figure 3: Mangrove area gains (green) and losses (red) from 1996 to 2019 for 8 selected Asian coastal countries, shown as bar charts for specified time intervals corresponding to Global Mangrove Watch (GMW) data availability.

EO Analysis of Aquaculture Ponds and Mangrove Conversion

To assess the direct role of aquaculture expansion, we combined an object-based aquaculture pond time series [1] with the Global Mangrove Watch (GMW) dataset [2]. Individual pond activity were mapped from Sentinel-1, Sentinel-2, and Landsat imagery, enabling annual reconstruction of pond activation dynamics at single-pond level [1,3]. A harmonized temporal index was applied to align annually resolved pond activation data with the irregular observation years of the mangrove dataset. By intersecting pond geometries with mangrove extent layers, we quantified mangrove area located within pond boundaries and tracked temporal changes in mangrove presence before and after pond activation (**Fig. 4**). This spatial overlay allowed us to quantify mangrove area directly affected within individual pond boundaries and to identify the timing of first conversion events. A conservative temporal rule was applied to attribute mangrove loss only when it occurred shortly after pond activation, strengthening causal interpretation.

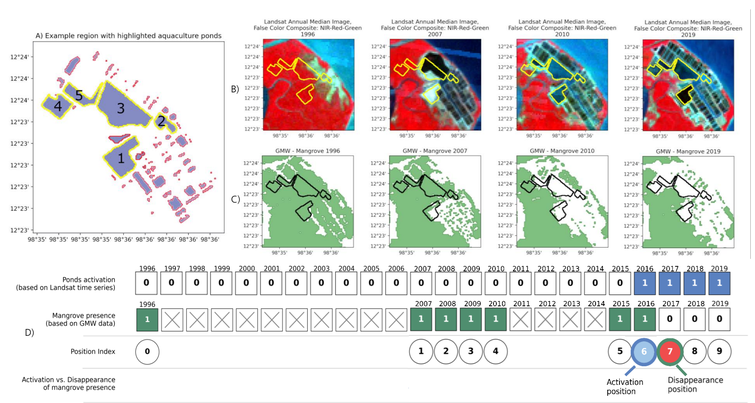


Figure 4: Spatial and temporal dynamics of selected aquaculture ponds and adjacent mangrove cover: (A) pond locations; (B, C) changes in pond activity [1] and mangrove presence from satellite imagery (available for 1996-2019) and GMW data (available for 1996, 2007-2010, 2015-2019); (D) detailed dynamics of one pond (1996–2019), showing activation in 2016 and mangrove disappearance in 2017.

Aquaculture-Driven Mangrove Loss Hotspots

Aquaculture-driven mangrove loss in Asia is strongly clustered in distinct regional hotspots where pond expansion has replaced former mangrove forests. Indonesia is the main hotspot, combining the largest mangrove extent with the highest aquaculture-related losses, with ~13,000 ha lost between 1996–2007 (**Fig. 5**), followed by 5,300 ha (2007–2008), 2,700 ha (2008–2009), and 2,200 ha (2010–2015). In East Borneo, Southeast Sumatra, and Sulawesi, large-scale pond aquaculture has replaced formerly continuous mangrove landscapes (**Fig. 6**). Myanmar, Vietnam, and Thailand form secondary hotspots, with Myanmar showing major losses of nearly 3,000 ha (1996–2007) and about 1,000 ha in 2010–2015, while Vietnam and Thailand experienced more moderate but persistent early losses that decline to <60 ha per period after 2010. Spatial patterns show strong overlap between pond density and historical mangrove areas, as aquaculture is concentrated in flat, low-lying coastal zones originally covered by mangroves. Temporally, mangrove conversion occurs in phases, with intensified losses especially between 1996–2007 and in later shorter intervals (**Fig. 5**). Overall, aquaculture-driven mangrove loss is highly uneven across Asia, concentrated in specific coastal systems where environmental suitability and development pressure coincide, making these regions key priorities for conservation and sustainable aquaculture planning.

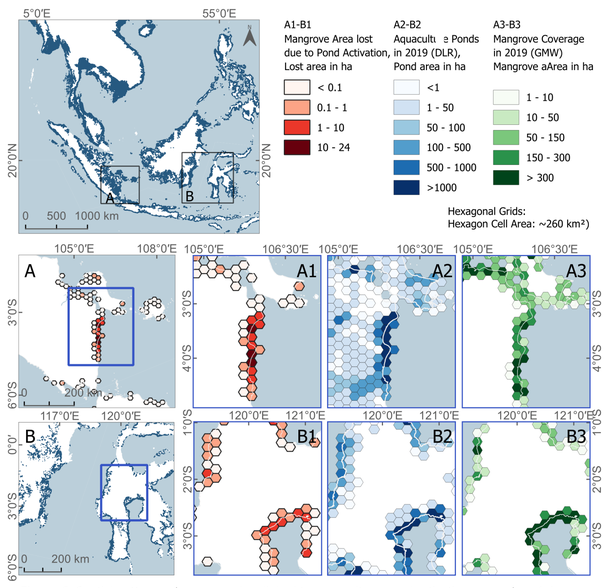


Figure 6: Spatial patterns of mangrove loss linked to aquaculture pond activation across four Asian coastal regions (A–D): (1) mangrove loss due to pond activation, (2) aquaculture pond coverage in 2019, (3) pond area per hexagon in 2019, and (4) mangrove extent in 2019.

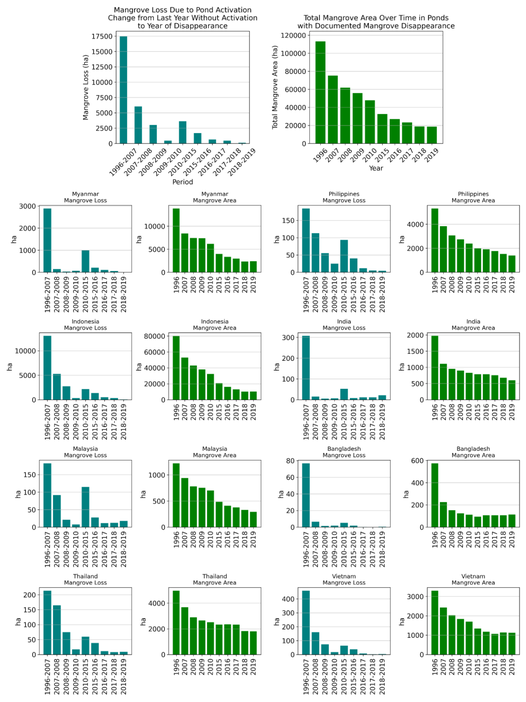


Figure 5: Mangrove loss due to pond activation (cyan) and total mangrove area (forest green) across 12 countries (1996–2019); top row shows overall totals, bottom rows show country-wise paired plots of loss per period and total mangrove area in ponds over time.

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[2] Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., Tadono, T., Worthington, T.A., Spalding, M., Murray, N.J., Rebelo, L.-M., 2022. Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. Remote Sensing 14, 3657. https://doi.org/10.3390/rs14153657
[3] Ottinger, M., Bachofer, F., Huth, J., Kuenzer, C., 2022. Mapping Aquaculture Ponds for the Coastal Zone of Asia with Sentinel-1 and Sentinel-2 Time Series. *Remote Sensing,* 14, 153. https://doi.org/10.3390/rs14010153

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