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Article

Restoring mangroves lost by aquaculture offers large blue carbon benefits

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Highlights

- Aquaculture expansion in China and southeast Asia has caused substantial mangrove loss
- Approximately 60% of aquaculture ponds are suitable for mangrove restoration
- Indonesia is identified as a top priority for mangrove restoration efforts
- Priority restoration can remove 84 (75–96, 95% CI) Mt CO₂

Science for society

Conservation and restoration of blue carbon ecosystems, such as mangrove forests, represent a vital nature-based solution for [climate change](#) mitigation. Historically, mangroves have experienced extensive [deforestation](#) due to human activities, particularly aquaculture. Deforested areas now offer opportunities for achieving mangrove restoration targets, as they may still possess suitable environmental conditions for mangrove growth. Evaluating the feasibility of mangrove restoration at a fine scale allows for the identification of priority areas, thereby guiding on-the-ground restoration efforts. Our study indicates that aquaculture ponds historically converted from mangroves remain largely suitable for mangrove restoration and hold the potential for substantial blue carbon benefits. These findings can better formulate cost-effective strategies for mangrove restoration, thereby mitigating climate change more efficiently.

Summary

[Mangrove forests](#) show great potential for mitigating [climate change](#) due to their high carbon densities but have faced extensive [deforestation](#) due to aquaculture. Aquaculture areas offer opportunities for mangrove restoration, as most still maintain suitable landscape-scale biophysical conditions. Despite this potential, the scale and biophysical suitability of aquaculture areas for large-scale mangrove restoration, along with associated carbon benefits and costs, remain poorly understood. We assess the restoration suitability of mangroves deforested by aquaculture and identify patch-scale priority areas in China and southeast Asia. Long-term satellite observations show that aquaculture expansion has caused the loss of 165,079 ha of mangroves. Habitat suitability modeling estimates that 60% of these lost mangroves are biophysically feasible for restoration and potentially removing 84 (75–96, 95% confidence interval) Mt CO₂. Our findings provide spatially explicit guidance for mangrove restoration planning and highlight the contribution that mangrove restoration can make to nationally determined contributions for [climate change mitigation](#).

Graphical abstract



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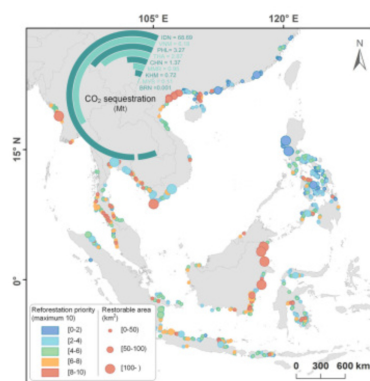
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Introduction

Coastal wetlands, located at the land-sea interface, are vital ecosystems known for their rich biodiversity, high productivity, and the provision of a variety of ecosystem services.^{1,2} Mangroves, in particular, are recognized as a promising natural climate solution (NCS) to offset greenhouse gas emissions and mitigate climate change.³ Nevertheless, human activities in coastal regions have substantially reduced the global extent of mangroves, impacting their important ecological functions.^{4,5} This widespread loss contributes to the annual release of 0.08–0.32 petagram (Pg) CO₂, accounting for ~2%–6% of the total CO₂ emissions from global deforestation.^{6,7} Given their high carbon storage density over long timescales, the conservation and restoration of mangroves are an important NCS to draw down atmospheric carbon emissions for many countries.⁸

Through several international conservation strategies and policies, global mangrove restoration initiatives are collectively working to finance \$4 billion USD to secure the future of over 15 million ha of mangroves globally by 2030.⁹ Over the past 40 years, approximately 200,000 ha of mangroves have been planted, although the survival rates of planted mangroves are generally low.¹⁰ For instance, Indonesia has planted around 24 million seedlings in 60 mangrove restoration projects, but many of these initiatives have failed.^{11,12} Low survival rates are primarily due to afforestation and restoration efforts being conducted in areas biophysically unsuitable for mangrove growth.^{13,14} Recent studies indicate that successful mangrove restoration yields greater carbon benefits compared to afforestation,¹⁵ suggesting that management initiatives should prioritize restoration—for example, planting in historically existing mangrove areas. Consequently, stakeholders have advocated for a shift in mangrove restoration targets from simply expanding planted areas to improving the success of large-scale restoration by identifying feasible biophysical locations for restoration.^{12,16}

The expansion of aquaculture ponds has been the primary anthropogenic factor causing mangrove loss over the past few decades,¹⁷ especially in China and southeast Asia^{18,19} (including Brunei, Cambodia, Indonesia, Myanmar, Malaysia, the Philippines, Singapore, Thailand, Timor-Leste, and Vietnam). The development of aquaculture ponds has led to widespread mangrove deforestation, yet these areas often still possess macroclimatic, environmental, and hydrodynamic conditions favorable for mangrove growth,²⁰ and thus provide potential priority settings for mangrove restoration.²¹ Prior research has assessed suitable areas for mangrove restoration globally,¹⁰ or for a specific country,¹² although they primarily offer a broad perspective on which broad landscapes deserve more attention for mangrove restoration, lacking detailed patch-scale information that focuses specifically on the restoration of aquaculture ponds, the main driver of mangrove loss. As a result, spatially explicit quantitative estimates of the carbon and economic benefits associated with mangrove restoration are highly anticipated.

Here, we (1) map the spatial distribution of mangrove deforestation driven by aquaculture expansion and quantify the associated carbon emissions, and (2) identify priority areas within aquaculture ponds for potential mangrove restoration, factoring in restoration costs and carbon benefits. We first mapped mangrove loss attributed to aquaculture by cross-referencing mangrove and aquaculture cover data in China and southeast Asia, where >32% of the global mangrove extent is located²² and has experienced substantial aquaculture expansion since the 1970s.²³ We then applied a habitat suitability model to determine aquaculture ponds that should be prioritized for mangrove restoration, considering eight biophysical factors related to mangrove establishment and growth attributes, such as climate, marine environment, and human disturbance. We further estimated carbon losses from mangrove deforestation due to aquaculture and assessed the potential carbon and economic benefits of mangrove restoration in these priority areas. Our findings indicate that aquaculture ponds

contributed to approximately 25% of mangrove deforestation in China and southeast Asia since 1996, with >60% of these ponds retaining favorable conditions for restoration, potentially offsetting 3% of carbon emissions from deforestation in these regions. Our study highlights the cost-effectiveness and carbon advantages of restoring mangrove forests within their historical ranges, offering actionable insights for policymakers and stakeholders to support forest restoration and carbon mitigation objectives.

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Aquaculture-induced mangrove loss, 1996–2020

Using object-oriented image classification techniques, we mapped mangrove patches deforested due to aquaculture expansion and detected widespread mangrove deforestation across China and southeast Asia from 1996 to 2020 (Figure 1). The mangrove area decreased by 165,079.38 ha, which corresponds to a 25% reduction of the mangrove area in China and southeast Asia since 1996. Indonesia experienced the largest aquaculture-induced mangrove losses—118,781.13 ha—accounting for 72.0% of total mangrove ...

Study region

Southeast Asia is recognized a global hotspot for mangrove distribution, holding nearly one-third of the world's mangrove forests, with diverse tree species and substantial carbon storage.^{50,51} However, the region has also experienced extensive mangrove losses.^{4,52} In addition to southeast Asia, China has suffered considerable mangrove loss in recent decades, largely attributed to coastal aquaculture development.⁵³ Consequently, we included China in our analysis to ensure comprehensive coverage ...

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Lead contact

Further information and requests for datasets should be directed to the lead contact, Yi Li (yili@xmu.edu.cn). ...

Materials availability

This study did not generate new unique materials. ...

Data and code availability

All data used in this study are publicly available online. The distribution of biophysical feasibility of mangrove restoration data products are viewable at Google Earth Engine (<https://ee-zq970919.projects.earthengine.app/view/mangrove-reforestation-priority>), last access: November 21, 2024), and are publicly available as of the date of ...

Acknowledgments

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Author contributions

Y.J., Z.Z., Yangfan Li, and Yi Li conceived the original idea and designed the overall study. Y.J. developed the model, performed the study, and interpreted the results, with key inputs from Z.Z., D.A.F., Yi Li, and Yangfan Li. Y.J., Z.Z., and Yi Li wrote the main manuscript, with important contributions from D.A.F. and Yangfan Li. Q.Z. designed the visualization. All authors discussed the results and revised the manuscript. ...

Declaration of interests

The authors declare no competing interests. ...

References (96)

J.A. Rodríguez-Rodríguez *et al.*
[Mangrove restoration in Colombia: Trends and lessons learned](#)
For. Ecol. Manag. (2021)

D.C. Wodehouse *et al.*
[Mangrove area and propagule number planting targets produce sub-optimal rehabilitation and afforestation outcomes](#)
Estuar. Coast Shelf Sci. (2019)

C. Ren *et al.*
[Rapid expansion of coastal aquaculture ponds in China from Landsat observations during 1984–2016](#)
Int. J. Appl. Earth Obs. Geoinf. (2019)

J.H. Primavera
[Development and conservation of Philippine mangroves: institutional issues](#)
Ecol. Econ. (2000)

M. Ilman *et al.*
[A historical analysis of the drivers of loss and degradation of Indonesia's mangroves](#)
Land Use Pol. (2016)

J. Luo *et al.*
[Rapid expansion of coastal aquaculture ponds in Southeast Asia: patterns, drivers and impacts](#)
J. Environ. Manag. (2022)

M.A. Akber *et al.*
[Major drivers of coastal aquaculture expansion in Southeast Asia](#)
Ocean Coast Manag. (2020)

Z. Zhang *et al.*
[Spatially discontinuous relationships between salt marsh invasion and mangrove forest fragmentation](#)
For. Ecol. Manage. (2021)

I. Nagelkerken *et al.*
[The habitat function of mangroves for terrestrial and marine fauna: a review](#)
Aquat. Bot. (2008)

K.W. Krauss *et al.*
[Environmental drivers in mangrove establishment and early development: a review](#)
Aquat. Bot. (2008)

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[Planted mangroves reflect low genetic diversity of natural stands in Southern Cameroon](#)
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