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Systematic review for carbon dynamics and ecosystem services of species in mangrove ecosystems in Asia and Pacific

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Abstract

Background

Mangrove ecosystems are home to coastal flora and fauna and store and sequester high densities of carbon as part of major global carbon cycles. Consequently, it is essential to assess the carbon dynamics (storage and sequestration) of mangrove ecosystems and their association with natural climate variability and anthropogenic drivers, including land-use and land-cover change (LULCC). While monitoring data and literature on mangrove carbon dynamics have been increasingly available over the past two decades, there is little understanding of the effect of climate variability combined with anthropogenic drivers in moderating mangrove carbon storage and sequestration

resiliency. This work will revise and improve a previous systematic review by Sasmito et al (2016), specifically, by collating literature published since 2018 and strengthening the analysis of tree biomass carbon loss and recovery between species, local and regional climate variability, as well as across different types of LULCC of mangrove forests.

Methods

The current systematic review will be specifically focused on field-based data population generated from the Asia–Pacific mangrove region, comprising the world's largest area and diversity of mangroves and the most studied mangroves compared to other regions, as assessed by previous systematic reviews. A literature search will be performed through several databases, including Scopus and Web of Science, as well as search engines, including Google Scholar. We will adopt the previous systematic review structure by Sasmito et al (2016) for conducting the literature search, screening and data extraction. Data analysis will be performed by comparing carbon storage and sequestration between locally and regionally varied climatic variables and anthropogenic drivers. Further assessments will be made via geographical mapping of species' distribution and diversity together with estimation of carbon storage and recovery capacity within the Asia–Pacific region.

Keywords: species distribution, species diversity, carbon dynamic, land-use change, land-cover change, blue carbon

Background

Mangrove ecosystems across the globe provide various ecological functions and services. These coastal wetlands are among the most efficient natural carbon (C) sinks on Earth and are as highly productive as tropical forests and coastal wetlands (Alongi 2014). Mangrove forests across the world have been decreasing in area, with total loss of 0.13% between 2000 and 2016, an average annual rate equal to 3363 km^2. Conversion through multi-purpose LULCC was reported as the main cause of mangrove deforestation in Asia (FAO 2007, Richards and Friess 2016), gradually decreasing the ecosystems' ecological functions and services (Sannigrahi et al 2020), specifically contributing to substantial carbon emissions.

LULCC in mangroves directly impacts the stability of C dynamics, including stocks, emissions and sequestrations (Sasmito et al 2019). The loss of mangrove areas significantly impacts regional and global coastal C budgets due to the decrease of C sequestration rates but increase in emissions. In tropical northeast monsoon mangroves, *Rhizopora* sp, one of the most dominant species, has higher C absorption ability than *Bruguiera* sp of the same age (Dewiyanti et al 2019). Other studies reported that *Rhizopora* sp stored high C stocks owing to high C uptake ability in this species compared to *Octornia octodonta, Sonneratia alba, Ceriops tagal* and *Avicennia marina* in tropical northwest monsoon areas (Putra et al 2019). By contrast, *Kandelia obovata* had the highest C density (148.03 Mg ha^{-1}) followed by *Avicennia marina* (104.79 Mg ha^{-1}) and *Aegiceras corniculatum* (99.24 Mg ha^{-1}) in another tropical monsoon climate (Bin et al 2022). Further understanding and assessment of mangroves species' ability to absorb and store C in different climate zones is essential for an effective approach to mangroves species-specific rehabilitation programmes and mitigation of further ecosystem loss, by applying suitable species.

The current review will provide a concise synthesis for policy makers associated with land-use planning in coastal wetland areas and strengthening current understanding of the crucial role of mangroves as the highest blue C reservoir in the Asia–Pacific region. Indonesia and other Asian countries are premier sites of mangrove ecosystems and research. For example, Indonesia is currently being supported by developed countries, including the UAE, Republic of Korea and Japan, to maintain continuity of its contribution to conserving and restoring mangrove forests and increasing C sinks. Emission reduction will come from improved management of LULCC and forestry, in which blue C ecosystems play important roles.

Objectives and question of the review

The primary question of the review is:

How do local and regional climate characteristics affect mangrove species carbon storage and uptake -> sequestration? under changing land-use conditions?

Methods

The literature search aims to find relevant documentation of C dynamics of mangrove species, including C stocks, fluxes and sequestration, species' diversity, biophysical parameters (e.g. forest structure, soil properties, habitat setting), climate parameters (e.g. air temperature, tide condition, precipitation) and types of LULCC.

The database search examines the following bibliographic databases.

- Web of Science
- Scopus
- Google scholar

All search results (along with abstracts when possible) are stored in an online Endnote library for screening.

Results

1. Data availability

Focusing on species-specific carbon storage and carbon sequestration ability, we used the following keywords to collect data from Scopus, Web of Science and Google Scholar (Table 1). Using PRISMA analysis (Fig. 1), a total of 497, 425 and 26,200 papers were identified from the literature search on Scopus, Web of Science and Google Scholar from 1980 onwards on mangrove forests and species C sequestration related topics. Only 31 papers were eligible for data extraction, with specification of species C sequestration and C stocks with environmental parameters as comparison variables. Many papers reported the carbon storage and carbon sequestration as general habitat but very few considered a species-specific assessment.

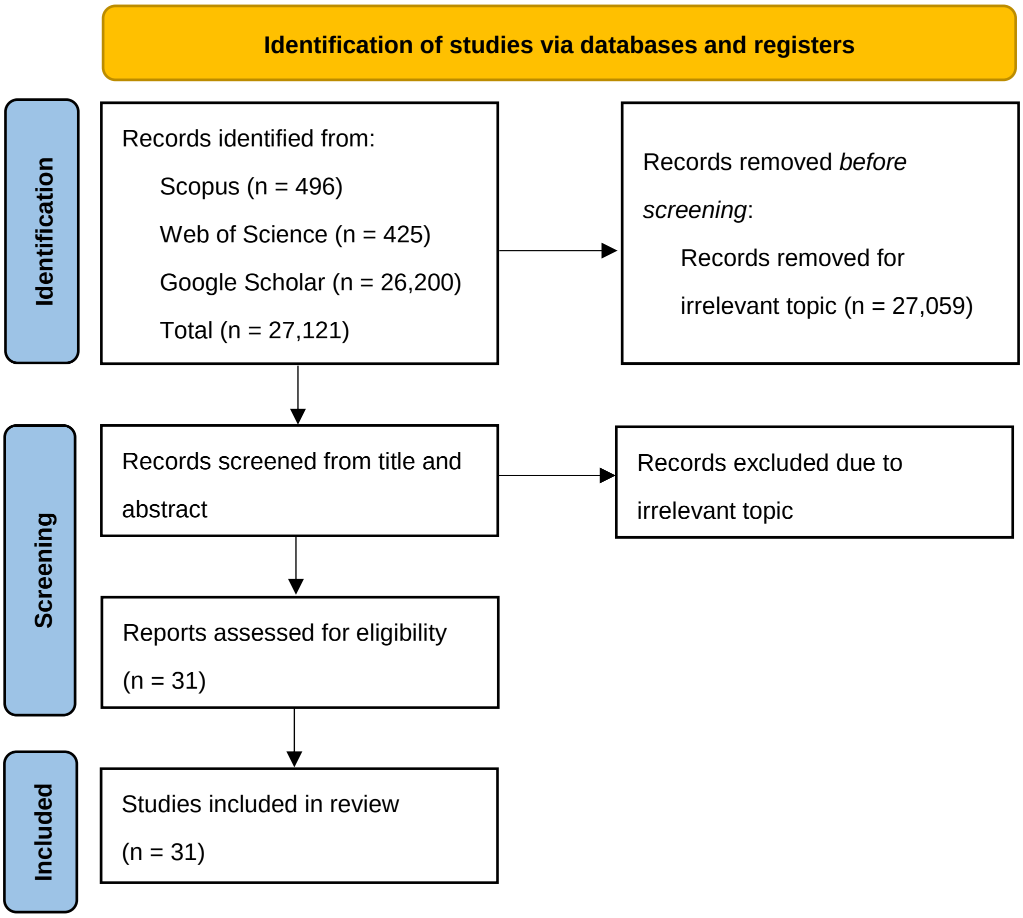


Figure 1. PRISMA flowchart of the literature search and text selection process

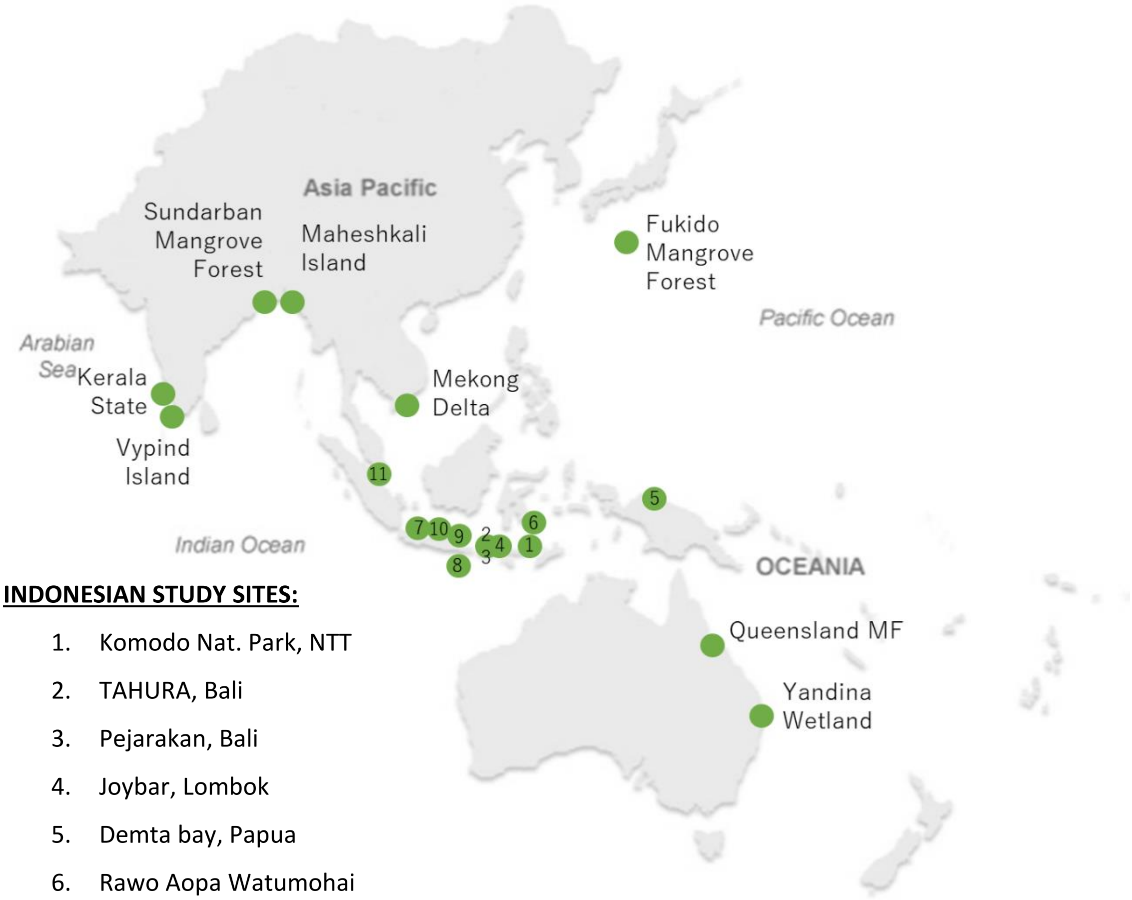
Table 1. Rules and keywords for database search

Rules	**Keywords**	**Refine**
Rule 1	mangrove* OR "coast* ecosystem*" OR Rhizophora OR Avicennia OR “coast* wetland*” OR “Intertidal wetland*” OR “tidal wetland*” OR “estuarine wetland”	Year: 2019 - Present Doc. Type: Article Source Type: Journal Language: English Pub. stage: Final Country/territory: All
Rule 2	Rule 1 AND carbon OR biomass OR dynamic* OR flux* OR emission* OR stock* OR storage* OR respiration OR sequest* OR absorption OR photosynthe*	Year: 2019 - Present Doc. Type: Article Source Type: Journal Language: English Pub. stage: Final Country/territory: All
Rule 3	Rule 1 AND Rule 2 AND china OR japan OR mongolia OR north*korea OR south*korea OR bangladesh OR bhutan OR india OR maldives OR nepal OR pakistan OR sri AND lanka OR brunei OR cambodia OR indonesia OR laos OR malaysia OR myanmar OR philippines OR singapore OR thailand OR timor*leste OR vietnam OR australia OR new*zealand OR fiji OR papua*new*guinea OR solomon*island OR polynesia OR micronesia OR melanesia	Year: 2019 - Present Doc. Type: Article Source Type: Journal Language: English Pub. stage: Final Country/territory: Asia Pacific
Rule 4	Rule 1 AND Rule 2 AND Rule 3 AND tropic* OR subtropic* OR monsoon* OR coast*zone* OR climate*classification* OR habitat*suitability OR physic*condition*	Year: 2019 - Present Doc. Type: Article Source Type: Journal Language: English Pub. stage: Final Country/territory: Asia Pacific

Final	mangrove* OR "coast* ecosystem*" OR Rhizophora OR Avicennia OR “coast* wetland*” OR “Intertidal wetland*” OR “tidal wetland*” OR “estuarine wetland” (Topic) and carbon OR biomass OR dynamic* OR flux* OR emission* OR stock* OR storage* OR respiration OR sequest* OR absorption OR photosynthe* (Topic) and china OR japan OR mongolia OR north*korea OR south*korea OR bangladesh OR bhutan OR india OR maldives OR nepal OR pakistan OR sri AND lanka OR brunei OR cambodia OR indonesia OR laos OR malaysia OR myanmar OR philippines OR singapore OR thailand OR timor*leste OR vietnam OR australia OR new*zealand OR fichina OR japan OR mongolia OR north*korea OR south*korea OR bangladesh OR bhutan OR india OR maldives OR nepal OR pakistan OR sri AND lanka OR brunei OR cambodia OR indonesia OR laos OR malaysia OR myanmar OR philippines OR singapore OR thailand OR timor*leste OR vietnam OR australia OR new*zealand OR fiji OR papua*new*guinea OR solomon*island OR polynesia OR micronesia OR melanesiaji OR papua*new*guinea OR solomon*island OR polynesia OR micronesia OR melanesia (Topic) and tropic* OR subtropic* OR monsoon* OR coast*zone* OR climate*classification* OR habitat*suitability OR physic*condition* (Topic) and 2023 or 2022 or 2021 or 2020 or 2019 (Publication Years) and Article (Document Types) and English (Languages) and PEOPLES R CHINA or INDIA or AUSTRALIA or JAPAN or MALAYSIA or VIETNAM or INDONESIA or BANGLADESH or THAILAND or SINGAPORE or NEW ZEALAND or PHILIPPINES or TAIWAN or PAKISTAN or SOUTH KOREA or CAMBODIA or MYANMAR or BRUNEI or FIJI or MICRONESIA or PAPUA N GUINEA or SRI LANKA (Countries/Regions)	

2. Distribution of study sites

The highest study distribution of mangrove species' C uptake ability was found in Indonesia (Figure 2). Eleven study sites across Sumatra, Java, Sulawesi, Bali, Lombok and Papua main islands were recognized species-specific ability of C uptake across Indonesian mangrove regional habitat characteristics. The other studies were in China, Japan, India, Viet Nam, Bangladesh and Australia for various mangrove management purposes, such as rehabilitation, tourism, management, conservation, farm activity and residential area (Figure 2, Table 2).



INDONESIAN STUDY SITES:

1. Komodo Nat. Park, NTT
2. TAHURA, Bali
3. Pejarakan, Bali
4. Joybar, Lombok
5. Demta bay, Papua
6. Rawo Aopa Watumohai Nat. Park, Southeast Sulawesi
7. Tunda Island, Banten
8. Pancer cengkong, East Java
9. Peliat Island, Madura
10. Segara Anakan, Central Java
11. Cawan Island, Riau

Figure 2. Map of distribution of the study of species' C sequestration and C stocks in Asia and Pacific

Table 2. Number of studies on species' C sequestration and C stocks in each mangrove management purpose in countries of the Asia–Pacific

Mangrove management purpose	Indonesia	Australia	Bangladesh	Japan	India	Viet Nam
rehabilitation	2	-	-	-	1	-
tourism	1	-	-	-	-	-
management	1	-	-	-	-	-
conservation	7	2	5	4	3	1
farm activity	2	1	-	-	-	-
residential area	1	0	-	-	-	-

3. Relationship between environmental condition and species ability on C uptake

From references, we successfully collected the data of seven dominant true mangrove species: *Bruguierra gymnorrhiza, Rhizopora stylosa, Rhizopora apiculata, Rhizopora mucronata, Sonneratia alba, Ceriops tagal,* and *Avicennia marina.* These species are the only available species with information on habitat characteristic relationship with their ability for C uptake. Many references reported species' C absorption ability without specifically relating that to the local habitat characteristics. Most information was limited only to general site physical conditions, such as annual temperature, precipitation and humidity. Meanwhile, in mangrove forests, other physical information is crucial, such as soil pH, water temperature, water salinity, and substrate content. Thus, this review only successfully gathered information related to soil pH, water temperature, and water salinity. The other challenge was that the number of replications from references was low and difficult therefore to perform the statistical analysis.

Independent t-tests were used to examine the statistically significant differences between soil pH, water temperature, and water salinity to species' C sequestration (t/ha). All statistical analyses were performed with SPSS (version 25, *SPSS Inc.,* Chicago, Illinois, USA). Among seven species, only *S. alba* showed the most significant relationship between soil pH and C sequestration (p<0.001), as well as water temperature and C sequestration (p <0.001) (Figure 3). It is believed that the higher the soil pH and water temperature, the higher the C sequestration this species would perform. *R. apiculata* showed less significant results for soil pH (p=0.253) and water temperature, which suggests that the ability of this species to perform C sequestration is not affected by soil pH and water temperature (Table 3). In the water salinity variable, *B. gymnorrhiza* showed the most significant relationship to C sequestration ability (p <0.001). The opposite was true for *R.mucronata*, which showed less of a relationship to C sequestration (p = 0.263).

From these results, it is believed that the genus *Rhizopora* is the most tolerable to physical habitat characteristics by showing less significant affect on C sequestration ability by soil pH, water temperature, and water salinity. Soil pH strongly relates to nutrient availability while water temperature affects the capacity of root water absorption. This is linked to the performance of *Rhizopora* as the most dominant true mangrove species and most found species in mangrove forests of Asia and Pacific. *Rhizopora* sp is also considered to have high salinity tolerance.

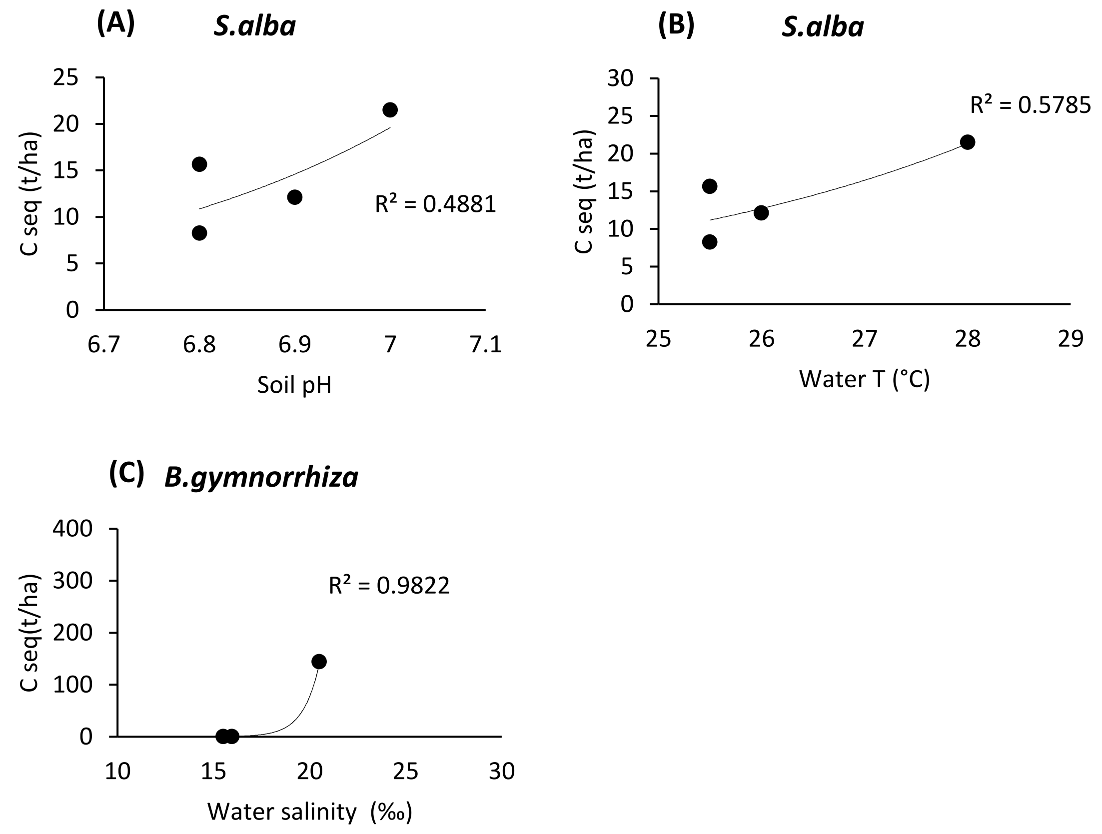


Figure 3. The relationship between soil pH (a), water temperature (b), and water salinity (c) with *S. alba* and *B. gymnorrhiza*. the represented graphs showed only the strongest relationship between all variables

Table 3. Statistical analysis using independent t-test of n=7; p value <0.05 is significant different. asterisk symbols are significant differences of each variables and each species

Species	**Soil pH**		**Water T (°C)**		**Water salinity (‰)**	
	R^2	***p***	R^2	***p***	R^2	***p***
B.gymnorrhiza	0.704	0.432	0.377	**0.05***	0.982	**<0.001***
R.apiculata	0.018	0.235	0.005	0.241	0.036	0.231
R.mucronata	0.105	0.123	0.379	0.06	0.013	0.263
R.stylosa	0.011	0.125	0.159	0.112	0.066	0.254
S.alba	0.488	**<0.001***	0.579	**<0.001***	0.288	0.121
A.marina	0.028	0.223	0.073	0.122	0.001	0.211
C.tagal	0.077	0.145	0.128	0.114	0.022	0.114

Summary

The number of studies on investigation of mangrove species' C dynamics, including C sequestration, in the Asia and Pacific is still very limited. The distribution of studies is also limited only to the tropical monsoon climate with a low number of studies in another climate zone. Consideration of species' selection for habitat characteristics is crucial, especially for successful rehabilitation purposes of mangrove forests in the future. Recovery C emissions is determined by understanding the ability of each mangrove species for up-taking C. Thus, further study on species-specific C sequestration ability is highly recommended.

Selecting the most suitable species to one habitat characteristic is very challenging. However, considering *Rhizopora* sp is the most tolerable species to soil and water condition, planting this species in an area with high dynamics of soil pH and water conditions is suggested. Besides, considering *S. alba* to be planted in areas with relatively high soil pH and water temperature is another option. Meanwhile, *B. gymnorrhiza* is suggested to be planted in areas with relatively high-water salinity. These kinds of consideration are extremely necessary for arrangement of planting strategies.

Future approach

Considering the very low number of studies on the C dynamics, especially on C sequestration, of mangrove species and the challenge of data collection, we considered using allometric calculations to estimate the C stocks and C sequestration that each species would perform in various mangrove typologies. We considered that by using the allometric equation on above- and belowground biomass, we would be able to relate the results to the environmental conditions, in this case, specifying the mangrove typology (delta, estuarine, lagoon and fringe). initially, we conducted the literature search from various databases and successfully collected 54 papers from 1980 onwards for allometric equations. We selected some dominant species that were most found in other references so that we could compare each species' performances in each mangrove typology. We considered that the combination of the current results with this future approach would be comprehended to understand species-specific C dynamics in various mangrove ecosystems.

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