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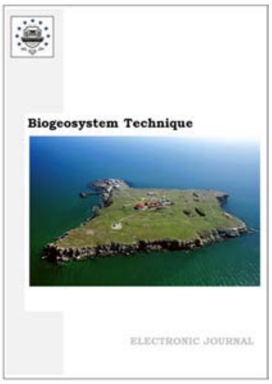

Effects of Light and Temperature on Photosynthetic Capacity of Mangrove Species in the Southern Coastal Region of Vietnam

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Abstract

Mangrove forests play a vital role in coastal protection and biodiversity maintenance, yet they are under severe pressure from climate change and human activities. This study evaluates the effects of light and temperature on the photosynthetic performance of five mangrove species (*Sonneratia alba*, *Avicennia alba*, *Excoecaria agallocha*, *Ceriops zippeliana*, and *Bruguiera gymnorrhiza*) in the southern coastal region of Vietnam, aiming to clarify their adaptability to climate change. We measured key photosynthetic parameters (A_{max}, light saturation point, and T_{opt}) at different canopy positions and analyzed their relationships with environmental variables. The results reveal significant differences in productivity and adaptation among species. *Avicennia alba* and *Ceriops zippeliana* exhibited higher photosynthetic capacity, while *Excoecaria agallocha* showed a higher light saturation point but lower productivity. The optimal temperature for photosynthesis ranged from 28–32 °C, with *E. agallocha* having a lower T_{opt}. These findings highlight the physiological diversity and adaptive traits of mangrove species that influence their distribution and ecological success under changing climates. The study provides scientific evidence for species selection in mangrove restoration and sustainable management strategies in the context of climate adaptation.

Keywords: mangrove plants, photosynthesis, climate change, light, temperature.

1. Introduction

Mangrove ecosystems play an exceptionally important role in environmental protection and the maintenance of biodiversity in coastal regions (Rahmadi et al., 2023), including in the southern areas of Vietnam (Dang et al., 2022). Mangrove forests not only provide habitats for numerous aquatic organisms and rare species of flora and fauna but also serve as a crucial natural barrier

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protecting coastlines from erosion, mitigating the impacts of climate change, reducing wave energy, and preventing soil salinization (Nagelkerken et al., 2008; Rajpar, Zakaria, 2014). Moreover, these ecosystems offer significant economic and ecological benefits, such as fisheries resources, medicinal materials, and livelihoods for local communities (Bandaranayake, 1998; Hussain et al., 2010; Das et al., 2022). Therefore, the conservation and sustainable development of mangrove ecosystems have become an urgent task for scientists, environmental managers, and policy makers (Ferreira et al., 2022).

Photosynthetic capacity plays a central role in the growth and development of mangrove plants, reflecting not only their ability to capture solar energy but also their adaptability to harsh environmental conditions such as salinity, oxygen deficiency, and temperature fluctuations (Joshi et al., 1984; Nandy et al., 2007). In the context of intensifying climate change, studies on the photosynthetic performance of mangroves are crucial for assessing their adaptability and developing appropriate conservation strategies (Gilman et al., 2008; Ellison, 2015). Factors influencing photosynthesis include atmospheric composition, light intensity, salinity, temperature, and ecological competition (Sand-Jensen, 1989; Lovelock et al., 2016; Wang et al., 2021). In recent years, modern analytical technologies-such as automated photosynthesis systems, portable photosynthetic sensors, and Infrared Gas Analyzers (IRGA)-have enabled researchers to measure and monitor photosynthetic processes quickly and accurately, thereby identifying key influencing factors and proposing effective management solutions to enhance ecosystem resilience (Field et al., 1989; Tamayo et al., 2001; Douthe et al., 2018).

Automated photosynthesis systems, for instance those using Non-Dispersive Infrared (NDIR) technology to measure CO_2 and H_2O concentrations, allow for precise and continuous monitoring of leaf photosynthesis and transpiration under controlled conditions (Hodgkinson et al., 2013; Rolle et al., 2018). Portable photosynthesis sensors-such as chlorophyll fluorescence meters-provide a rapid and non-invasive method for evaluating photosynthetic performance and detecting early stress symptoms in plants (Dong et al., 2019; Herritt et al., 2020). Meanwhile, gas measurement instruments like the Infrared Gas Analyzer (IRGA) remain the standard tools for assessing leaf gas exchange rates and determining key physiological indicators such as A_{max}, CO_2 compensation point, and dark respiration (Toro et al., 2019; Macedo et al., 2021).

In the southern coastal region of Vietnam, mangrove ecosystems are increasingly affected by climate change, urbanization, industrialization, and excessive resource exploitation (Thanh et al., 2004; Giang et al., 2024). This region hosts many typical mangrove species such as *Avicennia marina*, *Rhizophora apiculata*, *Sonneratia alba*, and others that play essential roles in maintaining coastal ecological balance (Campbell, 2012; Warner et al. 2016; Do et al., 2022). However, physiological characteristics-especially photosynthetic capacity-of these species remain insufficiently investigated for conservation and sustainable management purposes. In fact, variations in photosynthetic performance can sensitively reflect negative environmental impacts (Krauss et al., 2008; Rovai et al., 2013), thereby helping to identify species most suitable for changing conditions or management interventions to enhance ecosystem resilience (Dasgupta et al., 2011).

Given the ecological importance of mangroves, studying the photosynthetic capacity of species in the southern coastal areas of Vietnam is essential to provide accurate and up-to-date physiological data under local environmental conditions. The main objectives of this paper are: (1) To evaluate the photosynthetic performance of several dominant mangrove species in southern Vietnam using modern analytical methods; and (2) To analyze environmental factors influencing their photosynthetic activity. The findings aim to provide a scientific foundation for practical applications in mangrove management, conservation, and sustainable development. This study not only supplies reliable physiological data but also enhances understanding of the ecological roles of mangrove species in coastal ecosystems, thereby supporting evidence-based conservation strategies and sustainable development initiatives.

2. Materials and methods

2.1. Study Species and Sites

The study was conducted on five mangrove species: *Sonneratia alba*, *Avicennia alba*, *Excoecaria agallocha*, *Ceriops zippeliana*, and *Bruguiera gymnorrhiza*. Representative individuals of each species were randomly selected from seven distinct study sites to ensure healthy and consistent growth conditions (Figure 1).

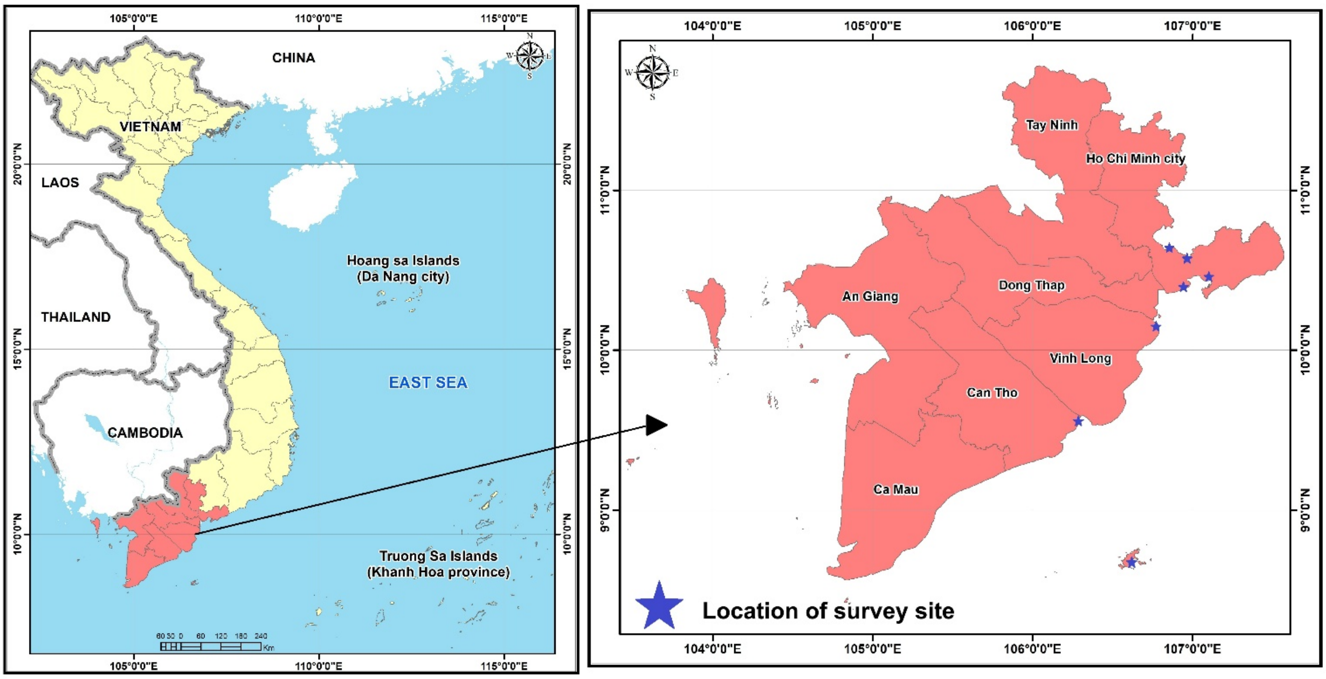

Fig. 1. Location map of the study sites

2.2. Sample Collection

To ensure representativeness and objectivity, the sampling process was carefully performed in accordance with standard scientific protocols (Figure 2). The selection of branches for measurement followed the criteria below:

Maturity: Selected branches carried fully mature leaves with a deep green color and stable size. Young, senescent, damaged, or diseased leaves were excluded.

Canopy position: To evaluate differences in photosynthetic activity at various canopy heights, samples were collected from three vertical positions: Upper, middle, and lower canopy. These positions were defined based on their relative height from the canopy apex and corresponding light availability.

Branch size: Each branch was cut to a length of 15–25 cm, ensuring a sufficient number of leaves for accurate measurement.

Sampling time: Collections were conducted in the early morning (8:00-10:00 a.m.), when photosynthetic activity was high and environmental conditions (temperature and humidity) were relatively stable.

Sample preservation: After cutting, branches were stored in polyethylene bags containing distilled water to maintain moisture and minimize dehydration. Samples were transported immediately to the laboratory and analyzed within two hours of collection.

Fig. 2. Field collection and photosynthesis measurement of mangrove plants at study sites

Adhering to these criteria ensured that the collected samples were representative of mangrove populations in the study area and that photosynthetic measurements were accurate and reliable.

2.3. Photosynthesis Measurement

Photosynthetic parameters were measured using the portable photosynthesis system LI-6800 (LI-COR Biosciences, Lincoln, Nebraska, USA) (LI-COR, 2023). The following environmental parameters were maintained within the measurement chamber: Leaf chamber air temperature: 30°C; Relative humidity: 70 %; CO_2 concentration: 400 μmol mol⁻¹. Each sample measurement was completed within five minutes, yielding approximately 20 recorded data points per run.

2.4. Data Analysis

Assuming that the intercellular CO_2 concentration in the mesophyll (Ci) is known from experimental data, the relationship between photosynthetic rate and light intensity was described using the biochemical model for C_3 photosynthesis proposed by Farquhar (Farquhar et al., 1980), commonly referred to as the *non-rectangular hyperbola model*: $\boldsymbol{\theta A_g{}^2 - A_g(a_iQ + A_{max})J + a_iQA_{max} = 0}$

Net photosynthetic rate (A_n) was calculated as: $\boldsymbol{A_n = A_g - R_d}$

Where: a_i is the initial quantum yield (mol mol^{-1}); A_n is the net photosynthetic rate; A_g is the gross photosynthetic rate; R_d is mitochondrial respiration (dark respiration); A_{max} is the maximum photosynthetic rate, and θ is the curvature factor of the light response curve, reflecting the degree of nonlinearity of the electron transport response. The model mainly involves the following parameters:

Initial quantum yield depends on C_i (μmol mol^{-1}), can be expressed by the Ball–Farquhar equation:

$$\boldsymbol{a_i = a_{io} \cdot (C_i - \Gamma) / (C_i + 2\Gamma)}$$

Where a_{io} is the maximum quantum yield of CO_2 assimilation and Γ (μmol mol^{-1}) is the CO_2 compensation point under non-photorespiratory conditions. The value of Γ increases with temperature due to the higher affinity of Rubisco for O_2 relative to CO_2. The relationship between Γ and leaf temperature (T_k, in Kelvin) is described as (Farquhar et al., 1989): $\boldsymbol{\Gamma = 1{,}7\, T_k}$

Intercellular CO_2 concentration (C_s): C_s varies with atmospheric CO_2 concentration (C_a); A_n and stomatal conductance (g_s). Under well-watered conditions, this relationship can be expressed using the semi-empirical Ball–Berry model (Ball et al., 1987):

$$\boldsymbol{g_s = \alpha \frac{A_n \cdot \mathrm{RH}}{C_s} + g_o}$$

Where g_o is the residual conductance (experimentally determined), RH is relative humidity at the leaf surface, C_s is the CO_2 concentration at the leaf surface, and α is an empirical coefficient. Leuning later modified this model by substituting relative humidity (RH) with vapor pressure deficit (VPD) (Leuning, 1995):

$$\boldsymbol{g_s = \alpha \frac{A_n}{(C_i - \Gamma)(1 - VPD/VPD_o)} + g_o}$$

At low light (I → 0), $A_n \rightarrow 0$, and assuming $g_o \approx 0$, we obtain:

$$\boldsymbol{C_i = C_s - \alpha(C_s - \Gamma)(1 + \frac{VPD}{VPD_o})}$$

The maximum rate of photosynthesis A_{max} is primarily limited by Rubisco enzyme activity and depends on CO_2 concentration and temperature:

$$\boldsymbol{A_{max} = V_{max} \cdot (C_s - \Gamma)/(C_i + C)}$$

Where V_{max} is the maximum catalytic capacity of Rubisco per unit leaf area. The Michaelis constant (C) for CO_2 and O_2 in the Rubisco reaction is treated as constant in this study. The temperature dependence of V_{max} follows an Arrhenius-type relationship: $\boldsymbol{V_{max} = V_{m25}\{1 + exp[(-a_l + bT_a)/RT_a]\}^{-1}}$

Where: V_{m25} is the value at 25°C; a, b is the activation energy; R is the universal gas constant (8.314 J mol^{-1} K^{-1}), and T_a is absolute temperature (K).

3. Results and discussion

3.1. Dependence of Photosynthesis on Light Intensity and Temperature

The measured data on photosynthetic parameters of mangrove species in the southern coastal areas of Vietnam are presented in Table 1.

Table 1. Photosynthetic parameters of mangrove species in the southern coastal region of Vietnam

Species	Leaf position	A_{max} (µmol m^{-2} s^{-1})	Saturation PAR (µmol m^{-2} s^{-1})	Rd (µmol m^{-2} s^{-1})	Γ (µmol mol^{-1})	θ	A_{opt} (µmol m^{-2} s^{-1})	T_{opt} (°C)
Sonneratia alba	Upper canopy	6.2 ± 0.8	373 ± 13	-1.6 ± 0.2	15 ± 3	0.023	13.2 ± 0.4	31.7 ± 0.3
	Middle canopy	4.9 ± 0.7	358 ± 11	-1.1 ± 0.2	17 ± 3	0.022	13.0 ± 0.3	31.7 ± 0.2
	Lower canopy	3.8 ± 0.6	346 ± 12	-0.9 ± 0.2	16 ± 3	0.023	10.1 ± 0.3	30.5 ± 0.2
Avicennia alba	Upper canopy	10.2 ± 0.5	565 ± 17	-0.9 ± 0.2	12 ± 3	0.016	8.5 ± 0.5	29.3 ± 0.3
	Middle canopy	8.5 ± 0.4	562 ± 13	-0.9 ± 0.2	11 ± 3	0.016	11.1 ± 0.3	31.1 ± 0.2
	Lower canopy	7.7 ± 0.5	558 ± 9	-1.0 ± 0.2	12 ± 3	0.016	9.2 ± 0.3	28.7 ± 0.2
Excoecaria agallocha	Upper canopy	3.4 ± 0.3	1031 ± 11	-0.7 ± 0.2	34 ± 3	0.32	7.9 ± 0.4	26.5 ± 0.4
	Middle canopy	4.1 ± 0.3	1029 ± 18	-0.7 ± 0.2	31 ± 5	0.21	7.5 ± 0.4	30.1 ± 0.3
	Lower canopy	4.0 ± 0.3	1003 ± 28	-0.6 ± 0.2	32 ± 7	0.25	7.4 ± 0.4	24.7 ± 0.2
Ceriops zippeliana	Upper canopy	9.6 ± 0.4	531 ± 21	-0.7 ± 0.2	24 ± 5	0.02	14.3 ± 1.0	31.4 ± 0.4
	Middle canopy	10.1 ± 0.3	559 ± 28	-0.9 ± 0.3	18 ± 7	0.018	11.6 ± 0.7	29.8 ± 0.3
	Lower canopy	6.5 ± 0.3	527 ± 18	-1.7 ± 0.2	22 ± 4	0.021	10.3 ± 0.5	30.7 ± 0.2
Bruguiera gymnozhira	Upper canopy	8.2 ± 0.4	621 ± 13	-1.1 ± 0.2	21 ± 3	0.02	6.7 ± 0.3	28.8 ± 0.3
	Middle canopy	7.6 ± 0.3	613 ± 15	-0.8 ± 0.2	21 ± 3	0.02	6.3 ± 0.2	28.0 ± 0.2
	Lower canopy	7.5 ± 0.3	618 ± 20	-1.6 ± 0.2	21 ± 3	0.023	8.4 ± 0.2	28.2 ± 0.2

Analysis of the photosynthetic parameters of the five mangrove species (*Sonneratia alba*, *Avicennia alba*, *Excoecaria agallocha*, *Ceriops zippeliana*, and *Bruguiera gymnorrhiza*) revealed considerable variation in photosynthetic capacity, light saturation point, and optimal temperature among species and leaf positions (Table 1). This reflects physiological and adaptive differences of each species to distinct environmental conditions.

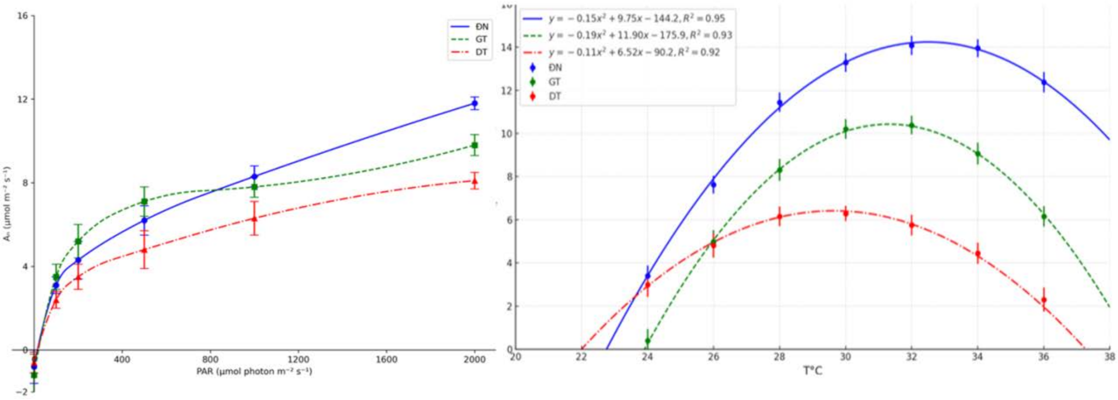

Fig. 3. Relationship between photosynthesis, light intensity, and temperature for *Sonneratia alba*.

The maximum photosynthetic rate (A_{max}), a key indicator of photosynthetic capacity, ranged from 3.4 ± 0.3 µmol m^{-2} s^{-1} (*Excoecaria agallocha*) to 10.2 ± 0.5 µmol m^{-2} s^{-1} (*Avicennia alba*). This indicates that *Avicennia alba* and *Ceriops zippeliana* tend to achieve higher photosynthetic performance than *Sonneratia alba*, *Bruguiera gymnorrhiza*, and especially *Excoecaria agallocha*. Variations in A_{max} values are often related to morphological and physiological traits such as leaf structure, chlorophyll content, and water-use efficiency.

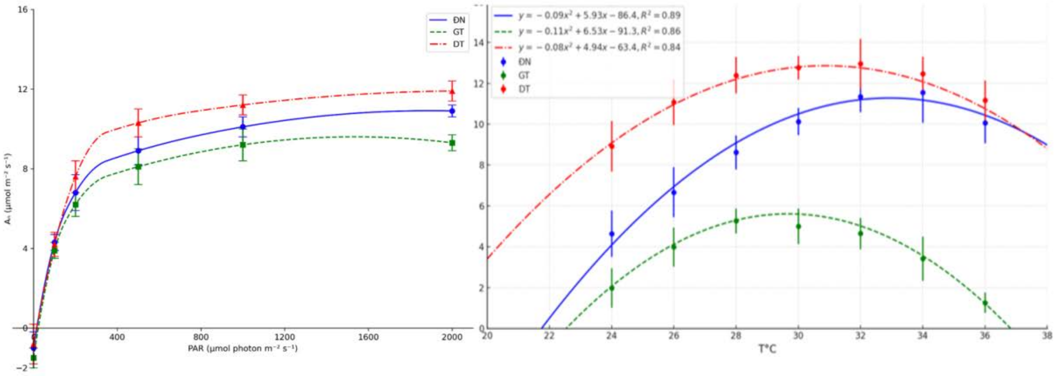

Fig. 4. Relationship between photosynthesis, light intensity, and temperature for *Avicennia alba*

The light saturation point, representing the light intensity required to achieve maximum photosynthesis, also varied among species. *Excoecaria agallocha* had the highest light saturation point (1003 ± 28 to 1031 ± 11 µmol m^{-2} s^{-1}), while the remaining species ranged between 346 ± 12 and 621 ± 13 µmol m^{-2} s^{-1}. This suggests that *E. agallocha* requires stronger light to reach optimal photosynthesis, whereas other species are better adapted to shaded or lower-light conditions.

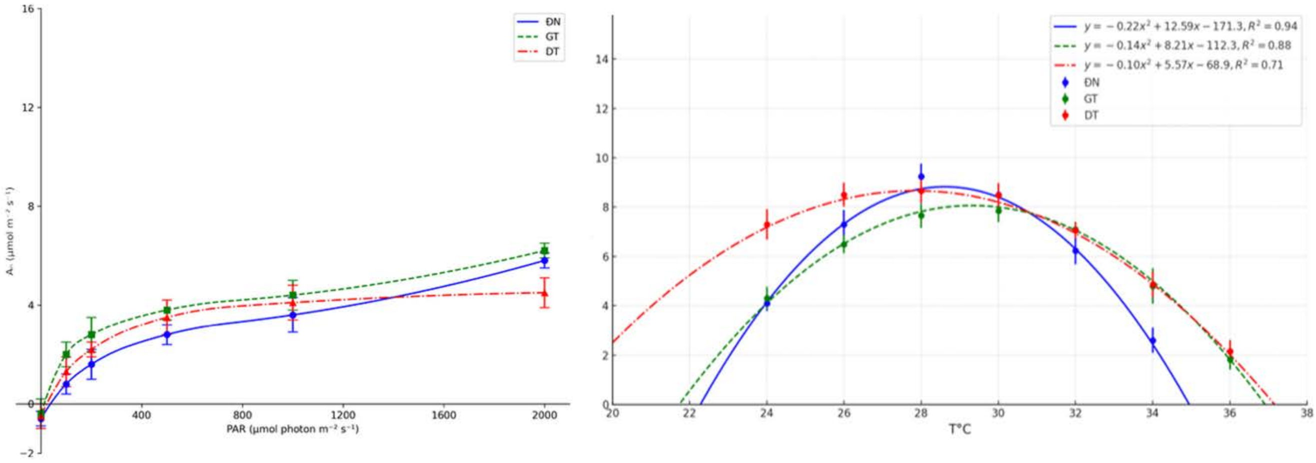

Fig. 5. Relationship between photosynthesis, light intensity, and temperature for *Excoecaria agallocha*

T_{opt} showed less variation among species compared to A_{max} or light saturation points. Most species exhibited T_{opt} values between 28°C and 32°C, consistent with tropical environmental conditions. *Excoecaria agallocha* showed slightly lower T_{opt} values (24.7 ± 0.2 to 30.1 ± 0.3°C), suggesting greater tolerance to cooler conditions.

Differences in photosynthetic capacity were also observed among canopy positions. Generally, A_{max} decreased from the upper canopy to the lower canopy, corresponding to light availability. However, the extent of this reduction varied among species, reflecting differing adaptation strategies.

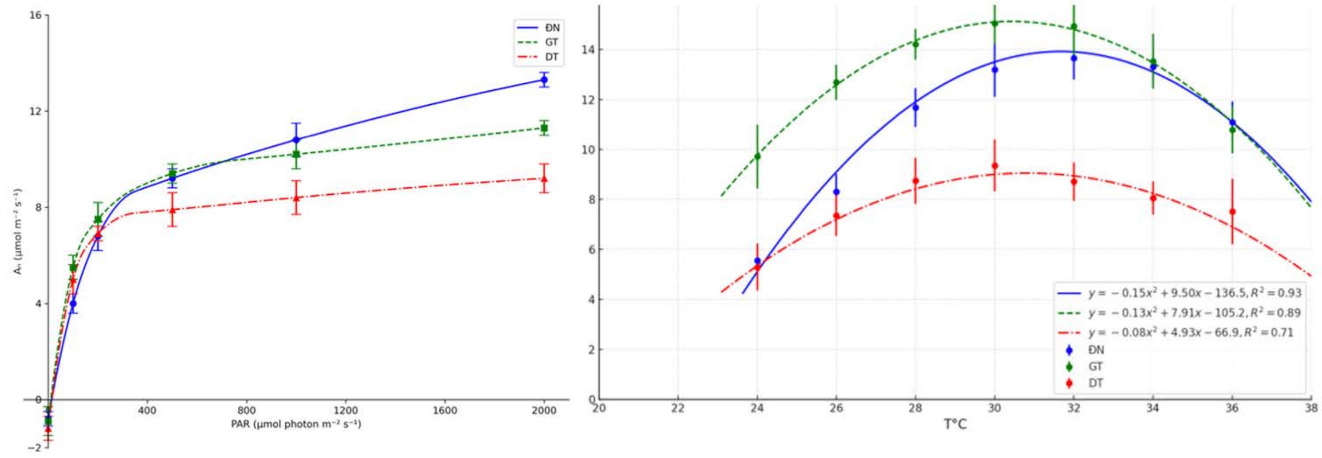

Fig. 6. Light and temperature dependence of photosynthesis in *Ceriops zippeliana*

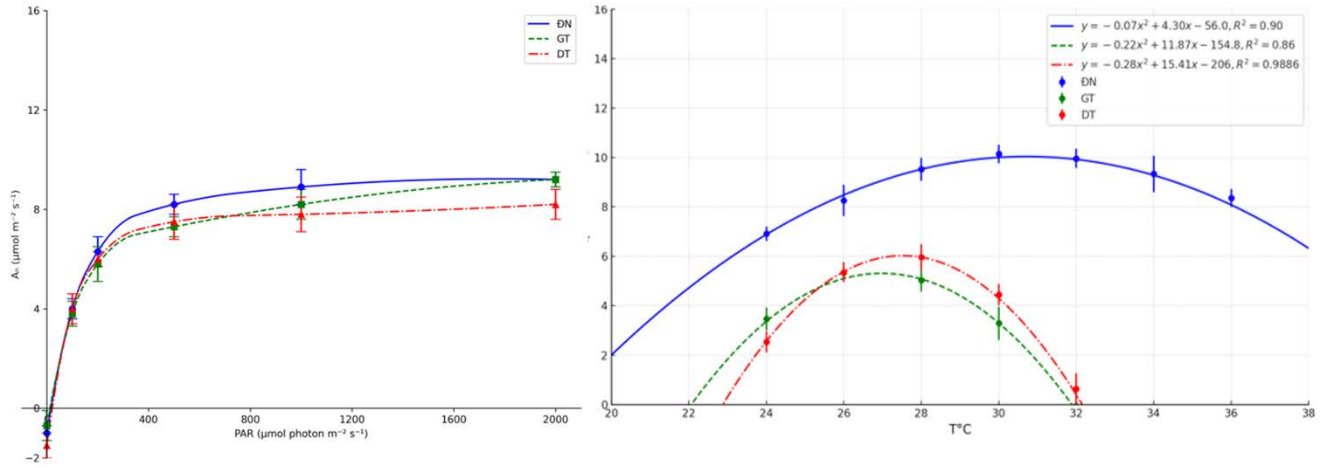

Fig. 7. Light and temperature dependence of photosynthesis in *Bruguiera gymnorrhiza*

According to Table 2, *Sonneratia alba* showed the greatest decrease in A_{max} (38.7 %), indicating significantly lower photosynthetic productivity in lower-canopy leaves. *Bruguiera gymnorrhiza* showed the smallest reduction (8.5 %), maintaining relatively high photosynthetic performance even under shade. Interestingly, *Excoecaria agallocha* showed a negative A_{max} reduction (-17.6 %), likely due to natural variability or increased exposure of lower leaves to diffused light.

Table 2. Variation of A_{max} by canopy position

Species	A_{max} (Upper canopy)	A_{max} (Lower canopy)	% Decrease
Sonneratia alba	6.2 ± 0.8	3.8 ± 0.6	38.7%
Avicennia alba	10.2 ± 0.5	7.7 ± 0.5	24.5%
Excoecaria agallocha	3.4 ± 0.3	4.0 ± 0.3	-17.6%
Ceriops zippeliana	9.6 ± 0.4	6.5 ± 0.3	32.3%
Bruguiera gymnorrhiza	8.2 ± 0.4	7.5 ± 0.3	8.5%

3.2. Comparison of Productivity and Adaptability among Mangrove Species

Photosynthetic Productivity

The maximum photosynthetic rate reflects the carbon fixation potential of plants. Results showed that *Avicennia alba* and *Ceriops zippeliana* achieved the highest A_{max} values (10.2 ± 0.5 and 9.6 ± 0.4 µmol m^{-2} s^{-1}, respectively, at upper canopy leaves), suggesting higher light-use efficiency and growth potential under favorable conditions. Conversely, *Excoecaria agallocha* exhibited the lowest A_{max} (3.4 ± 0.3 μmol m^{-2} s^{-1}), indicating energy limitations under low light or strong competition.

A_{max} generally decreased from upper to lower canopy across most species, consistent with canopy light distribution. For instance, *Sonneratia alba* showed a pronounced reduction from 6.2 ± 0.8 to 3.8 ± 0.6 μmol m^{-2} s^{-1}, suggesting light limitation and reduced photosynthetic performance in shaded leaves.

Adaptation to Light Conditions

The light saturation point reflects a species' adaptation to light environments. *Excoecaria agallocha* exhibited the highest light saturation (>1000 μmol m^{-2} s^{-1}), indicating a requirement for high light intensity and confirming its pioneer role in open, disturbed, or newly accreted areas. In contrast, *Sonneratia alba* and *Bruguiera gymnorrhiza* had lower light saturation points, reflecting better adaptation to shaded or low-light environments such as beneath dense canopies. The curvature factor (θ) further supported these findings: light-demanding species showed lower θ values, indicating higher light-use efficiency.

Adaptation to Temperature

Table 3. Variation of T_{opt} by canopy position

Species	Upper canopy	Middle canopy	Lower canopy	Mean T_{opt}
Sonneratia alba	31.7 ± 0.3	31.7 ± 0.2	30.5 ± 0.2	31.3 ± 0.2
Avicennia alba	29.3 ± 0.3	31.1 ± 0.2	28.7 ± 0.2	29.7 ± 1.0
Excoecaria agallocha	26.5 ± 0.4	30.1 ± 0.3	24.7 ± 0.2	27.1 ± 2.3
Ceriops zippeliana	31.4 ± 0.4	29.8 ± 0.3	30.7 ± 0.2	30.6 ± 0.6
Bruguiera gymnorrhiza	28.8 ± 0.3	28.0 ± 0.2	28.2 ± 0.2	28.3 ± 0.4

In general, most species exhibited T_{opt} values within the range of 28–32°C, suitable for tropical environmental conditions. T_{opt} varied slightly among species (Table 3). *Sonneratia alba* showed the highest mean T_{opt} (31.3 ± 0.2°C), indicating superior tolerance to higher temperatures. *Excoecaria agallocha* exhibited the lowest mean T_{opt} (27.1 ± 2.3°C), suggesting better adaptation to cooler environments. Other species had intermediate T_{opt} values (28.3–30.6°C), consistent with tropical climatic conditions.

3.3. Adaptive Potential under Climate Change Scenarios

Based on the analysis of photosynthetic parameters, the adaptive responses of the five mangrove species were evaluated under climate change scenarios.

Sonneratia alba demonstrated strong adaptability to temperature increases under both RCP4.5 and RCP8.5 scenarios. Rising temperatures, if not accompanied by water scarcity, could enhance carbon assimilation and population growth in this species. *Avicennia alba* adapted well under RCP4.5 but showed reduced tolerance under RCP8.5, as extreme heat may exceed the optimal range for mid-canopy leaves, indicating vulnerability to heat stress.

Excoecaria agallocha was identified as sensitive to high solar radiation and unsuitable for areas with low rainfall and high annual sunshine. This species may struggle under hotter, drier climates. In contrast, *Ceriops zippeliana* exhibited strong light preference and adaptability to both RCP4.5 and RCP8.5 scenarios, showing flexible photosynthetic responses to increasing temperatures. *Bruguiera gymnorrhiza* also demonstrated resilience to thermal stress under both scenarios, with upper canopy leaves displaying superior resistance to heat and dehydration compared to lower leaves.

These results collectively highlight interspecific differences in photosynthetic capacity and resilience, offering critical insights for selecting and managing mangrove species in climate adaptation and restoration strategies.

3.4. Discussion

In the context of climate change and its increasing impacts on mangrove ecosystems, understanding the photosynthetic characteristics of individual species is of great importance-not only to better comprehend their adaptive capacities but also to support smart and effective management decisions (Cheeseman et al., 1991; Cheeseman et al., 1997). The results of this study reveal notable differences in photosynthetic productivity and adaptability among five mangrove species. *Avicennia alba* and *Ceriops zippeliana* exhibited higher A_{max} values than the other species, whereas *Excoecaria agallocha* showed the highest light saturation point but the lowest A_{max}. T_{opt} among species ranged between 28-32°C, although *Excoecaria agallocha* tended to have lower T_{opt} values.

Differences in A_{max} may reflect variations in survival strategies and distribution patterns among mangrove species. *Avicennia alba* and *Ceriops zippeliana*, with higher A_{max} values, may be better adapted to nutrient-rich environments or possess a greater ability to compete for light. Conversely, *Excoecaria agallocha*, with its lower A_{max}, may be better suited to nutrient-poor or shaded environments (López-Hoffman et al., 2006; Wang et al., 2021). Such differences in A_{max} are often associated with variations in leaf morphology, chlorophyll content, water-use efficiency, and stomatal regulation capacity (Chang et al., 2022). The high light saturation point of *Excoecaria agallocha* aligns with its ecological role as a pioneer species typically found in open, high-light environments. In contrast, species with lower light saturation points-such as *Sonneratia alba* and *Bruguiera gymnorrhiza* – are better adapted to shaded conditions, for example, under dense canopy cover (Farnsworth et al., 1996; Ball, 2002; Krauss et al., 2003).

Differences in T_{opt} among species likely reflect adaptations to varying temperature regimes within the study region. The lower T_{opt} observed in *Excoecaria agallocha* suggests that this species may have originated from cooler habitats or possesses higher tolerance to lower temperatures (Field, 1995; Quisthoudt et al., 2012). Our results are consistent with previous studies on the photosynthetic responses of mangrove species (Moorthy et al., 1999; Das et al., 2002). However, some variations may result from differences in measurement methods, environmental conditions, or genetic characteristics among populations (Gutiérrez-Rodríguez et al., 2000; Reynolds et al., 2000).

Nevertheless, this study has several limitations that should be considered. First, measurements were conducted at a single time point (September 2023); thus, seasonal or environmental variations in photosynthetic performance could not be assessed (Suwa et al., 2008; Lele et al., 2021). Second, measurements were made only on mature leaves, so potential differences in photosynthetic response among developmental stages could not be evaluated (Okimoto et al., 2008). Furthermore, only five mangrove species were examined, preventing broad generalizations across all mangrove taxa in the region. Future studies should aim to measure photosynthetic parameters seasonally, across developmental stages, and under diverse environmental conditions to better understand temporal and physiological variations (Kaipiainen, 2009). Expanding research to include additional mangrove species will also provide a more comprehensive understanding of species diversity and functional adaptation in mangrove ecosystems.

The findings of this study have significant implications for understanding mangrove ecophysiology and for practical applications in mangrove restoration and management. Species selection for reforestation or rehabilitation projects can be guided by photosynthetic parameters such as A_{max}, light saturation point, and T_{opt}. Moreover, understanding how environmental factors affect mangrove photosynthesis can inform effective management strategies for protecting and restoring these critical ecosystems.

4. Conclusion

This study elucidated the differences in photosynthetic capacity among five key mangrove species in the southern coastal region of Vietnam, providing valuable insights into their ecology and adaptive mechanisms. The results demonstrate that *Avicennia alba* and *Ceriops zippeliana* possess higher photosynthetic productivity, while *Excoecaria agallocha* shows adaptation to high light intensity and lower temperature conditions. These findings highlight not only the physiological diversity among mangrove species but also offer essential scientific foundations for conservation and restoration efforts under changing climatic conditions. Selecting species that best match local environmental parameters is a crucial factor in ensuring the success of restoration projects.

For a more comprehensive understanding, future research should focus on assessing mangrove photosynthetic responses under varying environmental conditions (e.g., seasonal changes, salinity gradients, and pollution levels) and on examining genetic factors that may influence their adaptive capacities. This study aims to contribute to raising awareness of the importance of mangrove conservation and to encourage concrete actions to protect these invaluable ecosystems for future generations.

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References

Ball et al., 1987 – *Ball, J.T., Woodrow, I.E., Berry, J.A.* (1987). A Model predicting stomatal conductance and its Contribution to the control of photosynthesis under different environmental conditions. Progress in Photosynthesis Research. Biggins, J. (eds.). Springer. Pp. 221-224.

Ball, 2002 – *Ball, M.C.* (2002). Interactive effects of salinity and irradiance on growth: implications for mangrove forest structure along salinity gradients. *Trees*. 16: 126-139. DOI: https://doi.org/10.1007/s00468-002-0169-3.

Bandaranayake, 1998 – *Bandaranayake, W.M.* (1998). Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes*. 2: 133-148. DOI: https://doi.org/10.1023/A:1009988607044

Campbell, 2012 – *Campbell, I.C.* (2012). Biodiversity of the Mekong Delta. In: The Mekong Delta System: Interdisciplinary Analyses of a River Delta. Renaud, F.G., Kuenzer, C. (eds.). Springer. Pp. 293-313.

Chang et al., 2022 – *Chang, Y., Fan, Y., Li, Z., Guanghui, L.* (2022). Relationship between photosynthetic characteristics, anatomical structure, and physiological indexes of two halophytes in different habitats. *Forests*. 13(12): 2189. DOI: https://doi.org/10.3390/f13122189.

Dang et al., 2022 – *Dang, N.T.An, Michael Reid, Lalit Kumar* (2022). Assessing potential impacts of sea level rise on mangrove ecosystems in the Mekong Delta, Vietnam. *Regional Environmental Change*. 22: 70. DOI: https://doi.org/10.1007/s10113-022-01925-z.

Das et al., 2002 – *Das, A., Parida, A., Basak, U., Das, P.* (2002). Studies on pigments, proteins and photosynthetic rates in some mangroves and mangrove associates from Bhitarkanika, Orissa. *Marine Biology*. 141:415-422. DOI: https://doi.org/10.1007/s00227-002-0847-0

Das et al., 2022 – *Das, S.C., Das, S., Tah,* J. (2022). Mangrove Forests and People's Livelihoods. In: Mangroves: Biodiversity, Livelihoods and Conservation. Das, S.C., Pullaiah, Ashton E.C. (eds.). Springer. Pp. 153-173.

Dasgupta et al., 2011 – *Dasgupta, N., Nandy, P., Das, S.* (2011). Photosynthesis and antioxidative enzyme activities in five Indian mangroves with respect to their adaptability. *Acta Physiologiae Plantarum*. 33: 803-810. DOI: https://doi.org/10.1007/s11738-010-0605-8

Do et al., 2022 – *Do, H.L., Dang, T.T.* (2022). Productivity response and production risk: A study of mangrove forest effects in aquaculture in the Mekong River Delta. *Ecological Economics*. 194: 107326. DOI: https://doi.org/10.1016/j.ecolecon.2021.107326

Dong et al., 2019 – *Dong, T., Shang, J., Chen, J.M., Liu, J., Qian, B., Ma, B., Morrison, M.J., Zhang, C., Liu, Y., Shi, Y., Pan, H., Zhou, G.* (2019). Assessment of portable chlorophyll meters for measuring crop leaf chlorophyll concentration. *Remote Sensing*. 11(22): 2706. DOI: https://doi.org/10.3390/rs11222706

Douthe et al., 2018 – *Douthe, C., Gago, J., Ribas-Carbó, M., Núñez, R., Pedrol, N., Flexas, J.* (2018). Measuring photosynthesis and respiration with infrared gas analysers. In: Advances in Plant Ecophysiology Techniques. Sánchez-Moreiras, A.M., Reigosa M.J., (eds.). Springer. Pp. 51-75.

Ellison, 2015 – *Ellison, J.C.* (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management*. 23: 115-137. DOI: https://doi.org/10.1007/ s11273-014-9397-8

Farnsworth, Ellison, 1996 – *Farnsworth, E.J., Ellison, A.M.* (1996). Sun-shade adaptability of the red mangrove, Rhizophora mangle (Rhizophoraceae): Changes through ontogeny at several levels of biological organization. *American Journal of Botany*. 83(9): 1131-1143. DOI: https://doi.org/10.1002/j.1537-2197.1996.tb13893.x

Farquhar et al., 1980 – *Farquhar, G.D., Caemmerer, S., Berry, J.A.* (1980). A biochemical model of photosynthetic CO2 ssimilation in leaves of C3 species. *Planta*. 149: 78-90. DOI: https://doi.org/10.1007/BF00386231

Farquhar et al., 1989 – *Farquhar, G.D., Hubick, K.T., Condon, A.G., Richards, R.A.* (1989). Carbon Isotope Fractionation and Plant Water-Use Efficiency. In: Stable Isotopes in Ecological Research. Rundel, P.W., Ehleringer, J.R., Nagy, K.N. (eds.), Springer. Pp. 21-40.

Ferreira et al., 2022 – *Ferreira, A.C., Borges, R., Lacerda, L.D.* (2022). Can Sustainable Development Save Mangroves? *Sustainability*. 14(3): 1263. DOI: https://doi.org/10.3390/su14031263

Field et al., 1989 – *Field, C.B., Ball, J.T., Berry, J.A.* (1989). Photosynthesis: principles and field techniques. In: Plant Physiological Ecology: Field methods and instrumentation. Pearcy, R.W., Ehleringer, J.H., Mooney H.A., Rundel P.W. (eds.). Springer. Pp. 209-253.

Field, 1995 – *Field, C.D.* (1995). Impact of expected climate change on mangroves. In: Asia-Pacific Symposium on Mangrove Ecosystems. Wong, Y.S., Tam, N.F. (eds.). Springer. Pp. 75-81.

Giang et al., 2024 – *Giang, P.Q., Khanal, R.* (2024). What next for marine ecosystem management in Vietnam: assessment of coastal economy, climate change, and policy implication. *Environmental Research Communications*. 6:025002. DOI: https://doi.org/10.1088/2515-7620/ad19a5

Gilman et al., 2008 – *Gilman, E.L., Ellison, J., Duke, N.C., Field, C.* (2008). Threats to mangroves from climate change and adaptation options: A review. *Aquatic Botany*. 89(2): 237-250. DOI: https://doi.org/10.1016/j.aquabot.2007.12.009

Gutiérrez-Rodríguez et al., 2000 – Gutiérrez-Rodríguez, M., Reynolds, M.P., Larqué-Saavedra, A. (2000). Photosynthesis of wheat in a warm, irrigated environment: II. Traits associated with genetic gains in yield. Field Crops Research. 66(1):51-62. DOI: https://doi.org/10.1016/S0378-4290(99)00078-7.

Herritt et al., 2020 – *Herritt, M.T., Pauli, D., Mockler, T.C., Thompson, A.L.* (2020). Chlorophyll fluorescence imaging captures photochemical efficiency of grain sorghum (Sorghum bicolor) in a field setting. *Plant Methods*. 16: 109. DOI: https://doi.org/10.1186/s13007-020-00650-0

Hodgkinson et al., 2013 – *Hodgkinson, J., Smith, R., Ho, W.O., Saffell, J.R., Tatam, R.P.* (2013). Non-dispersive infra-red (NDIR) measurement of carbon dioxide at 4.2μm in a compact and optically efficient sensor. *Sensors and Actuators B: Chemical*. 186: 580-588. DOI: https://doi.org/10.1016/j.snb.2013.06.006

Hussain et al., 2010 – *Hussain, S.A., Badola, R.* (2010). Valuing mangrove benefits: contribution of mangrove forests to local livelihoods in Bhitarkanika Conservation Area, East Coast of India. *Wetlands Ecology and Management*. 18: 321-331. DOI: https://doi.org/10.1007/s11273-009-9173-3

Joshi et al., 1984 – *Joshi, G.V., Sontakke, S., Bhosale, L., Waghmode, A.P.* (1984). Photosynthesis and photorespiration in mangroves. In: Physiology and management of mangroves. Teas, H.J. (eds.). Springer. Pp. 1-14.

Kaipiainen, 2009 – *Kaipiainen, E.L.* (2009). Parameters of photosynthesis light curve in Salix dasyclados and their changes during the growth season. *Russian Journal of Plant Physiology*. 56: 445-453. DOI: https://doi.org/10.1134/S1021443709040025

Krauss et al., 2003 – *Krauss, K.W., Allen, J.A.* (2003). Influences of salinity and shade on seedling photosynthesis and growth of two mangrove species, Rhizophora mangle and Bruguiera sexangula, introduced to Hawaii. *Aquatic Botany*. 77(4): 311-324. DOI: https://doi.org/10.1016/j.aquabot. 2003.08.004

Krauss et al., 2008 – *Krauss, K.W., Lovelock, C.E., McKee, K.L., López-Hoffman, L., Ewe, S.M.L., Sousa, W.P.* (2008). Environmental drivers in mangrove establishment and early development: A review. *Aquatic Botany*. 89(2): 105-127. DOI: https://doi.org/10.1016/j.aquabot.2007.12.014

Lele et al., 2021 – *Lele, N., Kripa, M.K., Panda, M., Das, S.K., Nivas, A.H., Divakaran, N., Naik-Gaonkar, S., Sawant, A., Pattnaik, A.K., Samal, R.N., Thangaradjou, T., Saravanakumar, A., Rodrigues, B.F., Murthy, T.V.R.* (2021). Seasonal variation in photosynthetic rates and satellite-based GPP estimation over mangrove forest. Environmental Monitoring and Assessment. 193: 61. DOI: https://doi.org/10.1007/s10661-021-08846-0

Leuning, 1995 – *Leuning, R.* (1995). A critical appraisal of a combined stomatal-photosynthesis model for C3 plants. *Plant, Cell & Environment*. 18(4): 339-355. DOI: https://doi.org/10.1111/j.1365-3040.1995.tb00370.x

López-Hoffman et al., 2006 – *López-Hoffman, L., DeNoyer, J.N., Monroe, I.E., Shaftel, R., Anten, N.P., Martínez-Ramos, M., Ackerly, D.D.* (2006). Mangrove seedling net photosynthesis, growth, and survivorship are interactively affected by salinity and light. *Biotropica*. 38(5): 606-616. DOI: https://doi.org/10.1111/j.1744-7429.2006.00189.x

Lovelock et al., 2016 – *Lovelock, C.E., Krauss, K.W., Osland, M.J., Reef, R., Ball, M.C.* (2016). The Physiology of Mangrove Trees with Changing Climate. In: Tropical Tree Physiology: Adaptations and Responses in a Changing Environment. Goldstein, G., Santiago L.S. (eds.). Springer. Pp. 149-179.

Macedo et al., 2021 – *Macedo, F.C., Daneluzzi, G.S., Capelin, D., Barbosa, F.S.,Silva, A.R., Oliveira, R.F.* (2021). Equipment and protocol for measurement of extracellular electrical signals, gas exchange and turgor pressure in plants. *MethodsX*. 8:101214. DOI: https://doi.org/10.1016/j.mex.2021.101214

Moorthy et al., 1999 – *Moorthy, P., Kathiresan, K.* (1999). Effects of UV-B radiation on photosynthetic reactions in Rhizophora apiculata. *Plant Growth Regulation*. 28: 49-54. DOI: https://doi.org/10.1023/A:1006279815159

Nagelkerken et al., 2008 – *Nagelkerken, I., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.O., Pawlik, J., Penrose, H.M., Sasekumar, A., Somerfield, P.J.* (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany*. 89(2): 155-185. DOI: https://doi.org/10.1016/j.aquabot.2007.12.007

Nandy et al., 2007 – *Nandy, P., Das, S., Ghose, M., Spooner-Hart, R.* (2007). Effects of salinity on photosynthesis, leaf anatomy, ion accumulation and photosynthetic nitrogen use efficiency in five Indian mangroves. *Wetlands Ecology and Management*. 15:347-357. DOI: https://doi.org/10.1007/s11273-007-9036-8.

Okimoto et al., 2008 – *Okimoto, Y., Nose, A., Ikeda, K., Agarie, S., Oshima, K., Tateda, Y., Ishii, T., Dang, N.D.* (2008). An estimation of CO2 fixation capacity in mangrove forest using two methods of CO2 gas exchange and growth curve analysis. *Wetlands Ecology and Management*. 16: 155-171. DOI: https://doi.org/10.1007/s11273-007-9062-6

Quisthoudt et al., 2012 – *Quisthoudt, K., Schmitz, N., Randin, C.F., Dahdouh-Guebas, F., Robert, E.M.R., Koedam, N.* (2012). Temperature variation among mangrove latitudinal range limits worldwide. *Trees*. 26: 1919-1931. DOI: https://doi.org/10.1007/s00468-012-0760-1

Rajpar, Zakaria, 2014 – *Rajpar, M.N., Zakaria, M.* (2014). Mangrove ecosystems of Asia: Status, challenges and management strategies. In: Mangrove Fauna of Asia. Faridah-Hanum, I., Latiff, A., Hakeem, K.R., Ozturk, M. (eds.). Springer. Pp. 153-197.

Rahmadi et al., 2023 – *Rahmadi, M.T., Yuniastuti, E., Suciani, A., Harefa, M.S., Persada, A.Y., Tuhono, E.* (2023). Threats to mangrove ecosystems and their impact on coastal biodiversity: A study on mangrove management in Langsa City. Indonesian Journal of Earth Sciences. 3(2):A627. DOI: https://doi.org/10.52562/injoes.2023.627.

Reynolds et al., 2000 – *Reynolds, M.P., Delgado, B.M.I., Gutiérrez-Rodríguez, M., Larqué-Saavedra, A.* (2000). Photosynthesis of wheat in a warm, irrigated environment: I: Genetic diversity and crop productivity. *Field Crops Research*. 66(1): 37-50. DOI: https://doi.org/10.1016/S0378-4290(99)00077-5

Rolle, Sega, 2018 – *Rolle, F., Sega, M.* (2018). Carbon dioxide determination in atmosphere by non dispersive infrared spectroscopy: A possible approach towards the comparability with seawater CO2 measurement results. *Measurement*. 128:479-484. DOI: https://doi.org/10.1016/j.measurement.2018.07.007

Rovai et al., 2013 – *Rovai, A.S., Barufi, J.B., Pagliosa, P.R., Scherner, F., Torres, M.T.A., Horta, P.A., Simonassi, J.C., Quadros, D.P.C., Borges, D.L.D., Soriano-Sierra, E.J.* (2013). Photosynthetic performance of restored and natural mangroves under different environmental constraints. *Environmental Pollution*. 181: 233-241. DOI: https://doi.org/10.1016/j.envpol.2013.06.023

Sand-Jensen, 1989 – *Sand-Jensen, K.* (1989). Environmental variables and their effect on photosynthesis of aquatic plant communities. *Aquatic Botany*. 34(1-3): 5-25. DOI: https://doi.org/10.1016/0304-3770(89)90048-X

Suwa, Hagihara, 2008 – *Suwa, R., Hagihara, A.* (2008). Seasonal changes in canopy photosynthesis and foliage respiration in a Rhizophora stylosa stand at the northern limit of its natural distribution. *Wetlands Ecology and Management*. 16: 313-321. DOI: https://doi.org/10.1007/s11273-007-9066-2

Tamayo et al., 2001 – *Tamayo, P.R., Weiss, O., Sánchez-Moreiras, A.M.* (2001). Gas exchange techniques in photosynthesis and respiration infrared gas analyser. In: Handbook of Plant Ecophysiology Techniques. Reigosa Roger, M. J. (eds.). Springer. Pp. 113-139.

Thanh et al., 2004 – *Thanh, T.D., Saito, Y., Huy, D.V., Nguyen, V.L., Ta, T.K.O., Tateishi, M.* (2004). Regimes of human and climate impacts on coastal changes in Vietnam. *Regional Environmental Change.* 4:49-62. DOI: https://doi.org/10.1007/s10113-003-0062-7

Toro et al., 2019 – *Toro, G., Flexas, J., Escalona, J.M.* (2019). Contrasting leaf porometer and infra-red gas analyser methodologies: an old paradigm about the stomatal conductance measurement. Theoretical and Experimental Plant Physiology. 31:483-492. DOI: https://doi.org/10.1007/s40626-019-00161-x

Wang et al., 2021 – *Wang, C.W., Wong, S.L., Liao, T.S., Weng, J.H., Chen, M.N., Huang, M.Y., Chen, C.I.* (2021). Photosynthesis in response to salinity and submergence in two Rhizophoraceae mangroves adapted to different tidal elevations. *Tree Physiology*. 42(5):1016-1028. DOI: https://doi.org/10.1093/treephys/tpab167

Wang et al., 2021 – *Wang, Y.S., Gu, D.J.* (2021). Ecological responses, adaptation and mechanisms of mangrove wetland ecosystem to global climate change and anthropogenic activities. *International Biodeterioration & Biodegradation.* 162: 105248. DOI: https://doi.org/10.1016/j.ibiod.2021.105248

Warner et al., 2016 – *Warner, R., Kaidonis, M., Dun, O., Rogers, K., Shi, Y., Nguyen, T.T.X., Woodroffe, C.D.* (2016). Opportunities and challenges for mangrove carbon sequestration in the Mekong River Delta in Vietnam. *Sustainability Science.* 11: 661-677. DOI: https://doi.org/10.1007/s11625-016-0359-3