



Supplement of

Predicting mangrove forest dynamics across a soil salinity gradient using an individual-based vegetation model linked with plant hydraulics

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1 Note S1: Derivation of species-specific morphological traits

Tree height (*H*, m) and crown diameter (*D*_{crown}, m) of individual trees were constrained
in the mangrove growth model using the field data-derived species-specific morphological
traits. The *H* of individuals usually obeys allometric scaling relationship expressed as

5
$$H = \beta_H \text{DBH}^{\alpha}$$
 (S1)

6 where β_H is the normalization term, α is the scaling exponent, and DBH is the diameter at breast 7 height (m) (West et al., 2009). However, mangroves probably show some flexibility in the 8 DBH-H relationship depending on environmental variables such as soil salinity (Peters et al., 9 2014). Figure S1a-b shows the compilation of DBH-H data from Fukido mangrove forest for the two species, and indeed the data showed some variabilities of *H* relative to DBH especially 10 11 for relatively large trees (DBH > 0.1 m). To allow flexibility in the DBH-*H* relationship but to 12 constrain it within the observed range, we derived two allometric relationships for H - DBH-13 maximum tree height (H_{max}) and DBH-minimum tree height (H_{min}) relationships – as follows. 14 We first binned H data with the DBH width of 0.01 m for *Rhizophora stylosa* and 0.02 m for Bruguiera gymnorrhiza, where the choice of different binning widths was attributed to the 15 16 different data densities in bins between the two species. Maximum and minimum H were then 17 extracted for each bin, and were fitted to Eq. (S1) to obtain DBH- H_{max} and DBH- H_{min} 18 relationships, respectively. Here, we removed from the fitting some binned data that could be outliers to avoid under- or overestimation of H_{max} and H_{min} . Additionally, we derived the 19 20 general allometric relationship of DBH-*H* for each species by fitting all the data to Eq. (S1). 21 This relationship was used to estimate H of trees whose H was not measured in the field as 22 described in the Section 2.2. The fitted curves are shown in Fig. S1a-b.

The parameter D_{crown} also usually follows an allometric scaling relationship, where the scaling exponent is often assumed to be 2/3 based on a metabolic scaling theory (West et al., 25 2009; Shenkin et al., 2020):

26
$$D_{\rm crown} = \beta_{\rm crown} DBH^{2/3}$$

where β_{crown} is the normalization term for crown diameters. However, crown structures are 27 significantly influenced by tree competition, resulting in variability of D_{crown} (Pretsch, 2014; 28 29 Jucker et al., 2015). Here, we assumed that the crown diameter of the allometric ideal trees (D^*_{crown}) follows Eq. (S2), where we refer to allometric ideal as the condition where the crown 30 31 expansion is not influenced by local competition. We derived the coefficient β_{crown} of D^*_{crown} 32 for the two species using a similar approach of deriving DBH- H_{max} relationships. For B. 33 gymnorrhiza, the data of D_{crown} were binned with DBH width of 0.02 m, and the maxima in 34 bins of DBH < 0.1 m were extracted. The maxima were assumed to represent D^*_{crown} and were fitted to Eq. (S2) to derive β_{crown} (Fig. S1d). We removed the maxima of DBH > 0.1 m from 35 36 fitting because of less certainty in the representation of D^*_{crown} for large trees due to data scarcity compared to smaller trees. Alternatively, D_{crown} of R. stylosa showed significantly 37 different trend from B. gymnorrhiza – none of the measured D_{crown} exceeded 2.0 m, which 38 implies the strong influence of local competition for this species. Therefore, we supplemented 39 40 the data with D_{crown} from two different mangrove forests in the Philippines and Indonesia (see 41 Note S2 for the details). Specifically, supplemented data for large trees (DBH > 0.1 m) were from relatively open canopy forests, thus it is more probable that the data represent D^*_{crown} . 42 Note that the supplemented data used are from R. apiculata and R. mucronata, which are so 43 44 far the only available data on the crown diameter of *Rhizophora* species, and may apply to *R*. stylosa. After combining the data from Fukido mangrove and other two sites, we binned the 45 46 data with DBH width of 0.02 m, and the maxima were fitted to Eq. (S2) to estimate β_{crown} for *R. stylosa* (Fig. S1c); some maxima that could be outliers were removed from the fitting. 47



49 Figure S1. Field data-derived morphological traits of Rhizophora stylosa and Bruguiera gymnorrhiza. (a–b) DBH-tree height (H) relationships and (c–d) DBH-crown diameter (D_{crown}) 50 relationships of the two species in Fukido mangrove forest. In panels (a–b), the solid and dot-51 dash lines indicate DBH-maximum height (H_{max}) and DBH-minimum height (H_{min}) 52 53 relationships, respectively, while the rectangular and triangular markers indicate the maxima 54 and minima of selected bins used for the derivation of DBH-H_{max} and DBH-H_{min} relationships, 55 respectively. The dashed lines indicate the general allometric relationship of DBH-H. In panel (c), the supplemented data from R. apiculata and R. mucronata in Bakhawan Ecopark and 56 57 Karimunjawa, and R. stylosa in Fukido were used.

58 Note S2: Supplementary data on crown diameters

Supplementary measurements of crown diameter for the genus Rhizophora were 59 conducted in a planted mangrove forest in Bakhawan Ecopark, Panay Island, Philippines and 60 a dwarf mangrove forest in Karimunjawa Island, Central Java, Indonesia. In Bakhawan 61 Ecopark, ~10- (11.7195°N, 122.3927°E), ~20- (11.7180°N, 122.3892°E), and ~30-year-old 62 63 forests (11.7180°N, 122.3911°E) were selected so that the measurement will have a wide range in tree size variability. In each forest, 20 trees were randomly selected, and the crown diameters 64 65 were measured using the same protocol as described in Section 2.2. The forests are mix of R. apiculata and R. mucronata stands, and sampled trees cover diameters at breast height (DBH) 66 67 of ~0.05 m, 0.05–0.13 m, and 0.1–0.2 m at ~10-, ~20-, and ~30-year-old forests, respectively. 68 Photographs of the canopy taken by looking upward are shown in Fig. S2a-c. The canopy of 69 ~10- and ~20-year-old forests are closed while the canopy of ~30-year-old forest is relatively open. The mangrove forest in Karimunjawa Island is a mix of natural and planted stands of *R*. 70 71 apiculata and R. mucronata. The canopy is completely open; thus, no influence of competition 72 is expected (Fig. S2d). The sampled trees cover DBH of 0.02–0.17 m.





- Figure S2. Upward-looking view of canopies in (a) ~10-, (b) ~20-, and (c) ~30-year-old forests
- 75 in Bakhawan Ecopark, and (d) view of a dwarf mangrove forest in Karimunjawa Island.

76 Note S3: Minor modification of processes in SEIB-DGVM

77 Tree establishment

78 The computational domain is divided into $1 \text{ m} \times 1 \text{ m}$ grid-cells, and the establishment 79 of a tree is simulated at each grid-cell at yearly time step according to establishment probability 80 and some criteria. The original SEIB-DGVM defines criteria of climate conditions for the 81 establishment to reproduce the global vegetation distribution (Sato et al., 2007). However, the site of model application in this study is small and the spatial variations in atmospheric 82 83 variables are not expected, thus such criteria were not considered in this study. Therefore, the environmental factor that affects the establishment is only annual-mean midday 84 85 photosynthetically active radiation at the forest floor in a grid-cell (PAR_{floor}). If PAR_{floor} > PAR_{min}, the grid-cell has the potential of new establishment of a species, where PAR_{min} is the 86 minimum PAR_{floor} required to establish the species. If several species satisfied this condition, 87 88 the species that will establish in the grid cell is determined according to the fraction of total 89 biomass of each species in the computational domain such that the dominant species has a higher probability of establishment. Simultaneously, it is sometimes randomly selected with a 90 91 probability *Est*_{random}, where the value of *Est*_{random} was set as 0.05 in this study. This corresponds 92 to Scenario 4 in the tree establishment scheme in SEIB-DGVM (see Sato, 2015 for the detail). Then, the determined species establishes at the grid cell with a probability $P_{\text{establish}}$ (m⁻² year⁻¹). 93

94 *Mortality*

Mortality occurs at a yearly time step in SEIB-DGVM. Mortality is usually modeled as
 a sum of growth efficiency mortality (*mort*greff, year⁻¹) and background mortality (*mort*bg, year⁻¹)
 in dynamic vegetation models. Additionally, SEIB-DGVM introduced heat stress- or cold
 stress-induced mortality to describe global vegetation distribution (Sato et al., 2007), but these

99 additional factors were not considered in this study for the same reason as the establishment. 100 The SEIB-DGVM also defines the maximum age that trees can survive, but it was also not 101 considered in this study due to the uncertainty in the longevity of mangroves. Also, the 102 formulation of growth-efficient mortality was replaced with the following equation which is 103 used as such in Sitch et al. (2003) and Thum et al. (2019):

104
$$mort_{greff} = \frac{k1_{mort_greff}}{1+k2_{mort_greff} \times eff_{growth}}$$
 (S3)

where $k1_{mort_greff}$ (year⁻¹) and $k2_{mort_greff}$ (m² leaf year g⁻¹ Dry Weight) are parameters and effgrowth (g DW m⁻² leaf year⁻¹) is the net primary production minus tissue turnover per unit leaf area which is described as

108
$$eff_{\text{growth}} = \frac{NPP - TO}{LA}$$
 (S4)

where *NPP* is the annual net primary production (g DW tree⁻¹ year⁻¹), *TO* is the annual wholeplant turnover demand (g DW tree⁻¹ year⁻¹), and *LA* is the whole-plant leaf area (m² leaf tree⁻¹). The equation was replaced because the original equation in SEIB-DGVM has a parameter
with a physically complicated unit.

In this study, we introduced additional mortality that is related to salt stress (*mort*salt, year⁻¹). As described in Section 2.3.2, if a tree is stressed by salt, the tree adjusts plant hydraulics from the sapwood area or root biomass (Eq. (7)). Consequentially, *H* of the tree could go below the DBH- H_{min} curve shown in Fig. S1a–b, depending on salt stress. In such a case, the tree was regarded as "salt-stressed tree" and high mortality was given. In this study, *mort*salt was set to 0.3 for salt-stressed trees and 0.0 for non-stressed trees. Then, the mortality of a tree (f_{mort} , year⁻¹) is calculated by adding each mortality factor:

120
$$f_{mort} = min(mort_{greff} + mort_{bg} + mort_{salt}, 1.0)$$
 (S5)

121 *Maintenance respiration*

122 In SEIB-DGVM, a parameter called the specific respiration rate per unit nitrogen in the plant tissue at 15.0 °C (*RM*, g DW g⁻¹ N day⁻¹) is used to calculate the maintenance respiration 123 rate of each tree organ. However, for the leaf respiration, we used the dark respiration rate per 124 unit area at 25 °C ($R_{d,25}$, µmol C m⁻² s⁻¹) instead of *RM*, which is a common parameter for leaf 125 respiration rate. For the temperature response of $R_{d,25}$, a function used in Kumarathunge et al. 126 (2019) (also see Note S4) was used. For maintenance respiration of other organs, the 127 parameters *RM*_w and *RM*_{FR} (respiration rate per unit biomass at 15.0 °C, g DW g⁻¹ DW day⁻¹) 128 for woody organ and fine root, respectively, were used instead of *RM* to adopt literature values. 129 130 Temperature response of maintenance respiration of these organs was kept the same as in the original SEIB-DGVM. Likewise, as in the original SEIB-DGVM, if the whole-plant gross 131 primary production (g C tree⁻¹ day⁻¹) is insufficient for satisfying the whole-plant demand of 132 133 maintenance respiration, the deficit is supplemented from the stock carbon pool.

134 *Crown layer purge*

In SEIB-DGVM, trees purge the bottom crown layer at yearly time step depending on the balance between resource gain and maintenance cost of the layer. Here, the resource gain of the layer is expressed using leaf-level net primary photosynthesis rate at the layer ($Crownc_{gain}$, g C m⁻² leaf day⁻¹), while the maintenance cost ($Crownc_{cost}$, g C m⁻² leaf day⁻¹) is expressed using:

140
$$Crown_{C_{cost}} = \frac{TO_1 \times C_M}{SLA \times 10^{-4}}$$
(S6)

where TO_1 is the leaf turnover rate (day⁻¹), C_M is the carbon mass per unit dry weight in plant tissue (g C g⁻¹ DW), *SLA* is the specific leaf area (cm² leaf g⁻¹), and the multiplication of 10⁻⁴ is for unit conversion of *SLA*. 144 In this study, nitrogen (N) uptake was also considered in addition to carbon uptake by 145 photosynthesis, which emerges as an additional need for the consideration of gain and cost 146 balance for N. The N uptake by a crown layer ($Crown_{N_{gain}}$, g N m⁻² leaf day⁻¹) is expressed as:

147
$$Crown_{N_{gain}} = T_{layer} \times DIN \times \frac{14}{1000}$$
 (S7)

148 where T_{layer} is the leaf-level transpiration rate at the bottom layer (mm day⁻¹), DIN is the 149 dissolved inorganic nitrogen concentration in porewater (mol N m⁻³), and the multiplication of 150 14/1000 is for unit conversion. The N cost by the layer (*Crown*_{N_cost}, g N m⁻² leaf day⁻¹) is 151 expressed as:

152
$$Crown_{N_cost} = \frac{TO_l \times C_M \times (1 - NRE)}{SLA \times CN_l}$$
 (S8)

where CN_1 is the C/N ratio in the leaf (g C g⁻¹ N), and *NRE* is the nitrogen resorption efficiency (fraction). A tree purges the crown layer if the annual mean of $Crown_{c_{gain}}$ or $Crown_{N_{gain}}$ is less than $Crown_{c_{cost}}$ or $Crown_{N_{cost}}$, respectively.

156 Note S4: Leaf flux model

157 *Leaf temperature and transpiration*

- 158 Leaf temperature and transpiration rates are calculated at each crown layer of each tree159 using the equations presented by Bonan et al. (2014); these are summarized below.
- 160 The leaf energy balance can be written by equating the net radiation $(R_{n,i}, W m^{-2})$ to the 161 sum of sensible heat flux $(H_i, W m^{-2})$ and latent heat flux $(\lambda_w E_i, W m^{-2})$ at each crown layer, 162 where the symbol "*i*" indicates crown layer index here and hereafter:

$$163 R_{n,i} = H_i + \lambda_w E_i (S9)$$

where λ_w (J mol⁻¹) is the latent heat of vaporization of water and E_i is leaf transpiration rate at crown layer *i* (mol m⁻² s⁻¹). The sensible heat flux H_i is represented as:

166
$$H_i = 2c_p (T_{l,i} - T_a)g_{bh,i}$$
 (S10)

where c_p is the specific heat of air at constant pressure (J mol⁻¹ K⁻¹), $T_{l,i}$ is the leaf temperature (K), T_a is the air temperature (K), and $g_{bh,i}$ is the boundary layer conductance for heat (mol m⁻¹ 2 s⁻¹). The parameter $g_{bh,i}$ is a function of leaf size (d_l , m) and wind speed. Here, wind speed profile within the canopy is calculated from a model proposed by Barnard and Bauerle (2016) by approximating a horizontally uniform canopy structure. Latent heat flux is given by:

172
$$\lambda_{\rm w} E_i = \frac{c_{\rm p}}{\gamma} (e_{{\rm l},i} - e_{\rm a}) g_{{\rm v},i}$$
 (S11)

173 where γ is the psychrometric constant (Pa K⁻¹) given by $\gamma = c_p P_a / \lambda_w$ with P_a atmospheric 174 pressure (Pa), $e_{1,i}$ the leaf vapor pressure (Pa), e_a the air vapor pressure (Pa), and $g_{v,i}$ the 175 conductance for water vapor (mol m⁻² s⁻¹) expressed as a series of stomatal conductance ($g_{s,i}$, 176 mol m⁻² s⁻¹) and boundary layer conductance ($g_{bv,i}$, mol m⁻² s⁻¹) with $g_{v,i} = 1/(g_{s,i}^{-1} + g_{bv,i}^{-1})$. The 177 parameter $g_{bv,i}$ is a function of leaf size and wind speed, similar to $g_{bh,i}$. It is assumed that the 178 water vapor pressure in the stomatal pore is saturated; therefore $e_{1,i}$ is a function of leaf 179 temperature $T_{1,i}$. Here, once the value of $g_{s,i}$ is given, the values of $T_{1,i}$ and $E_{1,i}$ were determined 180 from Eqs. (S9)–(S11).

181 Leaf photosynthesis

Leaf photosynthesis is calculated using the biochemical model of Farquhar et al. (1980),
which was adapted by the leaf flux model of Bonan et al. (2011) and (2014). The equations are
summarized below.

185 The net leaf photosynthesis rate at a crown layer i ($A_{n,i}$, µmol CO₂ m⁻² s⁻¹) is given by:

186
$$A_{n,i} = \min(A_{c,i} - A_{j,i}) - R_d$$
 (S12)

187
$$A_{c,i} = \frac{V_{cmax}(c_{i,i} - \Gamma_*)}{c_{i,i} + K_c (1 + o_i / K_o)}$$
(S13)

188
$$A_{j,i} = \frac{J_i(c_{i,i} - \Gamma_*)}{4c_{i,i} + 8\Gamma_*}$$
 (S14)

where $A_{c,i}$ and $A_{j,i}$ (µmol m⁻² s⁻¹) are the Rubisco carboxylation-limited and RuBP-regeneration-189 limited photosynthetic rates, respectively, R_d is the leaf respiration rate (µmol m⁻² s⁻¹), $c_{i,i}$ is the 190 intercellular CO₂ concentration (μ mol mol⁻¹), Γ * is the CO₂ compensation point (μ mol mol⁻¹), 191 $V_{\rm cmax}$ is the maximum rate of Rubisco activity (µmol m⁻² s⁻¹), o_i is the intercellular O₂ 192 concentration (209 mmol mol⁻¹), K_c (µmol mol⁻¹) and K_o (mmol mol⁻¹) are the Michaelis-193 Menten coefficients of Rubisco activity for CO_2 and O_2 respectively, and J_i is the electron 194 transport rate at a crown layer *i* (μ mol m⁻² s⁻¹), which is related to absorbed PAR at the layer 195 (APAR_{*i*}, μ mol photon m⁻² s⁻¹); these are described as: 196

197
$$\theta_{\text{PSII}} J_i^2 - (I_{\text{PSII}} + J_{\text{max}}) J_i + I_{\text{PSII}} J_{\text{max}} = 0$$
 (S15)

198
$$I_{\text{PSII}} = 0.5(1 - f)\text{APAR}_i$$
 (S16)

where θ_{PSII} is the curvature for electron transport (0.7), I_{PSII} is the PAR absorbed by PS II (µmol photon m⁻² s⁻¹), *f* is a fraction of PAR absorbed by non-photosynthetic materials (0.15), and J_{max} is the maximum electron transport rate (µmol m⁻² s⁻¹). In Eqs. (S12)–(S15), the parameters 202 V_{cmax} , J_{max} , R_d , Γ_* , K_c , and K_o vary with leaf temperature, thus the values may vary within crown 203 layers. Following Kumarathunge et al. (2019), the values and temperature responses of Γ_* , K_c , 204 and K_o were adapted from Bernacchi et al. (2001) and Medlyn et al. (2002), respectively. The 205 temperature response of V_{cmax} and J_{max} are given by the peaked Arrhenius function:

206
$$k_1(T_v) = k_{25} \times \exp\left[\frac{E_a(T_v - 298.15)}{298.15RT_v}\right] \frac{1 + \exp\left(\frac{298.15\Delta S - H_d}{298.15R}\right)}{1 + \exp\left(\frac{T_v\Delta S - H_d}{T_vR}\right)}$$
 (S17)

207 while the temperature response of R_d is given by:

208
$$k_2(T_v) = k_{25} \times \exp\left[\frac{E_a(T_v - 298.15)}{298.15RT_v}\right]$$
 (S18)

where $k_1(T_v)$ and $k_2(T_v)$ are the process rates at a given temperature, T_v (K), k_{25} is the process rate at 25 °C, *R* is the universal gas constant (J K⁻¹ mol⁻¹), E_a is the activation energy (J mol⁻¹), H_d is the deactivation energy (J mol⁻¹), and ΔS is the entropy term (J K⁻¹ mol⁻¹).

Gas exchange is regulated by the diffusion process between the atmosphere and the leaf through the stomata. The net photosynthesis rate $A_{n,i}$ can also be expressed using the diffusive rate given by:

215
$$A_{n,i} = \frac{(c_a - c_{i,i})}{1.4g_{bv,i}^{-1} + 1.6g_{s,i}^{-1}}$$
(S19)

where c_a is the atmospheric CO₂ concentration (µmol mol⁻¹), $c_{i,i}$ is the intercellular CO₂ concentration (µmol mol⁻¹), $g_{s,i}$ and $g_{bv,i}$ are the stomatal conductance and boundary layer conductance for water vapor (mol m⁻² s⁻¹), respectively, and the factor 1.4 and 1.6 are for adjusting the diffusivity of CO₂ compared with H₂O for the boundary layer and stomatal conductance (Bonan, 2019). The value of $A_{n,i}$ can then be obtained once the value of $g_{s,i}$ is given by equating Eqs. (S12) and (S19).

222 Stomatal conductance optimization

The leaf transpiration rate, temperature, and photosynthetic rate at a crown layer depend on stomatal conductance at the layer. Here, the stomatal conductance at a layer, $g_{s,i}$, is estimated from the optimization theory. The theory assumes that plants regulate stomatal conductance to keep the marginal water use efficiency (WUE) constant (Cowan and Farquhar, 1977), which has been used in the models of Bonan et al. (2014) and Xu et al. (2016). The stomatal conductance is optimized at each crown layer to achieve the condition:

$$229 \quad \frac{\mathrm{d}A_{\mathrm{n},i}}{\mathrm{d}g_{\mathrm{s},i}} - \lambda \frac{\mathrm{d}E_i}{\mathrm{d}g_{\mathrm{s},i}} = 0 \tag{S20}$$

230 where λ is the Lagrangian multiplier of the optimization problem representing optimal WUE. This is a condition that indicates that the further opening of stomata does not yield a sufficient 231 232 carbon gain per unit water loss, characterized by λ (Bonan et al., 2014). We followed Bonan et 233 al. (2014) for the numerical solution of $g_{s,i}$. The value of λ increases as leaf water potential (Ψ_1 , MPa) declines, as shown by a meta-analysis of Manzoni et al. (2011), where the increased λ 234 235 generally leads to the regulation of stomatal conductance, resulting in decreased A_n and E. Then, 236 following Xu et al. (2016), λ is determined at daily time step considering predawn leaf water 237 potential ($\Psi_{l,predawn}$, MPa):

238
$$\lambda = \lambda_0 \exp(\beta_0 \Psi_{l, \text{predawn}})$$
 (S21)

where λ_0 is the value of optimal WUE when there is no stress imposed by the decreased leaf water potential, and β_0 is an empirical parameter representing stomatal sensitivity. Additionally, when Ψ_1 falls below a species-specific minimum value given by $\Psi_{l,min}$, the model simulates stomatal closure to prevent further decrease in Ψ_1 that may cause xylem cavitation (Bonan et al., 2014).

244 Note S5: Daily C and N resources for tree growth

From the plant hydraulics module coupled with the photosynthesis module described in the section 2.3.1 and Note S4, the daily C (C_{gain} , g C tree⁻¹ day⁻¹) and N (N_{gain} , g N tree⁻¹ day⁻² uptake rates were calculated, where N_{gain} is given by:

248
$$N_{gain} = J_{sap,day} \times DIN \times \frac{14}{\rho_w} \approx T_{whole,day} \times DIN \times \frac{14}{\rho_w}$$
 (S22)

where, $J_{sap,day}$ and $T_{whole,day}$ are the daily sap flow and whole-plant transpiration rates (kg tree⁻¹) 249 day⁻¹), DIN is the dissolved inorganic nitrogen concentration in the porewater (mol N m⁻³), $\rho_{\rm w}$ 250 is water density (kg m⁻³), and the factor 14 is for unit conversion of N from molar to gram 251 252 concentration. Although the sap flow and whole-plant transpiration rates may differ at a short 253 time step (e.g., hourly), these are equivalent at relatively a long time scale (e.g., daily); therefore, $J_{sap,day} \approx T_{whole,day}$. The C_{grow} (daily C resources that can be used for tree growth, g C 254 tree⁻¹ day⁻¹) was calculated from C_{gain} using the following steps: subtraction for the whole-plant 255 256 woody and root maintenance respiration and C cost for turnover compensation after accounting 257 for growth respiration, and subtraction/addition of C deficit/surplus in the stock pool from the 258 target value characterized by a parameter β_{stock} (Table 1). Likewise, N_{grow} (daily N resources 259 that can be used for tree growth, g N tree⁻¹ day⁻¹) was calculated from N_{gain} by subtraction of N cost for turnover compensation, the addition of N resorbed from the senescent leaves 260 261 characterized by a parameter NRE (Table 1), and subtraction/addition of N deficit/surplus in the stock pool from the target value. Suppose Cgain or Ngain is insufficient for compensating the 262 263 respiration (only for C_{gain}) and turnover cost, the deficit is supplemented from the stock pool, 264 where the growth respiration is accounted for in the case of C compensation for the turnover 265 cost.

266 Note S6: Crown diameter expansion

267 When biomass is allocated to leaves in a tree, the model simulates the increase of crown 268 area or leaf area index (LAI) of the tree, depending on the crown morphology at a specific time. 269 We considered that plants preferentially increase crown area rather than LAI to increases their 270 occupied space if the expansion of crown diameter (D_{crown}) is not inhibited by allometric 271 (D^*_{crown}) or physical ($D_{crown.con}$) constraints. The crown diameter expansion is also beneficial 272 in terms of plant productivity because the increase in LAI attenuates radiation within the crown 273 more rapidly, decreasing the photosynthetic and transpiration rates per unit leaf area.

If an increase in leaf biomass is given by dM_L (g leaf tree⁻¹ day⁻¹) and the crown diameter expansion is not inhibited ($D_{crown} < \min(D^*_{crown}, D_{crown,con})$), the tree expands its crown by keeping the same LAI as follows:

277
$$\frac{M_{\rm L}}{A_{\rm crown}} = \frac{M_{\rm L} + dM_{\rm L}}{A_{\rm crown} + dA_{\rm crown}}$$
(S23)

where A_{crown} is the crown area, and dA_{crown} is the increase in crown area due to crown diameter expansion. Crown diameter after the expansion is then calculated from the value (A_{crown} + dA_{crown}).

| 282 | Table S1. Summary of environmental and vegetation variables at survey plots. AGB = above- |
|-----|---|
| 283 | ground biomass, DBH = diameter at breast height, $R.s = Rhizophora stylosa$, $B.g = Bruguiera$ |
| 284 | gymnorrhiza. The names of transects are indicated as A–D while plots along a transect line are |
| 285 | numbered from the nearest creek to landward (Fig. 1c). |

| Plot | Soil salinity (psu) | Porewater NH4 ⁺ $(\mu mol L^{-}$ | Porewater NO ₃ ⁻ $(\mu mol L^{-}$ | Porewater DIN (µmol L ⁻ | AGB (Mg ha ⁻ ¹), <i>R.s</i> | AGB (Mg ha ⁻ ¹), <i>B.g</i> | Mean DBH (m), <i>R.s</i> | Mean DBH (m), <i>B.g</i> |
|------------|---------------------------|---|---|--|--|--|-----------------------------------|-----------------------------------|
| A1 | 32.8 | 190 | 21 | 212 | 92 | 1 | 9.1 | 6.1 |
| A2 | 32.53 | 219 | 31 | 250 | 87 | 23 | 9.9 | 9.5 |
| A3 | 33.0 | 238 | 22 | 260 | 63 | 30 | 9.1 | 7.3 |
| A4 | 29.7 | 49 | 5 | 54 | 69 | 38 | 8.3 | 8.4 |
| A5 | 29.9 | 69 | 8 | 76 | 10 | 19 | 6.2 | 10.7 |
| B 1 | 31.2 | 154 | 5 | 159 | 71 | 39 | 9.9 | 9.5 |
| B2 | 31.7 | 272 | 7 | 279 | 87 | 26 | 10.4 | 9.1 |
| B3 | 29.3 | 293 | 8 | 302 | 94 | 29 | 9.8 | 9.7 |
| B4 | 27.8 | 124 | 4 | 129 | 108 | 19 | 10.3 | 12.2 |
| B5 | 27.2 | 83 | 4 | 87 | 0 | 127 | - | 17.0 |
| B6 | 24.1 | 98 | 9 | 107 | 0 | 144 | - | 23.9 |
| B7 | 25.3 | 119 | 26 | 145 | 4 | 110 | 13.7 | 14.2 |
| C1 | 29.3 | 115 | 6 | 121 | 0 | 180 | - | 16.5 |
| C2 | 30.0 | 143 | 11 | 154 | 0 | 124 | - | 14.4 |
| C3 | 24.5 | 186 | 20 | 206 | 16 | 120 | 12.8 | 15.0 |
| C4 | 27.6 | 242 | 29 | 272 | 0 | 143 | - | 15.2 |
| C5 | 31.7 | 262 | 20 | 283 | 11 | 143 | 12.3 | 10.5 |
| D1 | 28.7 | 233 | 15 | 249 | 16 | 122 | 12.2 | 11.4 |
| D2 | 30.7 | 247 | 18 | 265 | 12 | 114 | 9.5 | 13.4 |
| D3 | 29.0 | 290 | 20 | 311 | 40 | 59 | 9.3 | 8.6 |
| D4 | 26.2 | 181 | 9 | 190 | 0 | 185 | - | 19.3 |
| D5 | 19.0 | 183 | 8 | 191 | 0 | 197 | - | 19.4 |
| D6 | 22.2 | 167 | 11 | 178 | 0 | 152 | - | 20.6 |
| D7 | 20.8 | 312 | 19 | 332 | 0 | 184 | - | 16.9 |

| Symbol | Description | Units | R. s | B.g | Source |
|--------------------------|--|---|----------------------|----------------------|----------------------------|
| C _M | Carbon mass per unit dry weight in plant tissue | g C g ⁻¹ DW | 0.45 | 0.45 | Alongi (2003) |
| <i>a</i> 1 | Correction factor for tree height to water path length | - | 1.2 | 1.2 | Xu et al. (2016) |
| $F_{ m gr}$ | Growth respiration fraction | Fraction | 0.25 | 0.25 | Arora (2002) |
| PAR _{min} | Minimum PAR _{floor} required for establishment | µmol photon m ⁻² s ⁻¹ | 100 | 100 | |
| $P_{ m establish}$ | Establishment probability | m ⁻² year ⁻¹ | 0.1 | 0.1 | |
| k1mort_greff | Mortality parameter in Eq. (S3) | year-1 | 0.1 | 0.1 | |
| k2mort_greff | Mortality parameter in Eq. (S3) | m ² leaf year g ⁻¹ DW | 0.03 | 0.03 | |
| mortbg | Background mortality rate | year-1 | 0.007 | 0.007 | Fisher et al. (2010) |
| $RM_{ m W}$ | Maintenance respiration rate of woody organ at 15 °C | g DW g ⁻¹ DW day ⁻¹ | 6.5×10 ⁻⁵ | 6.5×10-3 | Vinh et al. (2019) |
| $RM_{\rm FR}$ | Maintenance respiration rate of fine root at 15 °C | g DW g ⁻¹ DW day ⁻¹ | 4.3×10 ⁻³ | 4.3×10 ⁻³ | Lovelock et al. (2006) |
| <i>R</i> _{d,25} | Dark leaf respiration rate at 25 °C | µmol C m ⁻² s ⁻¹ | 1.2 | 1.2 | Aspinwall et al. (2021) |
| $J_{ m max,25}$ | Maximum electron transport rate at 25 °C | $\mu mol \ C \ m^{-2} \ s^{-1}$ | $1.54 \times V_{cr}$ | nax,25 | Aspinwall et al. (2021) |
| $E_{\rm aV}$ | Activation energy of the maximum rate of Rubisco activity (V_{cmax}) | J mol ⁻¹ | 108200 | 108200 | Aspinwall et al. (2021) |
| $E_{ m aJ}$ | Activation energy of the maximum electron transport rate (J_{cmax}) | J mol ⁻¹ | 73100 | 73100 | Aspinwall et al. (2021) |
| $E_{ m aR}$ | Activation energy of the dark leaf respiration rate (R_d) | J mol ⁻¹ | 46400 | 46400 | Bonan et al. (2014) |
| $H_{ m dV}$ | Deactivation energy of $V_{\rm cmax}$ | J mol ⁻¹ | 200000 | 200000 | Kumarathunge et al. (2019) |
| $H_{ m dJ}$ | Deactivation energy of J_{cmax} | J mol ⁻¹ | 200000 | 200000 | Kumarathunge et al. (2019) |
| $\Delta S_{\rm V}$ | Entropy of V _{cmax} | J K ⁻¹ mol ⁻¹ | 655 | 655 | Aspinwall et al. (2021) |
| $\Delta S_{ m J}$ | Entropy of J_{cmax} | J K ⁻¹ mol ⁻¹ | 655 | 655 | Aspinwall et al. (2021) |
| d_1 | Leaf dimension | m | 0.1 | 0.1 | . , |

| Table S2. Summary of model parameters not shown in Table 2 |
|--|
|--|



Figure S3. Example of prop root allometry in Fukido mangrove forest. The parameter M_{AR} is 290 291 above-ground root (prop root) biomass, and M_s is stem biomass. The parameter M_s was 292 calculated from the diameter at breast height (DBH), tree height (H), and wood density (ρ) 293 using Eq. (1); *H* was calculated from the general allometric relationship shown in Fig. S1a. The prop root biomass was calculated by multiplying the prop root volume and ρ ; the prop root 294 295 volume was estimated from DBH and prop root diameter using the empirical model developed 296 for Fukido mangrove forest in Yoshikai et al. (2021). Here, the prop root diameter was set as 297 0.03 m based on field data. For trees with DBH < 0.03 m, the value computed for the tree with DBH = 0.03 m was applied. Note that H does not always follow the general allometric 298 299 relationship in the simulation, therefore the prop root biomass fraction may vary from the one shown here. 300





Figure S4. (a) Stem growth rate and (b) mean individual relative growth rate (RGR) of *R*. stylosa (*R*. s) and *B. gymnorrhiza* (*B. g*) along the soil salinity gradient. From each ensemble simulation, the modeled stem growth rate and mean RGR in steady states (> 300 years) were extracted and pooled for all ensembles, and the mean (circle marker) and standard deviation (error bar) values of the pooled samples were shown. The line and shade show the mean and standard deviation of data measured by Ohtsuka et al. (2019) in a *B. gymnorrhiza*-dominated site in Fukido mangrove forest.



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Figure S5. Results of "plot-wise simulation". Comparison of modeled and field-measured AGB at survey plots in Fukido mangrove forest, where panel (a) is a case where spatially averaged DIN (200 μ mol L⁻¹) was given while panel (b) is a case where plot-wise DIN is given. The results shown are from one simulation, where modeled AGB in steady states (> 300 years) was extracted and the median (circles) and the 90-th percentile (bars) were shown.





Figure S6. Sensitivity of above-ground biomass (AGB) of *R. stylosa* (*R. s*) and *B. gymnorrhiza*(*B. g*) across a soil salinity gradient to changes in parameter values of plant hydraulic traits:

318 sensitivity to (a, b) salt filtration efficiency (ε), (c, d) water potential at which 50% of xylem conductivity is lost (P₅₀), (e, f) critical leaf water potential (Ψ_{lk}) and minimum leaf water 319 potential ($\Psi_{l,min}$), and (g, h) sensitivity of marginal water use efficiency to leaf water potential 320 (β_0) . Sensitivities were examined by changing a value of one species (*R*. s or *B*. g) to the one 321 322 determined for the other species shown in Table 2. Median (solid line) and 90-th percentile 323 (shading) of AGB in steady states (> 300 years) are shown; the results are from one simulation without the ensemble approach, which caused some fluctuations in AGB along the soil salinity 324 325 gradient.



327 Figure S7. Modeled relationships of (a, b) shoot/root biomass ratio, (c, d) whole-plant leaf area (LA)/sapwood (A_{sap}) ratio, and (e, f) tree height (H) with DBH under different soil salinity 328 329 conditions. From each ensemble simulation result from 300–450 years, which is in steady states in terms of forest structural variables, the modeled individual trees' variables were extracted 330 331 every 10 years. The extracted samples were pooled for all ensemble simulations. The pooled samples were then binned with DBH width of 0.02 m, and the median value in each bin was 332 333 shown. Here, the shoot biomass refers to the sum of stem and leaf biomass, and the root 334 biomass refers to the sum of coarse and fine root biomass. Note that the above-ground root biomass (of R. stylosa) is not included in the shoot biomass both in the model result and the 335 336 data of Comley and McGuiness (2005). Also, note that Komiyama et al. (2005) data include B. 337 gymnorrhiza and B. sexangla. See Note S1 and Fig. S1 for field-data derived general DBH-H relationship details. 338

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