Population dynamics of a Sonneratia caseolaris *stand in the Lam River estuary of Vietnam: a restoration perspective*

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ORIGINAL PAPER

Population dynamics of a *Sonneratia caseolaris* stand in the Lam River estuary of Vietnam: a restoration perspective

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Abstract

Species composition, age distribution, and their relationship with land height from the datum line (LH) of the *Sonneratia caseolaris* stand, which grows in the Lam River estuary in Vietnam, were surveyed to obtain fundamental knowledge that aimed at contributing to mangrove restoration. The data gathered on the sandbar consists of three mangrove species and one mangrove associate species, with one non-mangrove species, and were divided into three communities. In terms of the age distribution of the *S. caseolaris–Aegiceras corniculatum* community, the tree-phase densities for both species are lower than those exhibited by younger phases. In its succession, the seedlings of *S. caseolaris* and *A. corniculatum* are primarily recruited at the mean tide level (MWL) in the early stages. Then, *A. corniculatum* expands to the lower tide zone primarily on mud flat bare land. For both species, full irradiance on the bare land in the low tide zone below MWL is crucial for growth, but *S. caseolaris*, which propagates by releasing small seeds, can barely survive in the low tide zone because its seeds are easily flushed away. In contrast, *A. corniculatum*, which propagates using crypto-viviparous seedlings, has a higher survival rate in the low tide zone. As a result, the LH of seedlings of *A. corniculatum* distribution is significantly lower than that of the distribution of *S. caseolaris* trees ($p < 0.05$). It is important to provide appropriate environmental conditions for forest restoration in order to promote succession. The findings from the current study on population dynamics related to LH and tidal conditions are expected to be applied to platforms for *S. caseolaris* stands and mangrove restoration.

Keywords *A. corniculatum* · Age classification · Seedlings · Crypto-viviparous · Succession

Introduction

The deforestation and degradation of mangrove forests due to conversion of mangroves to shrimp–culture ponds are still big concerns in Vietnam despite the increasing awareness of the value of mangrove ecosystems in the world (FAO 2008; Hong et al. 2020). Hung Hoa commune, Nghe An province in North Central Vietnam, is one of the regions where shrimps are widely cultured in the ponds and the area has been expanded since dike roads were constructed in 2005, providing convenient transport infrastructure to the region. The shrimp–culture pond area was 310 ha in 2018, and was mainly converted from mangroves. This represents a 1.6-fold increase prior to road construction, according to Hung Hoa Commune People's Committee. In general, shrimp–culture ponds can be used for 3–4 years after construction, and after which these become prone to diseases (Khoon et al. 2004). Thus, Takahashi et al. (2019) made recommendations to restore mangroves using an ecological restoration approach for recovering regional ecosystems. To implement this approach, the stand structure and population dynamics of regional mangroves need be understood (Lewis 1999).

Sonneratia caseolaris is one of the most widely distributed mangrove species which can be found in the Northern to Southern regions in Vietnam (UNEP 2008), and is also the most predominant species in Hung Hoa commune (Takahashi et al. 2020). It grows in bed alluvial sediments in the estuary as a canopy-forming species. It often forms a community with shrubs and herbs (UNEP 2008). In the

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Lam River estuary, *S. caseolaris* forms a community with *Aegiceras corniculatum* in the understory (Tang et al. 2020; Takahashi et al. 2020). Likewise, the species composition of *S. caseolaris* matured stands has been well-investigated; however, there is less information on the stand structure in the early stages of succession along with age distribution. These are required for planning for ecological restoration.

S. caseolaris stands in the coast of North Vietnam and grows on the newly accreted mud flat submerged by the mean tide during the pioneer stage. As the population expands with the development of the canopy at the mixed stage, it forms a community with *A. corniculatum*, *Acanthus ilicifolius,* and *Cyperus malaccensis,* which can be found growing in understories (Hong and San 1993). Its described succession, however, did not mention population dynamics considering seedling recruitment with regards to its relationship with accompanying species. There have been some reports stating that *S. caseolaris* seedlings are not affected by other species due to its different niche selection (Zan et al. 2003), however, these reports were based on exclusive *S. caseolaris* plantations. Thus, the competitive relationship of *S. caseolaris* with other mangrove species in natural *S. caseolaris* stands may be different from other plantations.

On the other hand, *A. corniculatum* is a pioneer species and its seedlings are established on mud flats and underneath sparse canopies (Jiang et al. 2019). It occasionally replaces mangrove forests following deforestation (Hinrichs et al. 2009). It was reported that the propagules are buoyant and reaches the intertidal zone, and the seedlings mainly dominate the lower tidal zone in competition with *Avicennia marina* (Clarke 1995). However, there have only been a few studies on seedling dynamics in competition with *S. caseolaris*.

With the background mentioned above, this study aims to elucidate the following: (1) species composition and (2) age structure of main component species and the geomorphological traits of the *S. caseolaris* stand in the Lam River estuary to understand the population dynamics of some mangrove species at the early successional stage for obtaining fundamental knowledge to contribute to mangrove restoration.

Methods

Study site

Hung Hoa commune Nghe An province, located at the Lam River estuary in North Central Vietnam (18°41′24″ N, 105°45′38″ E) (Fig. 1a). The study was conducted on the *S. caseolaris* young stands in the canal connected to the Lam River (Fig. 1b, c). There is a gate for irrigation to shrimp–culture ponds, it is operated irregularly, and water moves in and out, corresponding to tide fluctuations. The mean water level (MWL) is 1.71 m from the datum line (at Cua Hoi; 18°48′ N, 105°46′ E) and the mean high-water level (MHWL) and the mean low water level (MLWL) at spring tide are 2.70 m and 0.49 m from the datum line, respectively (Center for Oceanography 2018) (Fig. 2).

The climate in Nghe An province is affected by South West monsoon from May to October. It is rainy and the temperature reaches 30–35 °C, and is affected by the North East monsoon from November to April. It is dry and the temperature is low at 14–16 °C during this time (Giang et al. 2014). The average annual rainfall in Vinh city (18°40′ N, 105°40′ E) is 1,968 mm year^{-1} (Averyanov et al. 2003), the rainfall intensity during the rainy season is 3.0–3.7 times higher than what occurs during the dry season (rainy season: 71.8 ± 11.9 mm h^{-1}; dry season: 24.1 ± 10.3 mm h^{-1} from June 2017 to May 2018) (Tang et al. 2020).

The Lam River originates from the Nam Can area in Laos, flowing for 556 km mainly through Nghe An province, and flowing into Tonkin Bay (Vinh City People's Committee et al. 2011; World Bank 2012). The average downstream discharge of the Lam River (19.3 km from the study site at Chotrang, Hung Nguyen district) during the rainy and dry seasons are 1248.5 ± 324.4 m^3 s^{-1} and 458.8 ± 129.8 m^3 s^{-1}, respectively. The water salinity during the rainy and dry seasons are 0.4 ± 0.2 ppt and 5.1 ± 1.1 to 7.5 ± 2.8 ppt, respectively. The soil salinity of the riverbank when covered and uncovered with mangroves is reportedly from 3.8 ± 0.5 ppt to 5.9 ± 0.8 ppt (Tang et al. 2020).

Geomorphological survey

Transects of four meters in width (2 m for both sides from the center line) from shoreline to the end of vegetation were set up on the sandbar (three transects: SB1–SB3) and in the canal bank (eight transects: CB1–CB8; Fig. 1b, c). Above the center line of the transect, the tape measure was set up horizontally and perpendicular to the shoreline kept by a level and a compass, and the height from the land surface to the tape measure was recorded every 2.5 m or less at the SB1–SB3 and every meter at the CB1–CB8. Field measurements were converted to land height from the datum line (LH) based on the tide fluctuation chart in Cua Hoi (Center for Oceanography 2018). Cross-leveling at SB1 SB2, and SB3 was conducted on June 9th, July 12th and 13th, 2019, respectively, and cross-leveling at CB1–CB4 and CB5–CB8 was conducted on July 15th and 16th, 2019, and on September 15th and 16th, 2019, respectively.

Species distribution and relation to land height

Every species occurring in the transects (SB1–SB3) and land coverage by the crown or the plant body of herbs were recorded every 5 m or less, i.e., the size of each rectangle is

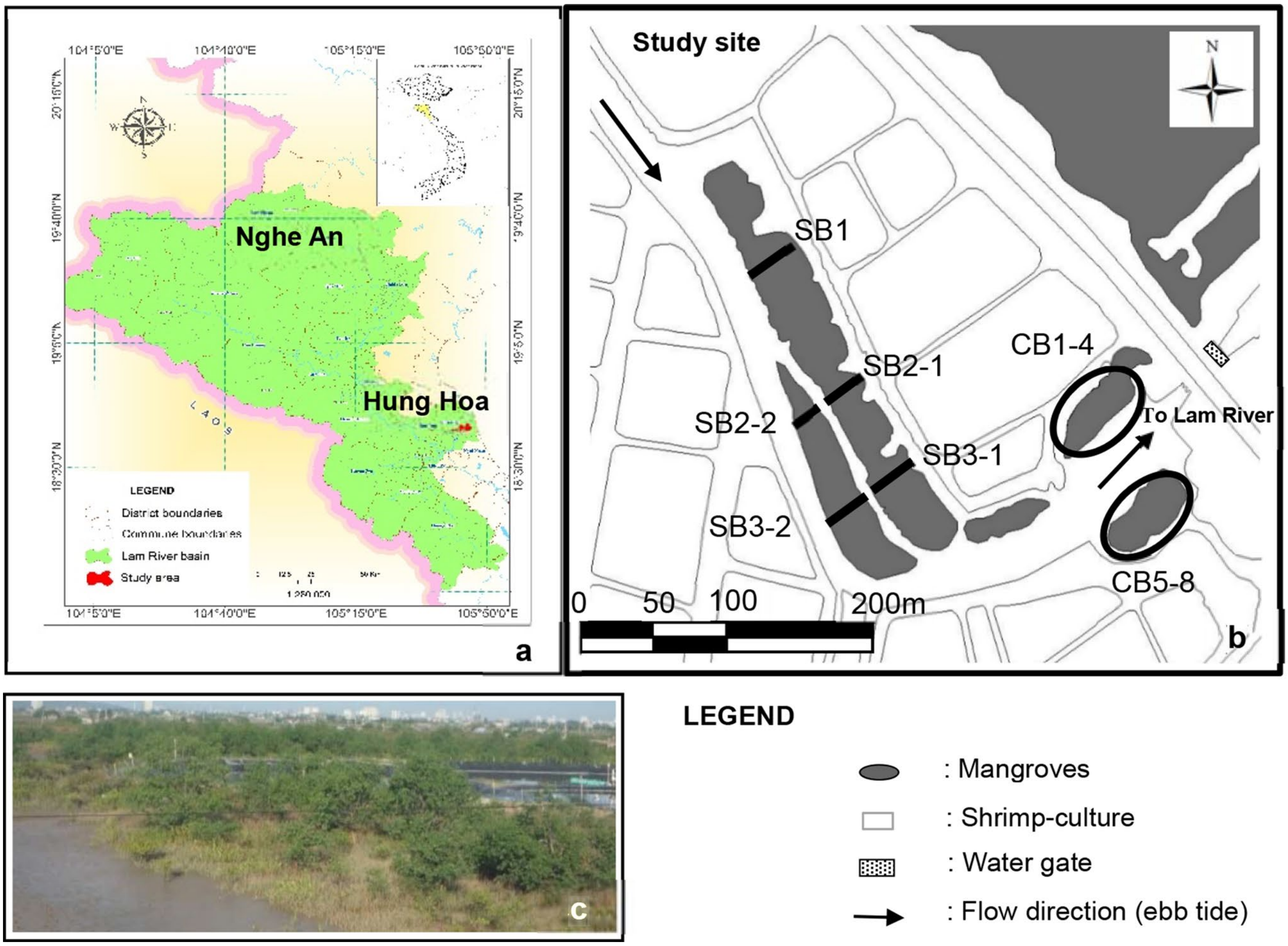


Fig. 1 Study area and study site. **a** Location of Nghe An province and Hung Hoacommune; **b** Study site, SB1–SB3 on the sand bar and CB1–CB8 in the canal bank; **c** Mangroves in the canal bank where CB1–CB4 were set up

4 m × 5 m or less. The LH of the species was represented by the median in LH of the center line for each rectangle. The survey was conducted at the same time that cross-leveling was conducted.

Age distribution of *S. caseolaris* and *A. corniculatum*

Every plant individual found in the transects (CB1–CB8) was recorded with species name, its position and LH, growth phase, plant height, and diameter. Position was described using two parameters: distance from the shoreline (vertical axis) and distance from the center line (horizontal axis). In case that herbaceous plants were distributed as a colony, their distribution ranges on the vertical and horizontal axes were recorded. The LH of each individual plant was represented by that on the center line. For *S. caseolaris* and *A. corniculatum*, the growth phase was divided into three age classifications: seedlings (height ≤ 30 cm), saplings (height > 30 cm, diameter < 10.2 cm) and trees (diameter ≥ 10.2 cm) (Good and Good 1972). The tree-phase of both species has reproductive ability based on the observations in the study site. The diameter was measured at the intermediate point of tree height (tree height < 2.6 m), except for *S. caseolaris.* The individuals of these plants have breast height diameters (at 1.3 m, tree height ≥ 2.6 m) that can be measured (Batcheler and Craib 1985). If trees are branched, the diameters of all the branches were measured. Tree height and diameter were not measured for individual trees with heights less than 30 cm and with diameters less than 1 cm. The survey was conducted at the same time that cross-leveling was conducted.

Relationship between seedling density and bare land ratio

Vegetation in the lower layer, inside the transects (CB1–CB8) were divided into two patterns: one was densely covered with herbaceous colonies of *C. malaccensis*, and another one did not have colonies of *C. malaccensis* (bare land). The ratio of the bare land to total transect area was

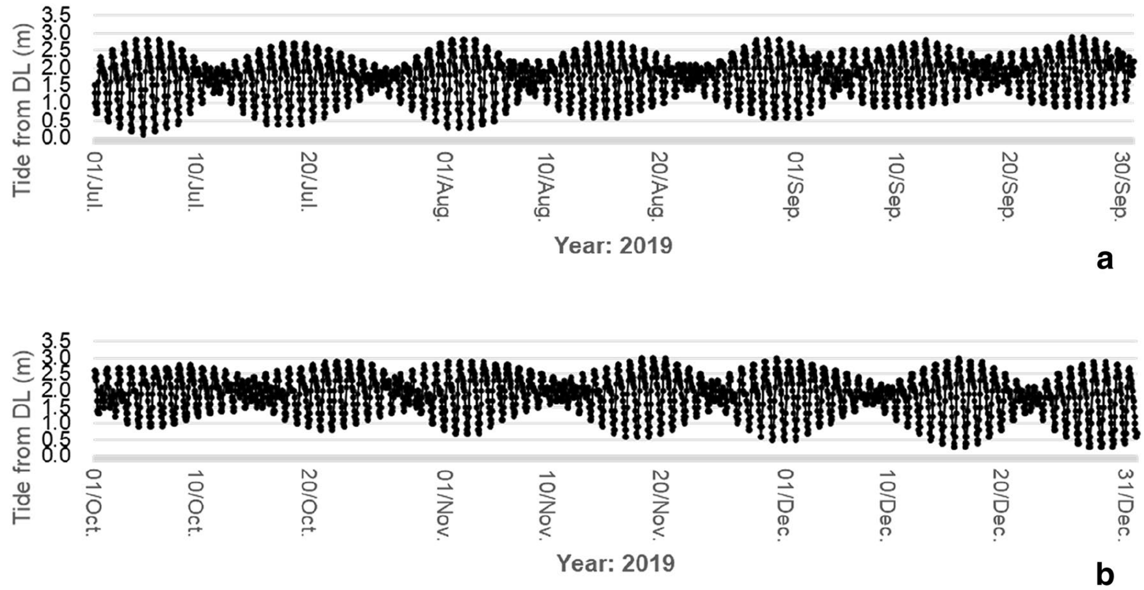


Fig. 2 Tidal changes estimated by Center for Oceanography (2018). **a** From July 1st to September 30th, 2019, growth phase; **b** from October 1st to December 31st, 2019, reproductive phase of the *S. caseolaris* stands

calculated for each transect (bare land ratio) by the Eq. (1), and the relationships between seedling density and bare land ratio among transects were compared.

$$\mathrm{BLR}(\%) = \frac{\mathrm{BLA}\left(\mathrm{m}^2\right)}{\mathrm{TA}\ \left(\mathrm{m}^2\right)} \times 100 \tag{1}$$

where BLR is Bare Land ratio, BLA is Bare Land Area, total area (TA) is Transect area in total.

Seedling density was calculated separately for *S. caseolaris* and *A. corniculatum*. The dominant species covering the land in the canal bank is *C. malaccensis* (Fig. 1c).

Results

Communities and distribution pattern

Table 1 is a summary of the vegetation survey on the sandbar, indicating plant communities growing on it. *S. caseolaris* is widely distributed, forming a sparse canopy for all transects. The *S. caseolaris* stand on the sandbar can be divided into three communities, focusing on component species in the shrub/herbaceous layer. The first one is a community with *A. corniculatum* in understory (Sc + Ac community), including subcommunity with less coverage of *A. corniculatum*, but more coverage of *C. malaccensis* and *Acanthus* sp. (Sc + Ac + Cm + Acn subcommunity). The second one is a community with *A. corniculatum* and *C. malaccensis*, having sparse coverage of *S. caseolaris* in the tree layer (Ac + Cm community), including subcommunity

Table 1 Mangrove communities and its dominant species

No.	Community	Sub-community	Tree layer	Shrub/herb layer				Transect
			S. caseolaris	*A. corniculatum*	*C. malaccensis*	*Acanthus* sp.	*P. australis*	
I	Sc + Ac	-	+	++++	--	--	-	SB2-2
		Sc + Ac + Cm + Can	+	+	+	+++	-	SB3-2
II	Ac + Cm	-	--	++	+++	-	-	SB3-1
		Ac + Cm + Pa	--	++	+	--	++	SB1
III	Pa	-	--	--	--	--	+++++	SB2-1

Average land coverage (%): - indicates no coverage, -- is coverage of less than 10 %, + indicates 10 %

containing *Phragmites australis* (Ac + Cm + Pa sub-community). The third one is the community dominated by *P. australis* (Pa community).

The habitats of the three communities were characterized by LH. Ac + Cm community in the transects SB1 and SB3–1 is distributed mainly from 125 to 150 cm in LH below MWL (MWL: 171 cm in LH). However, Pa community in the transect SB2–1 is distributed around MWL. Sc + Ac community in the transects SB2-2 and SB3-2 is distributed widely in LH from below to above MWL; approximately from 120 to 195 cm in LH (Fig. 3).

Component species of the *S. caseolaris* stand

Table 2 displays component species of the *S. caseolaris* stand in the canal bank. It includes the species occurring

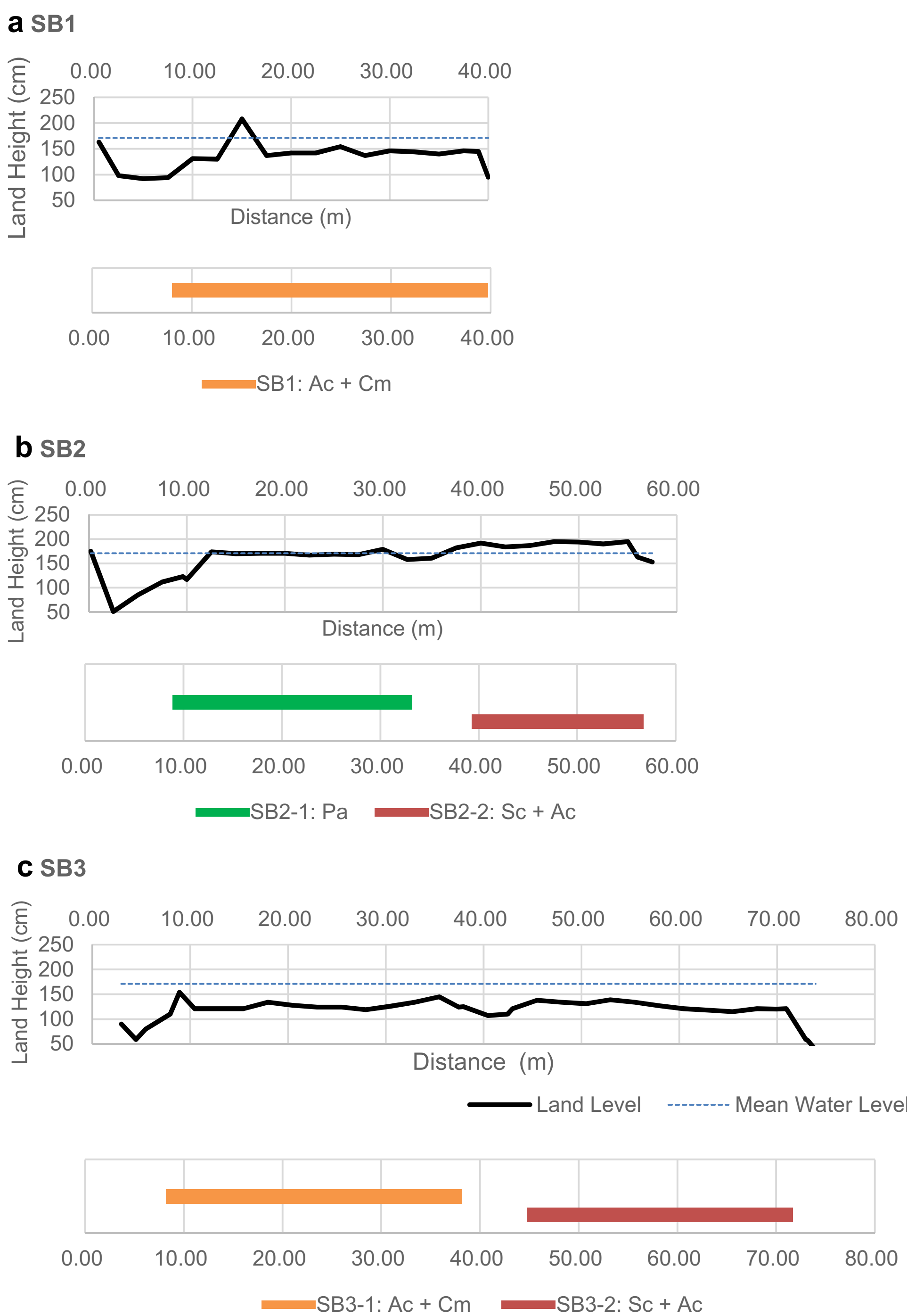


Fig. 3 Cross section of the sandbar and plant community distribution pattern. **a** SB1; **b** SB2; **c** SB3. Ac, Cm, Pa, Sc stand for *A. corniculatum*, *C. malaccensis*, *P. australis*, *S. caseloaris*, respectively

Table 2 Species composition of the *S. caseolaris* stand (canal bank)

Species	Life form	Growth stage	Density (indv./m^2)	Plant height (cm)	Diameter (cm)
Sonneratia caseolaris	Wood	Tree	0.012 ± 0.005	378.50 ± 32.11	20.03 ± 4.42
		Sapling	0.044 ± 0.011	184.25 ± 16.68	4.61 ± 0.43
		Seedling	0.003 ± 0.003	≤ 30.00	–
Aegiceras corniculatum	Shrub	Tree	0.019 ± 0.011	131.13 ± 5.65	24.10 ± 2.68
		Sapling	0.083 ± 0.022	90.74 ± 4.27	3.59 ± 0.47
		Seedling	0.068 ± 0.028	≤ 30.00	–
Cyperus malaccensis[a]	Herb		Dense	–	–
Acanthus sp.	Herb		Spotted	–	–
Acrostichum aureum	Fern		Spotted	–	–
Crinum asiaticum[a]	Herb		Spotted	–	–
Derris trifoliata[a]	Shrub		Spotted	–	–

[a]Indicates mangrove associates, others are true mangrove species (UNEP 2008)

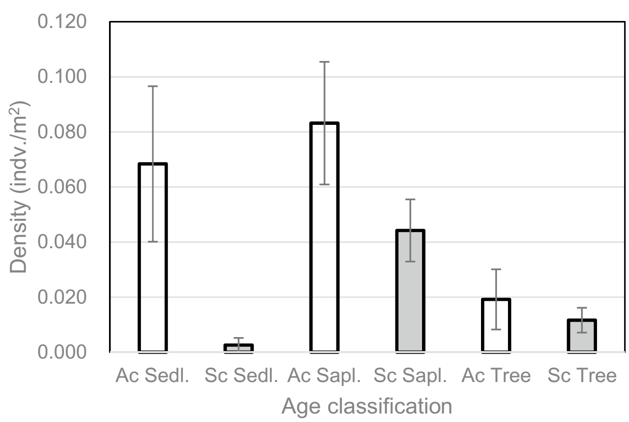


Fig. 4 Age distribution of *S. caseolaris* and *A. corniculatum*. Mean values with standard errors (SE) are shown for measurements of density. Ac and Sc stand for *A. corniculatum* and *S. caseolaris*, respectively. Sedl. and Sapl. stand for seedlings and saplings, respectively

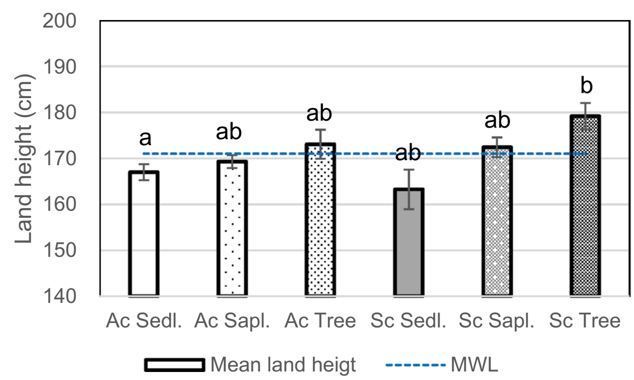


Fig. 5 LH distribution of *A. corniculatum* and *S. caseolaris*. Mean values with standard errors (SE) are shown for measurements of land height. Lowercase letters indicate significant differences in land heights at $p < 0.05$ based on Tukey's method. Ac and Sc stand for *A. corniculatum* and *S. caseolaris*, respectively. Sedl. and Sapl. stand for seedlings and saplings, respectively

on the sandbar except for *P. australis*. In addition, it contains *Acrostichum aureum, Crinum asiaticum*, and *Derris trifoliata*. The stand in the canal bank corresponds to Sc + Ac community based on its species composition.

Age distribution of *S. caseolaris* and *A. corniculatum*

Figure 4 displays the age distribution of the *S. caseolaris* stand (Sc + Ac community) in the canal bank. It is a young aged stand and the number of younger individuals both for *S. caseolaris* and *A. corniculatum* is higher than that of older individuals, implying it is in the succession phase. The number of seedlings, however, is less than that of saplings, especially for *S. caseolaris*.

In terms of LH distribution, there are no significant differences among growth phases for both species. However, seedlings of *A. corniculatum* inhabit at significantly lower LH than trees of *S. caseolaris* (Fig. 5; ANOVA, $p < 0.05$).

Seedling density of *A. corniculatum* with relation to land coverage

The herbaceous layer of the stand in the canal bank was widely covered with *C. malaccensis*. Some seedlings of *A. corniculatum* can be found on the bare land, but others can be found with *C. malaccensis* (Fig. 6). Figure 7 displays the relationship between seedling density of *A. corniculatum* and bare land ratio. Seedling density, in total, is positively correlated with bare land ratio ($r = 0.96$, $p < 0.01$). It implies that bare land is a more appropriate condition

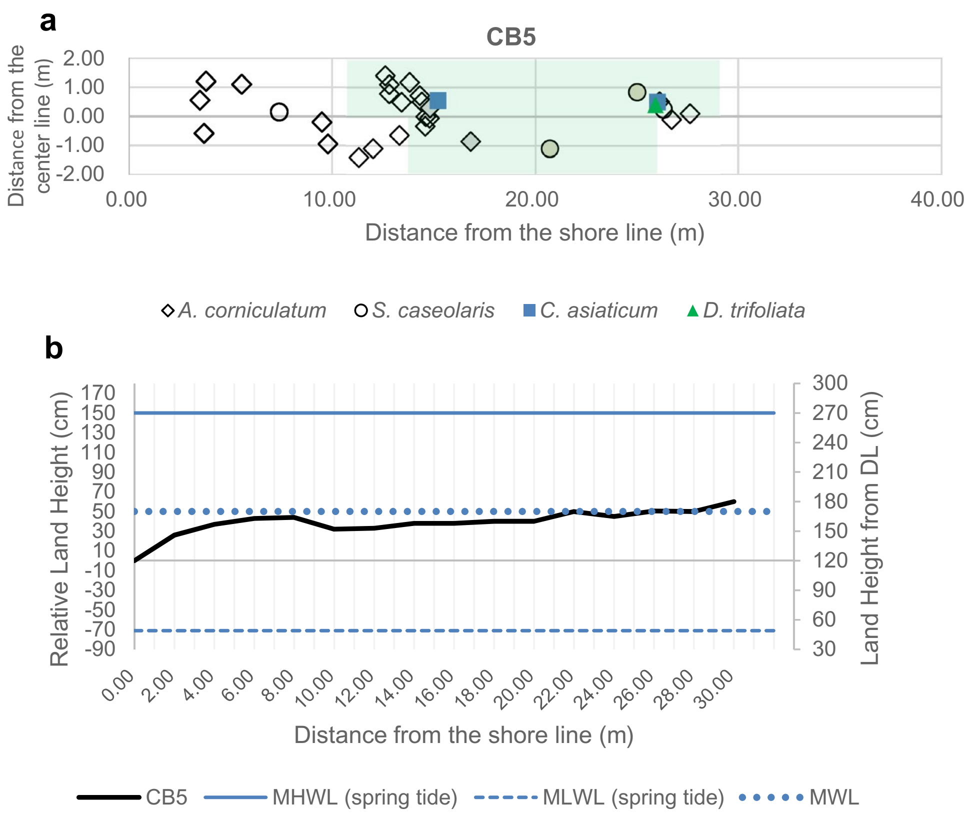
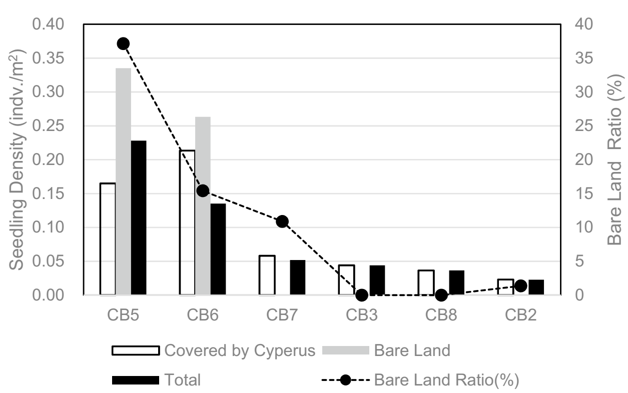


Fig. 6 Distribution of *A. corniculatum* seedlings in the transect CB5. **a** Distribution of plant individuals in transect CB5. Diamond and circle indicate *A. corniculatum* and *S. caseolaris*, respectively, and white and gray indicate seedlings and saplings, respectively. Green shaded displays the land covered by *C. malaccensis* colony. For distance from the center line, left side facing landward is expressed through a positive sign, and the right side is expressed by negative sign; **b** land cross section of the transect; CB5. MHWL, MLWL, and MWL are mean high-water level (spring tide), mean low water level (spring tide), and mean water level, respectively



	CB2	CB3	CB5	CB6	CB7	CB8
TA (m^2)	43.8	45.4	96.4	74.0	77.2	54.8
BLA (m^2)	0.6	0.0	35.8	11.4	8.4	0.0

Fig. 7 Seedling density of *A. corniculatum* vs. bare land ratio. Bars indicate seedling density for each transect; white, gray, and black bars indicate the density in the places covered by *C. malaccensis*, the density in the bare lands, total seedling density in the transect, respectively. Dotted line with black circles indicates bare land ratio. The table below the graph displays total area (TA) and bare land area (BLA) at each transect

for crypto-viviparous seedlings of *A. corniculatum* with extended hypocotyls, and developed shoots and roots, and that these seedlings can survive and grow even with the presence of *C. malaccensis* (Fig. 7; 0.02–0.21 indv./m^2 at *C. malaccensis* covered lands). On the other hand, seedlings of *S. caseolaris* were found both on the bare land and the land covered with *C. malaccensis*, but its total density was extremely low (Fig. 4; 0.003 indv./m^2).

Discussion

Population dynamics of *S. caseolaris* and *A. corniculatum*

S. caseolaris and *A. corniculatum* in the canal bank have similar LH distribution patterns and both of these were distributed around the MWL and seedlings were recruited near the previous habitat. The difference in LH distribution is that *A. corniculatum* seedlings are located at significantly lower LH than *S. caseolaris* trees ($p < 0.05$) (Fig. 5), indicating that the trees of *S. caseolaris* were distributed above the MWL and changed in relative position. It is significantly higher in LH as compared to *A. corniculatum*, as a result of *A. corniculatum* growing toward the lower spaces, with LH near the previous habitat. Hong and San (1993) reported that *S. caseolaris* is primarily recruited above MWL and then expands its distribution toward the lower tide zone. It was not observed in the study site used on this study; however, *A. corniculatum,* an accompanied species in the distribution area of the *S. caseolaris* stands, was recruited at the lower

LH, indicating that the *S. caseolaris* stand is expands toward the lower tide zone.

Effect of irradiance, tidal fluctuation, and soil salinity on seedling recruitment

Thampanya et al. (2002) reported that the seedlings of these two species can survive at the edges of stands or on open mud flats due to their high irradiance requirements. This allows *S. caseolaris* to proliferate because it meets the requirement of more than 80% of full irradiance to germinate and grow (Peng et al. 2009; Hinrichs et al. 2009), and the positive correlation between *A. corniculatum* seedlings and the bare land ratio in our results ($r = 0.96$, $p < 0.01$) indicates that *A. corniculatum* may also establish more seedlings under full irradiance condition.

Likewise, lighting conditions are important growth factors for both species. It is especially hard for *S. caseolaris* to germinate and grow in lands where *C. malaccensis* dominates. On the other hand, *A. corniculatum* is more tolerant against low irradiance conditions as compared to *S. caseolaris* (Chen et al. 2013); thus, it can grow in the presence of *C. malaccensis*.

Bare land during low tide provides full irradiance conditions. However, it produces negative conditions that affect the propagation of mangroves and it is more frequently disturbed by the tidal fluctuation and flood flow. In terms of flood flow, propagule dispersion and seedling establishment involving both *A. caseolaris* and *S. caseolaris* start after the rainy season (from May to October, Giang et al. 2014) in November and in late November to December according to field observations, respectively Therefore, flood flow does not frequently and seriously damage the seedling establishment of these two mangroves. However, tidal fluctuation cannot be avoided and it can affect mortality of seedlings for both species, especially for *S. caseolaris.* Its reproductive system becomes damaged even though it has lanceolate leaves to decrease water movement resistance (Tomlinson 1986). *S. caseolaris* propagates using small seeds that are 0.3 cm in diameter (Tomlinson 1986). Thus, it is easy to flush away and it is difficult for the seeds to remain in the tidal zone. On the other hand, *A. corniculatum* propagates with crypto-viviparous seedlings that are 5 cm or more in length (Tomlinson 1986; Das 2001). Seedlings with longer hypocotyls are not easily flushed away (Jiang et al. 2019). Because propagules size and morphology affect seedling mortality, *A. corniculatum* seedling density is significantly higher than that of *S. caseolaris* in the study site (Fig. 4); thereby, being important factors for growth and establishment.

Seedling establishment is affected also by soil salinity. However, both *S. caseolaris* and *A. corniculatum* have similar salinity tolerance, which are 0–15 ppt in soil salinity (Marisa and Sarno 2015) and 0–15 or up to 18 ppt in soil salinity (Joshi and Ghose 2003; Ye et al. 2005), respectively. These figures illustrate that the differences in seedling density of these two species in the low tidal zone is not attributed to soil salinity.

Conclusion: succession of *S. caseolaris* stand and its restoration perspective

Primary stage

S. caseolaris and *A. corniculatum* priorly grow at around MWL, and then both expand their distribution areas around the previous habitat. At the same time, *C. malaccensis* is widely recruited and occupies the herbaceous layer.

Secondary stage

Seedling recruitment area under appropriate irradiance conditions is limited, which makes it difficult for seedlings of *S. caseolaris* to be recruited in the lower LH as *S. caseolaris* is thriving with *C. malaccensis*. On the other hand, seedlings of *A. corniculatum* survive on the mud flat below MWL. Thus, it is recruited there, and continues to expand toward the lower tide zone.

Restoration perspective

The ecological restoration of a mangrove stand is none other than mangrove habitat restoration, i.e., providing appropriate environmental conditions to induce seedling recruitment and to promote succession (Kamali and Hashim 2011).

The current findings on seedling establishment and the expansion of the component species of the *S. caseolaris* stand in relation to geomorphological, hydrological, and vegetative characteristics can be applied for land modification designs for the *S. caseolaris* stand restoration.

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