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RESEARCH ARTICLE
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Land Suitability Assessment for Growth of *Rhizophora stylosa* and *Aegiceras corniculatum* for Development of Mangrove Forests in Coastal Areas of Nghe an Province, Vietnam

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ABSTRACT

Developing mangroves has long been a matter of interest to scientists. To properly plan mangrove development, it is necessary to assess the suitability of mangrove species. This study evaluated the suitability of two mangrove species, *Rhizophora stylosa* and *Aegiceras corniculatum*, for the coastal area of Nghe An province, Vietnam. The suitability assessment was conducted across eighteen land units using sixteen indicators grouped into four criteria: (1) Soil salinity, (2) Soil mechanical composition, (3) Tidal inundation, and (4) Current status of saline soil and mangrove forests. The results showed that five land units were classified as highly suitable (67.54ha, 9.43%); six as moderately suitable (237.83ha, 33.22%); two as a marginally suitable (31.2ha, 4.59%), and five as an unsuitable suitable (377.62ha, 52.75%) for the growth of *R. stylosa*; six land units were highly suitable (105.95ha, 14.8%); seven land units were moderately suitable (232.31ha, 32.45%); no land units were marginally suitable; five land units were not suitable (377.62ha, 52.75%) for the growth of *A. corniculatum*. The research results are the scientific basis for expanding the area and developing suitable mangrove trees in the coastal area of Nghe An province.

Keywords: Mangrove forest, Land suitability assessment, Rhizophora stylosa, Aegiceras corniculatum

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INTRODUCTION

Mangroves are intertidal wetlands along tropical, subtropical, and warm-temperate coastlines (Nguyen et al., 2021). These ecosystems thrive in sheltered coastal areas with relatively calm waters such as estuaries, accreting shores, bays, and lagoons (Cochard, 2008). Mangrove forests are one of the important ecosystems in the world, providing natural resources for the coastal areas around them. They provide food, habitats, and nursery grounds for many aquatic and terrestrial animals, protect coastal communities from extreme weather events, store large reserves of blue carbon, counteract coastal hazards and climate change, and contribute significantly to the socio-economic lives of coastal dwellers (Costanza et al., 1997; Nagelkerken et al., 2008; Koch et al., 2009; IPCC, 2014; Atwood et al., 2017; Ouyang et al., 2018; Hochard et al., 2019; Le et al., 2019). The flora in mangrove forests is diverse, including trees, shrubs, palm trees, and ferns, adapted to the harsh saline conditions of tidal phenomena. Although species numbers and diversity are lower than in terrestrial ecosystems, adaptations to survive in various harsh environments (e.g., strong winds, submergence, high salinity, and mud) make this ecosystem important for biological conservation and maintenance of water and soil quality through the use of naturally occurring and manmade nutrients (Jeffrey, 2017).

The largest mangrove areas in the world are located in Southeast Asia and South Asia with a total area of more than five million hectares, accounting for more than 43% of the world's total mangrove area (Donato et al., 2011). Vietnam has well-developed mangrove forests along 3,260km of coastline with a total mangrove area of 408,500ha (1.2% of the country) in 1943 (Hong & San, 1993).

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However, that area has shrunk a lot in the past 50 years due to many reasons (war destruction (Hong & San, 1993), aerial herbicide spraying (Tuan et al., 2003), conversion to shrimp farms (de Graaf & Xuan, 1998), etc.). According to the VietNam Ministry of Agriculture and Rural Development (MARD), the area of mangroves in Vietnam was only 235,569ha in 2019 (MARD, 2020). Many studies have been conducted to monitor and evaluate the mangrove ecosystem to serve mangrove management in Vietnam, these studies were mainly conducted in the Mekong Delta and Red River Delta regions (Lan et al., 2013; Nguyen et al., 2013; Tran Thi et al., 2014; Hauser et al., 2017; Pham & Brabyn, 2017; Son et al., 2014; Dat et al., 2020a, b; Hoa et al., 2020). However, provinces in the North Central region, such as Thanh Hoa and Nghe An, have not had many studies conducted.

Nghe An province has a coastline of 82km, with a total area of mangrove forests of 819.6ha (MARD, 2020). Although accounting for a small proportion, mangrove forests in Nghe An play an important role in helping to protect coastlines and estuaries from the frequent impacts of wind, storms, waves, and floods, and help stabilize the coastal lands. A recent study has shown that, over the past 47 years (from 1973 to 2020), the mangrove forest area of Nghe An province increased by 8.2% due to the implementation of mangrove planting programs with the support from many international organizations such as UNEP (United Nations Environment Program), UNESCO (United Nations Educational Scientific and Cultural Organization) (Nguyen et al., 2021). However, this increased area is not commensurate with the potential for developing mangrove forests in Nghe An province. One of the reasons the increase in mangrove areas is still low is that the survival rate of trees in mangrove planting programs is not high. This comes from the lack of research to evaluate and classify land suitability for each type of mangrove tree in Nghe An province.

The *Rhizophora stylosa* and *Aegiceras corniculatum* are widely distributed in tropical coastal areas with hot and humid climates such as Malaysia, Indonesia, Bangladesh, Thailand, Philippines, Papua New Guinea, and Vietnam. These plants play an important role in the mangrove ecosystem, in addition to their economic benefits, they also have medicinal properties. Several studies have reported that some extracts from *R. stylosa* and *A. corniculatum* have a variety of pharmacological activities, including antioxidant, antibacterial, and anti-inflammatory activities (Anjaneyulu et al., 2002; Laphookhieo et al., 2004; Li et al., 2007; Li et al., 2008; Takara et al., 2008; Mohapatra & Basak, 2021; Kalasuba et al., 2023). Several studies have examined the adaptation of these two mangrove species to theharsh environment of mangrove forests (Mulyaningsih et al., 2021; Ayyaz et al., 2023; Hu et al., 2024). To evaluate the suitability of planting mangrove forests, we need to consider three important factors related to the growth of mangrove species: soil type, tidal flooding regime, and soil mechanical composition (Babak & Roslan, 2011; Salmo et al., 2013; Sofawi et al., 2017). Besides, several other natural factors such as terrain, coastal seawater salinity, and ocean wave dynamics are also basic factors that directly affect the characteristics of mangrove soil and the planting of mangrove species.

Although *R. stylosa* and *A. corniculatum* are two native species of mangrove plants in Nghe An, no comprehensive analysis of the factors impacting the suitability of Nghe An coastal soil for the growth of these two plant species. This study aims to assess the land suitability of Nghe An's coastal areas for these two species, utilizing GIS technology. Section II presents the sampling method and land suitability assessment methods. The study results and discussions are presented in Section III, and the final section presents the conclusions.

MATERIALS & METHODS

Study Area

The research area is the coastal area of Nghe An province ($105^0$35'15"-$105^0$48'30"E, $18^0$40'00"-$19^0$18'45"N), in the North Central region of Vietnam, including 38 communes, located in 6 districts and towns: Hoang Mai Town, Quynh Luu District, Cua Lo Town, Dien Chau District, Nghi Loc District, and Vinh City (Fig. 1). The climate of this area is tropical monsoon, with an average annual temperature is 25.6°C (a maximum temperature of 40.4˚C, the lowest temperature of 5.6°C). The average relative humidity is 85%, and the region receives an average annual rainfall of 1,827mm, while the yearly average evaporation is 830mm. The tidal regime in this area is quite complex, a mixture of irregular diurnal and semi-diurnal tides with an average amplitude of 2 m, and salinity ranges from 31.6‰ - 35.7%.

Sample Collection and Analysis

The coastal area of Nghe An province has several mangrove species such as *Avicennia alba*, *Phizophora apiculate*, *Aegiceras corniculatum*, *Kandelia candel (L.) Druce*, *Bruguiera gymnorhiza (L.) Lam*, etc., of which R. stylosa and A. corniculatum (Fig. 2) are two typical mangrove plant species occupying a fairly large area in the study area.

R. stylosa is highly suitable to alum soils with high salinity and moderate salinity (15 - 30‰), the structure is compacted mud, with a sand ratio of less than 30%, and grows well in areas with tidal inundation of 30-60cm. R. stylosa is low suitable for soils with a structure of loose mud, hard clay, and soils with a sand ratio of 50% - 70% and profound tidal inundation (larger than 100 cm) and very shallow tidal inundation (less than 30cm); not suitable to sandy soil, with a sand ratio larger than 70% (Hogarth, 1999; MARD, 2016).

A. corniculatum is a plant commonly growing on river banks or mud flats near river mouths. It is suitable to highly saline soils and moderate salinity (the most suitable salinity is 10 - 25‰), soil of soft mud or compacted mud, with a sand ratio of less than 50%, shallow tidal inundation, and medium tidal inundation, most suitable tidal inundation is less than 30cm; *A. corniculatum* not suitable to loose muddy soils with a sand ratio of less than 10% and sandy soils with a sand ratio of larger than 90% (MARD, 2016).

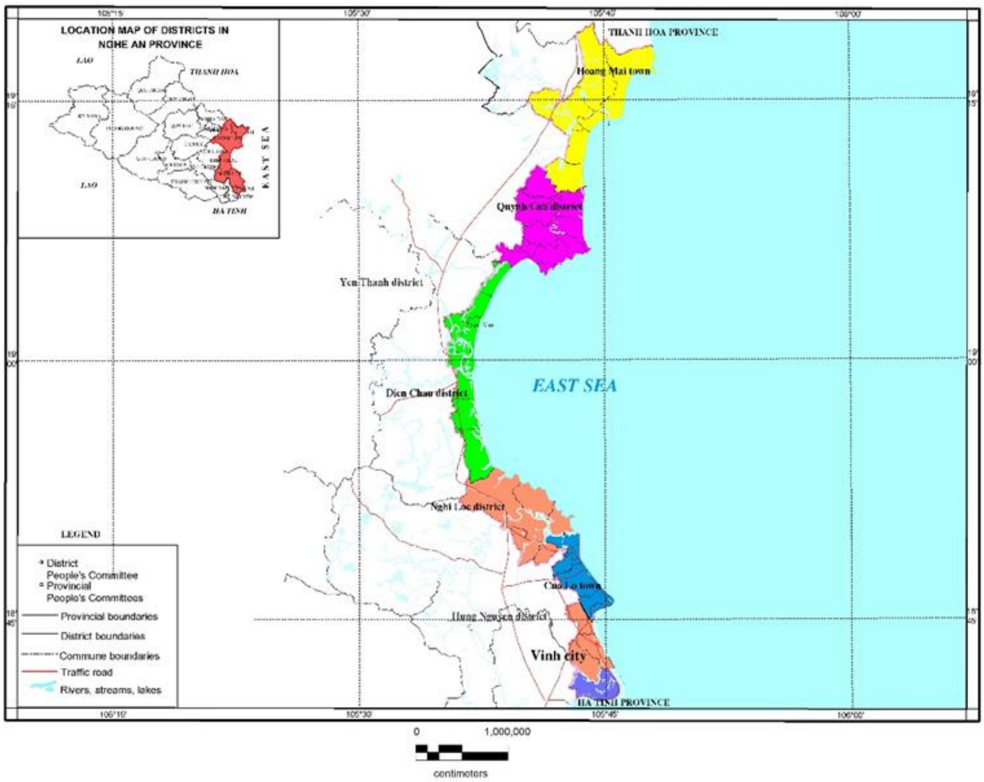

Fig. 1: The study area includes 6 districts and towns/city: Hoang Mai Town, Quynh Luu District, Cua Lo Town, Dien Chau District, Nghi Loc District, and Vinh City

Fig. 2: *Rhizophora stylosa* (a) and *Aegiceras corniculatum* (b) in the study area

To assess land suitability for the growth of two mangrove plant species *R. stylosa* and *A. corniculatum*, we surveyed the study area to take samples for experimental work to determine soil structure. We selected 29 sampling points, evenly distributed across the study area. At each point, three factors were determined to assess suitability: soil mechanical composition, tidal inundation, and soil salinity. To determine soil parameters, each point takes two soil samples, one in the dry season and one in the rainy season. Sample analysis was performed at the laboratory of the Department of Environment, School of Sciences, Hue University, Vietnam.

The tidal inundation level at sampling points was determined by driving wooden stakes tightly into the ground and using a ruler to measure the highest tide inundation level on the stakes. Salinity at sample points was determined using a Japanese refractometer ATAGO: S - 28, measured once a week, with measurement time from 9:00am to 2:00pm. One important factor in the land suitability assessment process is the current land use. In this study, different maps were used, such as administrative maps, land use current status maps, classification land maps, and mangrove forest current status maps of the study área. These maps were collected and inherited from conducted studies previously in Nghe An province and supplemented by field surveys by the research team.

Land Suitability Assessment Method

In this study, we use the land suitability assessment process according to the Food and Agriculture Organization of the United Nations - FAO (FAO, 1976; FAO, 1984). There have been many studies applying this method to evaluate the suitability of crops for different types of land (Rendana et al. 2021; Hdoush et al. 2022; Hoang et al. 2022; Kau et al., 2023). The steps of this method are as follows:

+ Step 1: Determine the ecological needs of two mangrove species *R. stylosa* and *A. corniculatum*.

+ Step 2: Identify and select assessment criteria. Selecting assessment criteria is the process of generalizing the most prominent features from the structural parts of the landscape for a specific plant object. In this study, we selected four assessment criteria: (i) Soil salinity, (ii) Soil mechanical composition, (iii) Tidal inundation, and (iv) Current status of saline soil and mangrove forests.

+ Step 3: Determine the weights for the criteria. Based on research results on the influence of criteria, to classify the level of suitability on the growth and development of tree species. To determine the weights for the criteria, the Analytic Hierarchy Process (AHP) method (Saaty, 1980; Saaty & Vargas, 1994; Janković & Popović, 2019; Zavadskas et al., 2020; Abate & Anteneh 2024) is used, in combination with the triangular matrix method using expert interviews.

+ Step 4: Create land unit maps. The land unit map is a combination of individual maps that have been established, including a soil salinity map, tidal inundation map, and current status map of land and mangrove forests. In this study, we have combined and established eighteen land units with a total area of 715.9ha. Each land unit is uniform in the following attributes/characteristics: (1) Soil salinity, (2) Soil mechanical composition, (3) Tidal inundation, (4) Current status of saline soil and mangrove forests.

+ Step 5: Create an assessment scale for land units. Based on the selected criteria and weights, use the weighted average method to calculate the score for each land unit according to as follows (FAO, 1976; FAO, 1984):

$$M_0 = \frac{1}{n}\sum_{i=1}^{n} k_i d_i \quad (1)$$

where M_0 is the general (combined) assessment score of the land unit; d_i is the assessment score for the i^{th} factor; n is the number of evaluation criteria; k_i is the weight of the i^{th} factor.

After obtaining the M_0 values of the land units according to Eq. (1), we determine the suitability levels. Each level of suitability corresponds to a value interval of the general assessment score. The distance between ecological suitability levels is calculated as follows (FAO, 1976; FAO, 1984):

$$\Delta D = \frac{D_{max} - D_{min}}{M} \quad (2)$$

where D_{max} is the highest general assessment score; D_{min} is the lowest general assessment score; M is the number of assessment levels.

+ Step 6: Create the land suitability map. From the collected and analyzed data, Acrgis and Mapinfo software were used to create a map to classify the level of suitability for *R. stylosa* and *A. corniculatum* in the study area.

RESULTS & DISCUSSION

Land Suitability Assessment Results

According to Step 3 in Section 2, the weights of the criteria are determined as shown in Table 1.

Based on ecological requirements of the two mangrove plant species *R. stylosa* and *A. corniculatum* (MARD, 2016), the soil characteristics of the study area and the weights, we created a table of evaluation criteria for the indicators of these two plant species (Table 1). Each criterion is divided into four indicators, which are attributes of land units in the study area. The corresponding suitability levels are ranked on a scale of four categories, with scores of (3, 2, 1, 0), respectively: Highly suitable (S1); Moderately suitable (S2); Marginally suitable (S3); and Not suitable (N). Details are shown in Table 2.

The land suitability level for the two mangrove species, *R. stylosa* and *A. corniculatum* was determined based on the score of each indicator in each criterion and the weight of each criterion according to Eqs. (1) and (2). The results of the classification of suitability levels are shown in Table 3.

From the data presented in Table 3 and the analysis results of the samples, we evaluated the land suitability for the growth of two mangrove species *R. stylosa* and *A. corniculatum* in the study area. The results are shown in Table 4.

Land Suitability Assessment Results for *R. stylosa* by District-level Administrative Unit

The study area has eighteen land units that were evaluated for their suitability for the growth of *R. stylosa*, the results are as follows: five land units with an area of 67.54ha are at the highly suitable level (S1), accounting for 9.43%; six land units with an area of 237.83ha that are moderately suitable (S2), accounting for 33.22%; two land units with an area of 32.88ha that are marginally suitable (S3), accounting for 4.59%, and there are five land units with an area of 377.62ha are not suitable (N), accounting for 52.75%. The distribution of land suitability levels of *R. stylosa* on land units in the coastal region of Nghe An is shown in Fig. 3.

Table 5 lists the results of land suitability levels for *R. stylosa* in the study area according to district-level administrative units.

Hoang Mai town has 6.66ha assessed as highly suitable (S1) and 32.60ha as moderately suitable (S2) for the growth of *R. stylosa*. The marginally suitable area (S3) is 12.10ha, the current land use is a shrimp pond, and the soil structure is mainly loose sand. The remaining 16.22ha is not suitable (N). The current land use is primarily coastal sandy beaches.

Quynh Luu has a total area of 203.77ha of mangrove land, of which 48.70ha is highly suitable (S1). These are land units whose soil mechanical composition is compact mud with a 30 - 50% sand ratio. The moderately suitable area (S2) is 45.54ha, these are land units with soil mechanical composition components of mud, soft clay, and hard clay. The marginally suitable area (S3) is 20.79ha with soil mechanical composition having a high sand ratio (larger than 70%). The remaining 88.75ha are not suitable for the growth of *R. stylosa*, the current land use is mainly loose sandy soil (sand ratio larger than 90%), poor in nutrients, weathering and erosion, strong leaching, and no porosity.

Dien Chau has 2.43ha assessed as highly suitable (S1) and 27.85ha as moderately suitable (S2). These are land units to the highly saline soil along the Lach Van River, the soil mechanical composition is soft silt soil, and soft clay (sand ratio about 30÷50%). In addition, 204.28ha not suitable for the growth of *R. stylosa* are coastal sandy beaches, the soil mechanical composition is loose sand, the sand ratio is larger than 80%, and little nutrition.

Table 1: Weight of criteria

Criteria	Soil salinity	Soil mechanical composition	Tidal inundation	Current status of saline soil and mangroves forests
Weight	0.2	0.2	0.4	0.2

Table 2: Classification of land suitability levels for growth of *R. stylosa* and *A. corniculatum*

Criteria	Indicators	Value	Level of suitability	Weight (K)	Score
Classification of land suitability levels for growth of R. stylosa					
Soil salinity	Highly saline	NaCl content> 0.5%	S1	0.2	3
	Moderately saline	NaCl content from 0.3 to <0.5%	S2		2
	Slightly saline	NaCl content <0.3%	S3		1
	Non-saline soil	-	N		0
Soil mechanical composition	Clay soil	Soil settlement from 15 to 30cm, soil with sand <30%	S1	0.2	3
	Soft mud or soft clay	Soil settlement from 5 - 15cm, or soil with sand content from 30 to 50%	S2		2
	Silty mud or heavy clay	Soil with sand content from 50 - 70%	S3		1
	Heavy clay or sandy soil	Soil settlement <5cm; soil with sand content> 70%	N		0
Tidal inundation	Average tidal inundation	Tidal inundation from 30 to 60cm; number of tidal days from 10 - 19 days/month	S1	0.4	3
	Deep tidal inundation or shallow tidal inundation	Tidal inundation from 60 to 100cm; number of tidal days from 20 to 25 days/month or from 5 to 9 days/month	S2		2
	Highly deep tidal inundation or highly shallow tidal inundation	Tidal inundation> 100cm or <30cm, number of tidal days from 5 to 9 days/month or over 25 days/month	S3		1
	Non tidal	-	N		0
Current status of saline soil and mangroves forests	Land with mangroves (available land for additional planting, or previously with mangroves)		S1	0.2	3
	Vacant land (no mangroves, with the potential to plant mangroves)		S2		2
	Vacant land (aquaculture)		S3		1
	Vacant land (other)		N		0
Classification of land suitability levels for growth of A. corniculatum					
Soil salinity	Highly saline	NaCl content> 0.5%	S1	0.2	3
	Moderately saline	NaCl content from 0.3 to <0.5%	S2		2
	Slightly saline	NaCl content <0.3%	S3		1
	Non-saline soil	-	N		0
Soil mechanical composition	Soft mud or heavy mud	Soil settlement from15 to 40 cm; or soil with sand content <50%	S1	0.2	3
	Soft clay, heavy clay	Soil settlement from 5 to 15 cm; or <5 cm or soil with sand content from 50 to 90%	S2		2
	-	-	S3		1
	Silty mud or sandy soil	Soil with sand content> 90%	N		0
Tidal inundation	Shallow tidal inundation	Tidal inundation <30 cm; number of tidal days from 10 - 16 days/month	S1	0.4	3
	Average tidal inundation	Tidal inundation from 30 to 60 cm; number of tidal days from 8 to 10 days/month	S2		2
	Deep tidal inundation	Tidal inundation from 60 to 100 cm, number of tidal days from 6 to 8 days/month	S3		1
	Non tidal wetland	-	N		0
Current status of saline soil and mangroves forests	Land with mangroves (available land for additional planting, or previously with mangroves)		S1	0.2	3
	Vacant land (no mangroves, with the potential to plant mangroves)		S2		2
	Vacant land (aquaculture)		S3		1
	Vacant land (other)		N		0

Table 3: Suitability level classification for *R. stylosa* and *A. corniculatum* in study areas

Purpose of assessment	Score distance	Rating score			
		Highly suitable	Moderately suitable	Marginally suitable	Not suitable
R. stylosa	0.47	>2.34	1.87 – 2.34	<1.87	Other soil types
A. corniculatum	0.42	>1.92	1.49 – 1.92	<1.49	Other soil types

Table 4: Land suitability assessment results for *R. stylosa* and *A. corniculatum*

Classification	*R. stylosa*		*A. corniculatum*	
	Area (ha)	Percentage (%)	Area (ha)	Percentage
Highly suitable	67.54	9.43	105.95	14.80
Moderately suitable	237.83	33.22	232.31	32.45
Marginally suitable	32.88	4.59	0	0
Not suitable	377.62	52.75	377.62	52.75
Total area	715.88	100	715.88	100

Table 5: Area of suitable levels of *R. stylosa* according to district administrative units

Place	Area of suitable levels (ha)				Total (ha)
	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	
Hoang Mai town	6.66	32.60	12.10	16.22	67.58
Quynh Luu	48.70	45.54	20.79	88.75	203.77
Dien Chau	2.43	27.85	0	204.28	234.55
Nghi Loc	0	107.35	0	18.06	125.41
Cua Lo town	0	0	0	50.32	50.32
Vinh city	9.75	24.50	0	0	34.25
Total	67.54	237.83	32.88	377.62	715.88
Percentage (%)	9.43	33.22	4.59	52.75	100.00

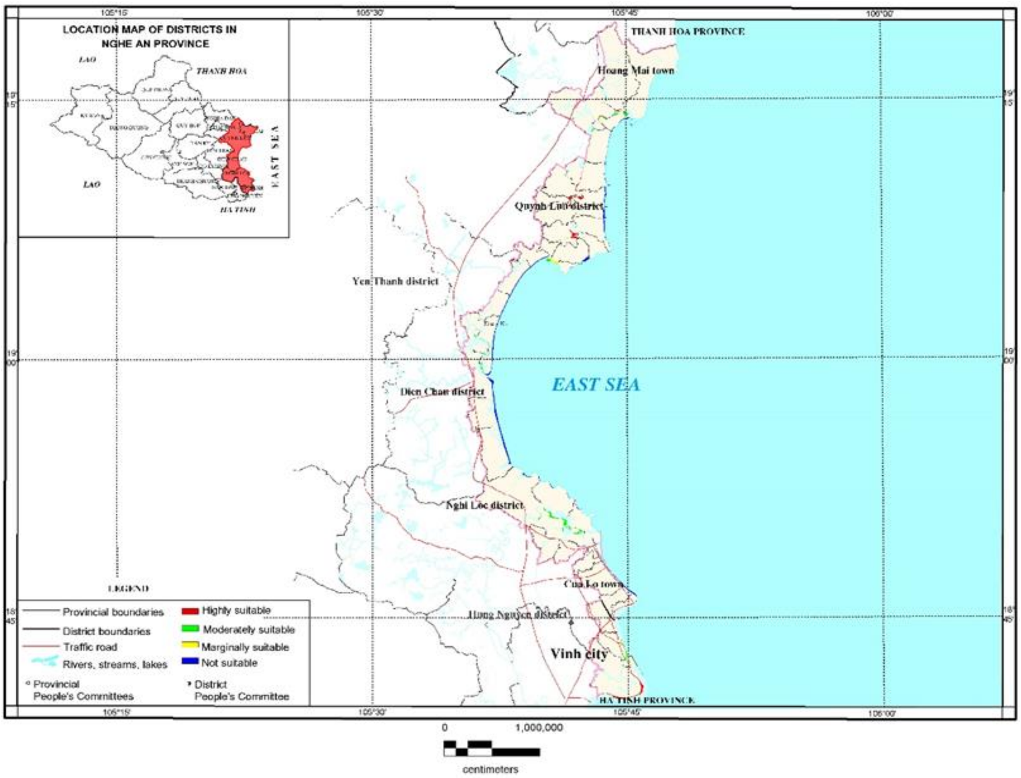

Fig. 3: The distribution map of land suitability levels for *R. stylosa* in the study area

Nghi Loc district, 107.35ha were classified as moderately suitable (S2). These areas have high saline soils along rivers and shrimp ponds, with the soil mechanical composition of hard clay (sand ratio of about 50 - 70%), which is a factor that limits the growth of *R. stylosa*. The remaining 18.06ha are coastal sandy beaches, not suitable for the growth of *R. stylosa*.

Cua Lo town has a total area of mangrove land of 50.32ha. This area is mainly planned as a beach for tourists; the entire area is not suitable for the growth of *R. stylosa*.

Vinh City has 9.75ha and is assessed as highly suitable (S1) for the growth of *R. stylosa*. These land units have a soil texture of soft silt or soft clay (sand ratio of about 30-50%). The remaining 24.50ha are moderately suitable (S2), with the current land status mainly bare land and some shrimp ponds.

Land Suitability Assessment Results for *A. corniculatum* by District-level Administrative Unit

The results of the land suitability assessment for the growth of *A. corniculatum* in the coastal area of Nghe An province are shown in Fig. 4. The area of mangrove land in the coastal area of Nghe An province is large. Still, the land fund for the growth of *A. corniculatum* is not much. Of the eighteen land units with an area of 715.88ha, only six land units with an area of 105.95ha, accounting for 14.80% of the total area, are highly suitable (S1); seven land units with an area of 232.31ha, accounting for 32.45%, are moderately suitable (S2) for the growth of *A. corniculatum*. There are no land units that are marginally suitable and five land units with an area of 377.62ha that are not suitable (N) for the growth of *A. corniculatum*.

The results of land suitability levels for *A. corniculatum* in the study area are listed according to district-level administrative units in the coastal area of Nghe An province as shown in Table 6.

Hoang Mai town has 2.56ha of mangrove land, which is highly suitable (S1) for the growth of *A. corniculatum*; these are soils with high salinity, with soil texture of soft mud and compact mud (sand ratio smaller than 50%), tidal inundation is 60-100cm. The moderately suitable area (S2) is 48.79ha; these are land units with high salinity; the soil mechanical composition is soft clay and hard clay (sand ratio larger than 50%), which is a type of soil that is somewhat limited for the growth of *A. corniculatum*. The remaining 16.2ha are not suitable (N), land units whose soil mechanical composition is loose sand (sand ratio larger than 90%), poor in nutrients, and no porosity.

Quynh Luu district has 69.14ha that are considered highly suitable (S1), these are land units with highly saline soil mechanical composition mainly soft mud soil (sand ratio larger than 30%) and compact mud soil (sand ratio of 30-50%), tidal inundation of 60-100cm; 45.89ha of moderately suitable land (S2), these are highly saline soils, the soil mechanical composition is soft clay (sand ratio 50-70%), hard clay (sand ratio larger than 70%), tidal inundation of 90 to 100cm, these soil types are somewhat limited for the growth of *A. corniculatum*; 88.75ha are not suitable (N) with a soil mechanical composition of loose sandy soil (sand ratio larger than 90), poor in nutrients, no porosity.

Dien Chau district has 30.28ha of land classified as moderately suitable (S2); this is a highly saline soil, the soil mechanical composition is compact mud (sand ratio of 30 - 50%), tidal inundation is 80 - 110 cm, moderately suitable for the growth of *A. corniculatum*; 204.3ha are coastal sand beaches with soil mechanical composition of loose sandy soil (sand ratio larger than 80%), not suitable for the growth of *A. corniculatum*.

Table 6: Area of suitable levels of *A. corniculatum* according to district administrative units

Place	Area of suitable levels (ha)				Total (ha)
	Highly suitable	Moderate suitable	Marginally suitable	Not suitable	
Hoang Mai town	2.56	48.79	0	16.22	67.57
Quynh Luu	69.14	45.89	0	88.75	203.78
Dien Chau	0	30.28	0	204.28	234.56
Nghi Loc	0	107.35	0	18.06	125.41
Cua Lo town	0	0	0	50.32	50.32
Vinh city	34.25	0	0	0	34.25
Total	105.95	232.31	0	377.63	715.88
Percentage %	14.80	32.45	0	52.75	100.00

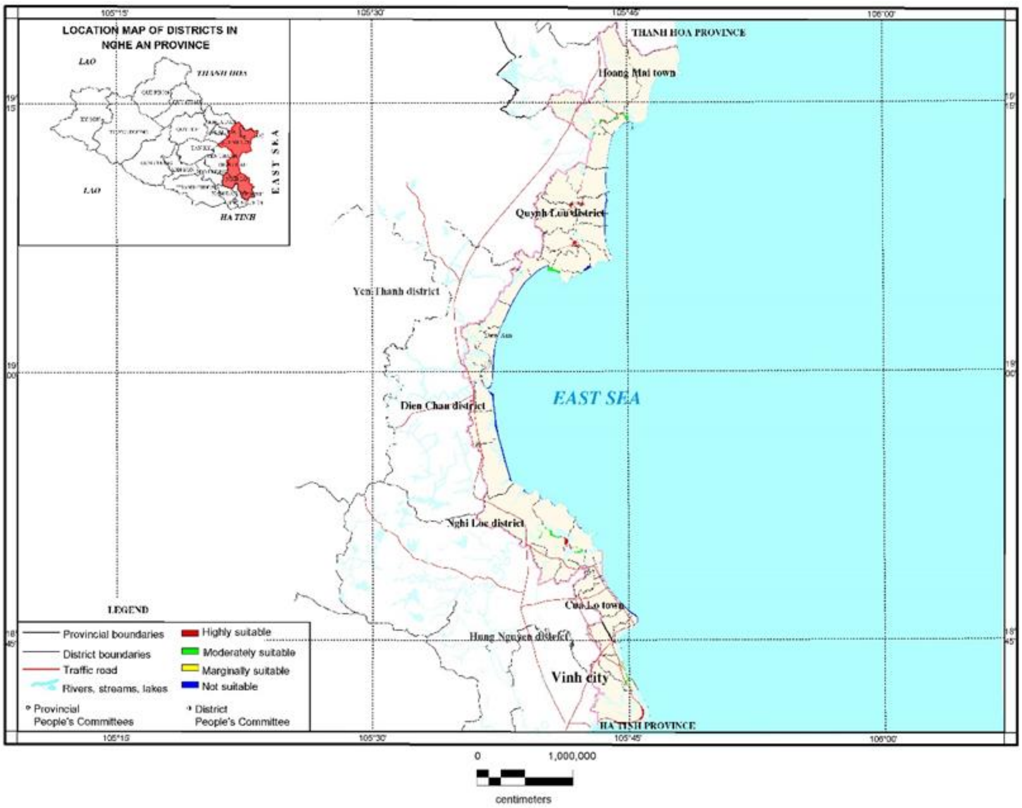

Fig. 4: The distribution map of land suitability levels for *A. corniculatum* in the study area.

Nghi Loc district has 107.35ha classified as moderately suitable (S2), this is highly saline soil, the soil mechanical composition is soft clay (sand ratio 50-70%), tidal inundation is 100-110cm, some limiting factors for the growth of *A. corniculatum*; 18.06ha with a soil mechanical composition of sandy soil (sand ratio of 80%), not suitable for the growth of *A. corniculatum*.

Cua Lo town has a total area of mangrove land of 50.32ha, which are land units of highly saline soil, the soil mechanical composition is loose sandy soil (sand ratio larger than 90%), this type of soil is not suitable for the growth of *A. corniculatum*.

According to the study results, the entire area of 34.25ha of mangrove land of Vinh City is highly suitable (S1), accounting for 100%, the land units here are soil mechanical composition of soft mud or soft clay (sand ratio of 30-50%), the current land use is mainly salty land along riverbanks and shrimp ponds.

Conclusion

Based on research results on ecological factors that affect the distribution and growth of two mangrove plant species *R. stylosa* and *A. corniculatum*, including 16 indicators of 4 criteria: (1) Soil salinity, (2) Soil mechanical composition, (3) Tidal inundation, and (4) Current status of saline soil and mangrove forests, this study has determined the land suitability level for *R. stylosa* and *A. corniculatum* in coastal areas of Nghe An province with four levels: Highly suitable (S1); Moderately suitable (S2); Marginally suitable (S3); Not suitable (N).

The results of the land suitability assessment for the growth of *R. stylosa* in Nghe An province show that in a total of 715.88ha of mangrove land, the highly suitable area (S1) is 64.54ha, accounting for 9.43%; moderately suitable (S2) is 237.83ha, accounting for 33.22%; marginally suitable (S3) is 32.88ha, accounting for 4.59%; not suitable (N) is 377.62ha, accounting for 52.75%. Although the area of mangrove land is quite large, the land fund for new planting and development of *R. stylosa* is not much.

Land suitability assessment results for the growth of *A. corniculatum* in the study area showed that six land units were highly suitable, with an area of 105.95ha, accounting for 14.80% of the total area; seven land units moderately were suitable (232.31ha; accounting for 32.45%), five land units were not suitable (377.62ha; accounting for 52.75%) and no land units were marginally suitable. The study results are the basis for planning mangrove development; improving the efficiency and quality of new mangrove planting areas, and ensuring safety and ecological sustainability for the coastal area of Nghe An province, Vietnam.

Author's Contribution: VLV, KTD, and DDT conceived and designed the experiment. VLV and ATH performed the study, and TTHN conducted lab analyses. ATH, VLV, and TTH conduct surveys. DDT, TTVL, and TQNP performed statistical analyses of experimental data and prepared the manuscript format. ATH, VLV, KTD, and TTH prepared the manuscript draft. All authors critically revised the manuscript and approved the final version.

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