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LEAF PHENOLOGY CHARACTERISTICS OF GREENING TREE SPECIES AND IMPLICATIONS FOR GREENING IN COASTAL SALINE LAND

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Abstract

Phenological characteristics of greening tree species in coastal saline land can not only determine the best afforestation time, but also guide the landscape configuration of plant communities. Taking 28 greening tree species in coastal saline area as the study objects, we investigated and analyzed the leaf emergence and leaf abscission phenology for one year in 2015. We found that the beginning of leaf emergence was from mid-March to early May, 2015 and mainly concentrated in the mid to late April, 2015 and the ending of leaf emergence was from early April to late May, 2015. Afforestation time for introducing 28 greening tree species was suggested from March to May. The beginning of leaf abscission ranged from early October to early November, 2015 and was mainly concentrated in October, 2015, while the ending of leaf abscission ranged from early November, 2015 to early January, 2016 and mainly concentrated in the period from late November to late December, 2015. According to the time of leaf emergence and the time of leaf abscission, the 28 tree species were divided into four categories. Tree species in the same category had the relative synchronicities and were similar in phenological matching relationship in leaf emergence and leaf abscission phenology. Therefore, they had certain mutual replacement function in landscape configuration. Landscape configuration of tree species could be conducted according to time of leaf emergence and leaf abscission. Tree species with early or late leaf emergence time and with early or late leaf abscission time could be planted together.

Key words: Leaf emergence; Leaf abscission; Afforestation time; Landscape configuration; Coastal saline land.

Introduction

Plant phenology refers to the natural phenomena for year cycle influenced by biological factors and non-biological factors such as climate, hydrology and soil. It includes budburst, leaf emergence, leaf expansion, flowering, leaf abscission and so on. Phenology studies are essential to increase knowledge of specific functions of plants in artificial ecosystems, and they must be taken into account in greening and rational management schemes.Phonological data of greening tree species can also guide afforestation time (Wang *et al.*, 2006) and provide scientific evidence for the optimal configuration of plants (Yang & Chen, 2000; Chang *et al.*, 2011; Chen *et al.*, 2011).

In recent years, due to the acceleration of urbanization process, saline lands in the coastal zone as an important land reserve resources have been gradually reclaimed, developed, and utilized in order to expand urban construction space and many new coastal towns have been built. However, due to short reclamation time, the high average salinity between 2.0% and 6.0% (Zhao & Fan, 2005), poor organic matter and nutrient in soil, few greening tree species are suitable for the coastal saline land. Therefore, the effects of greening afforestation in these areas are largely restricted. While the selection of salt-tolerant greening tree species and plant community construction are the main support technology to realize rapid greening in coastal saline land.

At present, the screening and evaluating of salt-tolerant greening tree species had been studied extensively (Biddiscombe *et al.,* 1981,1985; Morris, 1984; Pepper & Craig, 1986; Hussain & Gul, 1991; Van der Moezel *et al.,* 1989, 1991; Hafeez, 1993; Dunn *et al.*, 1994; Morris *et al.*, 1994; Singh *et al.*, 1994; Greenwood *et al.,* 1994, 1995; Sun & Dickinson, 1993, 1995a,b; House *et al.*, 1998; Niknam & McComb, 2000; Oba *et al.,* 2001; Tomar *et al.,* 2003; Rao *et al.,* 2004). However, these studies only focused on the screening and evaluating of tree species on a single type of species, but the research on when to plant and how to construct plant communities of tree species screened out was few (Zhao *et al.*, 2013). In this study, we selected 28 greening tree species in coastal saline lands as the research objects and investigated the three parameters of leaf emergence and leaf abscission phenology: the beginning, the ending and the time of leaf emergence and leaf abscission. Then, the correlation relationship among the leaf phenological parameters was analyzed. Finally, the tree species with similar phenological characteristics were grouped and divided into four phenological categories.

Materials and Methods

Study area: The study area is located in the eastern end of Chongming Island (121°09′-121°54′E, 31°27′-31°51′N), in Shanghai, China (Fig. 1). It is one of the biggest tidal mudflat wetland with the complete landform types in Yangtze Estuary and has been listed as an international important wetland. This areahas the subtropical maritime monsoon climate with distinct four seasons, prevailing southeast wind in hot and humid summer, and prevailing north wind in dry and cold winter. The common severe climate is characterized by typhoon, rainstorm, drought are. The annual average temperature is 15.3°C. The lowest monthly average temperature is 3.5°C in January and the highest monthly average temperature is 27.5°C in July. The annual average precipitation is 1055.6 mm and about 71% of annual precipitation is concentrated in the period from April to September. The average relative humidity is 82% and the annual average evaporation is 771.1 mm. Annual average sunshine hours is 2104.0 h. Soils are light loam and composed of the modern marine and alluvial deposits. The main salt is sodium chloride and the average salinity is between 0.2% and 0.6%. Over the past 30 years, the largecoastal tideland area had been successively reclaimed for agricultural usages. The study was conducted in the field with the area of about 300 ha. The field was reclaimed in 2000. After 10 years of ecological restoration, the field had become the ecological demonstration area of wetland protection and rational utilization (He *et al*., 2014). A number of greening tree species were introduced and planted for coastal saline land restoration, including 79 tree species, such as *Taxodium distichum*, *Sapium sebiferum*, and *Sapindus mukurossi*, and 92 shrub species, such as *Hibiscus hamabo*, *Amorpha fruticosa*,and *Hibiscus syriacus*.

In the study area, 28 cultivated deciduousgreening tree species with large planting area were selected (Table 1). The tree species were introduced in 2002. In early spring in 2015, before bud break, five trees of each species were chosen and three branches on each selected tree of each species were tagged withsilk belts. The branches were mostly sampled at the mid-crown of the plants and tagged in the position near to the apex. A total of 140 trees and 420 branches were selected. We began the leaf emergence investigation from early March, 2015. The number of the leaves between the silk and the growing tip was recorded for every 2 or 3 days until the number of leaves was not changed in three successive observation days. When the lamina was about 0.5 cm from the shoot axis, a new growing leaf was counted (Zhu & Sun, 2006). Furthermore, we began the observation of leaf abscission from late September, 2015. The number of leaves on the tagged branches was recorded every 2 or 3 days until all leaves were dropped. For the higher plant individuals, 6-m aluminum ladders were used, so that leaf numbers could be clearly recorded.

Before observation of leaf emergence, the largest leaf number on each tagged branch of each species was determined firstly during the leaf emergence period. The largest leaf number was divided by the leaf number observed on each tagged branch of each species in each observation period to obtain the leaf emergence rateof each observation period. The average value of leaf emergence rateof each observation period of all tagged branches was regarded as the leaf emergence rateof each observation period. For leaf abscission, the largest leaf number on each tagged branch of each species was determined before observation. Then, the number of the dropped leaves on each tagged branch was counted after each observation. The largest leaf number was divided by number of the dropped leaves on each tagged branch of each species in each observation time to obtain the leaf abscission rate during each observation period. The average value of leaf abscission rateof each observation period of all tagged branches was regarded as the leaf abscission rateof each observation period. The time when the accumulation rate of leaf emergence and leaf abscission of a species reached 10% and 90% was defined as the beginning and the ending of leaf emergence and leaf abscission, respectively. The time when the accumulation rate of leaf emergence and leaf abscission of a species reached 50% was defined as time of leaf emergence and time of leaf abscission, respectively (Zhu & Sun, 2006).Julian calendar dates of six phenology events were determined. Phenology events were recorded as the number of days after March 1, 2015 (Table 4). The observation of leaf phenology was started on March 1, 2015.

Weather stations were installed to record the climatic conditions.

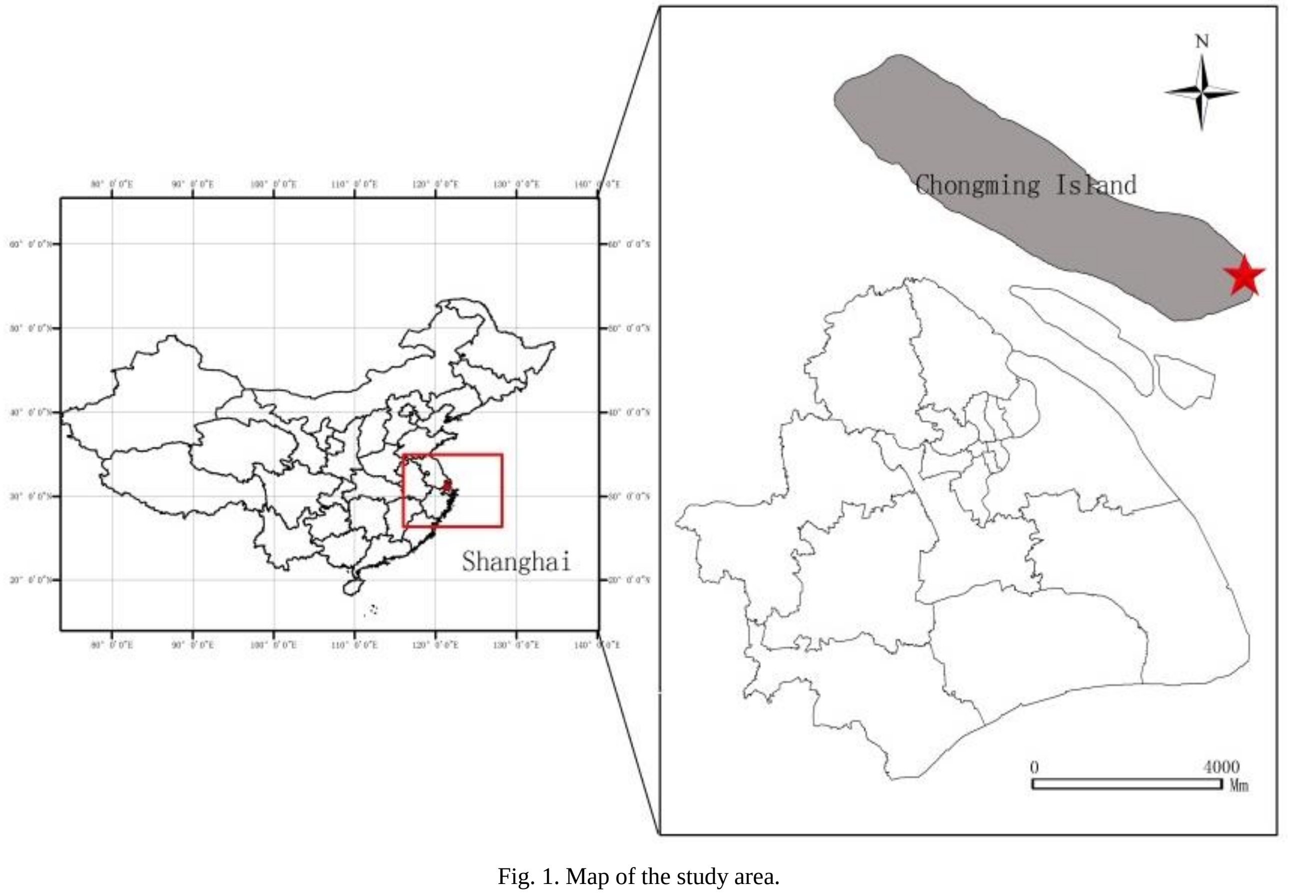

Fig. 1. Map of the study area.

Table 1. Species and data on leaf phenology (day) in coastal saline land.

Species	BLE	ELE	BLA	ELA	TLE	TLA
Taxodium distichum	52	82	235	284	67	268
Lagerstroemia indica	52	66	224	249	58	233
Amorpha fruticosa	53	83	227	273	68	252
Sapindus mukurossi	63	82	231	267	73	254
Hibiscus hamabo	53	84	255	293	71	284
Liquidambar formosana	39	59	223	257	51	239
Broussonetia papyrifera	44	77	223	279	60	243
Melia azedarach	55	79	233	296	68	279
Pyrus sorotina	29	47	231	283	43	256
Deutzia scabra	18	43	216	271	34	234
Gleditsia sinensis	42	49	231	275	47	259
Euonymus maackii	14	47	224	303	30	287
Acer buergerianum	29	54	231	283	47	253
Alchornea davidii	20	50	215	267	44	227
Wisteria sinensis	52	70	232	298	62	293
Celtis sinensis	36	47	228	279	42	251
Sophora japonica	52	87	237	299	68	275
Cercis chinensis	45	59	222	270	49	235
Koelreuteria paniculata	51	73	229	257	61	245
Ulmus parvifolia	50	75	225	279	65	255
Zizyphus jujube	63	81	235	270	72	261
Malus spectabilis	19	33	243	307	27	283
Hibiscus syriacus	49	62	223	259	55	234
Robinia pseudoacacia cv. *Idaho*	46	63	226	291	54	262
Hibiscus mutabilis	52	74	219	292	63	251
Sapium sebiferum	60	75	231	279	65	263
Albizia julibrissin	69	87	227	281	78	251
Ginkgo biloba	41	47	223	254	44	236

Soil sampling: According to the distribution area of observed species, five plots were selected and the size of each plot was about 20×50 m. In each plot, five replicate soil cores were selected randomly and soil samples were respectively obtained from various soil layers with different depths of 0-10, 10-20, 20-40, 40-60, and 60-80 cm with a soil auger with the diameter of 5 cm in the middle of each month from January to December, 2015. Soil samples were mixed evenly, loaded into 3 aluminum boxes, and immediately carried to the lab to determine the moisture content. Soil moisture content was measured after samples were heated at 105°C for at least 48 h according to an oven drying method. The soil moisture (SM) was calculated as follows: soil water content=(fresh weight − dry weight)/dry weight. The average of 3 measurements was used as the soil moisture content of each layer. The pooled samples were used to analyze soil salt concentration. Deionized water (50 mL) was added to 10 g of dry soil and the suspension was shaken for 1 h. The suspension of soil and water (1:5-w/w, $EC_{1:5}$) was used to measure the EC of the soil with a conductivity meter (B-173, Horiba, Kyoto Japan) at 25°C. The average of 3 measurements was calculated as the representative value of the EC for the layer (Jiang *et al.*, 2016). Soil electrical conductivity (EC) was used to indicate soil salinity in this paper.

Data analysis: In the correlation analysis among different leaf phenology parameters, non-parametric correlation analysis of Spearman test was adopted. In the regression analysis among leaf phenology parameters, least squares linear regression analysis method was adopted. Statistical analyses were performed with the SAS 9.0 software package (SAS Institute, Cary, NC) and differences were considered to be significant if $p< 0.05$.Statistical analysis results are shown in Figs. 2-7 and Tables 2-4.

Results

Leaf emergence phenology characteristics: The beginning of leaf emergence of tree species was from mid-March to early May, 2015 and mainly concentrated in the mid to late April, 2015 (Fig. 2a). The beginning of leaf emergence significantly varied with tree species. For example, *Euonymus maackii*, *Deutzia scabra*, *Malus spectabilis*, and *Alchornea davidii* were the earliest and began leafing in the middle March, 2015, while *Sapindus mukurossi*, *Zizyphus jujube*, and in the last *Albizia julibrissin* began leafing in the early May, 2015. The largest difference in the beginning of leafemergence among these tree species were 55 days. The ending of leaf emergence of these species was from early April to late May, 2015 (Fig. 2b). *Malus spectabilis*were the earliest to finish leafing in April 2, 2015 and *Sophora japonica* and *Albizia julibrissin*were the finished leafing in the last May 26, 2015. The largest difference in the ending of leaf emergence among these tree species were 54.

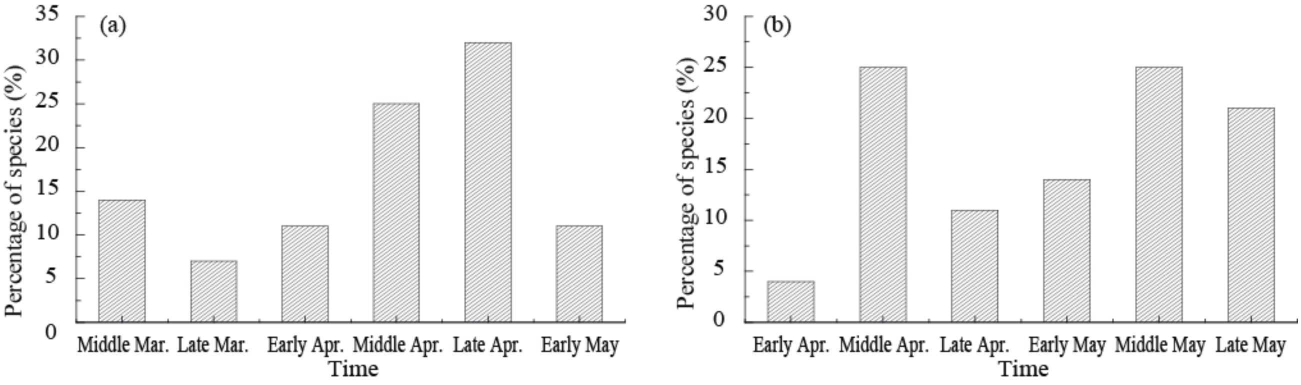

Fig. 2. Distributions of leaf emergence in 28 greening tree species in coastal saline land: (a) beginning of leaf emergence; (b) ending of leaf emergence.

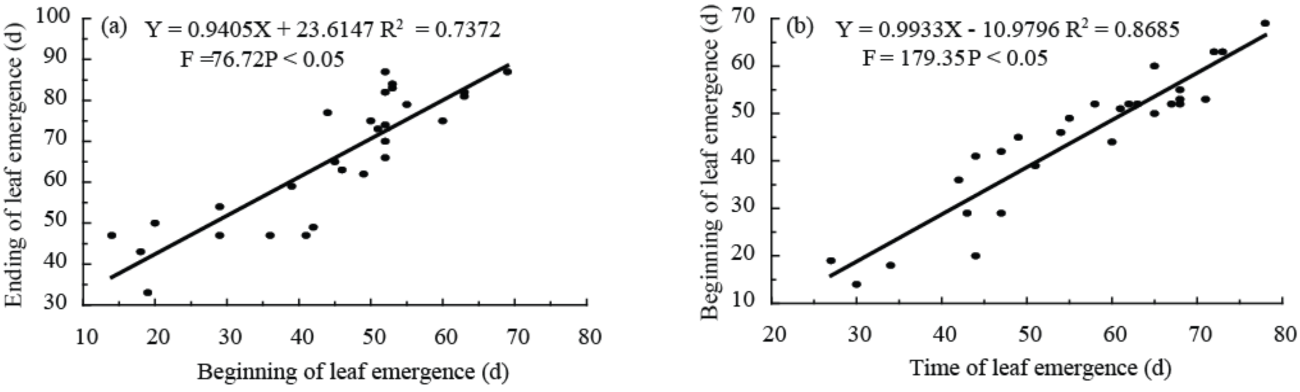

Fig. 3. Relationships among the parameters of leaf emergence in coastal saline land (n=28): (a) relationship between beginning and ending of leaf emergence; (b)relationship between beginning of leaf emergence and time of leaf emergence.

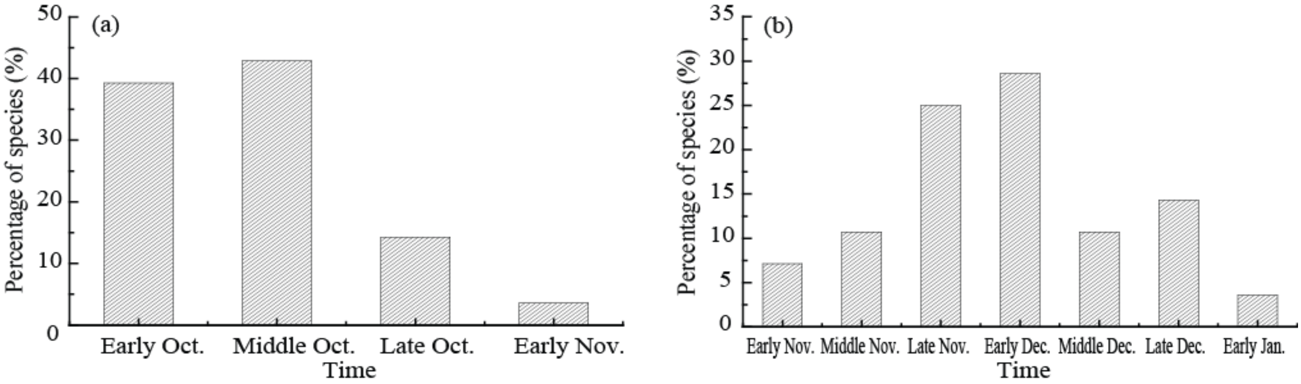

Fig. 4. Distribution of leaf abscission in 28 greening tree species in coastal saline land: (a) beginning of leaf abscission; (b) ending of leaf abscission.

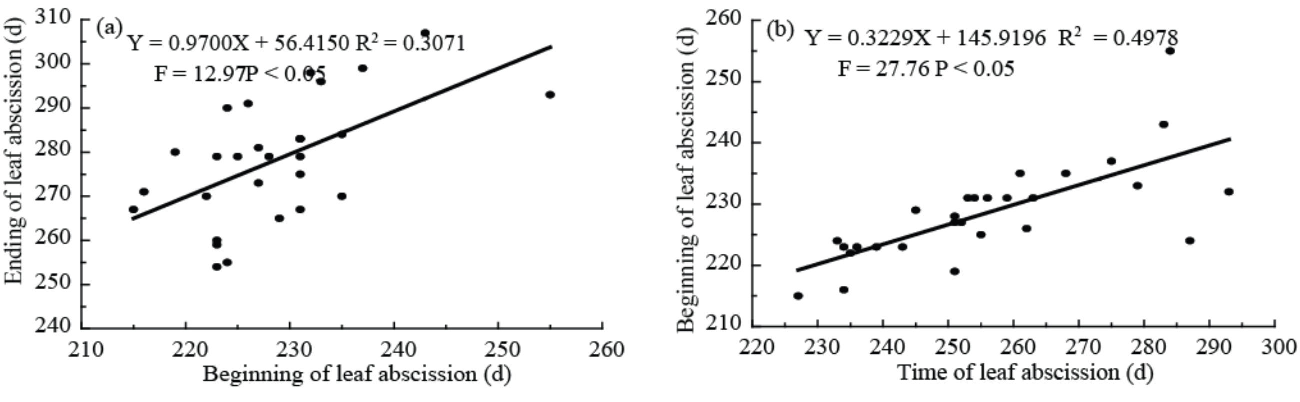

Fig. 5. Relationships among the parameters of leaf abscission in coastal saline land (n=28): (a) relationship between beginning and ending of leaf abscission; (b)relationship between beginning of leaf abscission and time of leaf abscission.

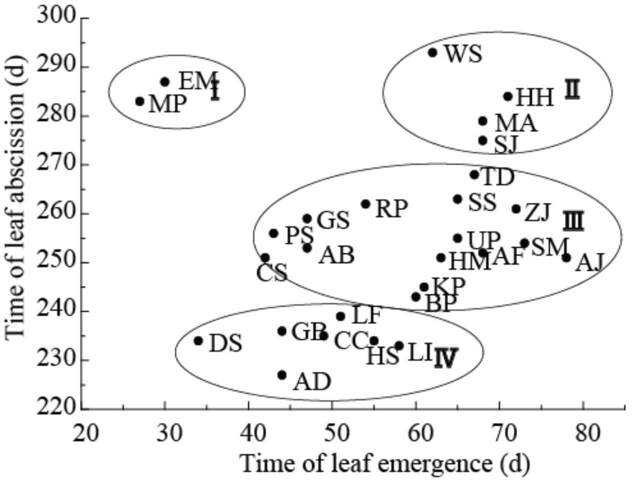

Fig. 6. Scatter plot of time of leaf emergence -time of leaf abscission of 28 greening tree species.
TD: *Taxodiumdistichum*; LI: *Lagerstroemia indica*; AF: *Amorphafruticosa*; SM: *Sapindusmukurossi*; HH: *Hibiscus hamabo*; LF: *Liquidambar formosana*; BP: *Broussonetiapapyrifera*; MA: *Meliaazedarach*; PS: *Pyrussorotina*; DS: *Deutzia scabra*; GS: *Gleditsiasinensis*; EM: *Euonymus maackii*; AB: *Acer buergerianum*; AD: *Alchorneadavidii*; WS: *Wisteria sinensis*; CS: *Celtissinensis*; SJ: *Sophora japonica*; CC: *Cercischinensis*; KP: *Koelreuteriapaniculata*; UP: *Ulmusparvifolia*; ZJ: *Zizyphus jujube*; MP: *Malusspectabilis*; HS: *Hibiscus syriacus*; RP: *Robiniapseudoacacia* cv. *Idaho*; HM: *Hibiscus mutabilis*; SS: *Sapiumsebiferum*; AJ: *Albizziajulibrissin*; GB: *Ginkgo biloba*.

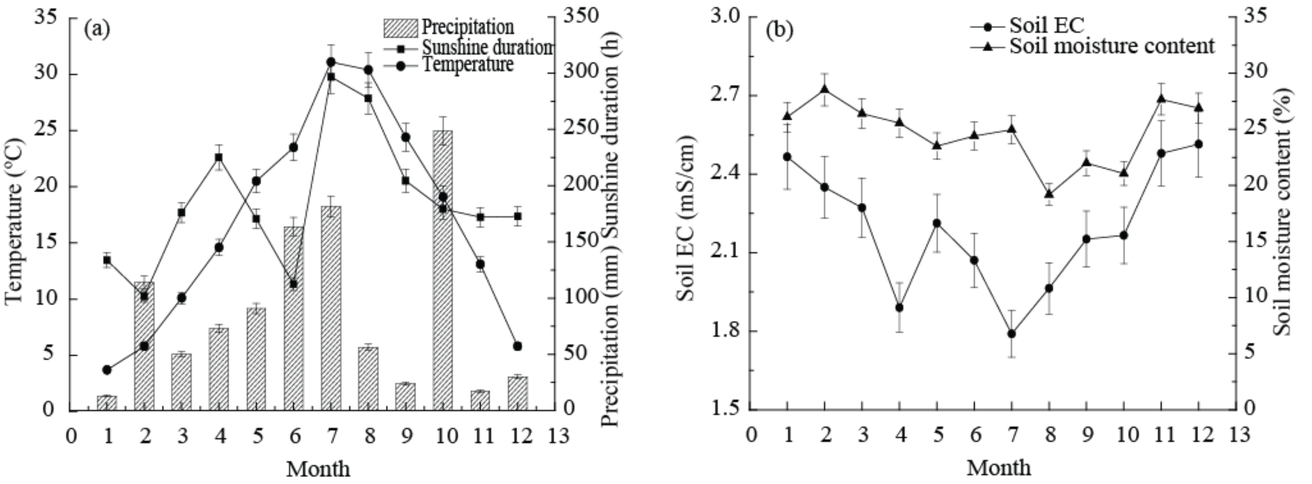

Fig. 7. Climatic and soil characteristics in coastal saline land during 2015: (a) climatic characteristics; (b) soil characteristics.

Table 2. Correlation coefficient matrix of leaf phenological parameters of 28 tree species in coastal saline land.

	BLE	ELE	BLA	ELA	TLE	TLA
BLE	1					
ELE	0.9**	1				
BLA	0.4*	0.4	1			
ELA	-0.0	0.1	0.5**	1		
TLE	0.9**	0.9**	0.4*	0.0	1	
TLA	0.2	0.3	0.8**	0.8**	0.2	1

*Correlation is significant at the level of $p<0.05$; **Correlation is significant at the level of $p<0.01$
BLE: beginning of leaf emergence, ELE: ending of leaf emergence, TLE: time of leaf emergence, BLA: beginning of leaf abscission, ELA: ending of leaf abscission, TLA: time of leaf abscission. The same below.

Table 3.Total variance explaining phenological parameters of tree species in coastal saline land produced by principal component analysis.

Components	Initial eigenvalues			Extraction of sum of squares loaded		
	Total	% Of variance	% Of accumulation	Total	% Of variance	% Of accumulation
1	3.1	51.3	51.3	3.1	51.3	51.3
2	2.2	37.0	88.3	2.2	37.0	88.3
3	0.5	7.8	96.3			
4	0.1	2.2	98.4			
5	0.1	1.3	99.8			
6	0.0	0.2	100.0			

Table 4. First two principal components from principal component analysis of phenological parameters of tree species in coastal saline land.

	PC1	PC2
BLE	0.9	-0.4
ELE	0.9	-0.3
BLA	0.6	0.6
ELA	0.3	0.8
TLE	0.9	-0.4
TLA	0.5	0.9

According to the correlative analysis results (Table 1), there were significantly positive correlation relationship among every two leaf emergence parameters of the beginning, the ending and the time of leaf emergence. This positive correlation relationship was verified by the regression analysis between the beginning of leaf emergence and the ending of leaf emergence, and between the beginning of leaf emergence and the time of leaf emergence, respectively (Fig. 3). This suggested that the earlier leaf emergence began, the sooner leaf emergence ended, and the earlier leaf emergence began, the earlier the time of leaf emergence was.

Leaf abscission phenology characteristics: The beginning of leaf abscission of 28 deciduous species ranged from early October to early November, 2015 and was mainly concentrated in October, 2015 (Fig. 4a). For example,*Alchornea davidii*, *Deutzia scabra*, and *Hibiscus mutabilis* were the earliest and *Hibiscus hamabo* were the latest to begin leaf abscission. The largest difference in the beginning of leaf abscission among these tree species was 40 days. The differences in the ending of leaf abscission among these tree species were significant. The ending of leaf abscission of these tree species ranged from early November, 2015 to early January, 2016 and was mainly concentrated in the period from late November to late December, 2015 (Fig. 4b). The ending of leaf abscission of *Lagerstroemia indica* and *Ginkgo biloba* were the earliest andthe ending of leaf abscission of*Malus spectabilis*was the latest. The largest difference in the ending of leaf abscission among these tree species were 58 days.

According to the correlative analysis results (Table 1), there were significantly positive correlation relationship among every two leaf abscission parameters of the beginning, the ending and the time of leaf abscission. This positive correlation relationship was verified by the regression analysis between the beginning of leaf abscission and the ending of leaf abscission, and between the beginning of leaf abscission and the timeof leaf abscission, respectively (Fig. 5). This suggested that the earlier leaf abscission began, the sooner leaf abscission ended, and the earlier leaf abscission began,the earlier the time of leaf abscission was.

Tree species classification according to leaf emergence and leaf abscission phenology: Principal component analysis was carried out for leaf emergence and leaf abscission phenology of 28 tree species (Table 3). The results showed that the contribution rate of the first two principal components was 51.3% and 37.0% respectively and the cumulative variance contribution rate was as high as 88.3%. Leaf emergence parameters in the first principal component had the higher load factor and could represent the beginning, the ending and the time of leaf emergence; leaf abscission parameters in the second principal component had the higher load factor and could represent the beginning, the ending and the time of leaf abscission (Table 4). The results were in accordance with the correlation analysis among leaf phenology parameters (Table 2). Cluster analysis was conducted according to time of leaf emergence and time of leaf abscission. The 28 tree species were divided into four categories and the results were as follows (Fig. 6).

Category I for the earliest leaf emergence and the latest leaf abscission includes 2 tree species: *Euonymus maackii* and *Malus spectabilis*. Leaves of the trees in this category emerged in late March, 2015 and mainly fell off in the middle of December, 2015. Leaves of the trees in this category emerged the earliest and shed off the latest.

Category II for the latest leaf emergence and later leaf abscission includes 4 tree species, such as *Melia azedarach*, *Sophora japonica*, *Hibiscus hamabo*, and *Wisteria sinensis*. Leaves of the trees in this category emerged in early April, 2015 and shed off in the early and middle of December, 2015. Leaves of the trees in this category emerged the latest.

Category III for later leaf emergence and earlier leaf abscission includes 15 tree species, such as *Broussonetia papyrifera*, *Koelreuteria paniculata*, and *Amorpha fruticosa*. Leaves of the trees inthis category emerged from mid-April to mid-May, 2015 and mainly shed off in November, 2015.

Category IV for earlier leaf emergence and the earliest leaf abscission includes 7 tree species, such as *Lagerstroemia indica*, *Hibiscus syriacus*, and *Liquidambar formosana*. Leaves of the trees in this category mainly emerged in April, 2015 and mainly shed off in early and middle of October, 2015. Species of this category shed leaves the earliest.

Tree species in the same phenological categories had the relative synchronicities and were similar in phenological matching relationship in leaf emergence and leaf abscission. Moreover, these tree species have certain mutual substitution function in landscape configuration using leaf phenology.

Discussion

Leaf emergence phenology and afforestation time: Leaf phenology can guide afforestation time (Zhao *et al.*, 2013). Leave emergence of tree species in this study mainly started in March and April, 2015 and ended in April and May, 2015. The leave emergence process was related to environmental factors of the study area. In this study area, the temperature in March and April rose rapidly. Due to the rising temperature, the plants began blooming and roots absorbed and utilized groundwater. Therefore, underground water level reduced and soil salinity also declined with water (Fig. 7). Soil salinity around plant roots decreased and this period was defined as the desalination stage (He, 2014). Soil salinity in spring was in lower level throughout the year. In addition, abundant rainfall and enough illumination time in this period were conducive to the growth of plants, so most trees began leaf emergence. Planting trees before the beginning of leaf emergence in spring can improve the survival rate of tree species (Zhao *et al.,* 2013). Leaves in different tree species emerged sooner or later, so the best time to plant trees could be chosen according to the beginning of leaf emergence in different tree species. The beginning of leaf emergence of the greening tree species in this study was from mid-March until early May, 2015. Afforestation time was suggested to conduct from March to May when introduced these greening tree species. The tree species with the earliest beginning of leaf emergence such as *Euonymus maackii*, *Deutzia scabra*, *Malus spectabilis* and *Alchornea davidii* were suggested to be planted before mid-March, and the tree species with the late beginning of leaf emergence such as *Sapindus mukurossi*, *Zizyphus jujube* and *Albizia julibrissin* to be planted before early May. In this way, the introduction and planting of these tree species could concentrate within a period of time, which avoided both the blindness and randomness of planting time and improved the survival rate of tree species.

Leaf phenology and plant landscape configuration: Landscape configuration of tree species could be conducted according to time of leaf emergence and time of leaf abscission. Tree species with earlier or later leaf emergence time and tree species with earlier or later leaf abscission time could be combinedly planted. In the four categories of tree species, time of leaf emergence of tree species in the former two categories was in late March or early May and leaf emergence was sooner or later, while time of leaf abscission was in early or middle December and leaf abscission was later. Time of leaf emergence of tree species in the latter two categories was in April to May, 2015 and leaf emergence was relatively concentrated, while time of leaf abscission was in middle or late October to November, 2015 and leaf abscission was earlier. Tree species of the former two categories and the latter two categories could be combined for planting in the plant landscape configuration. Firstly, time of leaf emergence of tree species in the former two categories was sooner or later and was not uniform, but that of the latter two categories was relatively uniform in time. Tree species of the former two categories and the latter two categories planted in random combination and configuration could form uniform and continuous spring landscape. Secondly, time of leaf abscission of tree species in the former two categories was late but that of the latter two categories was relatively early. Tree species of the former two categories and the latter two categories planted in random combination and configuration could form homogeneous and continuous autumn landscape. In addition, when making combination configuration, tree species in the same category could replace each other, and thus form a variety of combinations.For example, tree species which had both early leaf emergence and late leaf abscission in Category I such as *Malus spectabilis* and *Euonymus maackii* matched randomly with tree species which had both late leaf emergence and early leaf abscission in Category III such as *Hibiscus mutabilis*, *Ulmus parvifolia*, *Amorpha fruticosa*, *Sapindus mukurossi* and *Albizia julibrissin*; or, tree species which had both late leaf emergence and late leaf abscission. In Category II such as *Wisteria sinensis*, *Melia azedarach*, *Sophora japonica* and *Hibiscus hamabo* matched randomly with tree species which had both early leaf emergence and early leaf abscission in Category IV such as *Deutzia scabra*, *Alchornea davidii*, *Ginkgo biloba* and *Cercis chinensis*. Both continuous landscape in time and homogeneous distributed landscape in space were formed through these free combination and configuration.

Conclusion

Leaf emergence of greening tree species in coastal saline land was mainly concentrated in the period from March to May. Leaf abscission process lasted for a longer period from October to January of the next year. Leaf phenology could guide the greening in coastal saline land. First of all, planting trees before the beginning of leaf emergence in spring could improve the survival rate of tree species. The best planting time was different according to tree species and afforestation time was suggested to be from March to May when introduced the 28 greening tree species. Secondly, landscape configuration of tree species could be conducted according to time of leaf emergence and time of leaf abscission. Tree species with earlier or later leaf emergence time and those with earlier or later leaf abscission time could be combined together to be planted. For example, tree species which were both earlier leaf emergence and later leaf abscission matched randomly with tree species which were both later leaf emergence and earlier leaf abscission, or, tree species which were both later leaf emergence and later leaf abscission matched randomly with tree species which were both earlier leaf emergence and earlier leaf abscission.

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