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Variations in soil nutrients and salinity caused by tamarisk in the coastal wetland of the Laizhou Bay, China

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Citation: Liu, J., Q. Rong, and Y. Zhao. 2017. Variations in soil nutrients and salinity caused by tamarisk in the coastal wetland of the Laizhou Bay, China. Ecosphere 8(2):e01672. 10.1002/ecs2.1672

Abstract. The nature of resource islands created by patchy distribution of plants remains controversial in arid, semi-arid, and even some coastal ecosystems. This study explores these effects of isolated and clustered tamarisk (*Tamarix chinensis* Lour.) in coastal wetland of the Laizhou Bay. Soil samples were collected and analyzed from 0 to 30 cm depth near the trunks of isolated tamarisk plants, in clustered tamarisk communities, and in open land. The results showed that available nitrogen (AN), available phosphorus (AP), and soluble aqueous sodium (Na) concentrations of soil under the isolated and clustered tamarisk canopies were significantly higher than those from open land. The Na and electrical conductivity (EC) values of intra-canopy in clustered tamarisk were higher than those in the inter-canopy space, while Na and EC of intra- and inter-canopy space were significantly lower than those under the isolated tamarisk. Soil nutrients under isolated and clustered tamarisk canopies in the coastal zone of the Laizhou Bay exhibited significant resource island effects. However, the size of this resource island effect was significantly lower under clustered tamarisk than that of isolated tamarisk, indicating that this effect will weaken following the vegetation restoration or the succession of plant community in the studied area.

Key words: coastal wetland; resource island; soil electric conductivity; soil nutrients; *Tamarix chinensis* Lour.

Received 30 August 2016; revised 13 December 2016; accepted 20 December 2016. Corresponding Editor: Kristofer D. Johnson.

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INTRODUCTION

Soil properties commonly exhibit spatial heterogeneity in many ecosystems (Schlesinger et al. 1996, Abril et al. 2009, Allington and Valone 2014). In arid and semi-arid regions, soil properties typically exhibit significant spatial heterogeneity because soil nutrient resources are more abundant under the canopies of shrubs or trees than in soils of open land; this difference is caused by the patchy distribution of vegetation (Schlesinger et al. 1996, Gallardo et al. 2000). The spatial heterogeneity of soil resources caused by the patchy distribution of shrubs or trees has been described as the creation of "resource islands" or "fertile islands" (Daryanto et al. 2012). The formation of a resource island has been correlated with many biotic and abiotic processes, such as the accumulation and decomposition of litter fall (Li et al. 2007), the presence of shrub species and the shapes of canopies (Qian et al. 2004, Li et al. 2007), stemflow (Whitford et al. 1997), eolian processes (Li et al. 2008), and soil microbial activity (Stubbs and Pyke 2005). Resource islands have been shown to exert significant effects on species diversity, productivity, vegetation dynamics, and community structure (Anderson et al. 2004) by changing the soil physical and chemical properties under canopies (Wezel et al. 2000, Cantón et al. 2004, Yang et al. 2011).

Resource islands have been found in many ecosystems, including sagebrush steppe (Ryel et al. 1996), woodlands (Evans and Belnap 1999,

Eldridge and Wong 2005, Pinno and Wilson 2013), shrublands (Bochet et al. 1999), coastal zones (Alpert and Mooney 1996), and deserts (Schade and Hobbie 2005, Stubbs and Pyke 2005, Li et al. 2007, Allington and Valone 2010). Resource islands are persistent features of arid and semi-arid environments (Schlesinger et al. 1996, Qi et al. 2010, Allington and Valone 2014) and serve as an important factor that affects the symbiosis and competition of plants (Schlesinger and Pilmanis 1998, Li et al. 2011). However, some studies have indicated that resource islands are ephemeral or non-existent (Herman 1997, Stock et al. 1999). Many investigations suggest disturbance of local vegetation causes the formation of resource islands (Abril et al. 2009, Daryanto et al. 2012, Su et al. 2012). Some researchers believe that the resource islands effect will disappear during community succession after disturbance has been eliminated, and that these islands may be a by-product of disturbance (Titus et al. 2002, Allington and Valone 2010, 2014).

Tamarix, a genus that is native in Europe and Asia, is an invasive species in America and Oceania (Williams and West 2000, Lesica and Miles 2004, Natale et al. 2010, Pattison et al. 2011). The plants are very adaptable to stress, such as drought, saline-alkali soil, and extreme temperature; however, the possible effects of *Tamarix* on soil physical and chemical properties and the way it interacts with other plants are still controversial. Some researchers speculate that *Tamarix* excretes salt, leading to an increase in soil salt content, soil electrical conductivity, and soil pH under the canopy (Ladenburger et al. 2006, Yin et al. 2010, Su et al. 2012). These changes induce soil hardening and salinization (Zhang et al. 2002), hinder the growth of non-halophytes, cause a decline in biodiversity, and alter plant community structure (Zhang et al. 2002, Bateman et al. 2015). Other studies argue that *Tamarix* does not cause an increase in soil salt content under the canopy (Bagstad et al. 2006, Li et al. 2007), but that *Tamarix* may result in an increase in soil nutrient levels and thereby exert a fertile islands effect (Lesica and DeLuca 2004, Bagstad et al. 2006, Yin et al. 2010), which may not affect or may even increase local biodiversity (Riper et al. 2008, Johnson et al. 2010, Brand and Noon 2011, Lehnhoff et al. 2012).

Of the 18 species of *Tamarix* in China, six are endemic (Zhang et al. 2002). In China, *Tamarix* serves as an important species for vegetation reconstruction, the development of windbreaks, and is used to help fix sand dunes in the arid regions of northwest China (Zhang et al. 2002, Huang and Gao 2004). The plants are also of a high significance in the prevention of seawater intrusion and coastal erosion in the coastal areas of northern China (Cui et al. 2010, Zhang 2014). The Laizhou Bay is the most active region of land–sea interaction in China with the youngest and the largest wetland ecosystems and also has the most concentrated area of tamarisk (*Tamarix chinensis* Lour.) in northern China's coastal area (Cui et al. 2010, Zhang 2014). Previous researches related to tamarisk have mainly focused on the spatial patterns of soil physical and chemical properties, groundwater conditions, photosynthetic characteristics, and ecological stoichiometry of tamarisk (Cui et al. 2010, Rong et al. 2015, Xia et al. 2015). However, there are few data on the resource island effect of tamarisk and its influence on soil properties and community structure in this region area. Therefore, we hypothesize that there will be significant resource island effect of tamarisk in the coastal wetland of the Laizhou Bay, and this effect will weaken following the restoration of vegetation. This study was carried out (1) to determine whether a resource island effect exists and to determine its spatial characteristics as it is related to tamarisk in the selected area and (2) to determine whether the resource island effect of tamarisk will disappear following the restoration of vegetation after disturbance is eliminated.

Materials and Methods

Study area

The Laizhou Bay wetland is located between the Yellow River Delta and the northwestern Shandong Peninsula with a deposition origin and an age of approximately 150 yr. It is one of the three main bays of Bohai Sea, making up 10% of the total area (Pan et al. 2011). Due to the large volume of freshwater input from the Yellow River, the tidal currents in the bay are very complicated. This area experiences a semi-humid monsoon climate zone and lies in the warm temperate. Based on long-term (1995–2013) meteorological data, the average annual rainfall and temperature are about 600 mm and 12°C, respectively, with 60–70% of the rainfall distributed

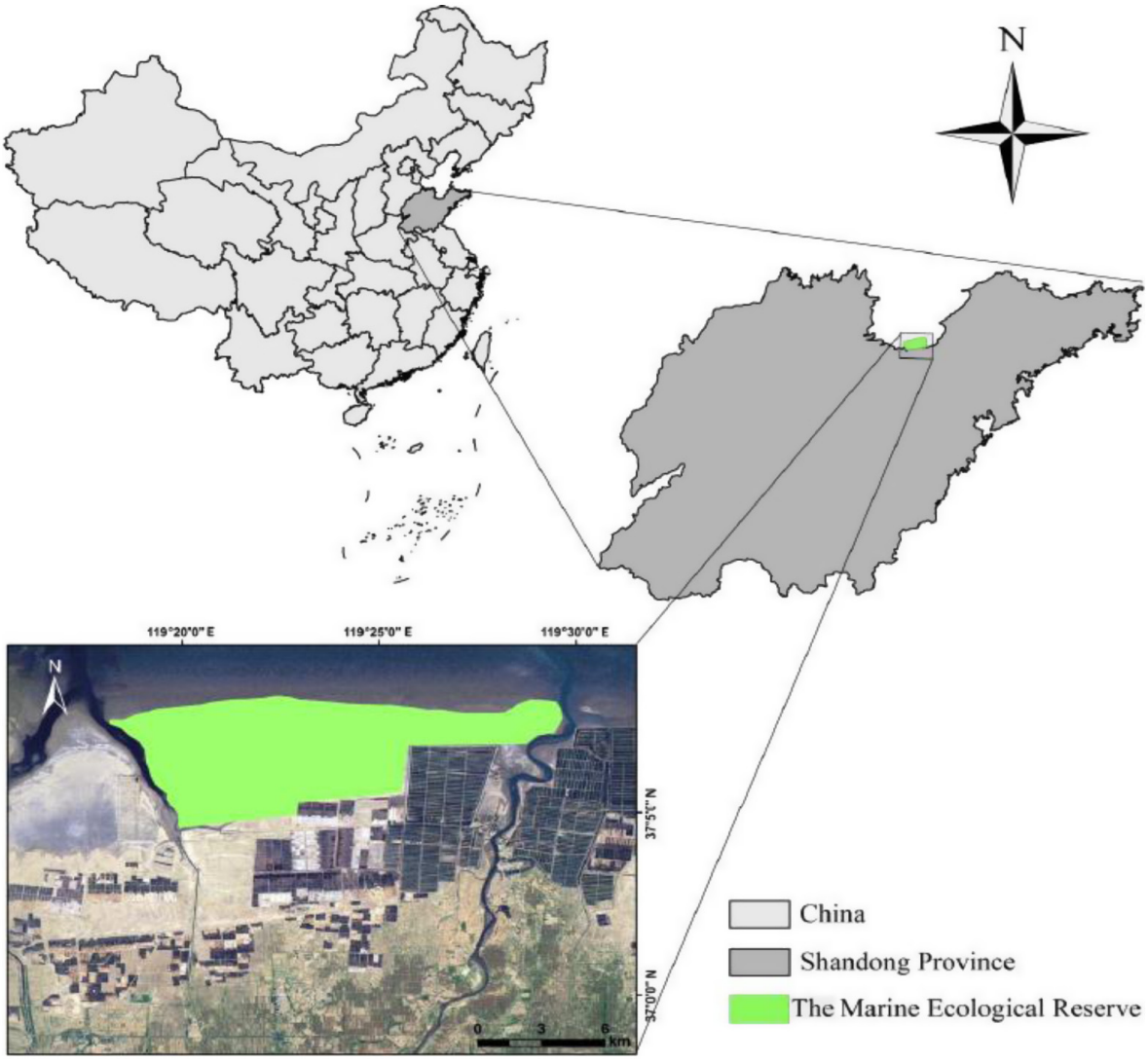


Fig. 1. The location of the study area.

between July and September. The average annual evaporation based on evaporating pan observations is about 1700 mm (Pan et al. 2011, Xia et al. 2013, 2015, Han et al. 2014).

This study was conducted in the National Marine Ecological Reserve in Changyi City, Shandong Province, China (central coordinates are 37°06′15″ N, 119°22′00″ E; Fig. 1). It is located in the south of the Yellow River Delta, near Bohai Bay, and covers about 2900 ha. The reserve is a shallow bay with flat terrain and a gentle slope from the coastal land to the ocean (Wang et al. 2009, Han et al. 2014). The mainly alluvial and saline soil supports vegetation composed of shrub communities mainly dominated by tamarisk. The dominant herbaceous plants with coverages less than 30% in coastal tidal flats are *Artemisia capillaris* Thunb., *Atriplex centralasiatica* Iljin, *Limonium bicolor* (Bunge) O. Kuntze., and *Suaeda salsa* (L.) Pall. The dominant vegetation on coastal inland areas includes *Aeluropus littoralis* (Gouna) Parl, *Chloris virgata* Swartz, *Cynanchum chinense* R. Br., *Phragmites australis* Trin., and *Setaria viridis* (L.) Beauv.

In the past decades, the industrial and urban development in and around the region has expanded rapidly. Because of the rich seawater

Table 1. Vegetation characteristics of the selected plots.

Traits	Habitats	
	Isolated tamarisk	Clustered tamarisk
Morphological traits of tamarisk		
Mean height (m)†	3.22 ± 0.12	2.73 ± 0.12
Crown diameter (m × m)†	(2.92 ± 0.22) × (3.15 ± 0.19)	(3.23 ± 0.28) × (3.30 ± 0.17)
Number of shoots (*N*)†	9 ± 2	11 ± 3
Main stem diameter (cm)†	7.46 ± 0.53	6.86 ± 0.36
Age (yrs)	9–11	13–15
Understory vegetation		
Coverage (%)	<10	20–30
Height (m)	0.20	0.25–0.35
Dominant species	*Aeluropus littoralis* (Gouna) Parl. *Artemisia capillaris* Thunb. *Limonium bicolor* (Bunge) O. Kuntze. *Setaria viridis* (L.) Beauv. *Suaeda salsa* (L.) Pall	*Aeluropus littoralis* (Gouna) Parl. *Atriplex centralasiatica* Iljin *Chloris virgata* Swartz *Cynanchum chinense* R. Br. *Phragmites australis* Trin. *Setaria viridis* (L.) Beauv.

† Mean ± SE.

and underground brine resources, the region has been included in the Binhai Economic Development Zone of Weifang that is mainly associated with the chemical industry (Pan et al. 2011). The reserve was established in 2007, but the chlor-alkali industries, aquaculture enterprises, and salterns had been built across the area prior to 2007 to extract underground brine as a raw material (Pan et al. 2011, Xia et al. 2013). The average groundwater table was below 20 m due to long-term underground brine extraction. The deforestation in order to extract underground brine prior to the establishment of the reserve resulted in the coexistence of both isolated and clustered tamarisk plants in the area.

Soil sampling and laboratory analysis

In this study, we selected nine tamarisk plants that had been isolated because of deforestation by human disturbances and six clustered tamarisk communities without nearby human activities in the reserve. Soil samples were collected in August of 2013 and 2014. Sampling was conducted under both isolated and clustered tamarisk plants with a similar height, crown shape, and age (Table 1 and Fig. 2).

To avoid the influence of any adjacent shrubs, the distance between any two isolated tamarisk plants used in this study was 10–20 m. The sampling points were established in the four cardinal directions from the base of the experimental plant. Sampling was initiated near the isolated tamarisk trunk as the starting point, and the soil was sampled at 1-m intervals until a 5 m distance from the trunk was reached (Fig. 3).

Soil samples were also collected at the canopy middle (sites near the middle of the vertical projected range of the shrub crown), at the canopy periphery (sites at the vertical projected edge or drop line of the shrub crown), and in the inter-canopy space (sites between the peripheries of two adjacent canopies) from the four cardinal directions in the clustered tamarisk colonies as well; in addition, samples were also collected in open land (sites at least two crown diameters away from the shrub trunk) where mostly bare soil was found (Fig. 4).

We collected all the soil samples from a soil depth of 0–30 cm with a 5 cm diameter soil auger, resulting in a total of 624 soil samples (isolated tamarisk: 9 sites × 6 sampling points × 4 replicates × 2 times; clustered tamarisk: 6 sites × 4 sampling points × 4 replicates × 2 times). The soil samples collected from each of four cardinal directions from the same sampling point under isolated or clustered tamarisk were mixed evenly to create a single specimen, and 156 mixed soil specimens were tested.

The soil specimens were air-dried and passed through a 2-mm sieve to remove pebbles, litter, organic material, and comminuted organic material. Subsequently, the specimens were pulverized in a grinder and passed through a 0.2-mm sieve. The electrical conductivity (EC) was determined

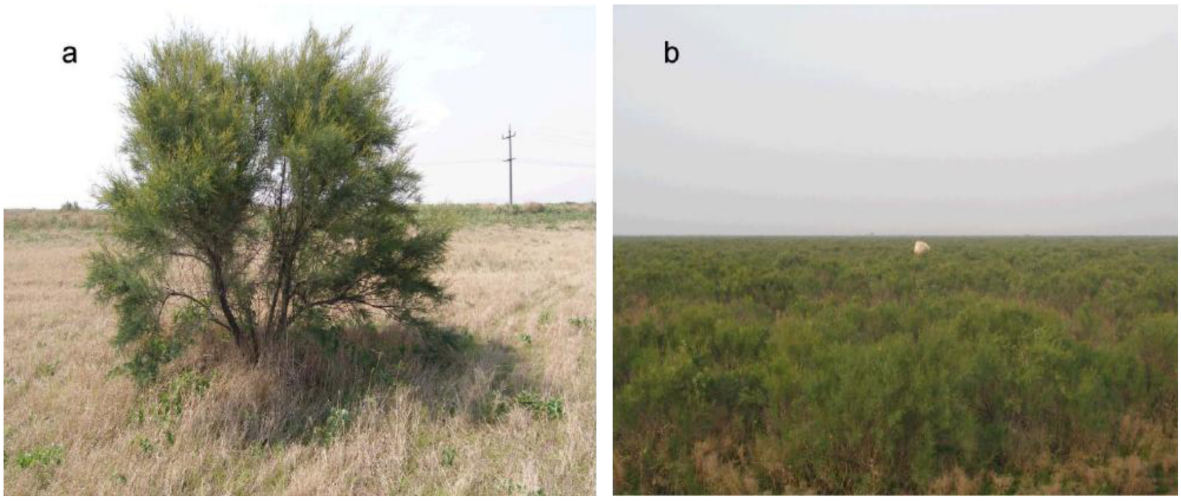


Fig. 2. Photographs of (a) an isolated tamarisk plant and (b) clustered tamarisk plants in the study area.

by a conductance instrument (OHAUS Corporation, Parsippany, New Jersey, USA) using a 1:5 ratio of soil to water suspension. Water soluble sodium (Na) was extracted by using a 1:5 ratio of soil to water after shaking the sample for 30 min, after which the extracts were filtered and analyzed by an atomic absorption spectrophotometer (Shimadzu, Kyoto, Japan). The KCl extracting technique was used to determine available soil nitrogen (AN, ammonium and nitrate; Evans and Ehleringer 1994, Stubbs and Pyke 2005). Soil specimen (about 20 g) was extracted with 50 mL of 2 mol/L KCl and was shaken for 60 min. A continuous flow injection analyzer (Seal Analytical

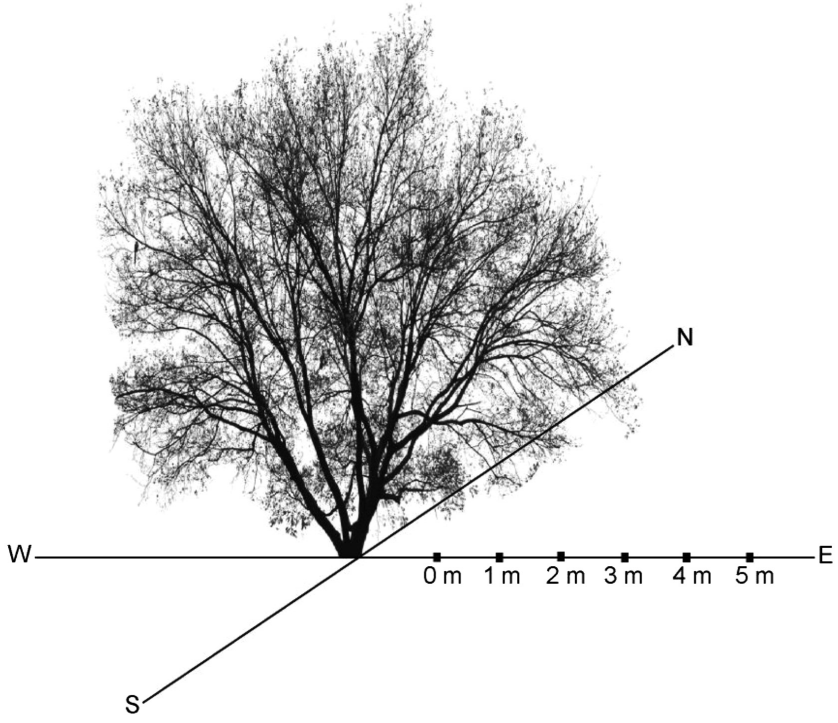


Fig. 3. Soil sampling points under an isolated tamarisk plant.

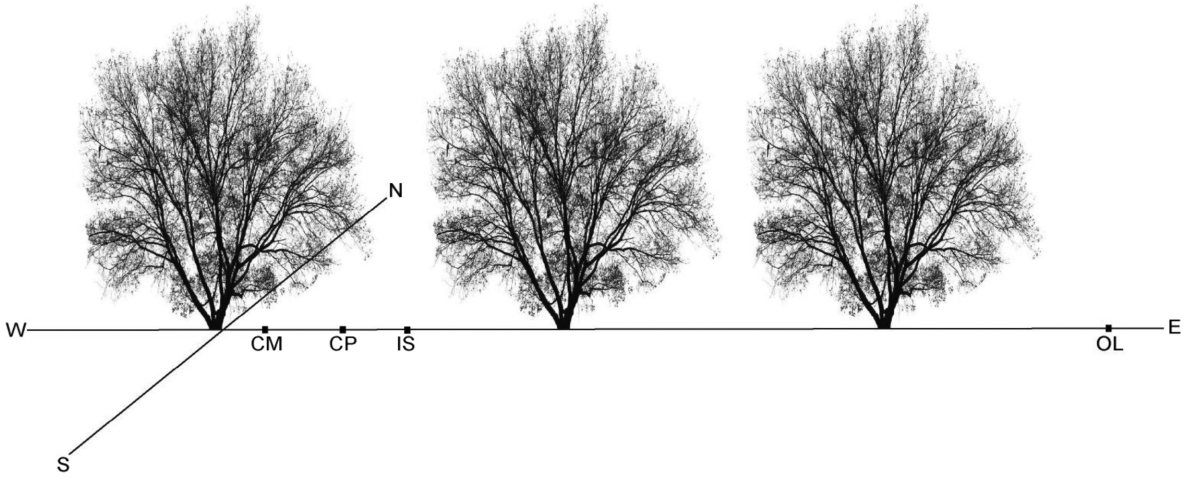


Fig. 4. Soil sampling points under clustered tamarisk plants. CM, canopy middle; CP, canopy periphery; IS, inter-canopy space; OL, open land.

GmbH, Norderstedt, Germany) was employed to determine the AN in the filtered extracts. We measured the available soil phosphorus (AP) by the molybdenum blue method with ascorbic acid as a reductant (Murphy and Riley 1962). A soil specimen (about 20 g) was extracted with 0.5 mol/L $NaHCO_3$ and was shaken for 60 min. A spectrophotometer was employed (Beijing Purkinje General Instrument, Beijing, China) to determine the AP in the filtered extracts.

Statistical analysis

The enrichment ratio (ER) can be used to estimate the effects of a soil resource island (Yin et al. 2010, Allington and Valone 2014). To assess the influence of plant on soil properties, we analyzed the soil properties under isolated and clustered tamarisk canopies by calculating ER using formula:

$$ER_x = \frac{\text{mean canopy soil property value}}{\text{mean open land soil property value}}$$

where ER_x is the enrichment ratio of soil properties in different habitats.

One-way analysis of variance was adopted to analyze the effects of tamarisk on soil properties. Fisher's least significant difference method was employed for the analysis of significant differences. Normal distribution and homogeneity tests were carried out on all the data prior to statistical analyses.

Results

Soil properties under isolated and clustered tamarisk plants

The results showed that surface soil properties exhibited inconsistent distribution patterns when comparing the different habitats. Under isolated tamarisk, AN, AP, and Na (but not EC) decreased with the increasing distance from the tamarisk trunk ($P < 0.05$; Fig. 5). Furthermore, significant changes were found around the canopy periphery. Therefore, we selected the sampling points at 0, 1, and 2 m as the intra-canopy area of the isolated tamarisk, and the sampling points of 3, 4, and 5 m as the open land area. The intra-canopy average values (mean ± SE) of soil AN, AP, Na, and EC under the isolated tamarisk were 23.18 ± 0.55 mg/kg, 6.92 ± 0.11 mg/kg, 81.91 ± 7.27 mg/kg, and 111.30 ± 5.29 μS/cm, respectively, which were significantly higher than those of the open land (18.4 4 ± 0.37 mg/kg, 3.25 ± 0.08 mg/kg, 18.47 ± 2.95 mg/kg, and 74.66 ± 2.15 μS/cm, respectively). No significant differences in AN or AP were observed within either the intra-canopy or open land sampling points ($P > 0.05$). The differences in Na or EC were significant ($P < 0.05$) for any paired sampling points of intra-canopy, but the differences for those of open land were inconsistent.

In the clustered tamarisk communities, the average AN, AP, Na, and EC of the intra-canopy (sites within the vertical projected range of the

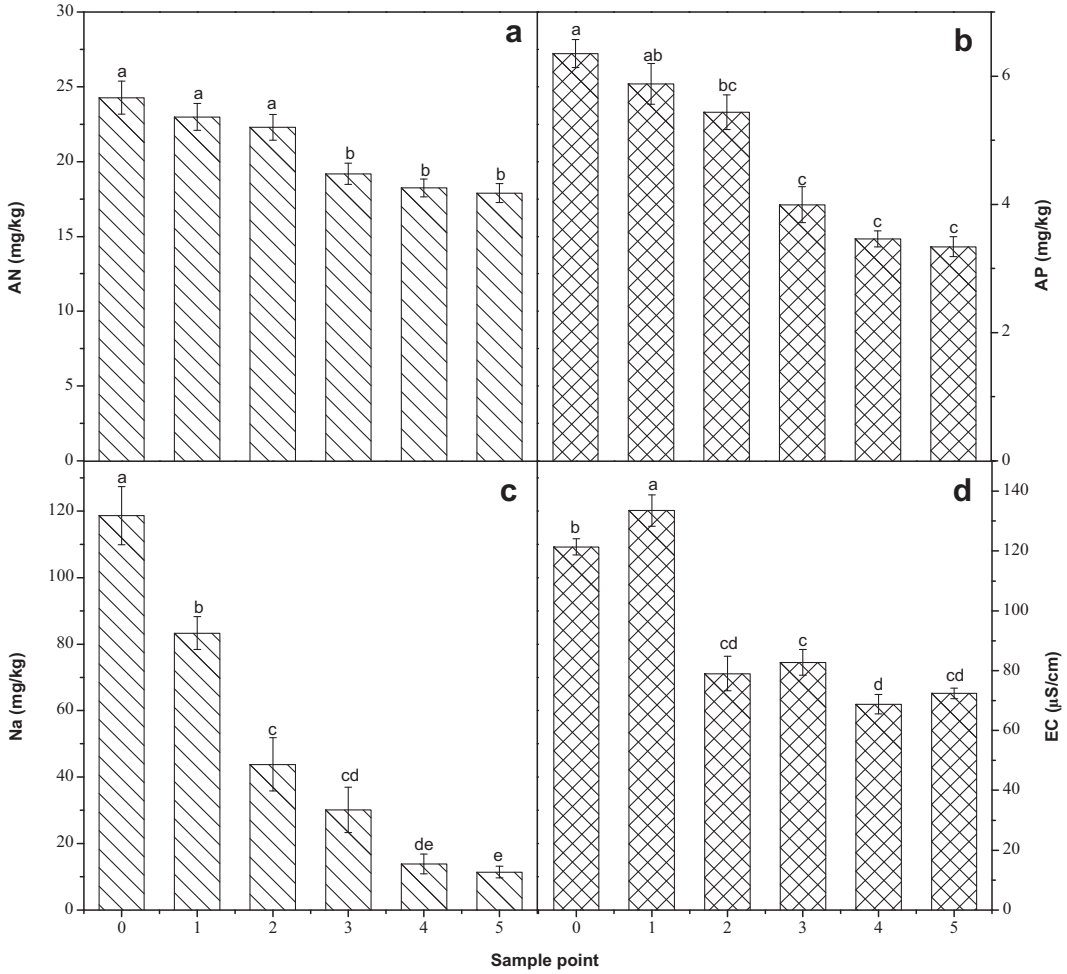


Fig. 5. Soil properties (mean ± SE) under isolated tamarisk plants. Different lower-case letters above bars denote significance differences (n = 18, $P < 0.05$) with a least significant difference test.

shrub crown, including canopy middle and canopy periphery) were 23.76 ± 0.40 mg/kg, 6.62 ± 0.13 mg/kg, 37.96 ± 4.21 mg/kg, and 86.30 ± 2.41 μS/cm, respectively, which were significantly higher than those of the open land ($P < 0.05$; Fig. 6). However, no significant differences in AN and AP were observed between the samples from the intra- and inter-canopy spaces, whereas the amounts of Na and EC in the intra-canopy space were significantly higher than those of the inter-canopy space.

Pairwise comparison showed no significant differences in AN in intra- and inter-canopy under isolated and clustered tamarisk, while the lowest AP was found in inter-canopy under clustered tamarisk. There were significant differences in Na and EC in intra- and inter-canopy under isolated and clustered tamarisk with the lowest in Na and EC of inter-canopy (Table 2).

Resource island effect size under isolated and clustered tamarisk plants

The ER varied significantly for the same nutrient in different habitats (Table 3). The $ER_{isolated}$ (soil property of intra-canopy under isolated tamarisk/open land) of AN and AP was not significantly different from ER_{open} (mean soil property of canopy middle, canopy periphery, and inter-canopy in clustered tamarisk/open land), and there were significant differences between those of Na ($P < 0.001$). The ER_{inter} (mean soil property of canopy middle and canopy periphery

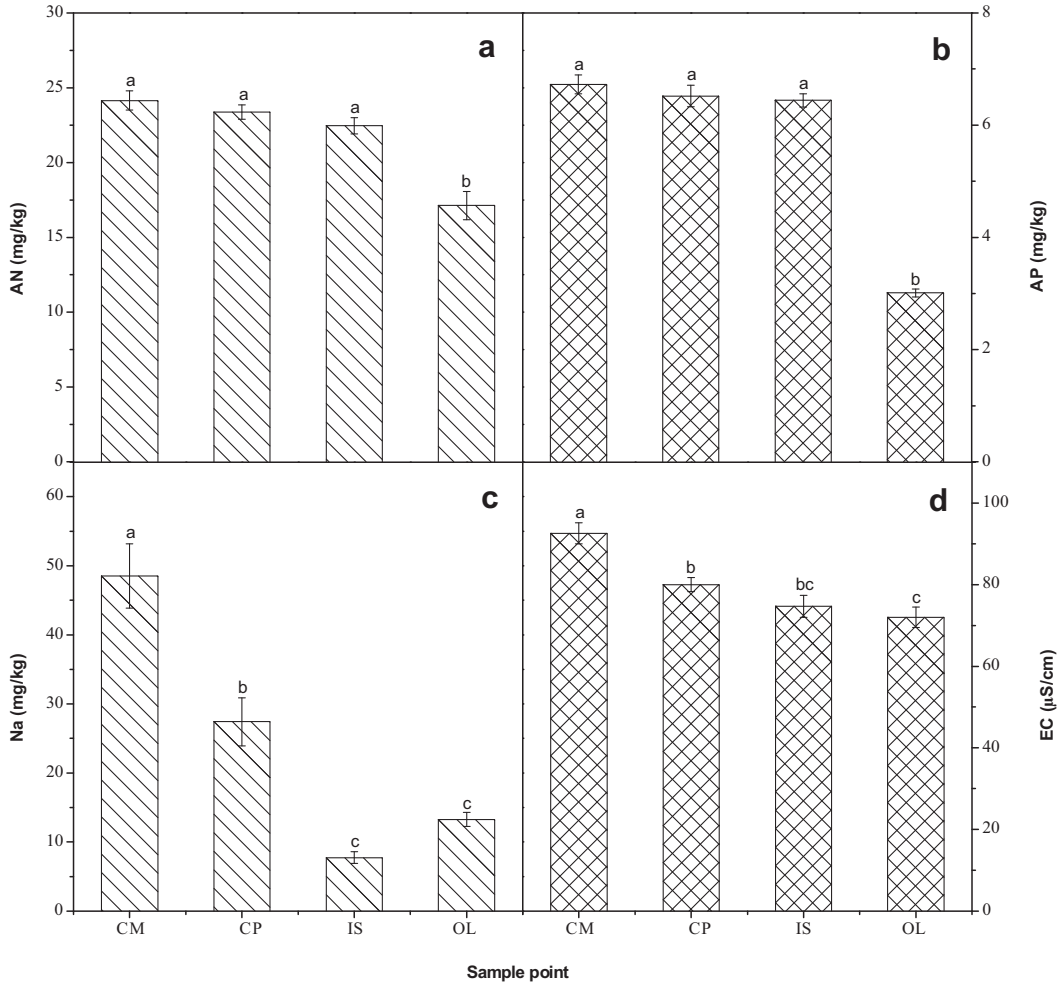


Fig. 6. Soil properties (mean ± SE) under clustered tamarisk plants. Different lower-case letters above bars denote significance differences (n = 12, $P < 0.05$) with a least significant difference test. CM, canopy middle; CP, canopy periphery; IS, inter-canopy space; OL, open land.

in clustered tamarisk/inter-canopy) of AN and AP was significantly lower than $ER_{isolated}$ and ER_{open} ($P < 0.001$). However, ER_{inter} of Na was about the same as the $ER_{isolated}$ and was significantly higher than the ER_{open} ($P < 0.001$).

Discussion

A resource island exerts a significant effect on ecological processes, including plant diversity, soil function, and landscape heterogeneity (Maestre et al. 2009, Eldridge et al. 2011), and many factors affect the formation of resource islands. Resource islands occur across a broad array of tree and shrub growth forms and species inhabiting diverse climatic zones. Scholes and Archer (1997) review that three mechanisms have been proposed to account for the formation of resource islands. Firstly, trees or shrubs may act as nutrient pumps, drawing nutrients from deep horizons and laterally from areas beyond the canopy, depositing them mainly beneath the canopy via litter fall and canopy leaching. The second mechanism is that the tall, aerodynamically rough tree or shrub canopies act as an effective trap for atmospheric dust. The dust contains nutrients, which wash off the leaves during precipitations and drip into the area under the canopy. A third mechanism may be of importance where trees or shrubs are sparse and may serve as habitats

Table 2. Soil properties of isolated and clustered tamarisk.

Habitats	Statistics	Soil property			
		AN	AP	Na	EC
Intra-canopy (isolated tamarisk)	Mean	23.18a	6.92a	81.91a	111.30a
	Minimum	21.15	6.52	61.07	99.30
	Maximum	24.47	8.12	100.59	121.60
	SE	0.36	0.17	4.07	2.73
Intra-canopy (clustered tamarisk)	Mean	23.78a	6.60a	37.98b	86.33b
	Minimum	22.30	6.30	25.60	82.90
	Maximum	26.00	6.80	49.70	93.20
	SE	0.52	0.09	3.79	1.68
Inter-canopy (clustered tamarisk)	Mean	22.47a	6.44b	7.75c	74.72c
	Minimum	21.12	6.12	4.84	62.60
	Maximum	24.15	6.93	10.22	80.70
	SE	0.54	0.12	0.84	2.68

Notes: AN, available nitrogen; AP, available phosphorus; Na, soluble aqueous sodium (Na); EC, electrical conductivity. Intra-canopy (isolated tamarisk): the sampling points at 0, 1, and 2 m under isolated tamarisk; intra-canopy (clustered tamarisk): the sampling points at the canopy middle and canopy periphery under clustered tamarisk; inter-canopy (clustered tamarisk): the sampling points between the peripheries of two adjacent canopies under clustered tamarisk. Means followed by the lower-case letters in the same column indicate significance ($P < 0.05$) with a least significant difference test between different habitats.

attracting roosting birds and mammals seeking shade or cover. Herbivores that take refuge in the shade of trees may enhance the local nutrient cycle. Perching birds may enrich soil nutrients and deposit seeds of other trees and shrubs whose germination and establishment may be favored in the habitats under the canopy.

Our study showed that intra-canopy soil contents of AN, AP, Na, and EC of isolated and/or clustered tamarisk plants were significantly higher than those in open land. The growth of tamarisk appeared to induce significant resource island effects on topsoil properties, a finding that is consistent with other resource islands studies involving tamarisk (Lesica and DeLuca 2004, Yin et al. 2010, Su et al. 2012). The resource island effect of tamarisk is caused by the accumulation of litter fall and soil particles under its hemispherical canopy (Li et al. 2007). The soil organic acids and soluble polyphenols coming from litter fall and the organic exudates of the leaves under the canopies of tamarisk are higher than those observed in open land (Lesica and DeLuca 2004). Leaf nutrients and exudates enter the soil by precipitation leaching and stemflow (Whitford et al. 1997, Li et al. 2011), leading to a higher concentration of soil nutrients under tamarisk canopies than were observed in open land.

Studies suggest that nutrients and salinity uptake in inter-canopy spaces and increasing rhizodeposition by the growth of roots result in the formation of resource islands (Burke et al. 1998, Su et al. 2004). Rhizosphere processes also influence the overall growth of tamarisk plants (Yin et al. 2010). The resource islands were attributed, in part, to rhizosphere processes that were important drivers in the distribution of soil nutrients beneath tamarisk canopies in our study area. Tamarisk plants can take up water and nutrients from groundwater through hydraulic lift (Gries et al. 2003, Arndt et al. 2004). Therefore, the availability and depth of groundwater may directly influence the growth status and the rhizosphere processes of tamarisk. Growth of tamarisk will be best above an optimum groundwater table compared to other groundwater tables because of the availability of water and decreased salinity (Song 2000). In our study, the ER_{open} of AN and AP was higher than $ER_{isolated}$, which is presumably due to superior growth of clustered tamarisk compared to the isolated tamarisk (Table 3). This likely

Table 3. Enrichment ratio statistics of available nitrogen (AN), available phosphorus (AP), and soluble aqueous sodium (Na) for isolated and clustered tamarisk plants.

Habitats	Statistics	Soil property		
		AN	AP	Na
$ER_{isolated}$	Mean	1.26a	2.14a	5.24a
	Minimum	1.11	1.86	3.18
	Maximum	1.42	2.59	9.45
	SE	0.04	0.08	0.75
ER_{inter}	Mean	1.06b	1.03b	5.00a
	Minimum	1.00	0.93	3.58
	Maximum	1.12	1.10	6.34
	SE	0.02	0.03	0.37
ER_{open}	Mean	1.38a	2.18a	2.20b
	Minimum	1.23	2.05	1.41
	Maximum	1.57	2.28	3.58
	SE	0.05	0.04	0.33

Notes: ER, enrichment ratio. Mean soil properties are listed as follows: $ER_{isolated}$: intra-canopy of isolated tamarisk/in open land; ER_{inter}: intra-canopy of clustered tamarisk (mean of canopy middle and canopy periphery)/in inter-canopy space; ER_{open}: in clustered tamarisk communities (mean of canopy middle, canopy periphery, and inter-canopy space)/in open land. Means followed by the lower-case letters in the same column indicate significance ($P < 0.05$) with a least significant difference test between different habitats.

resulted from an optimum groundwater table for the growth of clustered tamarisk.

In a saline environment, tamarisk leaves can accumulate and secrete excess salt, which contributes to the formation of a salt island. Our study provides evidence that the values of topsoil Na and EC under tamarisk canopies are significantly higher than those in open land. Other research results also reveal that salt secretion from tamarisk leaves results in increased soil salinity under the canopy (Lesica and DeLuca 2004, Li et al. 2007, Yin et al. 2010, Su et al. 2012). The induction of the salt island effect may be related to the high concentrations of Na in tamarisk leaves (Su et al. 2012). The sodium ions leached out from the leaves and sodium ions in leaf litter result in increased soil salinity and thus lead to the development of a salt island. However, the Na content and EC of soil under clustered tamarisk were significantly lower than those of isolated tamarisk. These results suggested that soil salinity within tamarisk resource islands was influenced by the growth status of tamarisk as well as soil fertility. Tamarisk plants absorb salts from deeper soil layers and transport it to the leaves of the tamarisk plants. The salts are eventually deposited on the soil surface under the tamarisk canopy after leaf secretion, leaching and litter fall (Yin et al. 2010).

Some studies suggest that the presence of tamarisk does not lead to an accumulation of salt in the surface soil, and a salt island is induced by soil capillarity and saline water irrigation (Tomar et al. 2003). However, our results showed that the salinity was higher under isolated tamarisk than that of clustered tamarisk (Table 2). This was presumably because of the fact that there were a lot of wells around isolated tamarisk plants in our selected study area, which led to the average groundwater table below 20 m due to the long-term extraction of underground brine as a raw material. However, there were almost no wells around the clustered tamarisk which would have a shallower groundwater table. At the optimum groundwater table, tamarisk growth will be greater when compared to other habitats because of the positive effects on the plant rhizosphere (Song 2000). Therefore, the soil Na content and EC were higher under isolated tamarisk than those of clustered tamarisk.

The presence of tamarisk could result in increased soil nutrient levels through litter fall, leaf organic secretions, and offset the negative effects on the soil properties caused by salt secretion (Lesica and DeLuca 2004, Su et al. 2012). Although the amounts of intra-canopy soil nutrients of the clustered and isolated tamarisk were not significantly different, the soil nutrient concentrations of the inter-canopy space were approximately equal to those of the intra-canopy in the clustered tamarisk community (Table 2, Fig. 6). The clustered tamarisk also manifested a salt island effect, but the soil Na and EC levels were significantly lower than those of the isolated tamarisk ($P < 0.01$; Table 2, Figs. 5, 6).

The lower spatial heterogeneity of soil resources under clustered tamarisk indicated that the resource island effect of tamarisk was gradually weakened following the community succession or vegetation restoration in the studied area. One of the possible reasons might be the competition between species, which could reduce the spatial heterogeneity of soil resources. The abiotic factors may also play a more important role in regulating the cycling of soil elements. The study area was located in coastal zone in the south of Laizhou Bay, where water and nutrients brought by the periodic flood tides could supply nutrients for the topsoil in this area. Secondly, it was because of the fact that understory biodiversity, biomass, and litter fall gradually increased following vegetation restoration, which improved soil infiltration and microbial activity, reduced soil erosion, and thus enhanced the soil nutrient content gradually. This is consistent with the findings of other studies indicating that the resource island effect would gradually weaken or disappear following the restoration of vegetation after the elimination of disturbances (Allington and Valone 2010, 2014).

Conclusions

Two major findings result from the present study of soil properties under tamarisk canopies in the coastal wetland of the Laizhou Bay. First, under both the isolated and clustered tamarisk plants, AN, AP, Na, and EC of soil under the canopy were significantly higher than those of the open land and decrease with an increase in the distance from the trunk, exhibiting a significant resource island

effect. Second, no significant difference in soil AN and AP concentrations was observed between intra- and inter-canopy space in the clustered tamarisk communities. The soil Na and EC under the clustered tamarisk plants were significantly lower than those under the isolated tamarisk individuals. These findings indicated that the resource islands effect would weaken following the succession of plant community or vegetation restoration after the elimination of disturbances in the studied area.

Acknowledgments

This study was funded by the National Natural Science Foundation of China (41201023 and 41501097). We declare that every author of the paper has no conflict of interest.

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