Similar seed dispersal systems between native and alien plant species with local frugivorous birds in a coastal seawall forest (#55858)

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Similar seed dispersal systems between native and alien plant species with local frugivorous birds in a coastal seawall forest

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Frugivorous birds play an important role in seed dispersal. Many alien plant species usually need local birds for their seed dispersal and established population in a new habitat. Alien plant species which produced similar fruits with the native species may be easier to attract local birds, and the new established mutualism systems would be similar with local ones. In autumn of 2018 and 2019, we selected an alien plant species, *Phytolacca Americana*, and a native plant species, *Cayratia japonica* in a coastal seawall forest to study their seed dispersal pattern. The fruit characteristics, local frugivorous birds foraging behaviors on the fruits, seedlings microhabitats and seed germination rates of both plant species were examined to find out if the seed dispersal system of alien species was similar to that of native one. Our results showed that the fruit type, color and ripening period of *Phytolacca americana* were much similar to those of *Cayratia japonica*, which were attracting the visitation of local birds. The positive correlation between the percent fruit ripening rate and the percent fruit missing rate of both plant species showed that local frugivorous birds have the potential to disperse the alien plant sufficiently to enable its spread in the coastal seawall forest (General Line Model, $P<0.01$). 11 bird species consumed fruits of both alien species and native species in the study period. Bird foraging behaviors as feeding frequency (*U*-test, $P>0.05$), feeding duration (*t*-test, $P>0.05$) and first stop distance (*t*-test, $P>0.05$) also were similar and showed that a stable relationship in the process of seed dispersal had been established between the alien plant and local frugivorous birds in the study site. The larger amount of the fruits of alien plant carried each time by birds even indicated that *Phytolacca americana* was a little more effective in its seed dispersal than that of *Cayratia japonica* (*t*-test, $P<0.01$). Seedlings of alien plant preferred forest gap microhabitat (*t*-test, $P<0.01$). Bird digestion treatment could promote seed germination success in both plant species. Our study suggests that in a narrow coastal seawall forest the alien plant species establish its population successfully relying on the similar seed dispersal systems with the local one.

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Abstract

Frugivorous birds play an important role in seed dispersal. Many alien plant species ~~usually~~ need local birds for their seed dispersal and ~~established~~ population in a new habitat. Alien plant species which produce~~d~~ similar fruits ~~with the~~ native species ~~may be easier~~ to attract local birds, ~~and~~ the new established ~~mutualism systems would~~ be similar ~~with~~ local ones. In autumn of 2018 and 2019, we selected an alien plant species, *Phytolacca ~~A~~mericana*, and a native plant species, *Cayratia japonica* in a coastal seawall forest to study their seed dispersal ~~pattern.~~ The fruit characteristics, ~~local~~ frugivorous birds foraging behavior~~s on the fruits,~~ seedlings microhabitat~~s~~ and seed germination rates of both plant species were examined to find out if the seed dispersal system of alien species was similar to that of native one. Our results showed that the fruit type, color and ripening period of *Phytolacca americana* were ~~much~~ similar to those of *Cayratia japonica*, which ~~were attracting the visitation of~~ local birds. The positive correlation between the ~~percent~~ fruit ripening ~~rate~~ and the ~~percent~~ fruit missing ~~rate of~~ both plant species showed that local frugivorous birds have the potential to disperse the alien ~~plant~~ sufficiently to enable its spread in the coastal seawall forest (General Line Model, $P<0.01$). ~~11~~ bird species consumed fruits of both alien species and native species ~~in~~ the study period. Bird foraging behavior~~s~~ as feeding frequency (*U*-test, $P>0.05$), feeding duration (*t*-test, $P>0.05$) and first stop distance (*t*-test, $P>0.05$) ~~also were~~ similar and showed that a stable relationship in the process of seed dispersal had been established between the alien plant and local frugivorous birds in the study site. The larger amount of ~~the~~ fruits of alien plant carried ~~each time~~ by birds ~~even~~ indicated that *Phytolacca americana* was a little more effective in its seed dispersal than that of *Cayratia japonica* (*t*-test, $P<0.01$). Seedlings of alien plant preferred forest gap microhabitat (*t*-test, $P<0.01$). Bird digestion treatment ~~could promote~~ seed germination success in both plant species.

Our study suggests that in a narrow coastal seawall forest the alien plant species establish its population successfully relying on the similar seed dispersal systems with the local one.

Introduction

Seed dispersal ~~was critical for maintenance~~ of plant ~~population~~ (*Butler et al., 2007*; *Wilson & Downs, 2012*), and alien invasions (*Schierenbeck, 2004*; *Buckley et al., 2006*). Some plant species ~~relied~~ on wind, water and other external forces to spread their seeds far away, while ~~more~~ others ~~were dependent~~ on frugivorous birds for seed dispersal (*Moles et al., 2005*; *Prado, 2013*). A reciprocal relationship between plant and frugivorous birds had been established ~~in~~ the evolution process (*Lu, 2003*; *Li et al., 2019*)~~.~~ Plants provide~~d~~ necessary nutrients for birds, ~~in~~ return, birds ~~dispersed seeds~~ to other habitats and improve~~d~~ plant regeneration (*Camargo et al., 2019*; *Morán-López et al., 2020*; *Galindo-González, Guevara & Sosa, 2000*). Bird-meditated seed dispersal ~~was~~ the most important pattern in the ecosystem, and birds ~~became~~ the most common seed disperser in the world (*Saavedra et al., 2014*; *Wang & Ives, 2017*).

Frugivorous birds play a key role in seed dispersal of many plant species (*Schleuning et al., 2011*; *Duan, Goodale & Quan, 2013*; *Lovas-Kiss, 2020*), including invasive alien plants (*Thabethe et al., 2015*). It ~~was~~ urgent for alien plant species which ~~relied~~ on birds for seed dispersal, to establish a ra~~pid~~ adaptation mechanism to settle down, build population and spread rapidly after being carried to a new habitat. Alien plants with fleshy fruits should establish effective dispersal interactions with local frugivorous birds (*Drummond, 2005*; *Kollmann et al., 2007*)~~.~~ Or else, they ~~would be failed~~ to settle in a new environment or greatly reduce~~d~~ ~~potential~~ for spreading ~~in the competition~~ with native plants (*Aslan, 2011*).

Relationship between alien plants and local birds who feed on their fruits and ~~dispersal~~ their seeds ~~have been carried in many researches~~ (*Renne et al., 2002*; *Gosper, Stansbury & Vivian-Smith, 2005*). The adaptability of ~~most~~ alien plant species ~~was based~~ on the variation seed dispersal systems to native plant species. For example, a study in a coastal belt forest in South Africa showed that fleshy fruit introduced plants ~~that were~~ effectively dispersed were small-seed, open habitats species with longer fruiting ~~length~~ (*Bitanni et al., 2020*). A study based on proportion of introduced plant fruits removed by birds in northern California, USA showed that all three non-native species, whose fruits differed greatly in type and appearance with native plants, had been assimilated into local bird diets, and there was no limitation for them to ~~dispersal~~ by birds (*Aslan, 2011*). In secondary forest sites on Bonin island, Japan, a study showed that the introduced plant fruits ~~can~~ dispersed differently by both native and non-native bird species, and new mutualistic relationships involving native and introduced birds and plants had been established again in a seed-dispersal system (*Kawakami, Frederiksen & Vestergaard, 2009*). ~~But if the seed dispersal system established by alien plant species and local frugivorous birds are the similar to native one has not been detailed reported yet.~~

An alien fleshy fruited plant species *Phytolacca americana* and a native one *Cayratia japonica* were found coexist in a coastal seawall forest in the Yellow Sea wetland, Jiangsu province, China. The forest was a long corridor with artificial trees, which could provide migration channels, foraging places and breeding sites for kinds of birds (*Liu et al., 2020*). The seed dispersal of *Phytolacca americana* had been reported both in China and its native land (*Mcdonnell et al., 1984*; *Li et al., 2019*), but not the plant species *Cayratia japonica*. Fruits of both the plant species were found to be feed by groups of frugivorous birds in autumn in the coastal seawall forest in previous observations, the forest was thus an excellent field site to study the seed dispersal system of native and introduced plant species with local frugivorous birds.

Both *Cayratia japonica* and *Phytolacca americana* were the dominate fruit plants in autumn in the study site, and we select these two species to examine the mutualistic systems established between the alien plant species and the local frugivorous birds, and whether the alien plant and the native plant have the similar seed dispersal system based on fruit characteristics, local frugivorous birds foraging behaviors, microhabitats selected by seedlings and seed germination rates.

Materials & Methods

Ethics statement

Field studies were conducted under the permission from the Administrative Bureau of Dafeng Milu National Nature Reserve.

Study site

The field work was conducted in Dongchuan coastal seawall forest in Dafeng Milu National Nature Reserve, Jiangsu Province, China (32°59'N~33°03'N，120°47'E~120°53'E). The forest was planted in the 1990s, mainly used for windbreak and dike consolidation. The region is characterized by a transition climate between subtropical and warm temperate. Mean annual precipitation in the area is approximately 1068 mm (concentrated in summer), and mean annual temperature is 14.1 ℃. The vegetation is dominated by *Robinia pseudoacacia*, with *Metasequoia glyptostroboides* and *Populus canadensis* slightly. The width of the forest is about 20~50m. The habitat in one side of the forest is intertidal zone with the main vegetation *Spartina alterniflora*, *Suaeda glauca*, *Phragmites communis* and *Imperata cylindrica*, the other side was farmland and culture pond. Many open forest gaps were exposed after some trees were blown every year by typhoon. Many bird species were living in the forest such as Light-vented Bulbul *Pycnonotus sinensis*, Common Blackbird *Turdus merula* and Black-billed Magpie *Pica pica*. From April to May in spring and September to October in autumn, many passerines passed through the forest to complete their migration life cycle, mainly including warblers and flycatchers. In autumn, there were also a small number of other fruits species in the study area beside *Cayratia japonica* and *Phytolacca americana*, such as *Lycium barbarum*, *Sapium sebiferum*, *Ligustrum lucidum*, and *Paederia scandens*.

Field observation

Fruits and seedlings investigation

From September to October, 2018, the two focal fruit plant species were inspected every 50m along the coastal seawall forest. The fruit characteristics, fruit height and microhabitat selecting were recorded. Fruit size were measured by a caliper based on 20 mature fruits each species. The density of each species was investigated in both study site and another site about 8 km away, representing a younger age of stand, in order to compare the density difference of these two fruit plants between older or younger age of stand. The number of ripe fruits of each species were investigated every 10 days, to calculated the rates of ripe and missing fruits. Seedlings of *Phytolacca americana* and *Cayratia japonica* were found along the coastal seawall forest. The microhabitats (forest gap or understory) which the seedlings located were also recorded.

Bird feeding behaviors

Behaviors of birds feeding fruits of the two plant species in the forest was observed from September to October in 2018 and 2019. Focal individual sampling was used to quantify visitation and fruit removal by birds at focal stands of each study species. Because most bird foraging occurs at dusk and dawn, observations were carried from 6 am. to 9 am., or from 4 pm. to 6 pm in the sunny day. Each observation continued until the focal bird disappeared. We counted the number of fruits swallowed, dropped, pecked and taken in flight by each bird species and the lasting foraging time in every observation. The first stopping distance of the focal bird was measured by a laser range finder. We calculated the whole feeding frequency number of each bird on each plant species in the study period. The average feeding duration per time on each plant species by birds were also recorded (*Li et al., 2019*).

Seed germination trials

The cumulative percentage germination success of defecated seeds by local frugivorous birds was compared with that of hand-cleaned seeds and intact fruits. All of seeds and fruits were collected in October 2018 in the study site. Defecated seeds from each individual bird, hand-cleaned seeds and the intact fruits were planted in separate bowls with a diameter of 10 cm. All bowls were then placed in a laboratory balcony and water daily in the first month. Seeds were considered germinated when the seedlings emerged through the soil surface. Seed germinated number was recorded at least once every 15 days, from early June to middle August. Once counted, seedlings were removed from the tray.

Data analysis

We compared the fruit height and fruit size of each plant species using *t*-test. *T*-test was also used to compare the density in older and younger age of stand of each plant species and to compare the microhabitats selecting of seedlings. We used a generalized linear model to test the correlation between fruit ripening rate and fruit missing rate each species. Total feeding frequency of each bird species on each plant species, averaged feeding duration per time, feeding fruit amount per time and first stopping distance of focal bird were compared by *U*-test or *t*-test. ANOVA tests were used to compare germination success of defected seeds to hand-cleaned seeds and intact fruits. All analyses were performed using SPSS 26.0 software, and Origin75 software. The level of statistical significance was set at $P<0.05$.

Results

Fruit characteristics of plant species

In autumn, *Phytolacca americana* and *Cayratia japonica* were the most common fruiting species in the coastal seawall forest. Both fruit types were berry. When was ripe, the fruits' color changed to black or purple black. There was a significant difference in the fruit size between the species (*t*-test, t=8.252, $P<0.01$, n=40) (**Table 1**).

Phytolacca americana mainly grew in the forest gap habitat, while *Cayratia japonica* was widely distributed in the understory along the seawall forest. The fruit ripening period of the two plant species basically overlapped, both ripening from late August to late October. There was a significant difference in the height of fruits distribution between the two species (*U*-test, Z=-5.420, $P<0.05$, n=40). The tree density of *Phytolacca americana* was higher in older age of stand, while the tree density of *Cayratia japonica* was higher in younger age of stand.

Fruits feeding and Seed dispersal by frugivorous birds

As time going on, the fruits of the two plant species gradually ripen, and fruit color changed from green to black or purple black. Ripen fruits were constantly eaten by frugivores, and in study period, no other animal groups except the birds were found to eat the fruits of *Phytolacca americana* or *Cayratia japonica*. The relationship between percent fully ripen fruits and the percent of fruit missing caused by birds feeding was a significant positive correlation for both plant species (General Line Model, $P<0.01$) (**Fig. 1 A & B**). It showed that the more ripen fruits, the greater proportion of missing fruit eaten by birds.

~~11~~ bird species were observed feeding on the fruits ~~of *Phytolacca americana* or *Cayratia japonica* in study period~~. They are Light-vented Bulbul, Common Blackbird, Black-billed Magpie, White-cheeked Starling *Sturnus cineraceus*, Black-napped Oriole *Oriolus chinensis*, Grey-backed Thrush *Turdus hortulorum*, Vinous-throated Parrotbill *Paradoxornis webbianus*, Great Tit *Parus major*, Blue-and-white Flycatcher *Cyanoptila cyanomelana*, Black-tailed Hawfinch *Eophona migratoria* and Black-faced Bunting *Emberiza spodocephala*. 7 of all bird species feed on both the fruits of the two plants. However, 3 species, the Blue-and-white Flycatcher, Vinous-throated Parrotbill, and Black-faced Bunting feed only on the fruits of *Phytolacca americanav* (**Fig.2**).

Light-vented Bulbul and Black-billed Magpie had the most feeding frequency on *Phytolacca americana* and *Cayratia japonica*, respectively. The longest foraging time on the fruits of *Phytolacca americana* and *Cayratia japonica* were Light-vented Bulbul and White-cheeked Starling, respectively. White-cheeked Starling was the species whose first stopping distance longest after feeding on both plants (**Table 2**). But there were no significant differences in bird feeding frequency (*U*-test, $P>0.05$), feeding duration (*t*-test, df= 16, $P>0.05$) and first stopping distance (*t*-test, t=1.401, $P>0.05$) between *Phytolacca americana* and *Cayratia japonica*.

However, the bird feeding amount each time on *Phytolacca americana* significantly larger than on *Cayratia japonica* (*t*-test, *df*=16, *P*<0.01) (**Table 2**).

Seedlings microhabitat

300 *Phytolacca americana* seedlings and 280 *Cayratia japonica* seedlings were found around 15 mother trees respectively in the study period. There were differences in microhabitat characteristics between the two plant species. Seedlings of *Phytolacca americana* preferred forest gap habitat, and much more seedlings were found in the forest gap habitat than in the understory habitat (*t*-test, *t*=5.684, *P*<0.01) (**Fig. 3, A**). However, seedlings of *Cayratia japonica* did not show obvious preference for microhabitat selection (*t*-test, *t*=0.092, *P*>0.05) (**Fig. 3, B**).

Seed germination rate

Seed germination experiments were carried from 20th, June to 20th, August. Seed germination rate of intact fruits was lower than both hand-cleaned seeds and defected seeds of both plant species. The final seed germination rates of *Phytolacca americana* with three different controls were as follows: 79% for defected seeds, 60% for hand-cleaned seeds and 13% for intact fruits (**Fig. 4, A**). And the final seed germination rates of *Cayratia japonica* were 87%, 71% and 18%, respectively (**Fig. 4, B**). There was extremely significant difference of seed germination rates with different controls between *Phytolacca americana* (ANOVA: $F_{2,15}$=13.283, *P*<0.01) and *Cayratia japonica* (ANOVA: $F_{2,15}$=4.591, *P*<0.05). The results showed that local frugivorous birds' digestion could promote seed germination success in both plant species.

Discussion

Similarity of the fruits characters of the two plant species

Bird-mediated seed dispersal is important for the establishment of many fleshy-fruited plant species (*Wenny, 2001*). Many alien plants with fleshy fruits are able to establish effective dispersal interactions with local birds, based on the attracting fruit characters to native plants (*Gosper, Stansbury & Vivian-Smith, 2005*). Our study showed that the fruit characteristics e.g. fruit type, fruit shape, ripen fruit color, fruit ripening period of alien *Phytolacca americana* were much similar to native *Cayratia japonica* (Table 1). This similarity indicates that the alien species *Phytolacca americana* have great potentiality to disperse its seeds by local frugivorous birds, which have established a positive reaction with the native plant species *Cayratia japonica*.

Some studies have found that small fruits and seeds appear to be removed and dispersed more effectively than larger ones (*Rey et al.,1997*), and birds prefer visiting trees with larger crop size (*Sallabanks, 1993*; *Korine, Kalko & Herre, 2000*). A study in a coastal belt forest in South Africa, which found that fleshy-fruited invasion plant species effectively dispersed by birds were small-seed, open habitat species with longer fruiting length than native plant species (*Bitani et al., 2020*). If the former conclusion is true, and based on the fact that the fruit size of *Phytolacca Americana* was smaller but containing more seeds than *Cayratia japonica*, the alien plant species

Phytolacca americana may be removed and dispersed more effectively by local frugivorous birds.

The forest gap microhabitat formed by light disturbance were more suitable for the growth of alien plant species (*Willamson & Fitter, 1996; Ridenour & Callaway, 2001*). Our study showed that the density of *Phytolacca americana* was higher in older age of stand in the forest, where more forest gap formed by typhoon disturbance every summer in the study site. The result suggests that the alien plant species *Phytolacca americana* prefers forest gap microhabitat in the study site.

Similar seed dispersal system

A fruit species can be consumed by a variety of potential bird dispersers, meanwhile, a potential bird disperser can remove a variety of fruit species (*Dugger et al., 2018*; *Schneiberg et al., 2020*). 7 of 11 local frugivorous birds consumed fruits of both the plant species in our study, which suggested that a stable relationship have already been established by the alien plant and local birds. Besides the 7 species, other 3 bird species were found only consume the alien species, showing that it had a wider niche to attracting more local bird species, according to the study by Levey, Gosper and Whelan (*Whelan & Willson, 1994*; *Levey & Martínez del Rio, 2001*).

Pycnonotus sinensis was a small and common frugivorous bird species in the study site according to the field observation. In autumn, the ripening fruits were the main food resource to them in the coastal seawall forest, where is a lack of insect resources. We usually observed 3-5 individuals of *Pycnonotus sinensis* foraging on the trees of *Phytolacca americana* with a large crop sizes and purple black ripen fruits color. Therefore, the *Pycnonotus sinensis* had a highest intensity interaction with the alien species.

There was no significant difference in bird feed frequency, feed duration, and first stop distance between the alien and native plant species. The results showed that there was no obvious "preference" in the selection and utilization of the seeds of these two plants by local birds, which reflected that the simulation degree of introduced plant species *Phytolacca americana* to native species *Cayratia japonica* was highly similar. But the higher efficiency of seed dispersal of *Phytolacca americana* by birds was showed according to the higher feed amount each time. We found that the frugivores feeding on the fruits were most of resident birds. The contribution of migratory birds to seed dispersal were small according to the lower feed frequency, shorter feed duration of the three migratory species, Black-napped Oriole, Grey-backed Thrush and Blue-and-white Flycatcher. So, the resident birds were the main contributors to seed dispersal of *Phytolacca americana* and *Cayratia japonica*. This might be due to the fact that the birds migrating through the seawall forest in the study site in autumn were mostly insectivorous flycatchers and warblers (*Liu et al., 2020*).

Effects of birds on seed germination rate

Birds' ingestion may increase seed germination rates of different plant species, especially the seeds of many invasive plant species have been shown to benefit from ingestion by frugivorous birds (*Combs et al., 2011*; *Carrion-Tacuri et al., 2012*; *Czarnecka, Orlowski & Karg, 2012*; *Thabethe et al., 2015*).

Our result showed that the seed germination rates of both plant species were lower from intact fruits than from ingested and manually de-pulped seeds (Fig.4), which consist to the results of *Barnea, Yom-Tov & Friedman (1990)*, *Yagihashi, Hayashida & Miyamoto (1999) and Traveset (1998)*. This suggested that local frugivorous birds' ingestion similarly and positively affected germination success of alien plant and native plant species in the study site. The local birds were legitimate seed dispersal agents of the fleshy-fruited alien plant. The factors of higher seed germination rate of ingested and manually de-pulped seeds may attribute to the removal of pulp or appropriate seed coat abrasion, but more trials were necessary to prove this conclusion. The final cumulative percentage germination of native plant species was much similar to alien plant species under three different controls (ingested seeds: 87% VS 79%; manually de-pulp seeds: 71% VS 60%; intact fruits: 18% VS 13%). This suggested that the seed dispersal pattern in seed germination of alien plant species *Phytolacca americana* was similar to native plant species *Cayratia japonica*.

We also found that seedlings of the alien plant species tended to occupy the microhabitat of forest gap which was suitable for seedling growth. But there was no preference tendency in microhabitat selecting by native plant species seedlings. This showed that seedlings of alien plant species had good developmental potential to successful population regeneration in the coastal seawall forest.

Conclusions

The alien species *Phytolacca americana* has a much similar fruit characteristics with the native plant species *Cayratia japonica* in autumn in the coastal seawall forest. A seed dispersal system between the alien plant species and local frugivorous birds has been established, and itis similar to the nativeone. Seeds of *Phytolacca americana* after ingestion by local frugivorous birds could promote the germination rate, and its seedling was more likely to occupy the microhabitat of forest gap than *Cayratia japonica* seedlings. All of these eventually enabled the alien plant species *Phytolacca americana* to stay and rapidly expand in the coastal seawall forest in our study site.

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Table 1(on next page)

Fruit characteristics of the two plant species and their distribution in Yancheng seawall forest.

Fruit characteristics	***Cayratia japonica***	***Phytolacca americana***
Type	Berry	Berry
Size (mm)	10.0±0.9	7.9±0.7
Shape and Color	Round, black	Round, Purple black
Ripening period	August to October	August to October
Fruit height (m)	0.2±0.1	1.3±0.3
Tree density（individuals/m^2）	0.5±0.3	0.1±0.1

Table 2(on next page)

List of bird species consuming fruits of native and alien plant species, followed by foraging statistics.

CY: *Cayratia japonica*; PA: *Phytolacca americana* Feeding pattern: S: Swallow; P: Pecking

Seasonal type: R: Resident birds; T: Travel birds; W: Winter birds

Bird species	Feeding frequency (times)		Feeding time (s)		Feeding amount (ind.)		First stopping distance(m)		Feeding pattern	Seasonal type
	CY	PA	CY	PA	CY	PA	CY	PA		
Pycnonotus sinensis	4.0	65.0	10.0	14.2	1.5	4.1	9.3	13.4	S	R
Turdus merula	3.0	18.0	6.7	7.3	1.3	3.7	25.0	28.6	S	R
Cyanoptila cyanomelana	0	11.0	0	5.2	0	1.8	0	8.3	S	T
Sturnus cineraceus	11.0	9.0	26.9	10.1	1.9	4.6	75.0	70.0	S	R
Pica pica	35.0	9.0	16.7	10.0	2.1	4.2	29.9	23.3	S	R
Oriolus chinensis	12.0	0	11.9	0	2.6	0	31.9	0	S	T
Turdus hortulorum	6.0	4.0	14.5	7.8	1.8	2.8	42.5	19.3	S	T
Paradoxornis webbianus	0	17.0	0	5.8	0	3.6	0	6.7	S/P	R
Parus major	1.0	13.0	5.0	6.8	1.0	2.2	12.0	12.2	S/P	R
Eophona migratoria	13.0	4.0	20.8	10.0	1.7	4.5	26.0	15.0	S/P	R
Emberiza spodocephala	0	13.0	0	11.6	0	2.0	0	7.2	S/P	W

CY: *Cayratia japonica*; PA: *Phytolacca americana*

Feeding pattern: S: Swallow; P: Pecking

Seasonal type: R: Resident birds; T: Travel birds; W: Winter birds

Figure 1

The relationship between percent fully ripen fruits and percent of fruit missing caused by bird foraging.

(A) *Phytolacca americana.*

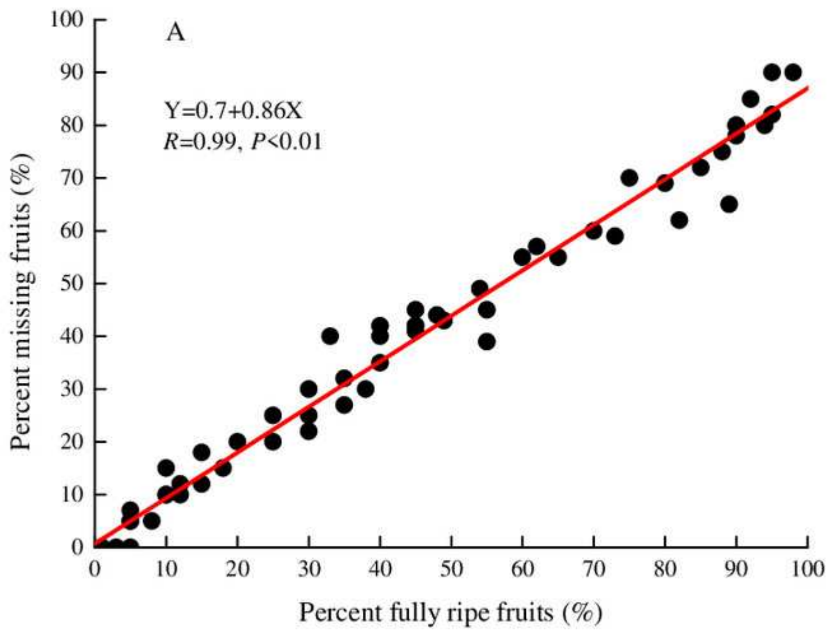

Figure 2

The relationship between percent fully ripen fruits and percent of fruit missing caused by bird foraging.

(B) *Cayratia japonica*

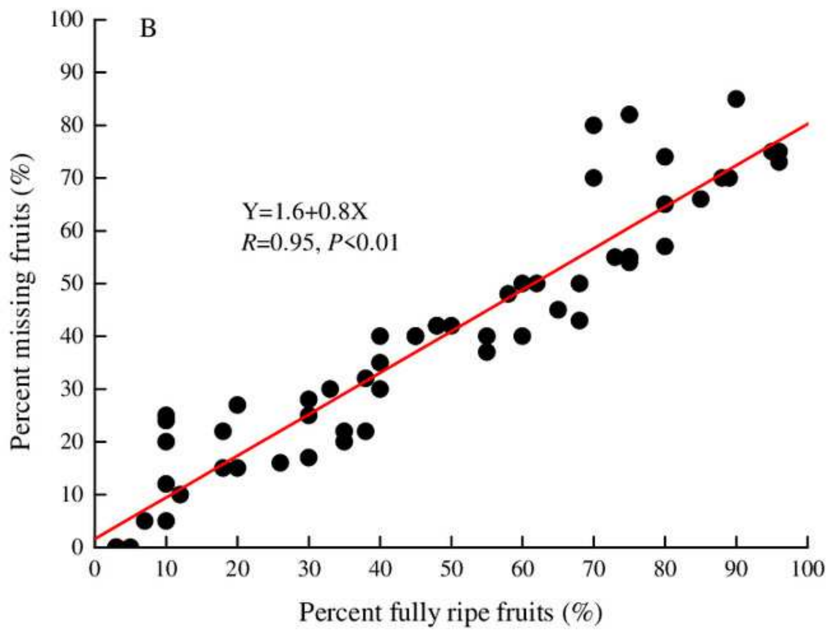

Figure 3

Correspondence relationship between avian frugivores and fruiting plants based on feeding behaviors.

Widths of connecting lines denote the relative number of observed interactions (wider represents higher intensity interaction) Avian frugivores: a. *Pycnonotus sinensis*; b. *Pica pica*; c. *Turdus merula*; d. *Sturnus cineraceus*; e. *Eophona migratoria*; f. *Paradoxornis webbianus*; g. *Parus major*; h. *Emberiza spodocephala*; i. *Oriolus chinensis*; j. *Cyanoptila cyanomelana*; k. *Turdus hortulorum*

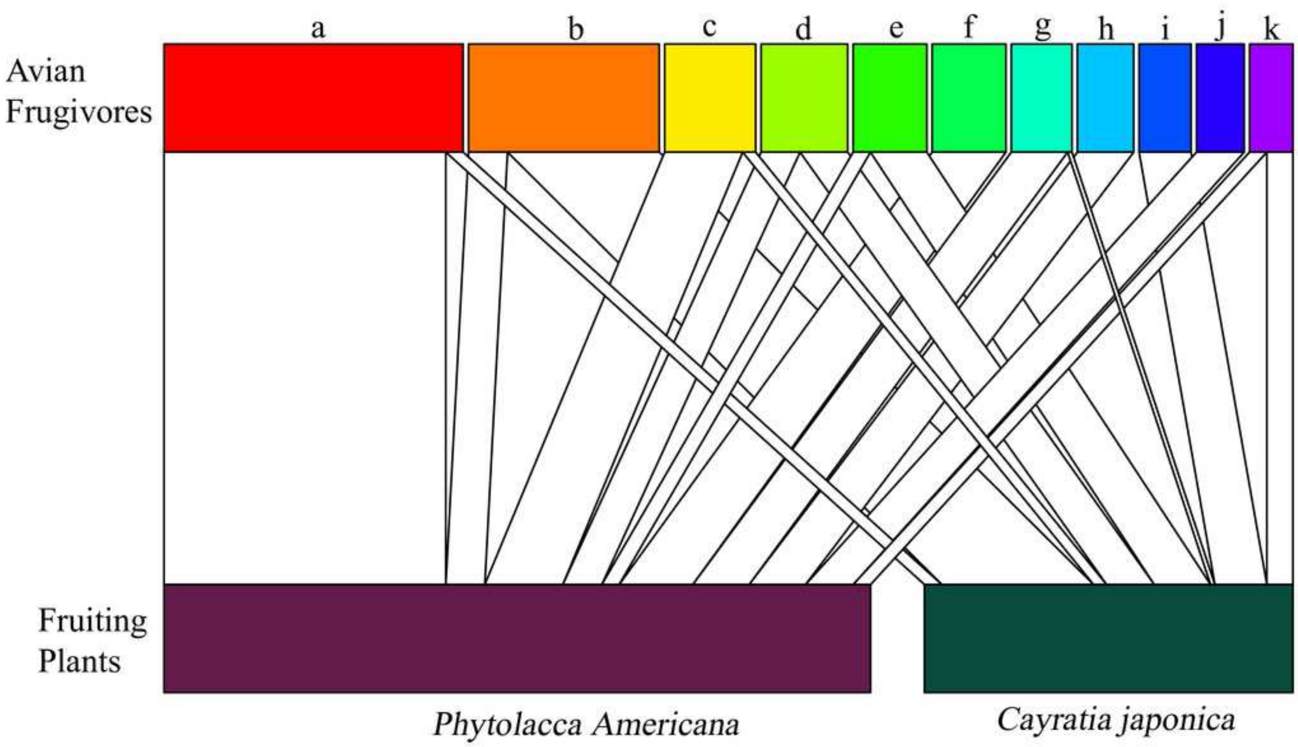

Figure 4

The microhabitat selecting of seedlings of the two plant species.

(A)*Phytolacca americana*

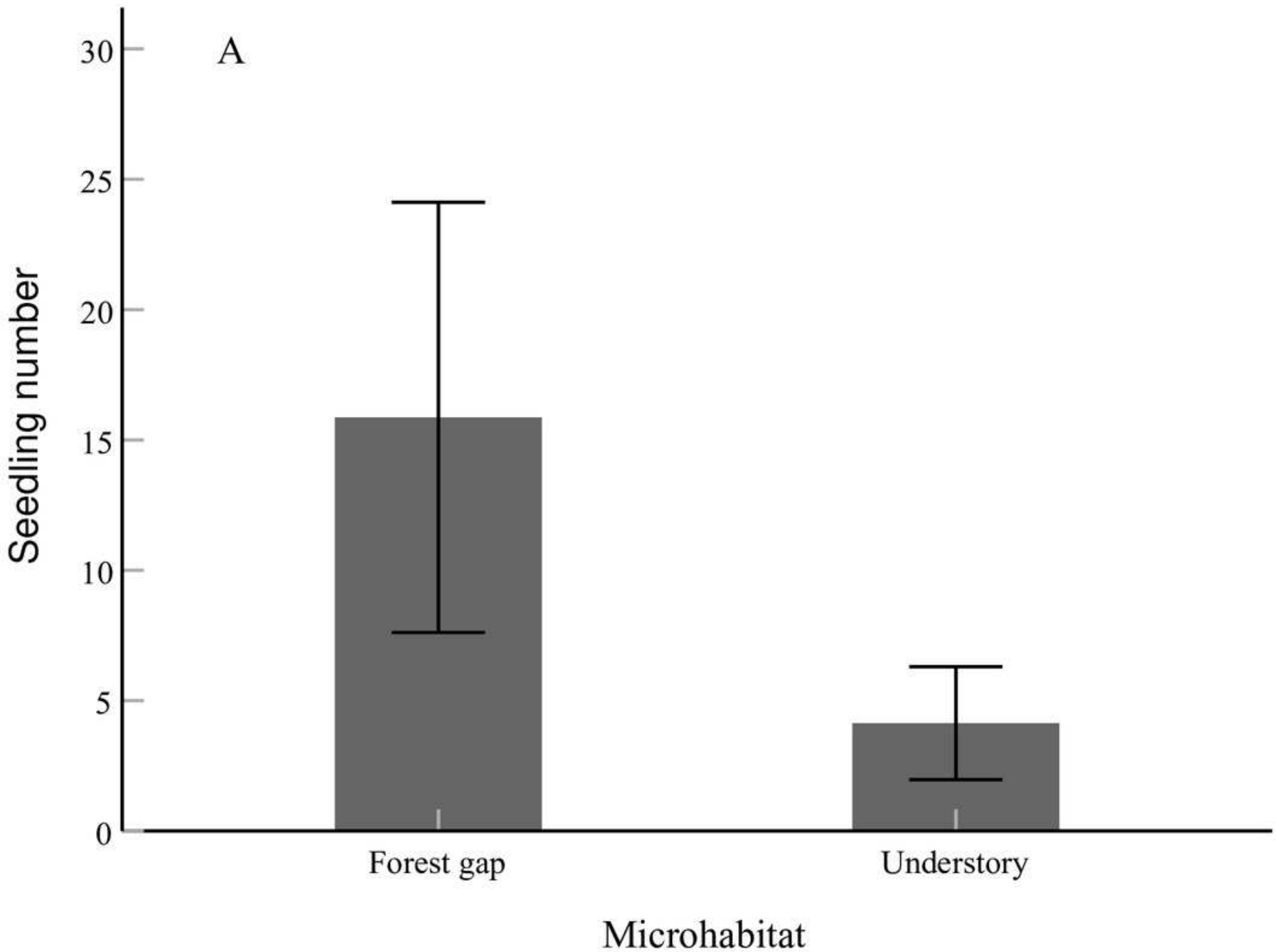

Figure 5

The microhabitat selecting of seedlings of the two plant species.

(B)*Cayratia japonica*

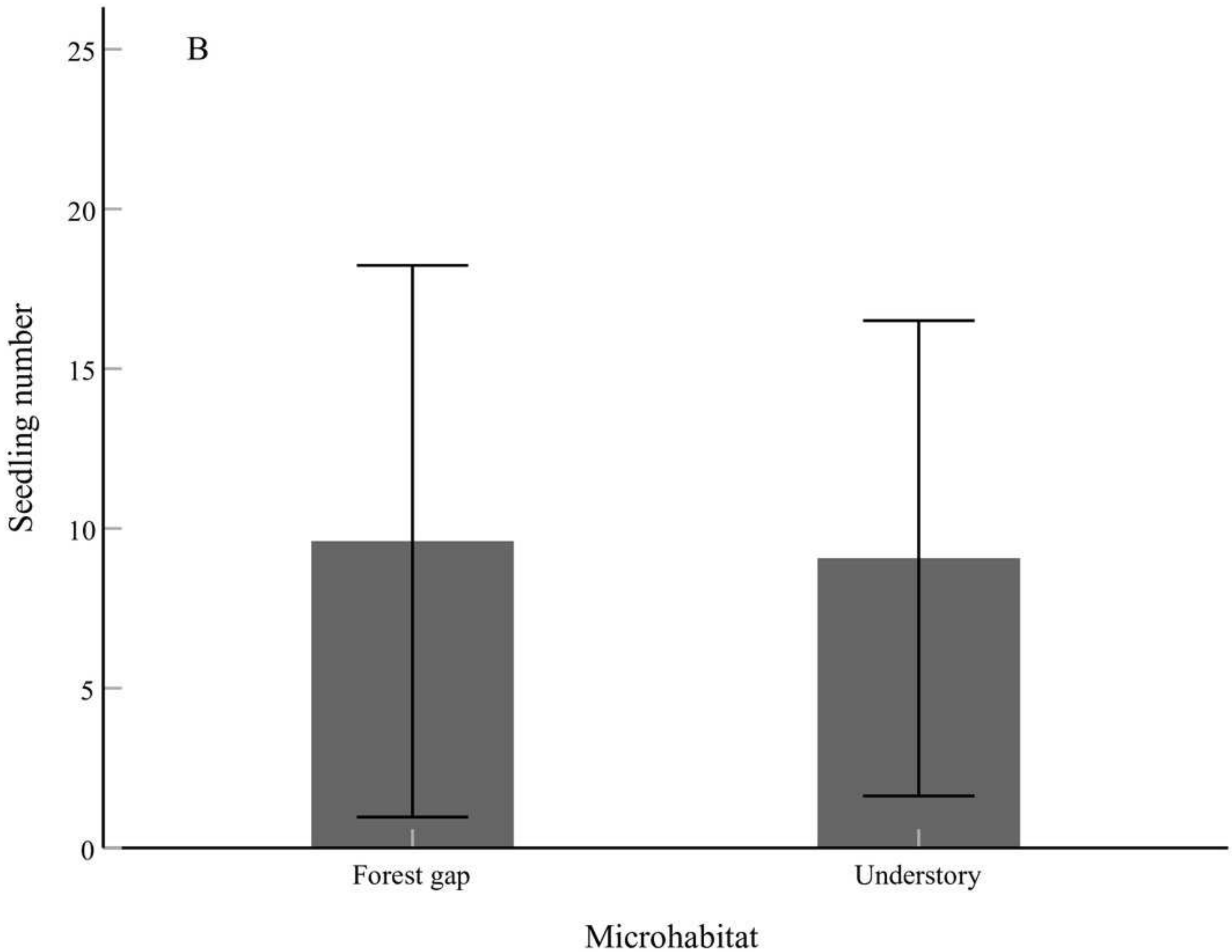

Figure 6

Comparison of the seed germination rates of the two plant species with different controls.

(A) *Phytolacca americana*

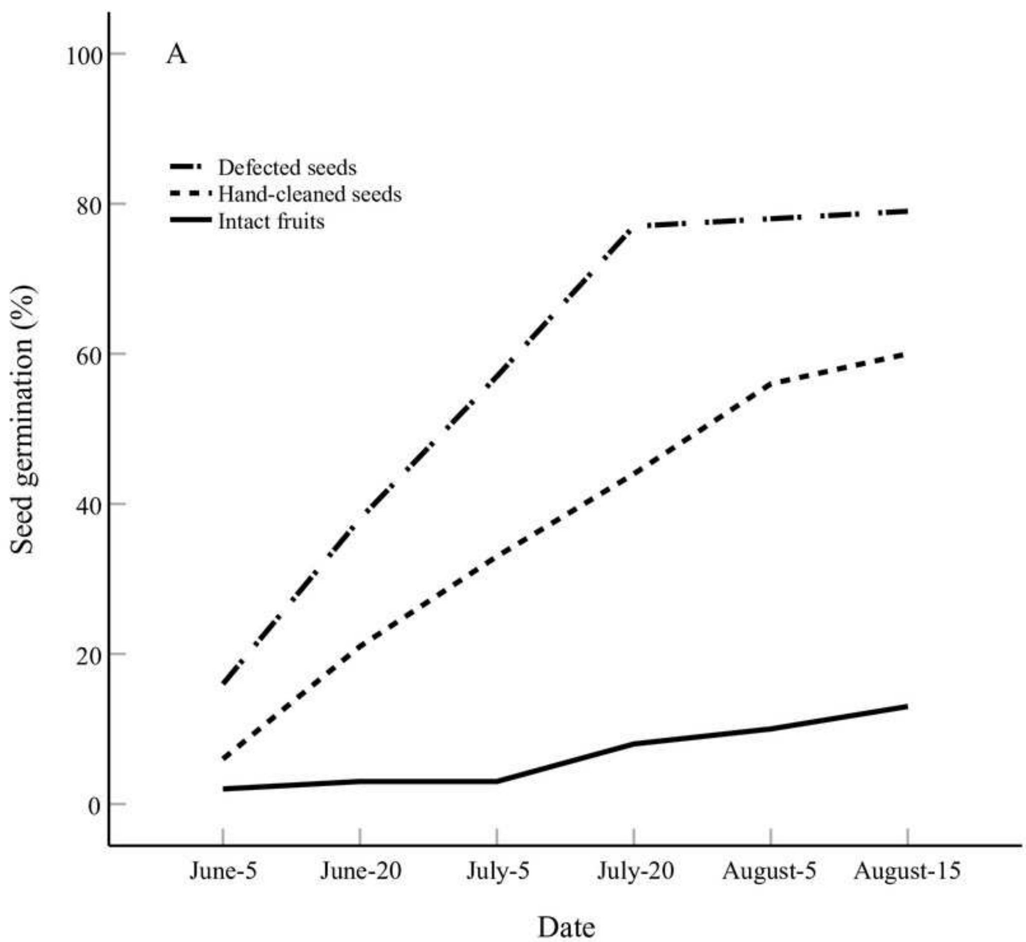

Figure 7

Comparison of the seed germination rates of the two plant species with different controls.

(B) *Cayratia japonica*