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Article

Temporal and spatial differences in gall induction on *Haloxylon* by *Aceria haloxylonis* (Acari: Eriophyidae) in the Gurbantünggüt Desert

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Abstract

Flower-like galls have been observed on *Haloxylon ammodendron* and *H. persicum* in the Gurbantünggüt Desert in northwest China. The galls were induced by *Aceria haloxylonis*, a new species of Eriophyidae. The galls began as small protuberances at the base of new stems and on small branches. As they matured, the galls changed color from green to dark brown. Some galls on *H. persicum* became red. At maturity, the galls and the infected branches became desiccated. Adult females of *A. haloxylonis* overwintered in galls or in branch crevices of *H. ammodendron* and *H. persicum*. There were more galls on *H. ammodendron* than on *H. persicum*. Several ecological factors influenced gall number, including terrain, tree size, branch direction and slope aspect. *H. ammodendron* trees in gravel desert had more galls than trees at sand dune edges. Trees in the interdune space had the fewest galls. Large *H. ammodendron* trees had significantly more galls than small trees. Branches on the south side of the tree had more galls than branches on the north, east, and west sides. Terrain * tree size had significant interaction on gall number on *H. ammodendron. H. persicum* trees on low sand dunes had more galls than trees on high sand dunes and trees on sunny slopes had more galls than trees on shady slopes. There were more galls on large *H. persicum* trees than on medium-sized trees. Few galls were observed on small *H. persicum* trees. The number of galls on *H. persicum* was significantly affected by terrain, tree size and slope aspect. The terrain * slope aspect interaction and tree size * terrain interaction were also significantly. This study is important for the conservation and recovery of the ecological environment in the Gurbantünggüt Desert.

Key Words: *Aceria haloxylonis,* Gall, Temporal, Spatial, *Haloxylon*

Introduction

Haloxylon is a perennial desert shrub in the Chenopodiaceae family. There are 11 *Haloxylon* species in the world. Two of them (*H. ammodendron* and *H. persicum*) are native to China (China Environmental Science Press. 1991). *Haloxylon* is highly drought resistant and it is considered a super-xerophyte. Because it reduces wind speed and blowing sand, *Haloxylon* is important for stabilizing desert ecosystems.

The Gurbantünggüt Desert lies in the Xinjiang Uyghur Autonomous Region of northwest China. It is the second largest desert in China and the largest fixed and semi-fixed desert (Guo *et al*. 2005). The dominant plant species in the Gurbantünggüt Desert are *H. ammodendron*, *H. persicum, Erodium oxyrrhynchum*, *Schismus arabicus* and *Salsola praecox* (Zhang *et al*. 2012).

In addition to climate change and human activities, plant disease and insect pests contribute significantly to the degradation of desert ecosystems (Liu *et al*. 2010; Yang *et al*. 2010). The main pests of *H. ammodendron* and *H. persicum* are *Julodis variolaris* Pallas (Song *et al*. 2008), *Loxostege stieticatis* Linni (Chen *et al*. 2007), *Desertobia heloxylonia* Xue (Li *et al*. 2007), *Lacydes spectabilis* (Yang *et al*. 2010), *Chromonotus sp* (Zang. 1986), and *Anomala exoleta* Faldermann (Chen *et al*. 2004).

Aceria haloxylonis is a new eriophyoid mite that has been recently observed on *H. ammodendron* and *H. persicum* in the Gurbantünggüt Desert. In a preliminary study at one site, *A. haloxylonis* was observed on *H. ammodendron* and *H. persicum* plants. The mites induce flower-like galls, especially at the base of new stems or on small branches (Xue *et al*. 2012).

Among Acari, Eriophyidae cause the second most economic damage after Tetranychidae (Chen *et al*. 2002). Eriophyidae harm host plants by (i) sucking sap resulting in plant abnormalities and stunted growth, (ii) secreting saliva which induces gall formation, and (iii) spreading plant viruses. More than a fourth of Eriophyidae species form galls on plant leaves, buds, short stems, and flowers (Keifer *et al*. 1982). For example, A kind of gall mite *(Cecidophyopsis ribis* Acari: Eriophyidae) causes the damaging condition known as "big bud" which is the most serious pest of blackcurrant (*Ribes nigrum* L.)(Brennan *et al*. 2009). *A. carvi* Nal. (Acari:Eriophyidae) can attacks the tissues of caraway and causes development of flower galls (Zemek *et al*. 2005).

Galls are abnormal plant tissue that varies in type and structural complexity. This accelerates plant cell division, resulting in the formation of a gall (Stone *et al*. 2003; Ma *et al*. 2008; Guo *et al*. 2012). Galls can be classified by their shapes: globular, cystic, bullet-shaped, flower-like, rhizoid, and columnar. The surface of galls may be smooth, fuzzy, or covered with small thorns. Depending on location, galls may be called bud galls, flower galls, leaf galls, branch galls and root galls (Ma *et al*. 2008; Blanche *et al*. 1995; Rosalind *et al*. 2001; Hong *et al*. 2001; Silva *et al*. 2011). Leaf galls are curly or panniform. Branch galls consist of bumps or knots (Ma *et al*. 2008; Jia *et al*. 2004). Flower galls and bud galls are inconsistent with form (Chen *et al*. 2006). Gall mites usually spread by wind, other insects, birds, rain, and farming activities.

The relationship with galls and gall-makers are effected by host plants distribution, host plant habitat, slope aspect, annual average relative humidity, average annual rainfall, latitude and altitude gradient (Li *et al*.2008; Dang *et al*.2011; Price *et al*.1998; Rosalind *et al*.2001). How about are occurrence degree of flower-like galls induced by *A. haloxylonis* on *H. ammodendron* and *H. persicum* in the Gurbantünggüt Desert? How do investigation and control of this pest mite in the vast desert?

This study studied that (i) Gall formation on *H. ammodendron* and *H. persicum*; (ii) Temporal and spatial differences in gall induction on *H. ammodendron* and *H. persicum* by *A. haloxylonis* in the Gurbantünggüt Desert; (iii) The relationship with galls, host plants and its surroundings such as slope aspect, tree size, branch direction, terrain and their interaction; The result can provide the basis on determine the most serious concurrent place and choose the best time to prevent and control galls which occurred in the largest number on *H. ammodendron* and *H. persicum*.

Materials and methods

The Gurbantünggüt Desert

The Gurbantünggüt Desert covers an area of 4.88×10^4 km^2 in the main part of the Junggar Basin in Xinjiang (44º11′–46º20′ N, 84º31′–90º0′ E). The desert is 444 km from east to west and 231 km from north to south (Wang *et al*. 2003). The heights of these dunes typically range between 10 and 50 m, although some dunes can be as high as 90 m.

Description of study site

The study site was on the southern edge of the Gurbantünggüt Desert at the Mosowan Agricultural Area, 149th Regiment, Company No. 1 (GPS: 44º51′23.9″N, 86º04′08.8″E).The annual average evaporation is 2000~ 2800 mm and annual precipitation is 80~160 mm. In winter, snow accumulates to 10~30 cm (Qian *et al*. 2007). Vegetation coverage can be as high as 15 to 50%, which is greater than in other deserts at the same latitude (Zhang *et al*. 2002; Chen *et al*. 2008).

H. ammodendron trees were surveyed in three types of terrain (1) in interdune space (i.e., the low area between two adjacent sand dunes, Fig.1-A); (2) at the edge of dunes and adjacent to flat desert (Fig.1-B); and (3) on gravel desert adjacent to farmland (Fig.1-C). We set three 20 × 20 quadrats, measured all trees crown diameter and classified into three sizes in each type of terrain: large (3.2±0.3m crown diameter) and small (1.5±0.3m crown diameter). Five trees in each size were studied in each type of terrain.

H. persicum trees were studied in low dunes (approximately 7 m high) and in high dunes (approximately 15 m tall) (Fig.1, D–G). Both terrains included two microhabitats: sunny slopes and shady slopes. The *H. persicum* trees on the sunny slope were divided into three size (the method was same as *H. ammodendron*): large (5.6±0.3m crown diameter), medium-sized (3.2±0.3m crown diameter), and small (1.4±0.3m crown diameter). There were only large trees on shady slope (5.6±0.3m crown diameter). Five trees were studied in each size on each microhabitat.

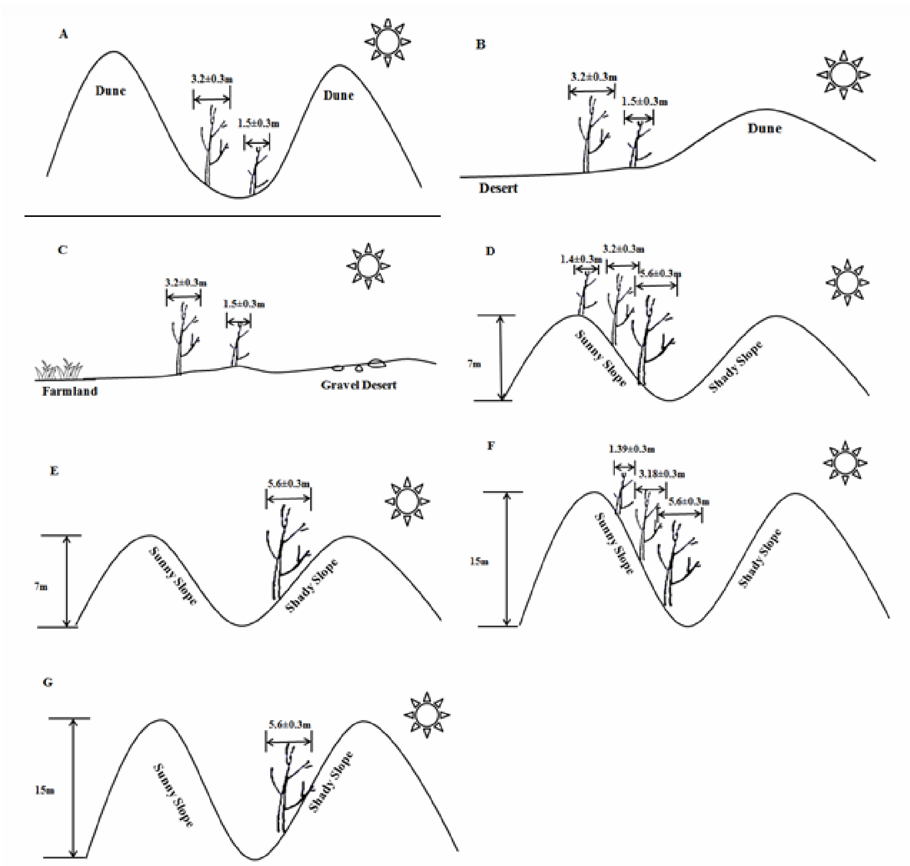


FIGURE 1. Habitats of *Haloxylon ammodendron* (A–C) and *Haloxylon persicum* (D–G) in this study. A, interdune space; B, sand dune edge, C, gravel desert; D, sunny slope on low dunes; E, shady slope on low dunes; F, sunny slope on high dunes; G, shady slope on high dunes.

Survey methods

We observed the galls, noted their characteristics, damage and dynamic of gall numbers in 2010. Temporal and spatial differences in gall induction on *Haloxylon* by *Aceria haloxylonis* (Acari: Eriophyidae) was done in 2011. Specifically, the number of fresh galls was counted on one branch in each direction on each tree at approximately seven day intervals between early May and early September.

Data analysis

ANOVA was done to find out the differences of terrain, tree size, branch direction and their interactions on *H. ammodendron* and slope aspect, tree size, branch direction, terrain and their interactions on *H. persicum*. Means were compared using Duncan's least significant difference (SPSS 19.0). Drawings were used Origin 8.5 to show the temporal and spatial differences in gall on *H. ammodendron* and *H. persicum* by *A. haloxylonis*.

Results

Host range

A. haloxylonis induced flower-shaped galls on the host plants both *H. ammodendron* and *H. persicum* (Fig. 2).

FIGURE 2. Galls induced by *Aceria haloxylonis* on *Haloxylon ammodendron* (A) and *Haloxylon persicum* (B).

Gall formation on H. ammodendron

The galls formed at the base of new stems and young branches of *H. ammodendron*. The galls began as protuberances and then grew larger, eventually becoming flower-shaped. Initially, the galls were green. They gradually turned yellow and then brown. Eventually, the galls and the parasitized branches became dry, especially basal branches. The galls were 11 to 22 mm long and 8 to 20 mm wide. There were 40 to 100 galls per branch on large *H. ammodendron* trees and 0 to 36 galls per branch on small *H. ammodendron* trees. Each *H. ammodendron* tree had 5 to 23 branches. There were typically 4000 to 8000 gall mites in each mature gall.

Gall formation on Haloxylon persicum

The position and shape of galls on *H. persicum* were similar to that described for *H. ammodendron*. However, all or part of some galls became red after late August. The galls on *H. persicum* were 7 to 14 mm long and 6 to 11 mm wide. There were 15 to 50 galls per branch on large trees and 0 to 30 galls per branch on small trees. Each *H. persicum* tree had 5 to 25 branches. There were typically 3000 to 6000 gall mites in each mature gall.

Effect of terrain on gall number on Haloxylon ammodendron

Gall numbers on *H. ammodendron* varied depending on the terrain. In gravel desert, gall numbers reached a peak of 52 galls per branch in early June and then declined to near zero in late July (Fig. 3). Gall numbers on *H. ammodendron* at the edge of sand dunes were greatest in late May and early June (averaging 42 galls per branch). After reaching a maximum, gall numbers declined more rapidly in trees at the dune edge than in the gravel desert. A few galls were observed on *H. ammodendron* in the interdune space.

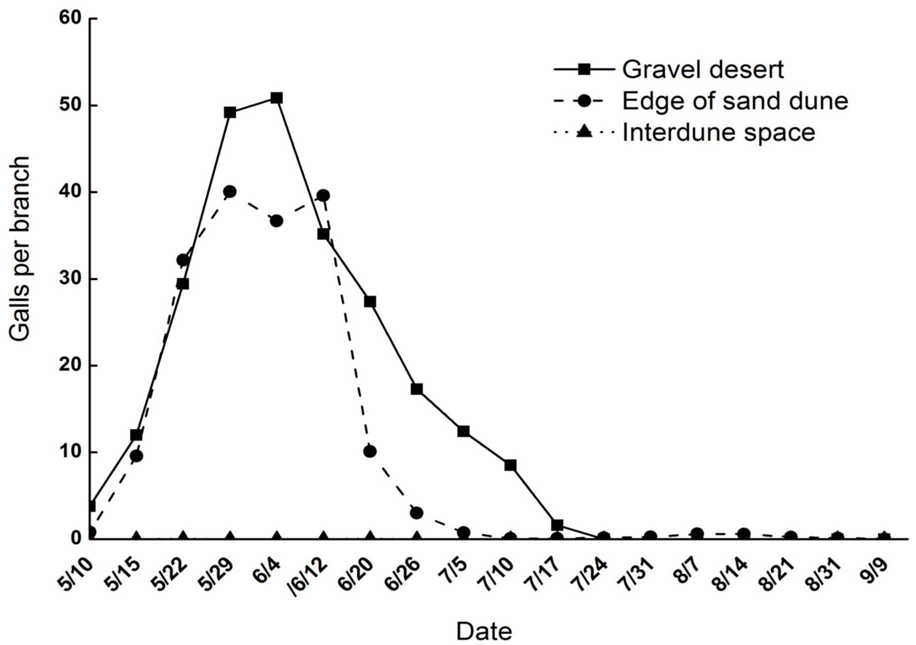


FIGURE 3. Temporal changes in the average number of galls per branch of *Haloxylon ammodendron* as affected by terrain.

Effect of terrain on gall number on Haloxylon persicum

Gall numbers on *H. persicum* in low sand dunes reached a maximum in mid-June (7.4 galls per branch) and then declined later in the month (Fig. 4). The second peak (3 galls per branch) was observed in mid-August. Trees on high dunes had significantly fewer galls than that on low dunes. Gall numbers on *H. persicum* growing on high dunes reached peaks in mid-June (0.5 galls per branch) and in late August (0.3 galls per branch).

H. persicum trees on sunny slopes had more galls than that on shady slopes (Fig. 5). Gall number on sunny slopes reached a peak in mid-June (4.4 galls per branch) and then declined. A second peak was observed in mid-August, averaging 1.8 galls per branch. On shady slopes, gall numbers on *H. persicum* were greatest in mid-June (2.3 galls per branch), then it declined gradually in July while increased again in late August. Trees on sunny slopes had more galls than that on shady slopes.

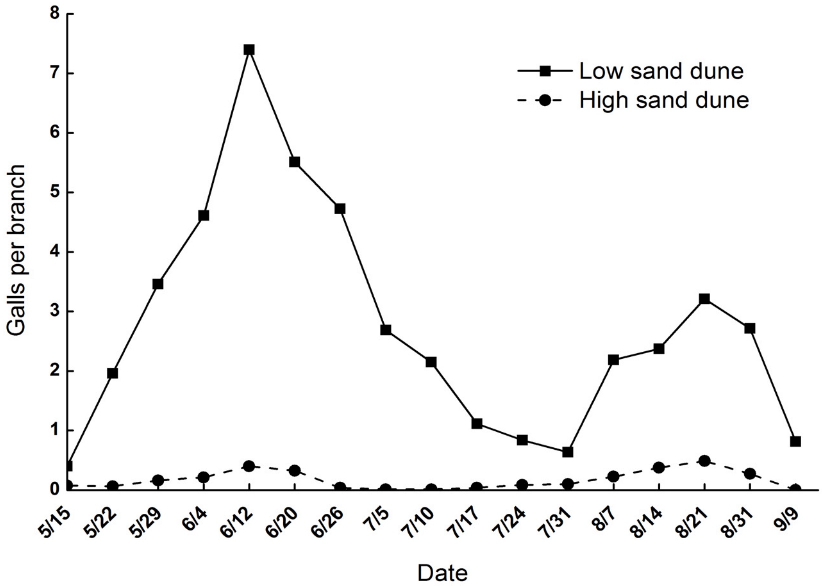
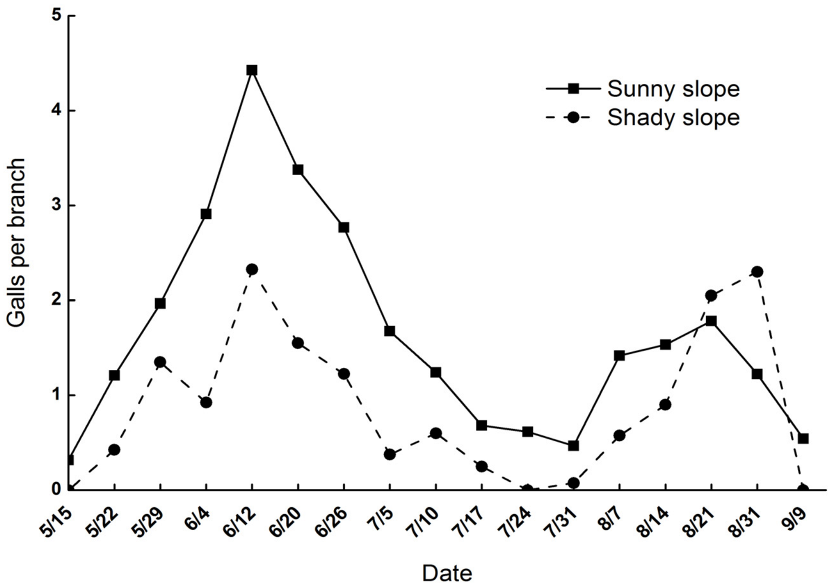


FIGURE 4. Temporal changes in the average number of galls per branch of *Haloxylon persicum* as affected by terrain.



FIGUER 5. Temporal changes in the average number of galls per branch of *Haloxylon persicum* as affected by slope aspect.

Factors influencing gall numbers

The number of galls on *H. ammodendron* was significantly affected by terrain, tree size, and branch direction (Table 1). Averaged across time, trees in gravel desert had the greatest number of galls (13.8±2.1 galls per branch). Trees at the sand dune edge had the second largest number of galls (9.7±1.4 galls per branch). Few galls were observed on trees in the interdune space (0.0±0.0 galls per branch). Average gall numbers were significantly greater on large trees than on small trees. Branches on the south side of *H. ammodendron* trees had significantly more galls than branches on the west, north and east sides of the trees. The tree size * terrain interaction significantly affected the number of galls on *H. ammodendron* (p=0.000). In contrast, terrain * branch direction (p=0.267), tree size * branch direction (p=0.535), and terrain * tree size * branch direction (p=0.749) had no significant effect on gall number.

The number of galls on *H. persicum* was significantly affected by terrain, tree size and slope aspect but not branch direction. Trees in low sand dunes had significantly more galls than that in the high sand dunes. There were fewer galls in trees on shady slopes (0.9±0.4 galls per branch) than on sunny slopes (4.6±1.7 galls per branch). Large trees had the greatest number of galls (4.6±1.7 galls per branch). The slope aspect * terrain interaction (p=0.002) and tree size * terrain (p=0.000) had significant effects on gall number on *H. persicum*. Terrain * branch direction (p=0.994), slope aspect * branch direction (p=0.964), tree size * branch direction (p=0.999), terrain * slope aspect * branch direction (p=0.964) and tree size * branch direction * terrain (p=0.999) had no significant effect on gall number.

Compare gall number on Haloxylon ammodendron *with* Haloxylon persicum

The gall started to form on *H. ammodendron* was early than on *H. persicum*. To sum up, there are more galls on *H. ammodendron* than on *H. persicum* (Fig. 6). Apparently, most of gall numbers concentrated on late May to Mid-June (the highest number reached 119 per tree), then gall numbers declined rapidly and kept lower number to the end. A few galls were on *H. persicum* (less than 20 per tree).

Discussion

The Gurbantünggüt desert is a temperate desert with low precipitation. Temperatures are hot in summer and cold in winter. The difference between day and night temperatures is large. The degenerate, acicular leaves of *H. ammodendron* and *H. persicum* are not good for feeding or for parasitism. During its evolutionary process with *Haloxylon*, *A. haloxylonis* developed the ability to form flower galls. This form was well adapted to the harsh environment, reducing water loss to evaporation. Wang *et al*. (2010) proposed that spherical- and spindle-shaped galls were advantageous in overcoming harsh climate condition, such as in deserts.

Many insects and mites can induce galls. The galls are beneficial to the survival of the gall-inducer. Gall-inducing arthropods spend most of their lives inside the gall, and as a result, it has evolved highly specialized nutritional dependencies on their host plants (Florentine *et al*. 2005). Insects and mites seem to control gall development by modifying the developmental pathways of plant so as to create a protected and favorable environment in which to live (Wool *et al*. 1999; Haiden *et al*. 2012).

Some factors can affect the formation of galls induced by insects or mites. Wang *et al*. (2015) reported that (i) the density of galls induced by *Trichagalma glabros*a was closely related to temperature and rainfall and (ii) the population death rate of *T. glabrosa* was influenced by total rainfall. Cao *et al*. (2014) observed that temperature is a critical factor for *Phylloxera notabilis* populations. The highest average temperature of Nanjing is in July and August which were the highest gall increasing period and largest total numbers. However, our study showed that the largest gall numbers were appeared from Mid-May to Mid-June on *H. ammodendron*, Maybe it has effect on temperature indirectly because of we all known that the highest temperature in July in the desert. The Gall numbers of *H. ammodendron* and *H. persicum* changed with temporal and spatial, but we could not identify a consistent pattern. It is possible that gall numbers are closely related to the growth stage and growth condition of *H. ammodendron* and *H. persicum*.

TABLE 1. Analysis of variance of the effect of five ecological factors on the number of galls on *Haloxylon ammodendron* and *Haloxylon persicum* by *Aceria haloxylonis*.

	Haloxylon ammodendron			*Haloxylon persicum*		
		n	Average number of galls per branch		n	Average number of galls per branch
Terrain	Interdune space	40	0.0±0.0 c	Low sand dune	40	5.5±1.6 a
	Sand dune edge	40	9.7±1.4 b	High sand dune	40	0.1±0.0 b
	Gravel desert	40	13.8±2.1 a	/	/	/
Tree size	Large	60	13.5±1.7 a	Large	40	4.6±1.7 a
	/	/	/	Middle	40	0.3±0.1 b
	Small	60	2.1±0.4 b	Small	40	0.0±0.2 b
Branch direction	South	30	10.3±2.5 a	South	20	3.3±2.0 a
	West	30	7.9±2.0 ab	West	20	2.3±1.5 a
	North	30	6.4±1.9 b	North	20	2.4±1.7 a
	East	30	6.7±1.8 b	East	20	3.0±1.8 a
Slope aspect	/	/	/	Sunny	40	4.6±1.7 a
				Shady	40	0.9±0.4 b

Note: Within a factor, different lowercase letters indicate significant difference among attributes (p<0.05).

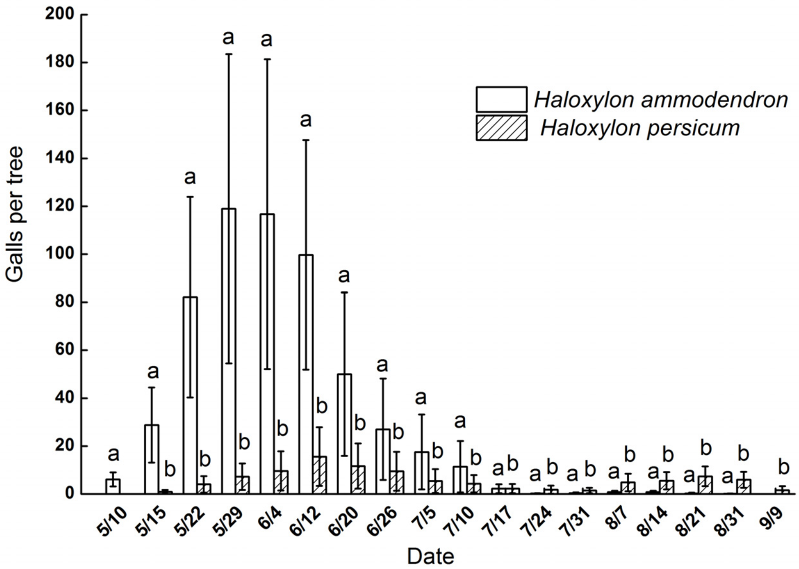


FIGURE 6. Compare the average number of galls per tree of *Haloxylon ammodendron* with *Haloxylon persicum*.

A. haloxylonis is spread by wind and some insects. It is unclear whether the induction of galls is related to surroundings (e.g., terrain or aboveground vegetation). *H. ammodendron* trees on gravel desert had more galls than those at the sand dune edge. Almost no galls were observed on *H. ammodendron* in the interdune space. The gravel desert was between farmland and flat desert. Trees in this area had better moisture supply and were more exposed to wind than trees in the other two types of terrain. There was almost no wind on the interdune space; therefore no galls developed there. In contrast, *H. persicum* grows mainly on sunny slopes and is rarely observed in shady areas, plant diseases and insect pests are more serious on sunny slopes than on shady slopes. Alternatively, shady slopes have less sunlight and lower temperature than sunny slopes. It is possible that the overwinter survival rate of gall mites was low on shady slopes, leading to a reduction in gall mites and gall numbers.

Gall numbers can vary among tree parts. We found that branches on the south side of *H. ammodendron* trees had significantly more galls than branches on the west, north and east sides of the trees. Similarly, *Dryocomus kuriphilus* induced the greatest number of galls on the south side of *Castaneamollissima* trees because the branches on the south side received growth well than branches on the other sides of the trees (Bu *et al*. 2009). It supported the result that the well-growth branches were benefit to the increasing gall numbers. In comparison, there was no noticeable difference in the number of galls on different branches of *H. persicum.* Maybe one of the reasons is that there were few galls on *H. persicum.*

Most gall-makers induce galls on plants that are growing vigorously or on plant organs that are growing vigorously (Guo *et al*. 2012). In our study, a large number of galls were observed on *H. ammodendron*. It is possible that *H. ammodendron* grew better and was more widely distributed than *H. persicum*. This made *H. ammodendron* a better choice for parasitism by *A. haloxylonis.* Balance *et al*. (1996) proposed that the distribution area of the host plant influenced insect species richness because of greater differentiation between more widespread locations in same genus. The results support the idea that the distribution of the host plant affects the ability of the gall-maker to induce galls.

Deterioration of ecological environment in arid areas especially desertification as global issues had already attracted the attention of scholars widely around the world. Chosen fixing stabilization of sands plants was one of the most fundamental measures to control arid, semi-arid and dry sub-humid area of northern China (Jia *et al*. 2008). Because *H. ammodendron and H. persicum* can reduce wind speed and stop blowing sand, and they are important for maintaining the stability of the fragile ecosystem in the Gurbantünggüt desert. The gall mites damaged *H. ammodendron* and *H. persicum* leading to a reduction in photosynthesis and plant growth. This was harmful to the *H. ammodendron* and *H. persicum* populations and it could indirectly influence the desert ecosystem. *A. haloxylonis* is a new species of Eriophyidae. This was a preliminary study about the biological and ecological characteristics of *A. haloxylonis* and its damage to *H. ammodendron* and *H. persicum.* The mechanisms of gall formation were not fully understood. However, the results of this study showed that reasonable prevention and treatment period could be chosen for gall management in *H. ammodendron, H. persicum* and the mixture forest. For instance, on *H. ammodendron*, the gall of big trees in interdune space and the edge of sand dunes should be surveyed and controlled before early May to middle June. For *H. persicum*, the gall of big trees on sunny slope of low sand dune could be taken measures before mid-May to mid-June. The major survey and control were focus on *H. ammodendron* for the mixture forest of *H. ammodendron* and *H. persicum*. Additional studies should be done about these factors to control *A. haloxylons* in the future. Specifically, additional information is needed about the enemies of *A. haloxylons,* how they form galls, and their relationship with *Haloxylon*.

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