BIOMASS CHARACTERISTICS AND GROWTH ANALYSIS OF VARIOUS COMPONENTS OF *ACHNATHERUM INEBRIANS* (DRUNKEN HORSE GRASS) POPULATION IN DIFFERENT HABITATS

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Abstract. *Achnatherum inebrians* (drunken horse grass) is one of the main poisonous grasses in Chinese' grasslands, and it is mainly distributed in the degenerated grassland in the northern pastoral area. Individual plants grown in desert, steppe and meadow ecosystems were collected from July to August in Xinjiang, China. The results showed that there was no significant difference in the inflorescences, stems and reproductive biomass in the desert, steppe and meadow ecosystems, while the leaf, above- and below-ground vegetative and total biomass in the desert was significantly lower than that in the steppe and meadow habitats. The allocation of the biomass into the leaf was the most and the inflorescences was the least in three habitats. The biomass of inflorescences/stems increased in all three habitats, but there was a certain fluctuation in the biomass of other components. The biomass of *A. inebrians* in steppe and meadow habitats distributed more resources into the above-ground part concerning the accumulation of total biomass, while the opposite trend was observed in the desert. In the process of growth, the resources in desert and grasslands decreased reproductive allocation and more resources were allocated into vegetative biomass. It can be seen that there are differences in growth characteristics, and biomass allocation of *Achnatherum inebrians* grown in different habitats, which shows the flexible growth and resource allocation strategies of *Achnatherum inebrians* in different habitats.
Keywords: *biomass; invasive plants, reproductive biomass allocation, vegetative biomass allocation, heterogeneous habitats*

Introduction

Growth and reproduction are two of the most fundamental life-history functions in plants (She et al., 2017). The pattern of resource allocation to sexual vs asexual growth is a core component of studies of plant life history (Bonser and Aarssen, 2009; Weiner et al., 2009). Plants can modify their biomass allocation patterns to adapt to different environments (Guo et al., 2012). Biomass is one of the basic biological and functional characteristics of plants and is the basic embodiment of material and energy accumulation (Hao et al., 2013). The pattern of the distribution of resources in plants to various organs is the main focus of studies of changes in plant growth patterns, while environmental changes will affect the distribution of biomass among various organs to varying degrees (Fan et al., 2017). Modular allocation in an organism refers to the proportion of assimilated resources used in roots, stems, leaves, inflorescences, fruits and other organs during plant growth and reproduction (Xiao et al., 2014). It reflects the ecological strategies of plants in different habitats (Weiner, 2004) and is the result of long-term adaptation to the environment (Poorter et al., 2012; Wang et al., 2017). As a functional index, the value representing plant modular allocation not only reflects the material circulation and energy flow in the ecosystem but also has very important

significance in the composition of ecosystem structure (Bloom et al., 1985; Hovenden et al., 2014; Luo et al., 2017). Therefore, the measurement of the biomass of plant components is of great significance in ecosystem research (Wang et al., 2015).

Invasive plants represent a serious threat to the structure and function of invaded ecosystems (Si et al., 2013). Approximately 30-40% of the world's endangered plants are disturbed and affected by exotic species (Walker et al., 1997), and invasive plants change the direction of community succession by altering environmental conditions. Invasive plants undergo a series of interactions with the environment during the invasion process; these interactions play an important role in further expanding the scope of plant invasions (Alpert et al., 2000; Liu et al., 2010). To study the influence of the invaded environment on the spread and distribution of invasive plants is helpful to reveal the rules of successful invasion in a particular location (Zhu et al., 2018). The distribution of an invasive alien plant is not only related to the biological characteristics and origin of the species itself but is also closely related to the environment in the invaded area (Wu et al., 2006). Invasive plants can use different reproductive strategies to colonize new areas. Ramets, which are produced via asexual reproduction, have higher growth and survival rates than seedlings, which are produced as a result of sexual reproduction, but their dispersal is generally restricted to short distances (Holsinger, 2000; Barrett et al., 2008). Consequently, exotic species using both strategies (sexual reproduction and asexual reproduction) may show greater invasion success than others (Winkler and Fischer, 2002). Identifying the relative contributions of each reproductive mode to the propagation of an invasive species is crucial for devising efficient control strategies. Control methods based on the misunderstanding of dispersal mechanisms risk failure because such efforts do not target plant parts from which new populations arise (Albert et al., 2015). Invasive plants are divided into narrow expansion and broad expansion. Broad expansion includes the expansion of native species and the expansion of alien species. *Achnatherum. Inebrians* (drunken horse grass) belongs to grassland species, if it spreads in the grassland, it belongs to local expansion, and to deserts and meadows belongs to local invasion.

A. Inebrians is a perennial herb belonging to *Achnatherum* Beauv. in Gramineae. It is one of the main toxic weeds in the natural grassland in north-western China. It is mainly distributed in Gansu, Inner Mongolia, Qinghai, Tibet, Xinjiang and other areas in China and is toxic to sheep, cattle, horses and other domestic animals (Ren, 1954). As early as 1876, American scholars named the *A. inebrians* collected in Inner Mongolia *Stipa inebriants* (Hance, 1876). Keng (1959) changed the classification status from *Stipa* to *Achnatherum* and named the plant *A. inebrians*; this name is still in use today. Due to its strong stress resistance and toxicity, it is not eaten by local livestock and gradually spreads. The direct economic loss caused by the decrease in grass production alone exceeds US$15 million per year, and this species has become the main limiting factor for the healthy development of animal husbandry in the grassland (Li et al., 2018). In recent decades, with the aggravation of grassland degradation, the harm caused by *A. inebrians* to livestock has gradually gained people's attention (Ren, 1954). Scholars have conducted a great deal of research on its botanical characteristics, eco-biological characteristics (Wang et al., 1991; Ji, 2009), endophytic fungi (Li et al., 1996; Chen et al., 2016), control and utilization (Yang et al., 2015; Jin et al., 2017). *A. inebrians* is not distributed only in steppes and meadows, like *Aconitum leucostomum*, or only in deserts, like *Anabasis aphylla*. *A. inebrians* species is distributed in deserts, steppes and meadows. Therefore, this study aims to investigate the quantity and biomass

characteristics of components, vegetative growth and reproductive growth of *A. Inebrians*, as well as the changes of biomass allocation between the above-ground and the below-ground, and discusses the propagation characteristics and adaptation strategies of the plants in different habitats.

Materials and methods

Study site

The studied areas are located in Heijiagou and Xiejiagou of in Urumqi City, Xinjiang, China (*Fig. 1*). Among them: Heijiagou is located in the low hills of the shallow mountain belt in the middle of the northern slope of Tianshan Mountain. The annual average precipitation is 221.3 mm, the annual average evaporation is 1765.4 mm, the annual average temperature is 4.3 °C, the annual frost-free period is about 129 days, and the soil is mountain brown desert soil. Xiejiagou is located in the middle and low mountain zone of the northern slope of Tianshan Mountain, with an annual average precipitation of 388.7-535.9 mm, an annual average evaporation of 1141.7-1564.9 mm, an annual average temperature of 2.1-3.3 °C and a frost-free period of 100-113 days. The soil is mountain chestnut soil. In terms of utilization, it is the spring and autumn grazing grassland for local livestock and sheep.

Heijiagou and Xiejiagou in Urumqi county correspond to three grassland types of desert, steppe and meadow respectively, forming three different environmental sample areas. These areas are typical areas invaded by *A. inebrians*, where this species has become the dominant species in the community (*Table 1*).

Research methods

Samples were collected during the fruiting stage (July to August 2018) of *A. inebrians* in desert, steppe and meadow areas. Each habitat included 3 parallel transects with a spacing of more than 10 m. Each transect had 5 plants with relatively consistent plant height (*Table 2*) that were more than 5 m apart, i.e., 15 plants were taken from each habitat, for a total of 45 plants.
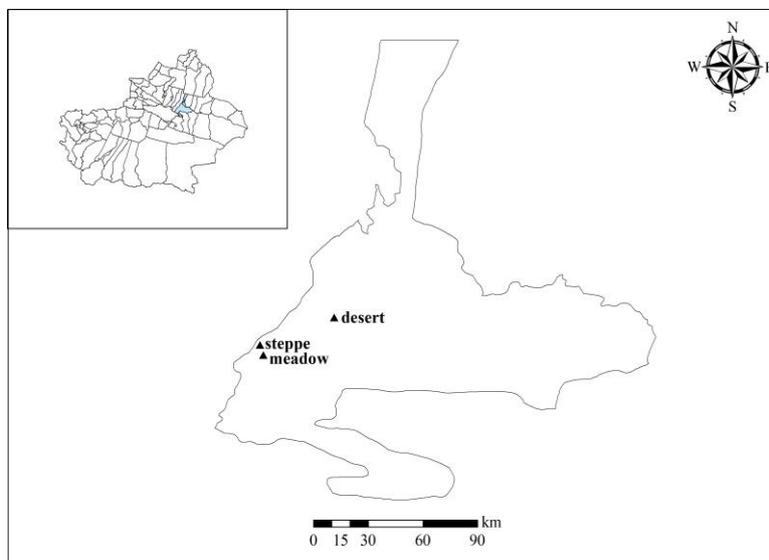

Figure 1. Location of the study sites

Table 1. *Sample information of three habitats (mean ± SD)*

Grassland type	Community information						Geographic information	
	Species composition		Height (cm/plant)	Coverage (%)	Density (plant/m²)	Plant biomass (g/plant)	Altitude (m)	Geographic coordinates
	Before degradation	After degradation (important value)						
Desert	*Nanophyton erinaceum + Anabasis brevifolia*	*Achnatherum inebrians* (0.423) + *Peganum harmala* (0.247) + *Carex turkestanica* (0.119)	111.30± 35.06	34.93± 7.19	118.22± 65.27	154.54± 41.02	1353	N 43°39′ E 87°23′
Steppe	*Caragana acanthophylla + Seriphidium borotalense + Carex turkestanica*	*Achnatherum inebrians* (0.537) + *Carex turkestanica* (0.280)	111.75± 20.11	66.58± 8.23	165.91± 34.01	220.98± 120.09	1660	N 43°31′ E 87°01′
Meadow	*Iris ruthenica + Poa angustifolia*	*Achnatherum inebrians* (0.470) + *Carex turkestanica* (0.137) + *Potentilla bifurca* (0.063)	165.59±5 2.63	59.62± 16.85	277.67± 165.86	226.46± 70.28	2180	N 43°28′ E 87°02′

Height: the scale measures the natural height of each species. Coverage: acupuncture method to determine species coverage. Density: the density of species is determined by the counting method, expressed as the number of species in a unit area. Biomass: fresh weight above and below ground for each plant in the sample. Important value = (relative height + relative density + relative coverage + relative biomass) / 4

Table 2. *Basic plant height parameters of A. inebrians*

Treatments	Max (cm)	Min (cm)	Mean (cm)	5%	1%	Standard deviation	Coefficient of variation (%)
Desert	109.00	95.00	101.33	a	A	4.87	4.80
Steppe	112.00	95.00	105.00	a	A	5.57	5.30
Meadow	112.00	95.00	105.40	a	A	4.78	4.53
Mean ($N = 15$)	112.00	95.00	103.91			5.30	5.10

Different small letters and large letters mean significant difference at 0.05 and 0.01 level

After measuring the plant height and inflorescence length in the field, the below-ground system was excavated and the above-ground parts were removed. When sampling, care was taken to maintain the integrity of each branch. After the roots were washed clean, the whole plant was taken back to the laboratory for air drying. Then, the dry weight of the roots, stems, leaves and inflorescences were measured individually with a 1/10,000 electronic balance.

Data analyses

One-way analysis of variance (ANOVA) and Pos hoc-LSD was used to analyze data utilizing SPSS 22.0 statistical analysis software. Relationships between vegetative and reproductive, above-ground and below-ground biomass allocation and total biomass were evaluated using regression analysis. All the quantitative relations were carried out regression analysis of the linear function $y = a + bx$, the power function $y = ax^b$, and the exponential function $y = ae^{bx}$, The Duncan test at the 5% confidence level was used for comparisons. The most correlated one was used as its description model (Liu, 2004). The figure was drawn with Origin 8.0. Inflorescence, leaf, stem, root, above-ground,

reproductive, vegetative biomass allocation were calculated as follows (Liu et al., 2012; Tian et al., 2018):

Inflorescence biomass allocation (%) = (Inflorescence biomass/total biomass) ×100%

Leaf biomass allocation (%) = (leaf biomass/total biomass) ×100%

Stem biomass allocation (%) = (stem biomass/total biomass) ×100%

Root biomass allocation (%) = (root biomass/total biomass) ×100%

Above-ground biomass allocation (%) = (above-ground biomass/total biomass) ×100%

Reproductive biomass allocation (%) = (reproductive biomass/total biomass) ×100%

Vegetative biomass allocation (%) = (vegetative biomass/total biomass) ×100%

Results

### *Comparison of the biomass of different plant parts among three habitats*

There was no significant difference in the inflorescences and stems biomass of *A. inebrians* in the three habitats ($P > 0.05$), but the leaves, roots and total biomass in the desert was significantly lower than that in the other two habitats ($P < 0.05$); there was no significant difference in the reproductive biomass in the three habitats ($P > 0.05$), but the vegetative biomass in the desert was significantly lower than that in the other two habitats ($P < 0.05$); the above and below-ground biomass showed significant difference in the desert, it was smaller than the other two habitats ($P < 0.05$) (*Fig. 2*).
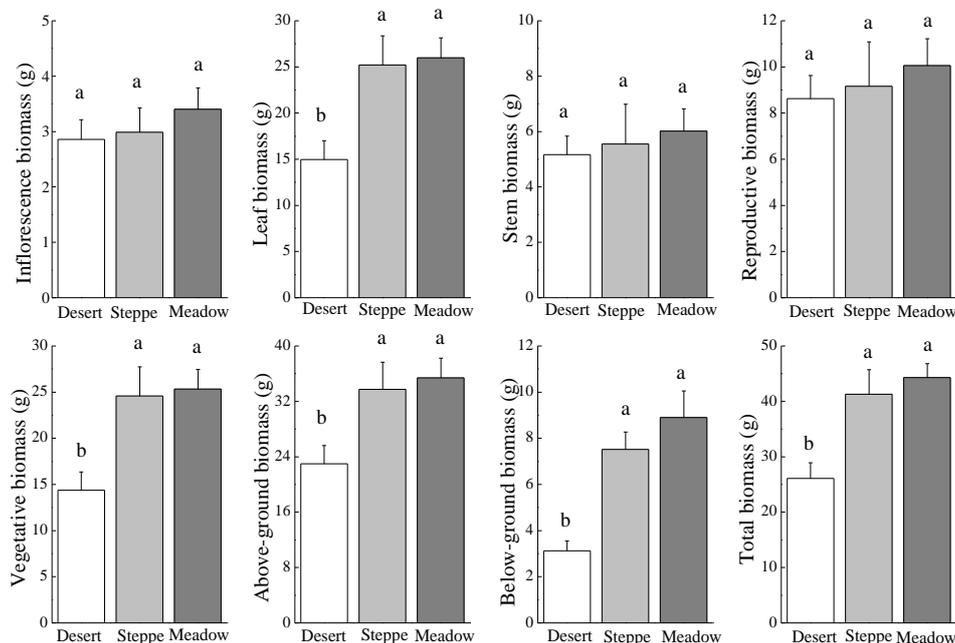
***Figure 2.** Biomass of different parts of A. inebrians in three different habitats (g/plant). The error bars indicate standard error. Means not sharing a letter in common differ significantly at 5% probability level. N = 15*

The inflorescences, leaves, stems and roots biomass of *A. inebrians* in the desert represented 13.56%, 53.35%, 20.99%, and 12.11% of the total biomass of the plant, respectively, and biomass partitioning to the leaves and roots increased by approximately 5.67% and 8% of the total biomass in steppe and 8.55% and 5.47% of

the total biomass in meadow, respectively, while the biomass allocation to stems and inflorescences (approximately -7.45% and -6.24% in steppe, -7.18% and -6.84% in meadow, respectively) decreased accordingly, The average inflorescences, leaves, stems and roots biomass allocation in the three habitats were 9.23%, 57.68%, 15.73% and 17.36%, respectively (*Fig. 3*).
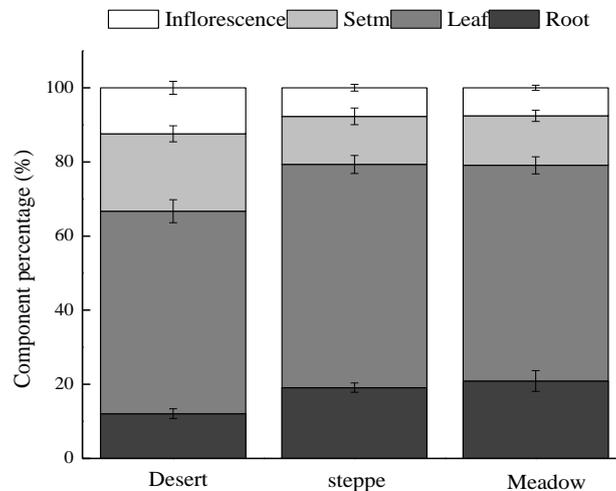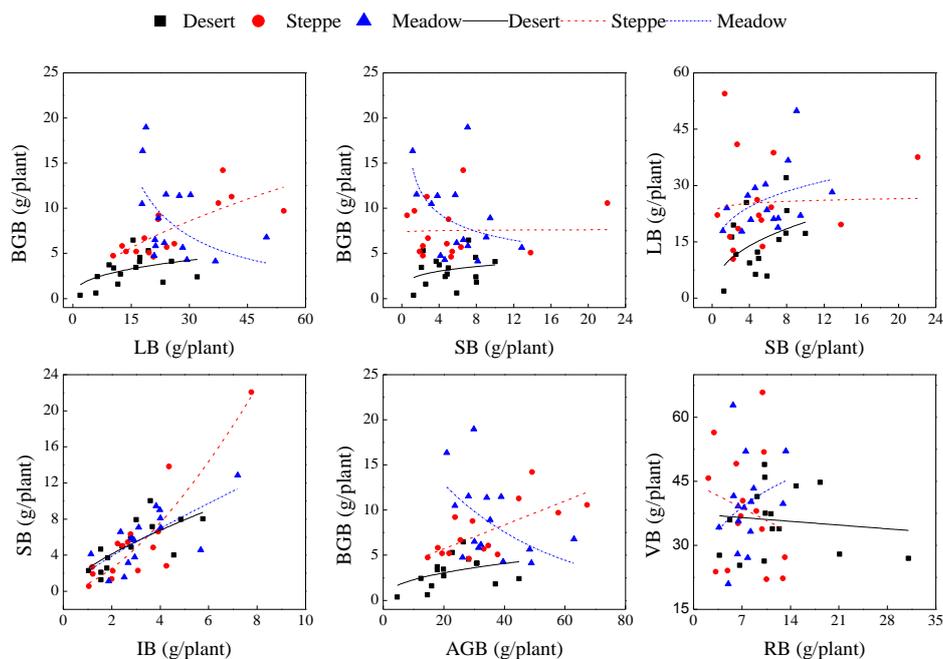

Figure 3. Biomass percentages of different organs in relation to the total biomass of A. inebrians in three different habitats. The error bars indicate standard error. Means not sharing a letter in common differ significantly at 5% probability level. N = 15

Changes of biomass of components in three habitats

Regression analysis of the root-leaf biomass, root-stem biomass, leaf-stem biomass, stem-inflorescence biomass and root-above-ground biomass correlations showed that there were similar positive linear correlations in desert and steppe, which reflected the structural and functional consistency and indivisibility of the individual plant organs. The coefficient of determination for the regressions including stem-inflorescence biomass showed a better fit across all three habitats than those involving the other organs, with R^2 values ranging from. The R^2 values of the root-leaf biomass, root-stem biomass, leaf-stem biomass, stem-inflorescence biomass, above-, root ground biomass and reproductive-vegetative biomass relationships fell within the ranges of 0.187-0.614, 0.001-0.231, 0.017-0.268, 0.347-0.636, 0.481-0.691 and 0.108-0.321, respectively, across all habitats, There are some differences in the biomass relationship of each component in the meadow habitat (*Fig. 4; Table 3*).

Relationship between the above- and below-ground biomass allocation and the total biomass of A. inebrians in three different habitats

The above-ground biomass allocation increased with the increase of the total biomass in steppe and meadow, while the above-ground biomass distribution decreased, indicating that more resources were allocated to the above-ground part with the accumulation of the total biomass of *A. inebrians*, while the change rule in desert habitat was just the opposite (*Fig. 5*). The determination coefficient R^2 of above-ground biomass allocation in each habitat was between 0.018 and 0.235, respectively. The coefficient R^2 of below-ground biomass allocation was between 0.011 and 0.235.

Figure 4. *The relationships between of the different organs biomass on the A. inebrians. The error bars indicate standard error. Means not sharing a letter in common differ significantly at 5% probability level. N = 15. BGB-below-ground biomass, SB-stem biomass, LB-leaf biomass, IB-inflorescence biomass, AGB-above-ground biomass, RB-reproductive biomass, VB-vegetative biomass*

Table 3. *The relationships between paired biomass parts of A. inebrians in three different habitats. The regression equations are from regression analysis. Probability (P) values denote significance levels from regression equation*

	Habitat	Function	df	R^2	F value	*P* value
Below-ground biomass vs leaf biomass	Desert	Power	15	0.533	14.803	0.002
	Steppe	Power	15	0.614	18.809	0.001
	Meadow	Power	15	0.187	3.167	0.099
Below-ground biomass vs stem biomass	Desert	Power	15	0.142	2.144	0.167
	Steppe	Linear	15	0.001	0.013	0.910
	Meadow	Power	15	0.231	3.900	0.070
Leaf biomass vs stem biomass	Desert	Power	15	0.268	14.941	0.002
	Steppe	Power	15	0.017	0.213	0.652
	Meadow	Power	15	0.188	2.679	0.126
Stem biomass vs inflorescence biomass	Desert	Power	15	0.589	5.711	0.033
	Steppe	Power	15	0.636	22.679	0.000
	Meadow	Power	15	0.347	1.483	0.005
Above-ground biomass vs below-ground biomass	Desert	Power	15	0.679	11.129	0.005
	Steppe	Linear	15	0.691	11.892	0.004
	Meadow	Exponential	15	0.481	3.905	0.070
Reproductive biomass vs vegetative biomass	Desert	Linear	15	0.108	0.155	0.700
	Steppe	Linear	15	0.215	0.629	0.442
	Meadow	Power	15	0.321	1.493	0.243

Figure 5. *Relationship between above-ground biomass, below-ground biomass and total biomass in A. inebrians. The error bars indicate standard error. Means not sharing a letter in common differ significantly at 5% probability level. N = 15*

Relationship between the reproductive and vegetative biomass allocation and the total biomass of *A. inebrians* in three different habitats
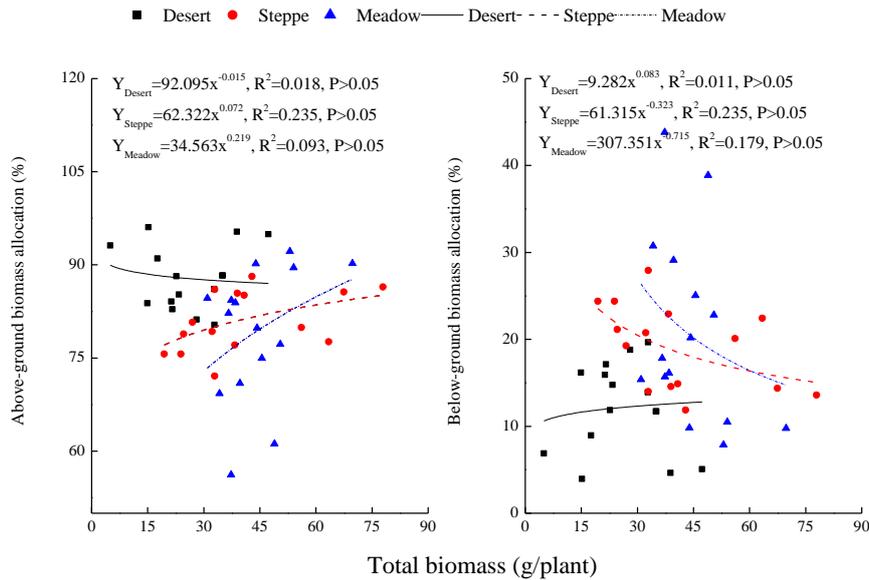
Reproductive allocation decreased with the increase of total biomass in desert and meadow habitats, but increased in steppe habitats. With the increase of total biomass, the nutrient distribution of three habitats showed an increasing trend. The coefficient R^2 of reproductive biomass allocation was 0.089-0.326 for each habitat, and vegetative biomass allocation 0.262-0.835 for each habitat. It can be seen that in all three habitats, the reproductive allocation of *A. inebrians* decreased and more resources were allocated for vegetative growth (*Fig. 6*).

Discussion

Biomass is an important indicator that reflects the interaction between plants and the environment. It is the embodiment of plant adaptability to the environment and its growth and development trends. Individual and modular organism biomass, are also the embodiment of the ecosystem's ability to obtain energy (Yu et al., 2001). The comparison of the biomass of each component in different habitats showed that there was no significant difference between the biomass of inflorescence and stem in the three habitats ($P > 0.05$), but the total, biomass of leaf and root in the desert habitat were significantly lower than those in other two habitats ($P < 0.05$). The results showed that the difference in total biomass mainly came from leaves and roots, which were the above-ground photosynthetic organs and the below-ground nutrient absorbing organs. The difference of environment mainly affected the biomass of the two components. The biomass of vegetative was significantly lower than that of the other two habitats ($P < 0.05$), but the biomass of reproductive was not significantly different ($P > 0.05$). It can be seen that under the fragile environment, the growth of *A. inebrians* decreased. The above-ground biomass was significantly lower than those in the other two habitats

($P < 0.05$), and the overall trend of above-ground components was that the above-ground components were smaller than those in the other two habitats ($P < 0.05$). The cumulative benefits of each component, especially the significant reduction of leaf biomass, led to the significant above-ground components biomass. It was lower than other habitats ($P < 0.05$); therefore, the total biomass showed the biomass of sacrificing leaves, vegetative branches and even roots, maintaining the growth of reproductive branches and inflorescences, and maintaining sexual reproduction.
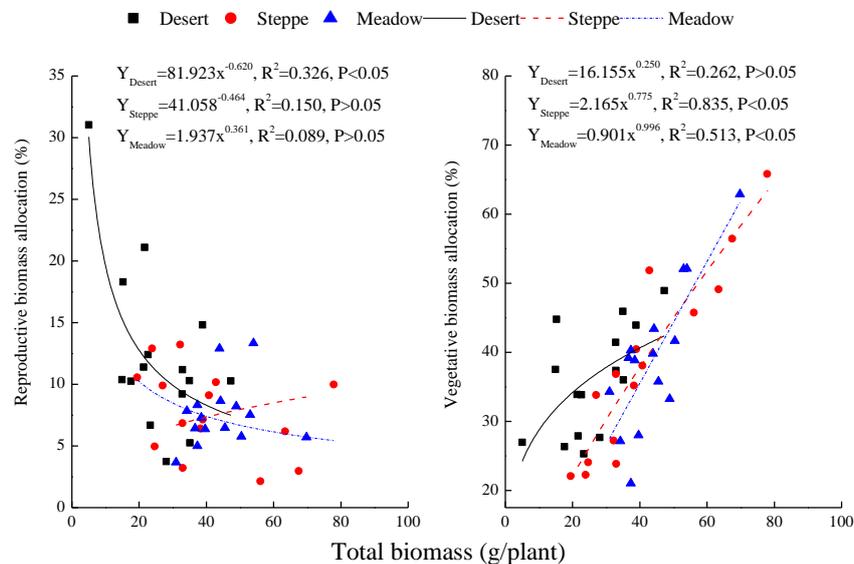
Figure 6. Relationship between reproductive allocation, vegetative allocation and total biomass in A. inebrians. The error bars indicate standard error. Means not sharing a letter in common differ significantly at 5% probability level. N = 15

The proportion of the biomass of various components to the total biomass represents the distribution ratio of assimilates to different organs and the coordinated relationships of various components during the growth process (Wang et al., 1995). In terms of biomass allocation, the biomass allocation into inflorescences and stems in the desert habitat was significantly higher than that in the steppe and meadow habitats, and the biomass allocation into the roots showed the opposite trends ($P < 0.05$). The proportion of leaf is the largest in biomass allocation of all habitats, Similar results have been obtained from previous studies (Yang et al., 2003). The mean value of the biomass allocation of each component in the three habitats indicated that leaf biomass allocation > root biomass allocation > stem biomass allocation > inflorescence biomass allocation; all of these differences were significant ($P < 0.05$) (*Fig. 3*). In terms of function, the leaves of plants are the production organs of nutrients, and the stems have multiple functions, such as nutrient transport and storage as well as supporting the leaves in expanding the growth space (Arenas et al., 2002). The distribution ratio to leaf biomass is the largest for all three habitats, and the distribution ratio to inflorescences biomass is the smallest. The pattern of biomass distribution in the three habitats is as follows: first to the leaves, then to the roots, and finally to the stem and inflorescences. This reflects that *A. inebrians* shows high ecological plasticity and strong adjustability. In response to different environments, *A. inebrians* uses different growth strategies to ensure its growth, development and reproduction.

The coefficient of determination for the regressions including stem- inflorescence biomass showed a better fit across all three habitats than those involving the other organs, with R^2 values ranging from 0.347 to 0.636. The differences in the species index and organ size may be due to the distribution of photosynthetic products, water and nutrients between the above-ground parts and roots (*Fig. 4; Table 3*).

It is generally believed that high root biomass allocation ratio is a common feature of plants responding to below-ground resource deficit in the process of desert succession (Gill et al., 2002). The above-ground biomass allocation increased with the increase of total biomass, but the below-ground biomass allocation showed the opposite trend. This reflects the growth law of the *A. inebrians*, with the accumulation of biomass, the *A. inebrians* in steppe and meadow habitat preferentially distributes more biomass into above-ground components by reducing the input of below-ground roots, which is an important way to ensure the sexual reproduction and population diffusion of plants (Li et al., 2009); In the desert environment, the above-ground biomass distribution decreases with the increase of total biomass, while the below-ground biomass distribution decreases with the total growth. The growth of root system is enhanced by the increase of biomass, so as to ensure the water and inorganic nutrition needed for growth and reproduction in arid environment. Similar results have been obtained from previous studies (Zhao et al., 2017; Zhou., 2015) (*Fig. 5*).

The biomass allocation of vegetative, reproductive allocation and total biomass allocation reflect the resource allocation strategies between sexual and asexual reproduction (Hong et al., 2007; Zhang et al., 2004). The results showed that the reproductive allocation of *A. inebrians* in desert and steppe decreased, while that of meadow increased. The biomass distribution of vegetative branches and the total biomass of three habitats increased. On the one hand, the spatial characteristics of desert, grassland and meadow were related to the environmental conditions. Compared with desert and steppe habitat, meadow habitat can provide enough space for the spread of the *A. inebrians*, and the light is sufficient. The most direct and effective growth strategy for the *A. inebrians* to rapidly occupy such a favorable space is asexual reproduction. On the other hand, after entering the invasion area and settling down, the population regeneration of *A. inebrians* is mainly carried out by vegetative reproduction; for the allocation of reproductive branches, *A. inebrians* is also kept at a medium average level, which shows that *A. inebrians* has strong sexual reproduction ability, which is similar to the previous research results (Hong et al., 2010). Therefore, this study further speculated that the local spread and diffusion of the *A. inebrians* in the invasion area, the population renewal mainly through nutrition reproduction, long-distance transmission, mainly through seeds, which need further study to investigate (*Fig. 6*).

Conclusion

There was no significant difference in the biomass of inflorescences, stems and reproductive branch of *A. inebrians* among the three different habitats of desert, steppe and meadow ($P > 0.05$), but the biomass of other components in the desert was significantly lower than those in the other two habitats ($P < 0.05$). The allocation of leaves biomass was the most and inflorescence was the least in three habitats, and the biomass of reproductive and vegetative, above-ground and below-ground biomass increased with the increase of total biomass. In the steppe and meadow habitats, more

energy is preferentially distributed to the above-ground components by reducing the input of below-ground biomass, but in the desert habitats, the opposite trend was observed.

In this paper, we only analyse the effect of different habitats on biomass and biomass allocation of *A. inebrians*. The allocation of biomass in the population of *A. inebrians* was neglected the influence of disturbance degree and genetic characteristics on them, and whether the difference of the relationship among the components of *A. inebrians* is related to their location Is it related to the level of phylogeny at present, certain regularity can be studied from these angles in the future Growth strategy of *A. inebrians* population.

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