# IMPACT OF ANTHROPOGENIC DISTURBANCE ON THE COMMUNITY PLANT DIVERSITY AND GROWTH OF THE ALIEN INVASIVE PLANT REDROOT AMARANTH (*AMARANTHUS RETROFLEXUS* L.)

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**Abstract.** Investigating the impact of anthropogenic disturbance on community plant diversity and alien plants growth is important for nature conservation. Field investigations were conducted by the quadrat method to determine the variations of community plant diversity and growth of the alien invasive plant redroot amaranth (*Amaranthus retroflexus* L.) under anthropogenic disturbance. The study compared a disturbed community, primarily affected by agricultural activities, and a natural community which experienced minimal disturbance. The results showed that plant diversity indices and growth of *A. retroflexus* varied during the investigation, and they were all significantly impacted by anthropogenic disturbance ($P < 0.05$). Plant diversity indices (Marglef, Simpson and Shannon-Wiener index) were significantly lower in the disturbed community ($P < 0.01$). However, growth parameters (plant height, basic stem diameter, biomass, relative growth rate) and the important value of *A. retroflexus* were significantly higher ($P < 0.05$). The results indicate that anthropogenic disturbance has a detrimental impact on community plant diversity while enhancing the growth potential of *A. retroflexus*. The variation caused by anthropogenic disturbance increases both community invasibility and plant invasiveness. Therefore, plant community should be protected from anthropogenic disturbance to maintain high biodiversity, which are favorable for community stability and resistance to the invasion of alien invasive plants.
**Keywords:** *Amaranthus retroflexus L., anthropogenic disturbance, plant community, diversity index, growth variation*

## Introduction

Biological invasion, a global environmental problem, has garnered significant attention. It severely threatens the biodiversity, environment and economy of invaded region (Xu et al., 2006). China suffers from biological invasion severely. Four lists of alien invasive species have been published, in which alien invasive plants are predominant. Redroot amaranth (*Amaranthus retroflexus* L.) is one of the 37 species in the Amaranthaceae family. It is an erect, annual broadleaf herb with a height ranging from 20 cm to 80 cm, and a maximum height of 100 cm. It is highly adaptable to various environments, such as farmland, orchards, roadsides, intertidal zones, and wastelands, where it readily establishes populations. It can invade these habitats and enforce negative impact on them (Gao et al., 2011; Bai and Zhao, 2022).


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Among the invasion mechanism studies, community invasibility is a measure of whether the community can be easily invaded or not. The changes of community characteristics are more important than alien species to determine the occurrence of biological invasion due to the mechanisms that the community involves (Zheng and Ma, 2010). Disturbance, a universal phenomenon in nature, is considered to be of influence on the succession of community structure and function directly. One of the important impact of disturbance is that it can improve the habitat heterogeneity and benefit the renewal and reestablishment of plant community (Song et al., 2011). Nowadays, biodiversity loss caused by various disturbance has become one of the most important environmental problems, in which the anthropogenic disturbance cannot be neglected. With the increase of human activity extension and intensity, anthropogenic disturbance has shown serious impact on the local ecosystem, and results in the structure and biodiversity changes of the ecosystem and community (Yang et al., 2007; Yan et al., 2010; Song et al., 2011), so does the community function (Liu et al., 2014). Anthropogenic disturbance plays a vital role in the biological invasion. It is considered to be of important impact on the invasion and diffusion of alien invasive plants (Sax, 2002), especially for the regions in China with dense population that the richness of alien invasive plants is positively correlated with the population and density (Liu et al., 2005). Although many studies have been reported about the impact of anthropogenic disturbance on the invasion of alien invasive plants (Alpert et al., 2002; Luo et al., 2021), little information is available on the invasion of *A. retroflexus* by anthropogenic disturbance, which causes the lack of systematic understanding of its invasive mechanism and strategies for inhibiting invasion. Therefore, field investigation was conducted to investigate the impact of anthropogenic disturbance on the community plant diversity and the growth of *A. retroflexus*. The study aimed to reveal its invasive mechanism and community's invasibility, and provide important theoretical support for the prevention of alien plant invasion and scientific references for the management and conservation of natural community.

## Materials and methods

### *Sample plot arrangement and investigation*

The investigation was conducted in the field in Qinhuangdao, northeast of Hebei province, China (39°52′19″N, 119°27′18″E). The climate was warm temperate semi-humid continental monsoon. The annual mean sunshine duration, rainfall, temperature and relative humidity were 2758 h, 695.5 mm, 11.1℃ and 61%, respectively (Ju, 2020). The soil type was brown, and the vegetation was herbs which belonged to the flora of East and temperate Asia. The herbs were mostly annual and the families of Poaceae, Asteraceae and Cyperaceae. The selected herb community was near the farmland, and the alien invasive plant *A. retrorlexus* distributed in the community. According to the early investigation, the natural environmental elements were the same which provided ideal condition for this study. The community closed to the farmland was disturbed by agricultural production activities such as trample, cutting and fertilization, while the farther community was rarely disturbed. According to the Technical Specification for Investigation and Assessment of National Ecological Status — Ecosystem Problems Assessment (HJ1174-2021) published by the Ministry of Ecology and Environment of China, the degradation index was about 52.63% that was the severe close to extremely


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severe degradation grade. Therefore, disturbance gradient existed along the distance to the farmland. The community closed to the farmland with anthropogenic disturbance was considered as the disturbed community, while the farther rarely disturbed community as the natural community (*Fig. 1*).

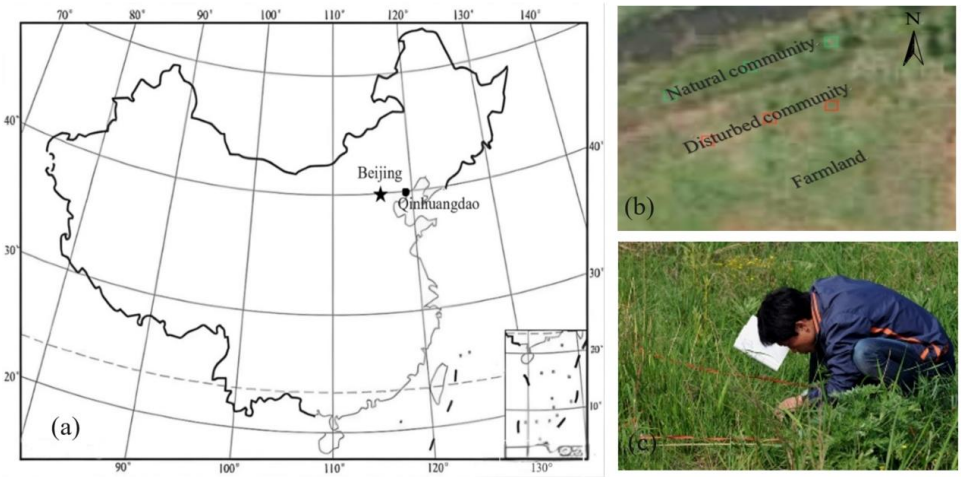


***Figure 1.*** *The study location (a), sketch map of sample plot arrangement (b) and investigation of diversity (c)*

Dynamic variations of the *A. retroflexus* community were investigated along the growth stage. Three sample plots with *A. retroflexus* in either community were arranged randomly. There were six sample plots in the disturbed and natural community in total. Each plot was 1 m × 1 m. Due to the fact that the vegetation was in seedling and wilting stage in April and October, respectively, the investigation lasted from May to September in 2019. The plant species and individual number of each sample plot were recorded for diversity indices calculation on May 18, June 20, July 19, August 18 and September 20, respectively. Besides, five whole plants of *A. retroflexus* outside the plots in either community were harvested for growth determination. The plant height, basic stem diameter and individual biomass (dry weight) were determined immediately. When *A. retroflexus* was in reproductive growth stage, the propagule biomass was also determined. The relative growth rate was calculated as follows:

$$RGR = \frac{LnW_t - LnW_0}{t} \quad \text{(Eq.1)}$$

where $W_0$ and $W_t$ were the individual biomass of two proximity investigation, and $t$ was the time interval (d) (Ma et al., 1991).

Important value of *A. retroflexus* was determined by the average of relative density, relative frequency and relative coverage.

### *Diversity indices calculation*

The community plant diversity indices included Margalef inidex ($D_M$), Simpson index (D), Shannon-Wiener index (H) and Pielou evenness index (E). They were calculated as follows (Ma et al., 1991):


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Margalef inidex $$D_M = \frac{S-1}{LnN} \quad \text{(Eq.2)}$$

Simpson index $$D = 1 - \sum_{i=1}^{N}\left(\frac{N_i}{N}\right)^2 \quad \text{(Eq.3)}$$

Shannon-Wiener index $$H = -\sum_{i=1}^{N}\left(\frac{N_i}{N} \cdot Ln\frac{N_i}{N}\right) \quad \text{(Eq.4)}$$

Pielou evenness index $$E = \frac{H}{LnS} \quad \text{(Eq.5)}$$

where $S$ and $N$ were the species and individual number of the plots, respectively. $N_i$ was the individual number of the $i$th species.

### *Statistical analysis*

Data analysis was performed with SPSS 16.0. The differences of diversity indices and individual growth parameters of *A. retroflexus* between the communities were tested by *t*-test at the level of $\alpha = 0.05$. Two-way analysis of variance (Two-way ANOVA), with disturbance gradient and investigation duration as factors, was used to test the significance of the indices after variances testing for normality. Multicomparison was also performed to determine the significant difference among individual means.

## Results

### *Variation of family, genus and species number*

Each species observed in the natural and disturbed communities and the occurred month were shown in *Table 1*. There were 23 and 10 species in the two communities in total, respectively. The family, genus and species number of the natural and disturbed communities varied in the investigation duration (*Table 2*). The family number in the natural community showed a U-shape change while downturn in the disturbed community. The genus and species number all increased except for the decrease in September in the natural community. Obviously, the family, genus and species number in the disturbed community were lower than that in the natural community, which were almost the half, respectively. The results of *t*-test also showed that there were significant differences of the family, genus and species number between the two communities (*Table 3*, $P < 0.001$).

### *Variation of diversity indices*

The diversity indices of Marglef, Simpson and Shannon-Wiener index showed fluctuation changes during the investigation (*Fig. 2*). The maximum of the three indices were in August, July and July in the natural community, respectively, while all in August in the disturbed community. Meanwhile, the minimum of the three indices were all in June in the natural community, and in May, May and September in the disturbed community,


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respectively. However, Pielou evenness index showed decrease trend in general, especially in the disturbed community. Multicomparison results showed that, except for Simpson index in the disturbed community, there were significant differences between the two communities ($P < 0.05$). Besides, the results of *t*-test showed that significant differences existed between the natural and disturbed communities (*Table 3*, $P < 0.01$). Marglef, Simpson and Shannon-Wiener index in the natural community were significantly higher than that in the disturbed community, while Pielou evenness index was significant higher in the disturbed community due to the negative relationship between the index and species number. The results of Two-way ANOVA showed that both investigation duration and disturbance had significant impact on the community diversity indices (*Table 4*, $P < 0.05$). And their interaction also affected Marglef, Shannon-Wiener and Pielou evenness indices significantly ($P < 0.01$). Therefore, the diversity indices of Marglef, Simpson and Shannon-Wiener index were significantly higher in the natural community than that in the disturbed community, while Pielou evenness index showed the contradictory result. The four diversity indices were all impacted significantly by disturbance and duration, so do their interaction except for Simpson index.

***Table 1.*** *Species observed in the natural and disturbed communities*

| No. | Species | Occurred month | No. | Species | Occurred month |
|---|---|---|---|---|---|
| **Natural community** | | | 18 | *Typha angustifolia* | M, J1, J2, A, S |
| 1 | *Carex pumila* | J1, J2, A, S | 19 | *Inula japonica* | J1, J2, A, S |
| 2 | *Cirsium setosum* | J1, J2, A, S | 20 | *Commelina communis* | A, S |
| 3 | *Triarrhena sacchariflora* | J1, J2, A, S | 21 | *Cirsium maackii* | M, J1 |
| 4 | *Amarantus retroflexus* | M, J1, J2, A, S | 22 | *Eriochloa villosa* | J2, A |
| 5 | *Setaria viridis* | J2, A, S | 23 | *Eragrostis ferruginea* | J2, A, S |
| 6 | *Kummerowia striata* | J2, A, S | **Disturbed community** | | |
| 7 | *Equisetum ramosissimum* | M, J2, A, S | 1 | *Echinochloa crusgali* | A, S |
| 8 | *Arthraxon hispidus* | J1 | 2 | *Xanthium sibiricum* | J1, J2, A, S |
| 9 | *Chenopodium album* | M, J2, A, S | 3 | *Amarantus retroflexus* | M, J1, J2, A, S |
| 10 | *Phragmites australis* | M, J1, J2, A, S | 4 | *Setaria viridis* | J2, A, S |
| 11 | *Humulus scandens* | M, J1, J2, A, S | 5 | *Capsella bursa-pastoris* | M, J1 |
| 12 | *Hemarthria altissima* | J2, A, S | 6 | *Chenopodium album* | M, J1, J2, A, S |
| 13 | *Juncellus serotinus* | M, J1, J2, A, S | 7 | *Humulus scandens* | M, J1, J2, A, S |
| 14 | *Carex breviculmis* | M | 8 | *Eleusine indica* | M, J1, J2, A, S |
| 15 | *Ambrosia artemisiifolia* | M, J1, J2, A, S | 9 | *Ixeris chinensis* | A, S |
| 16 | *Equisetum arvense* | M | 10 | *Ambrosia artemisiifolia* | M, J1, J2, A, S |
| 17 | *Roegneria ciliaris* | J1, J2 | | | |

M, J1, J2, A and S represent the months of May, June, July, August and September, respectively

***Table 2.*** *Family, genus and species number in different months*

| Community | Parameters | May | June | July | August | September |
|---|---|---|---|---|---|---|
| Natural community | Family | 10 | 7 | 9 | 10 | 10 |
| | Genus | 12 | 13 | 18 | 18 | 17 |
| | Species | 13 | 14 | 18 | 18 | 17 |
| Disturbed community | Family | 6 | 6 | 5 | 5 | 5 |
| | Genus | 6 | 7 | 7 | 9 | 9 |
| | Species | 6 | 7 | 7 | 9 | 9 |


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***Table 3.*** *t-test results of community plant diversity and individual growth of A. retroflexus in the natural and disturbed communities*

| **Parameters** | **$N_F$** | **$N_G$** | **$N_S$** | **$D_M$** | **D** | **H** | **E** |
|---|---|---|---|---|---|---|---|
| *t* value | $11.24^{***}$ | $10.53^{***}$ | $13.01^{***}$ | $11.22^{***}$ | $3.83^{**}$ | $8.87^{***}$ | $-4.33^{***}$ |
| **Parameters** | **PH** | **BSD** | **M** | **RGR** | **$M_P$** | **IV** | — |
| *t* value | $-2.40^{*}$ | $-3.03^{**}$ | $-2.91^{**}$ | $-2.83^{*}$ | $-3.78^{**}$ | $-18.12^{***}$ | — |

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$. $N_F$, $N_G$ and $N_S$ are the numbers of family, genus and species, respectively. $D_M$, Margalef index; D, Simpson index; H, Shannon-Wiener index; E, Pielou evenness index; PH, plant height; BSD, basic stem diameter; M, individual biomass; RGR, relative growth rate; $M_P$, propagule biomass; IV, important value. The same as follows

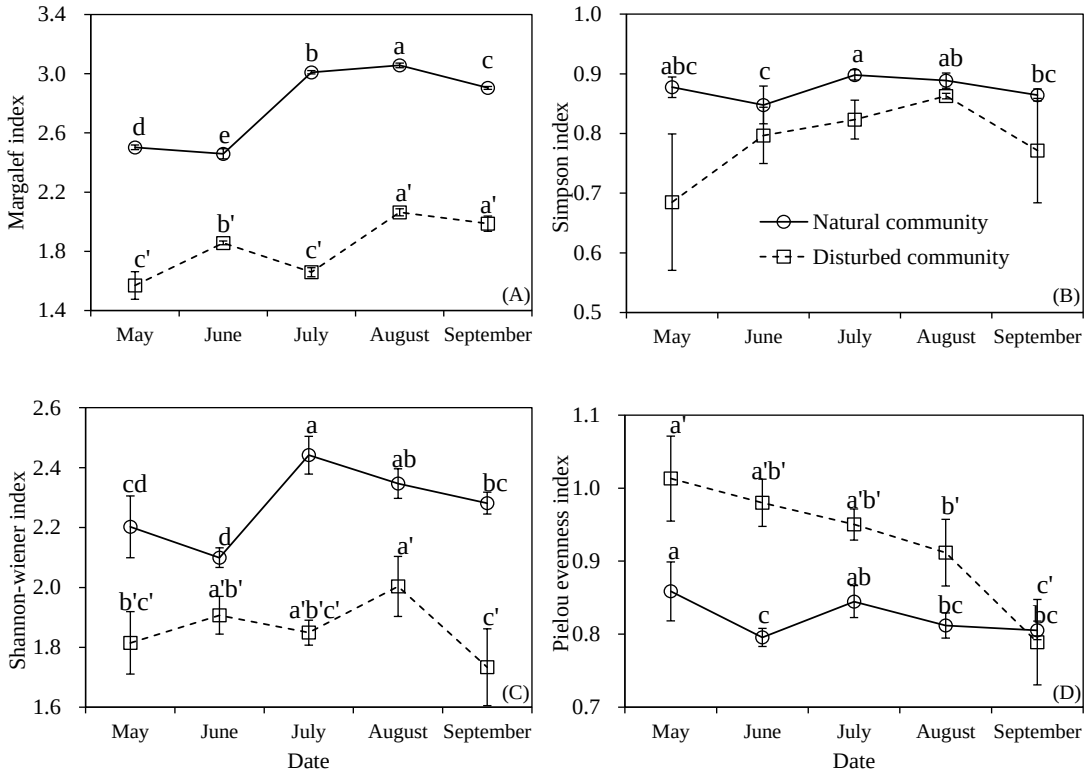


***Figure 2.*** *Variation of diversity indices (Marglef, Simpson, Shannon-Wiener and Pielou evenness index) in the natural and disturbed communities. Results are the means ± SD of the sample plots (n = 3). Different letters indicate the significant differences during the investigation (P < 0.05). Letters with "'" are the significant differences in the disturbed community. No letters mean no significant differences. The same as follows*

***Table 4.*** *Two-way ANOVA results of the impact of disturbance, investigation duration and their interaction on community plant diversity indices and individual growth of A. retroflexus*

| | **$D_M$** | **D** | **H** | **E** | **PH** | **BSD** | **M** | **RGR** | **$M_P$** | **IV** |
|---|---|---|---|---|---|---|---|---|---|---|
| DIS | *** | *** | *** | *** | *** | *** | *** | ** | *** | *** |
| ID | *** | * | ** | *** | *** | *** | *** | ns | *** | ns |
| DIS×ID | *** | ns | ** | ** | *** | *** | *** | * | *** | ns |

ns, P > 0.05. DIS, disturbance; ID, investigation duration; DIS × ID, the interaction between DIS and ID


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### *Growth variation of A. retroflexus*

With the changes of community diversity indices, growth of *A. retroflexus* also varied. Plant height, basic stem diameter and individual biomass all increased in the two communities and showed significant differences during the investigation ($P < 0.05$). However, relative growth rate showed fluctuation changes that it reached its maximum in August in the disturbed community while it was the minimum in the natural community (*Fig. 3*). There were also significant differences of the parameter in the disturbed community ($P < 0.05$), and no significant differences existed in the natural community. In July, *A. retroflexus* started the reproductive growth period, propagule biomass all increased significantly in the two communities during the following investigation (*Fig. 4*, $P < 0.05$). Important value of *A. retroflexus* decreased significantly in the natural community ($P < 0.05$), while showed the maximum in August in the disturbed community with no significant differences (*Fig. 5*).

Importantly, plant height, basic stem diameter, individual biomass and propagule biomass of *A. retroflexus* in the disturbed community were all significantly higher than that in the natural community (*Table 3*, $P < 0.05$), which indicated that *A. retroflexus* had stronger growth advantage in the disturbed community. Furthermore, both disturbance, investigation duration and their interaction had significant impact on plant height, basic stem diameter, individual biomass and propagule biomass of *A. retroflexus* (*Table 4*, $P < 0.001$). Disturbance also had significant impact on relative growth rate and important value of the plant ($P < 0.01$), while no significant impact were observed in investigation duration. The interaction of the two factors also had impact on relative growth rate significantly rather than important value ($P < 0.05$).

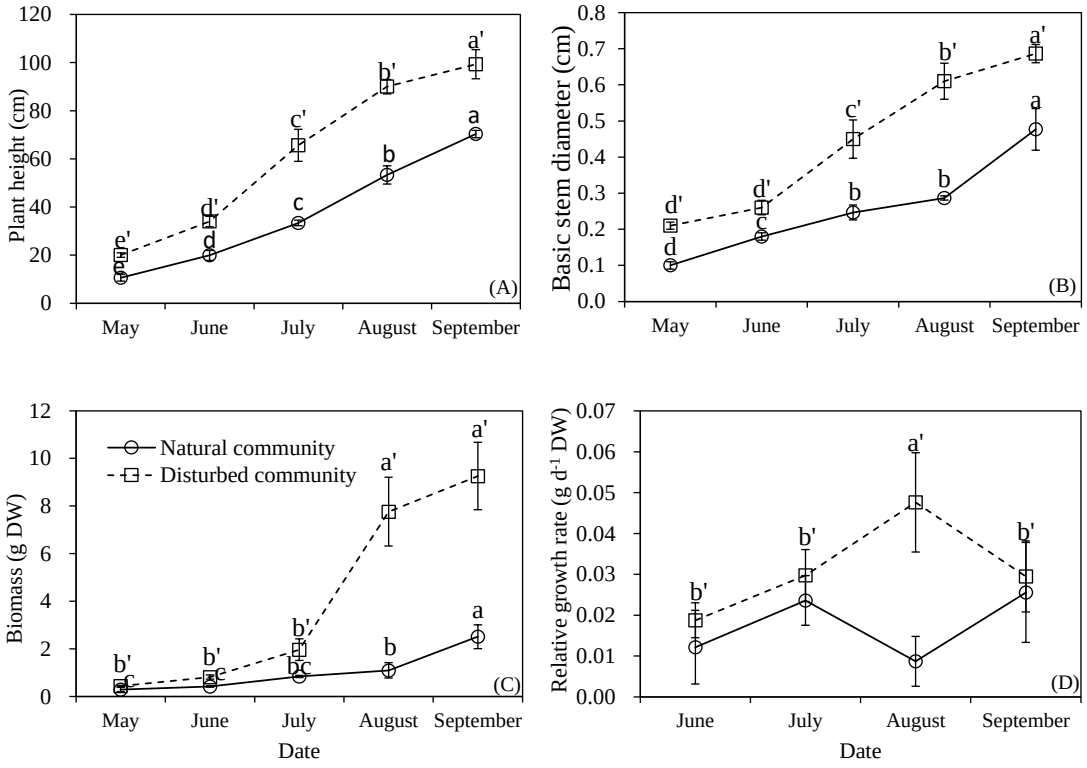


***Figure 3.*** *Growth variation (plant height, basic stem diameter, individual biomass and relative growth rate) of A. retroflexus in the natural and disturbed communities (n = 5)*


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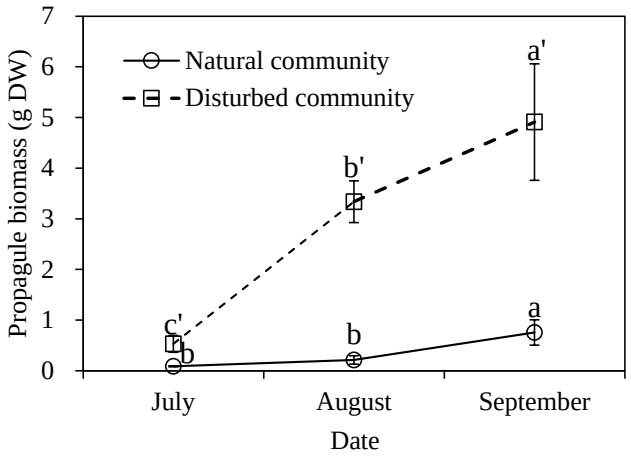


***Figure 4.*** *Propagule biomass variation of A. retroflexus in the natural and disturbed communities (n = 5)*

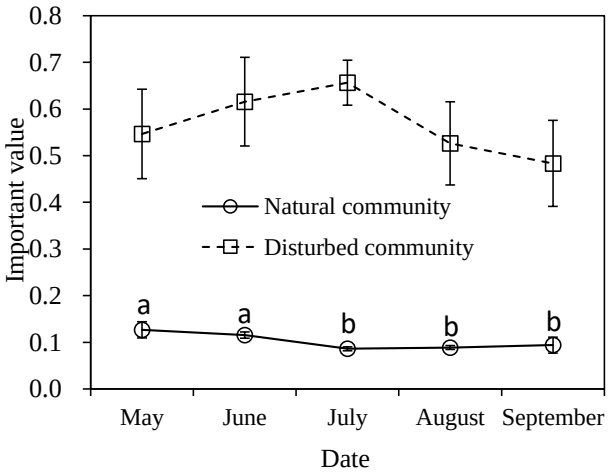


***Figure 5.*** *Important value variation of A. retroflexus between the natural and disturbed communities (n = 3)*

## Discussion

Disturbance is a discontinuous event to alter the structure of population, community and ecosystem. As one of the important factors for the changes of community plant composition and stability, not only can disturbance impact community plant diversity, but also promote the growth potential of the alien invasive plants and further increase their invasiveness into the community. This investigation indicated that there were significant differences of community plant diversity and growth potential of the alien invasive plant *A. retroflexus* in the natural and disturbed communities. Generally, disturbance caused by anthropogenic activities could reduce the community plant diversity significantly. Meanwhile, it also improved the growth potential of the plant significantly ($P < 0.05$). Such improvement might further increase its invasion possibility into the community.

Both the natural and disturbed communities had a certain amount of family, genus, species (*Table1, 2*) and plant diversity (*Fig. 2*). It indicated that the two communities


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had relative rich soil seed bank. The disturbed community closed to the farmland and was disturbed by agricultural production activities, which were all related to the community plant composition and alien plants invasion (Liu et al., 2008; Šipek et al., 2023). The soil seed bank was also affected by such disturbance because of the significantly lower family, genus and species number in the disturbed community than that in the natural community ($P < 0.05$). Different from the plant diversity variations by vegetation succession over years, plant diversity in the two communities varied significantly during the investigation. It might be attributed to the plant biotic characteristics and, more importantly, the interspecific competition of the community plants. Attentions have been paid to the relation between disturbance and plant diversity. It is generally considered that plant diversity can be impacted by disturbance, and the impact degree is related to the disturbance intensity (de Villalobos and Long, 2024). Among the hypothesis of disturbance theory, intermediate disturbance hypothesis and interference frequency hypothesis are the two that are generally approved. The first hypothesis considers that moderate disturbance can increase plant diversity, and community has the highest plant diversity under intermediate disturbance (Son et al., 2023; Zhu et al., 2020). The hypothesis bases on the balance between plant species tolerance to disturbance and their competitiveness. It is the adaptation of the community to external disturbance during its succession, and also a strategy of the ecosystem restoring stability (Zhang et al., 2024). However, due to the obvious changes of ecological factors and community reproductive strategies under different disturbance intensity, plant species number and distribution properties also vary, resulting in the different trend of plant diversity variation (Yang et al., 2009). The second hypothesis considers that community can remain high plant diversity when the time interval of disturbance occurring is shorter than competition (Liu et al., 2008). The disturbed community in this investigation was suffered from the anthropogenic disturbance of agricultural production activities. The significantly lower family, genus and species number indicated the disturbance intensity and/or frequency were high enough, and further resulted in the significantly lower community plant diversity.

Among the plant diversity indices, Marglef, Simpson and Shannon-Wiener index were significantly lower in the disturbed community. The results were in accordance with other studies that disturbance was an important factor in plant diversity variation (Gebrehiwot et al., 2019), while Pielou evenness index showed different results that it could be also affected by disturbance (Yan et al., 2010; Jin et al., 2021). The index was related to Shannon-Wiener index and species number, and the ratio of Shannon-Wiener index between the disturbed and natural community was 0.819, while plant species number is 0.494. This differences resulted in the high Pielou evenness index in the disturbed community. Except for this index, other three indices had the maximum or higher value in August when *A. retroflexus* had grown to be high and in reproductive growth stage. As an important alien invasive plant, its adverse impact to other plants might occur, including allelopathic impacts and competition to nutrients (Bai and Zhao, 2022), especially in the disturbed community. It was similar to the studies on *Solidago canadensis* that invasion of alien invasive plant could reduce the plant diversity of the invaded community (Guo et al., 2011).

Community invasibility is a focus research in biological invasion. Some features of the community provide certain possibility for the invasion of alien invasive species (Zheng and Ma, 2010). The features include resource availability, climatic factors, biological diversity and certainly disturbance (Renne et al., 2006; Belote et al., 2008).


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When the plant community is disturbed, interspecific competition reduces because of the enhancement of underlayer light and soil nutrient availability, and resource turnover rate and intensity also change, which can promote the growth of alien invasive plants and the advantage in competition (Niu et al., 2011). Besides, structure and function of the disturbed community also vary under the disturbance. However, the variation mainly focuses on structure simplification and functional deterioration, which can provide opportunity for alien invasive plants to invade into the community. Other views consider that, as an important factor for community invasibility, disturbance breaks the original interspecific relationship to provide ecological niche and settlement opportunity for alien invasive plants (Gill et al., 2018; Song et al., 2023). This investigation showed that plant richness and diversity were significantly impacted while there was stronger growth advantage of *A. retroflexus* in the disturbed community. Meanwhile, the results also indicated that anthropogenic disturbance impacted the disturbed community significantly, and resulted in the habitat heterogeneity reduction and the vacancy of ecological niche. The community variation became the key for the invasion of *A. retroflexus*.

The invasion of alien invasive plants is a complex ecological process that includes four stages of intrusion, settlement, adaptation and diffusion in general. Certain pathway is needed for the plants to invade into a new community, which is considered to be significantly impacted by disturbance (Theoharides and Dukes, 2007; Gill et al., 2018). However, disturbance is considered to be of significant influence only in some special stage during the invasion of alien invasive plants (Wu et al., 2010). It plays an important role during the intrusion stage while further invasion and distribution pattern are mainly affected by climatic factors, resource availability and biological diversity of the disturbed community. In other words, disturbance influence is mainly in the intrusion stage for successfully invaded plants, while they are mainly impacted by environmental factors in other stages, and the harm to invaded community are determined mainly by their biological properties (Gao et al., 2011). Anthropogenic disturbance can also vary the regional disturbance regime that may increase resource availability or change landscape pattern. The variation can create favorable plaques for the settlement and diffusion of alien invasive plants (Zheng and Ma, 2010). Nevertheless, not all the disturbed community can be invaded because it relates to the ability to resist invasive plant invasion. The community cannot be invaded easily if it has strong resistance, and vice versa. On a small scale, species loss can reduce the community resistance to alien plants invasion (Halassy et al., 2023), while community resistance may also reduce in that with higher diversity because environmental factors can lead to uneven supply of propagule on community scale. *A. retroflexus* is a constructive species in the natural community without obvious advantage. However, it has significantly higher important value and propagule biomass in the disturbed community. The fact may also provide possibility and opportunity for the plant for further diffusion and invasion.

## Conclusion

Community plant diversity and growth of the alien invasive plant *A. retroflexus* were significantly impacted by anthropogenic disturbance. Plant diversity indices (Marglef, Simpson and Shannon-Wiener index) were significantly lower in the disturbed community than that in the natural community ($P < 0.01$), while inversely for Pielou evenness index that was determined by high Shannon-Wiener index and low plant


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richness. However, plant growth potential of *A. retroflexus* was improved in terms of plant height, basic stem diameter, individual biomass and relative growth rate. Propagule biomass and important value of the plant were also significantly higher in the disturbed community ($P < 0.01$). Results of the investigation indicate that anthropogenic disturbance can significantly decrease the community plant diversity except for Pielou evenness index while increase the growth potential of *A. retroflexus*. It can further increase the community invasibility and the plant invasiveness, which may has detrimental impact on the community. Therefore, plant community should be protected from anthropogenic disturbance to maintain high biodiversity, which is favorable for the community stability. Meanwhile, it can also restrict the growth of *A. retroflexus* to reduce its invasion into the community.

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