DOI: 10.5586/asbp.3612

Publication history
Received: 2018-04-13
Accepted: 2019-01-16
Published: 2019-04-02

Handling editor
Łukasz Łuczaj, Faculty of Biotechnology, University of Rzeszów, Poland

Authors' contributions
YZ, HS, PA, YG, and LJ designed the study and conducted the experiment; SY, JZ, LL, and QS carried out the calculations and analyzed the results; HL and SY wrote the manuscript

Funding
This work was supported by the National Natural Science Foundation of China (grant Nos. 41330749 and 41401105).

Competing interests
No competing interests have been declared.

Citation
Li H, Yi S, Lai L, Zhou J, Sun Q Jiang L, et al. Responses of plant species to different aboveground removal treatments with implications for vegetation restoration in the Mu Us Sandland (Inner Mongolia). Acta Soc Bot Pol. 2019;88(1):3612. https://doi.org/10.5586/asbp.3612

ORIGINAL RESEARCH PAPER

Responses of plant species to different aboveground removal treatments with implications for vegetation restoration in the Mu Us Sandland (Inner Mongolia)

Heyi Li[1,2], Sangui Yi[1,2], Liming Lai[1], Jihua Zhou[1], Qinglin Sun[1,2], Lianhe Jiang[1], Yong Gao[3], Ping An[4], Hideyuki Shimizu[5], Yuanrun Zheng[1]*

[1] Key Laboratory of Plant Resources, West China Subalpine Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Xiangshan, Beijing 100093, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China
[3] Inner Mongolia Agricultural University, Hohhot 010018, China
[4] Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan
[5] National Institute for Environmental Studies, Tsukuba 305-8506, Japan

* Corresponding author. Email: zhengyr@ibcas.ac.cn

Abstract

It is generally assumed that plants can respond to varying degrees of physical damage by growth compensation via resprouting, and resprouting is a key functional trait in many species. Few studies have investigated how grass and shrub species distributed in moving dunes and semifixed dunes in semiarid areas respond to the combined effects of temperature and shoot removal. *Medicago sativa*, *Artemisia ordosica*, and *Artemisia sphaerocephala* plants were grown in a glasshouse for 8 weeks at air temperatures of 10/20°C, 12.5/22.5°C, 15/25°C, and 17.5/27.5°C (night/day) and were subjected to treatments of removing all leaves (LR), removing all leaves followed by cutting at half the plant height (HC), and removing all aboveground tissue (WC). The species, temperature, and damage extent had significant effects on the shoot number, leaf mass ratio, leaf area ratio and ratio of belowground to aboveground dry matter, and the species had a significant effect on the net assimilation rate, specific leaf area, and total biomass. The three species grew well under the HC and LR treatments, and high temperatures (15/25°C and 17.5/27.5°C) significantly promoted the regrowth of the three species. *Medicago sativa* grew faster than the two *Artemisia* species. *Medicago sativa* can be used for fertilizing or vegetation restoration in unimportant conservation areas, and the two *Artemisia* species can be effectively used for vegetation restoration in the Mu Us Sandland. Due to the low labor costs and the local climate conditions, plants should be clipped before the beginning of the main growing season (end of May or early June) to ensure rapid growth.

Keywords

Artemisia ordosica; *Artemisia sphaerocephala*; *Medicago sativa*; semiarid region; resprouting; temperature

Introduction

The regrowth of plants after the loss of biomass is an adaptation of species to environments with frequent disturbance, making them more persistent in ecosystems. However, the mechanisms of this process remain unclear. Many plants resprout after suffering from varying degrees of physical damage, showing a key functional trait that is common in many plants around the world [1]. The regeneration of aboveground tissues and the compensatory regrowth of part of the biomass that is lost during a disturbance, and in certain cases, the regrowth of all or even more than the lost biomass, enables plants to rebuild injured functional structures and resume disturbed photosynthesis, i.e., return to rapid functioning. This process prevents the decline in fitness to the lowest level [2,3]. Therefore, resprouters tend to be dominant in ecosystems with frequent disturbances that cause physical damage and biomass losses, such as fire or herbivory [3].

Resprouters are observed in many ecosystems, from rainforests to arid and semiarid shrubs and Mediterranean-type ecosystems [4–6]. In research involving 2,741 species in Mediterranean ecosystems on different continents, 57% of species were found to have the ability to resprout; these species are characterized by perennation, high allocation of biomass to roots, long time to sexual maturity, and thick bark when compared with nonresprouters [7,8]. Nonresprouters usually focus on seedling recruitment, while resprouters may occasionally employ both strategies [7]. However, several researchers have argued that this species-specific dichotomy is overly simplistic and inclined to the consideration that resprouting is a mode of regeneration that is better considered in the context of other modes, such as seeding [9].

Additionally, resprouting exists extensively across ecosystems and biomes under many different disturbance types and shows intensive growth pattern [10]. An old silvicultural method of forest restoration, coppicing, was conducted throughout European forests until 150 years ago. There has been renewed interest in this method for several decades in certain regions of Europe for biomass production and nature conservation and certain semiarid regions in northwestern China for the control of desertification. For example, to combat desertification, some species such as *Artemisia ordosica*, *A. sphaerocephala*, *Astragalus adsurgens*, *Caragana intermedia*, *C. korshinskii*, *Hedysarum laeve*, *Medicago sativa*, and *Salix psammophila* were established in desertified areas by air seeding or plants transplantation methods. These plants grew well and were able to fix moving sand dunes. However, after several years, the different species of the restored vegetation areas degraded, and when the aboveground parts were clipped, the vegetation began to restore and plant grew well [11,12]. Therefore, clipping aboveground parts has been regarded as a good way to restore degraded artificial vegetation in desertified areas. For many species, vegetative resprouting after top-cutting leads to regrowth of more biomass than was lost [13]. Sprouting of *Quercus rubra* from the base of the stem was induced by coppicing, and the relative growth rates of the resprouts were higher than the growth rates of the plants that were left intact [14]. Coppicing is regarded as a form of management in which trees are regularly cut back to encourage the growth of shoots from the base of the trunk [15]. For nature conservation or economic reasons, trees are cut near ground level and are expected to sprout from the cut stump [16]. Species such as sessile oak (*Quercus petraea*) and European hornbeam (*Carpinus betulus*) are able to resprout even at old age [16]. For herbaceous plants, the under compensatory and overcompensatory concepts are often involved [17]. The difference in the tolerance to herbivory between woody plants and herbaceous plants has resulted from several reasons [18]. First, on the individual level, woody plants are more easily eaten by herbivores due to their large body sizes. Second, short-lived plants are prone to allocating resources to reproduction. Third, herbivory may trigger the rejuvenation of woody plants by reducing their old twigs, branches, and stems. However, in contrast to many woody and herbaceous plants, grasses grow from the basal intercalary meristems with protective hard leaf sheaths but not terminal buds, which makes them particularly tolerant to herbivory [19].

Although different biomes face different disturbance regimes in different ecosystems, resprouting is often thought to be independent of the mechanism of damage [20]. A species would present its ability to resprout similarly to any type of disturbance, whether it is fire, herbivory, or drought, when two requirements are met; these requirements are when dormant buds are present and sufficient carbohydrates and nutrients are stored in the belowground organs for maintenance [21]. To accomplish this generalization, the characteristics of resprouting of species in other ecosystems that have thus far not received sufficient attention should be addressed.

The Mu Us Sandland in central Inner Mongolia is the second largest sandy land in China, and it has undergone decades of overgrazing and recent environmental degradation while simultaneously enduring shrub encroachment [22]. In such a habitat in which the main limiting factor for growth is water, plants select different drought-coping strategies, such as different root lengths, different allocation patterns, and differences in avoidance or tolerance to drought and hence represent a high diversity of drought-related traits. With the tendency of climate change towards warming, more severe drought, the increase in extreme weather events, and the persistent shrub encroachment, the plant communities in this ecosystem would be unstable for a very long time [22]. As mentioned above, resprouters are more likely to be observed in arid regions because of their high drought tolerance; thus, it is of great importance to study the resprouting characteristics of plants in arid and semiarid ecosystems, and our prediction of future plant community changes in this region would also be improved [1]. In addition, because the primary limiting factor of growth is water in the Mu Us Sandland, both water deficits and fire disturbances are present in Mediterranean-type ecosystems. Moreover, given that the two types of ecosystems are dominated by many different types of shrubs, it would be very valuable and meaningful to provide relevant data for comparing the similarities and differences of the characteristics of the two ecosystems [23]. Furthermore, the characteristics of resprouting in arid and semiarid ecosystems are still lacking, and such studies are more necessary than those in other biomes [6]. Finally, because the Mu Us Sandland is a center of desertification, cutting plants was found to be a good method to promote plant resprouting. However, the optimal locations and the time of the cutting remain unclear [12].

The aim of this study was to investigate the resprouting abilities of several species in different environments, such as moving dunes, semifixed and fixed dunes, in a semiarid ecosystem. These environments have remained relatively unnoticed in resprouting studies; thus, the results of this study will add to the global dataset of resprouters under drought stress beyond Mediterranean-type climate regions. Moreover, the responses of different plant functional types to the accelerated climate change in this arid region will be investigated. The second aim was to investigate the optimal clipping position and time to ensure the resprouting of restored vegetation in desertified regions. To achieve these objectives, the following statements were made: (***i***) a clipping experiment was conducted on three shrubs and herbaceous plant growing in the Mu Us Sandland under different temperature conditions to study the responses of resprouting characteristics to different functional and other traits and determine the severity of biomass losses that would trigger resprouting; (***ii***) different degrees of clipping might induce different resprouting results. We hypothesized that moderate clipping would promote resprouting, while severe clipping would inhibit resprouting.

Material and methods

Experimental design

The Mu Us Sandland in central Inner Mongolia, China, is located between 37°30′–39°20′ N and 107°20′–111°30′ E with a total area of approximately 40,000 km^2. The altitude is between 1,300 and 1,600 m in this area. The Mu Us Sandland is a semiarid ecosystem with an annual average temperature of 6–9°C and annual precipitation of 250–490 mm [22]. Three species that are often used for air seeding to restore the seriously desertified areas in the Mu Us Sandland in Northern China were selected [12]. These species are *M. sativa*, a perennial introduced forb species, and two semishrubs, *A. sphaerocephala*, which is distributed mainly in moving and semifixed sand dunes, and *A. ordosica*, which is mainly distributed in fixed dunes. Seeds of the three species were collected from the Mu Us Sandland in 2002 and later transported to Japan. The plants emerged within 15 days and were then transferred to pots (11.2 cm in diameter and 20 cm in height) made of PVC and filled with prepared sand mixed with artificial clay [24]; the plants were then grown until they were approximately 30 cm in height. The drainage outlets at the bottom of the pots were covered with strips of nylon mesh to prevent the loss of sand while allowing the drainage of excess water. The experiments were conducted at the National Institute for Environmental Studies, Japan.

Before the experiment, 12 individuals of each species were used to obtain the shoot number, leaf area, and dry weight of leaves, shoots, and roots of plants to provide initial growth values for every species.

Experiments were conducted in four greenhouses with automatic air temperature and air humidity control and naturally lit glasshouses, in which the relative air moisture was 50% during the day and 60% at night. Four temperature levels were set: 10/20°C (night/day), 12.5/22.5°C (night/day), 15/25°C (night/day), and 17.5/27.5°C (night/day). Plants were watered with 7.5 mm of tap water every 3 days in each temperature treatment. The temperature (12.5/22.5°C and 15/25°C night/day temperatures) and precipitation (75 mm per month) regimes in the control treatment were designed according to the monthly average temperature and precipitation during the main growing season (12.5/22.5°C and 15/25°C temperature from mid-June to mid-August) in the Mu Us Sandland based on the 30-year average of microenvironment data [12]. Plants were clipped in three ways, removing all leaves (LR), removing all leaves and cutting the plant at half its height (HC), and removing all aboveground tissue (WC). Pots with treated plants were randomly assigned to each treatment. The locations of pots with plants were changed every 3 days. Twelve replications were used for each treatment (each replicate had one pot with one plant). The experiment lasted 8 weeks. All leaves, shoots, and roots were harvested separately from every plant, and their dry mass were measured after 8 weeks of growth. The leaf area of every plant was measured using a planimeter (Li-Cor 3100, Lincoln, Nebraska, USA), and the dry weights were determined after oven drying at 80°C for 3 days. The shoot number of every plant was measured.

Growth analysis

The net assimilation rate (NAR) and the relative growth rate (RGR) of each plant were estimated using the following equations:

$$NAR = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \frac{1}{s}\frac{dW}{dt}dt = \frac{(w_2 - w_1)(\ln s_2 - \ln s_1)}{(s_2 - s_1)(t_2 - t_1)}$$

$$RGR = \frac{1}{t_2 - t_1}\int_{w_1}^{w_2} d(\ln w) = \frac{(\ln w_2 - \ln w_1)}{(t_2 - t_1)}$$

where w_1 and s_1 are the plant dry mass and total leaf area, respectively, at the initial time (t_1), and w_2 and s_2 are the plant dry mass and total leaf area at the final harvest (t_2) [25].

From the primary data, the following variables were derived: leaf mass ratio (LMR; leaf mass/total plant mass, in g g^{-1}), leaf area ratio (LAR; leaf area/total plant mass, in m^2 g^{-1}), specific leaf area (SLA; leaf area/leaf mass, in m^2 g^{-1}), and the ratio of belowground to aboveground dry matter (BAMR, in g g^{-1}) [26].

Statistical analyses

All observed values were log-transformed before statistical analysis to ensure homogeneity of variance. The transformed values were analyzed using a three-way analysis of variance (ANOVA). The relationships among shoot number, RGR, NAR, LAR, LMR, SLA, BAMR, and total biomass (g) were examined using Pearson's correlation analysis. All statistical analyses, including the test for homogeneity of variance, were performed using R 3.4.0 [27].

Results

The *F* values were highly significant for the responses of shoot number, LMR, LAR, and BAMR to species, temperature, and damage extent and for the responses of NAR, SLA, and total biomass to species ($p < 0.01$). The *F* values were significant for the response of SLA to temperature ($p < 0.05$). The *F* values were nonsignificant for the response of all growth variables for majority of interactions (Tab. 1, Tab. S1).

Tab. 1 Results of a three-way ANOVA with species, clipping method, and temperature.

	Effect						
Variables	**Species (S)**	**Temperature (T)**	**Damage extents (C)**	**S × T**	**S × C**	**T × C**	**S × T × C**
Shoot No.	933.776**	10.133**	381.903**	3.697**	33.543**	1.731	1.147
RGR	2.570	2.320	2.560	1.819	0.289	0.347	0.592
NAR	65.843**	1.203	0.277	1.237	0.432	0.242	0.611
LAR	201.585**	20.505**	13.463**	6.162**	2.026	0.670	1.396
LMR	182.767**	25.773**	34.617**	3.222**	2.533*	0.624	1.033
SLA	85.572**	3.481*	1.052	0.882	2.159	1.559	1.424
BAMR	135.607**	5.618**	4.337**	0.900	0.208	0.326	0.830
Total biomass	112.265**	2.313	2.532	1.826	0.303	0.338	0.590
df	2	3	2	6	4	6	12

Note: *F* values are shown. Three species of plants were exposed to three levels of clipping, whole cut (WC), half cut (HC), and leaf removal (LR) and four temperature levels (10/20, 12.5/22.5, 15/25, 17.5/27.5°C) in a growth chamber. Significance levels: ** $p < 0.01$; * $p < 0.05$. Abbreviations: RGR – relative growth rate; NAR – net assimilation rate; LAR – leaf area ratio; LMR – leaf mass ratio; SLA – specific leaf area; BAMR – the ratio of belowground to aboveground dry matter.

Shoot number

The shoot number was highest for *M. sativa* (209 in the LR and 15/25°C treatment) followed by the two *Artemisia* species. For the two *Artemisia* species, the shoot numbers in the HC and LR treatments were significantly higher than those in the WC treatment. For *M. sativa* and *A. sphaerocephala*, the shoot numbers tended to increase with increasing temperature, reaching the highest values at 15/25°C, and later declining. *Artemisia ordosica* had the highest shoot number in the LR treatment at 12.5/22.5°C (Fig. 1).

Relative growth rate (RGR) and net assimilation rate (NAR)

Species, damage extent, and temperature had no significant effect on the RGR (Tab. 1, Fig. 2). Species had a significant effect on the NAR, while the damage extent and temperature had no significant effect on the NAR (Tab. 1). *Artemisia sphaerocephala* had the highest NAR (9.1–13.9), followed by *A. ordosica* (5.9–8.3) and *M. sativa* (4.5–6.3) (Fig. 3).

Leaf morphological traits

The LARs were higher for *M. sativa* (0.002–0.0087 $m^2 g^{-1}$) than for the two *Artemisia* species (0.00007–0.003 $m^2 g^{-1}$) in each fixed damage extent and at each temperature. For *A. ordosica*, LR and HC significantly increased the LARs, and increasing temperature significantly increased the LARs in the HC and LR treatments. For *M. sativa*, the LARs were highest in the HC treatment at all temperatures. For *A. sphaerocephala*, the LR treatment significantly increased the LAR, and increasing temperature significantly increased the LARs in the HC and LR treatments (Fig. 4).

The SLAs were higher for *M. sativa* (0.024–0.034 $m^2 g^{-1}$) than for the two *Artemisia* species (0.010–0.024 $m^2 g^{-1}$) at all damage extents and temperatures. With increasing temperature, the SLAs significantly increased for the three species (Fig. 5).

Total biomass

Total biomass of *A. ordosica* (4.5–5.3 g) was lower than of *A. sphaerocephala* and *M. sativa* (5.6–7.2 g). For *A. ordosica*, the total biomass in the HC treatment was highest

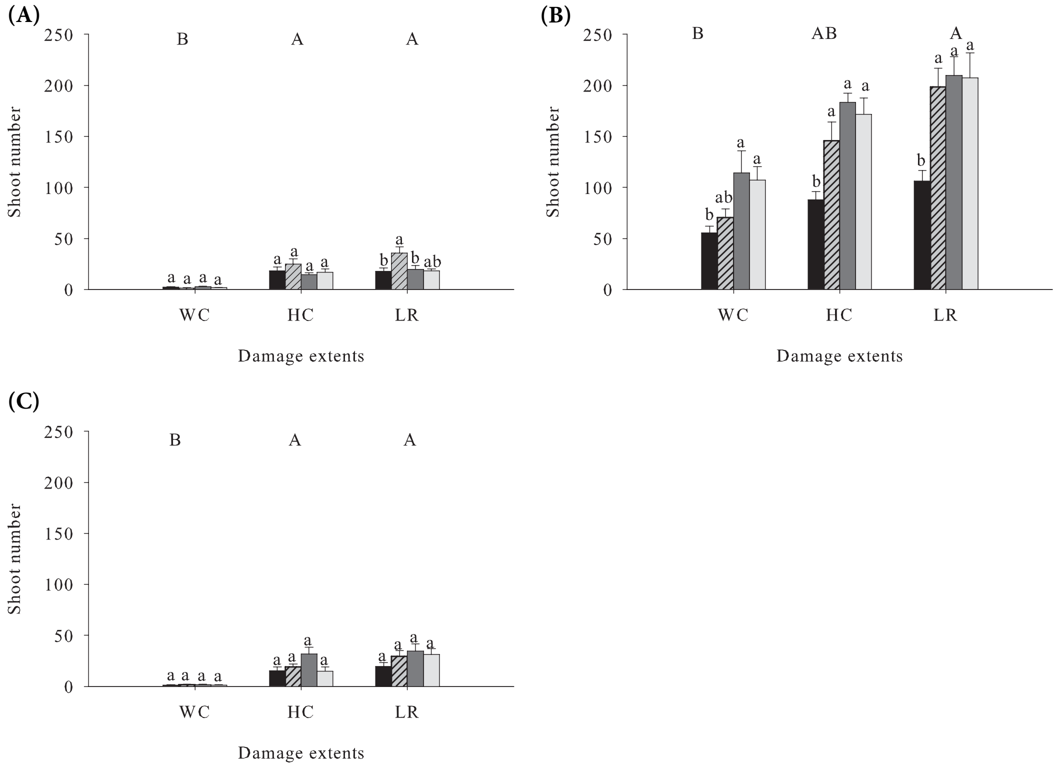

Fig. 1 Shoot numbers (±*SE*) of *Artemisia ordosica* (**A**), *Medicago sativa* (**B**), and *A. sphaerocephala* (**C**) under different temperatures (black bars – 10/20°C; stripped bars – 12.5/22.5°C; dark grey bars – 15/25°C; light grey bars – 17.5/27.5°C) (night/day) and different damage extents [whole cut (WC), half cut (HC), and leaf removal (LR)] in growth chambers. Each bar represents the mean of 12 replicates; bars with different lowercase letters are significantly different from each other for the same damage extent under different temperatures, and different capital letters indicate differences among damage extents at $p < 0.05$.

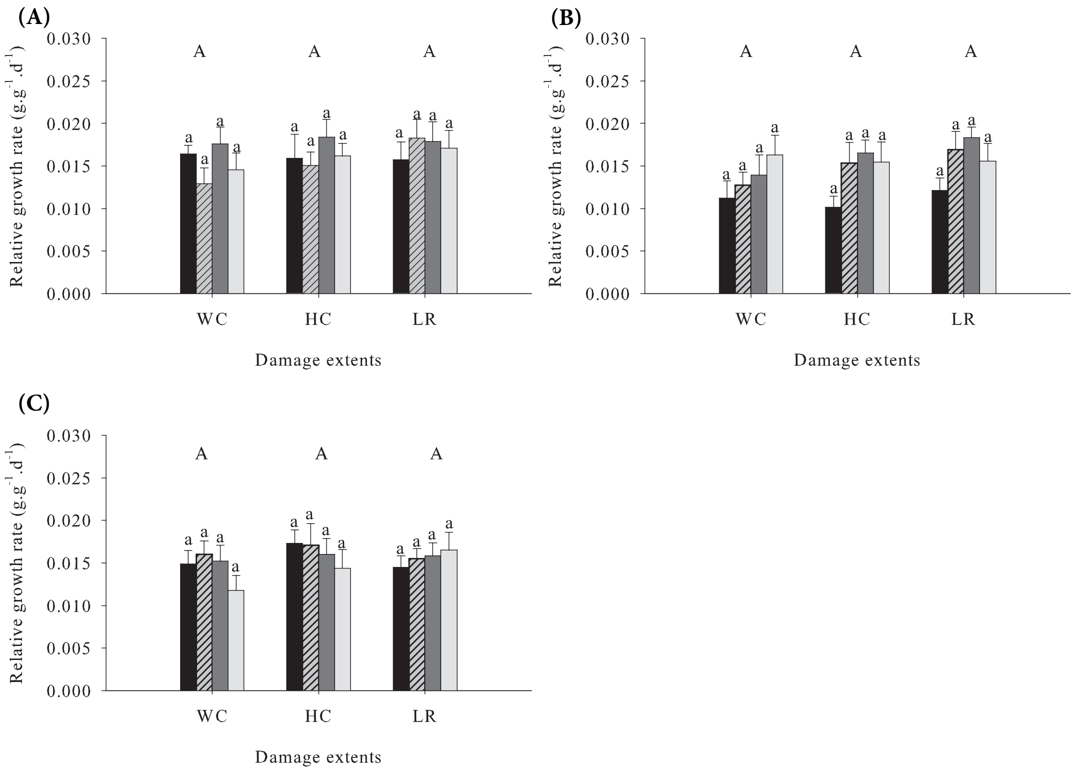

Fig. 2 Relative growth rates (±*SE*) of three species. The other descriptions are the same as in Fig. 1.

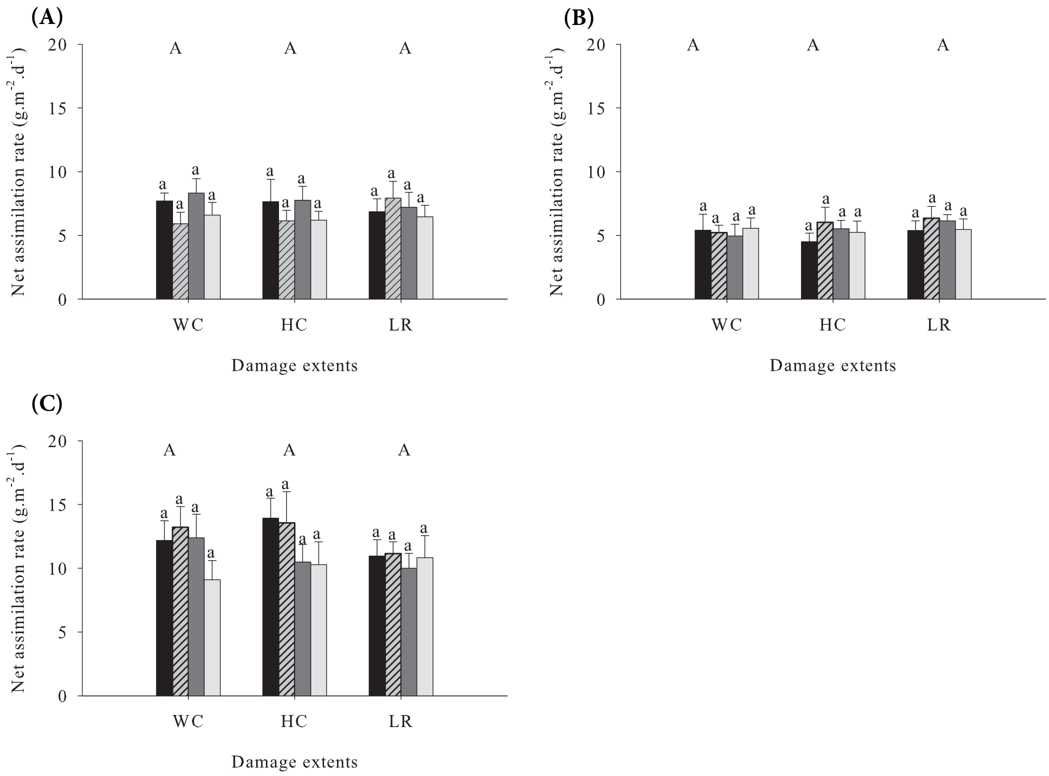

Fig. 3 Net assimilation rates (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

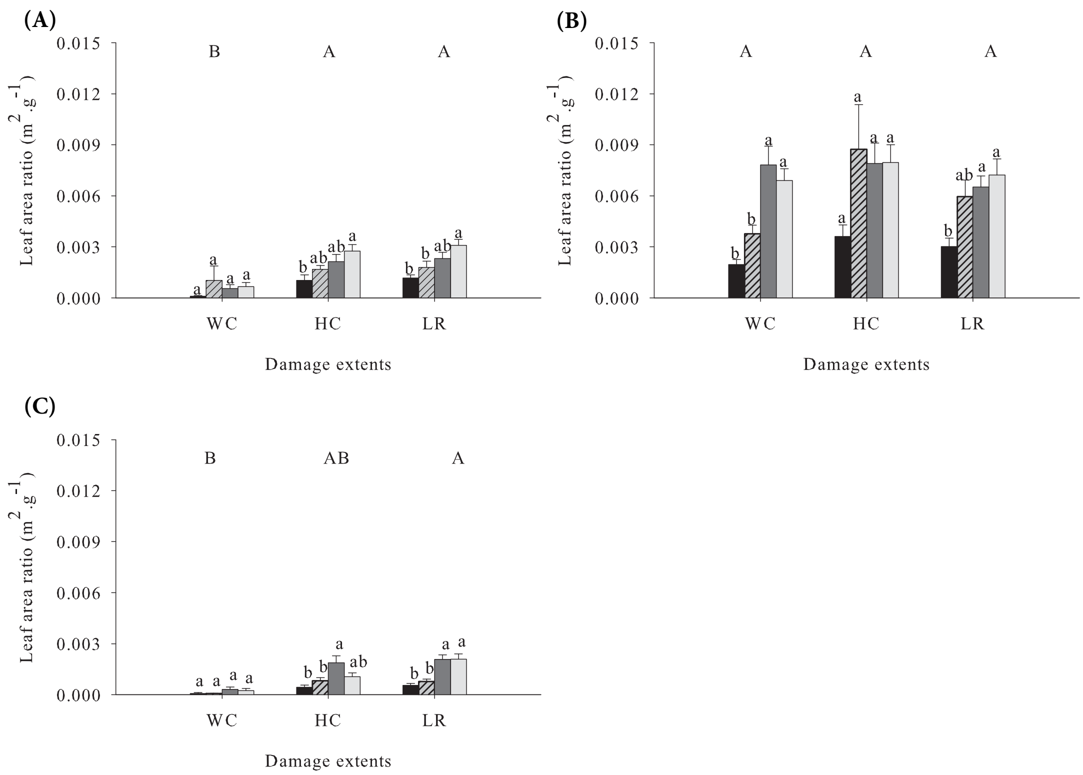

Fig. 4 Leaf area ratios (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

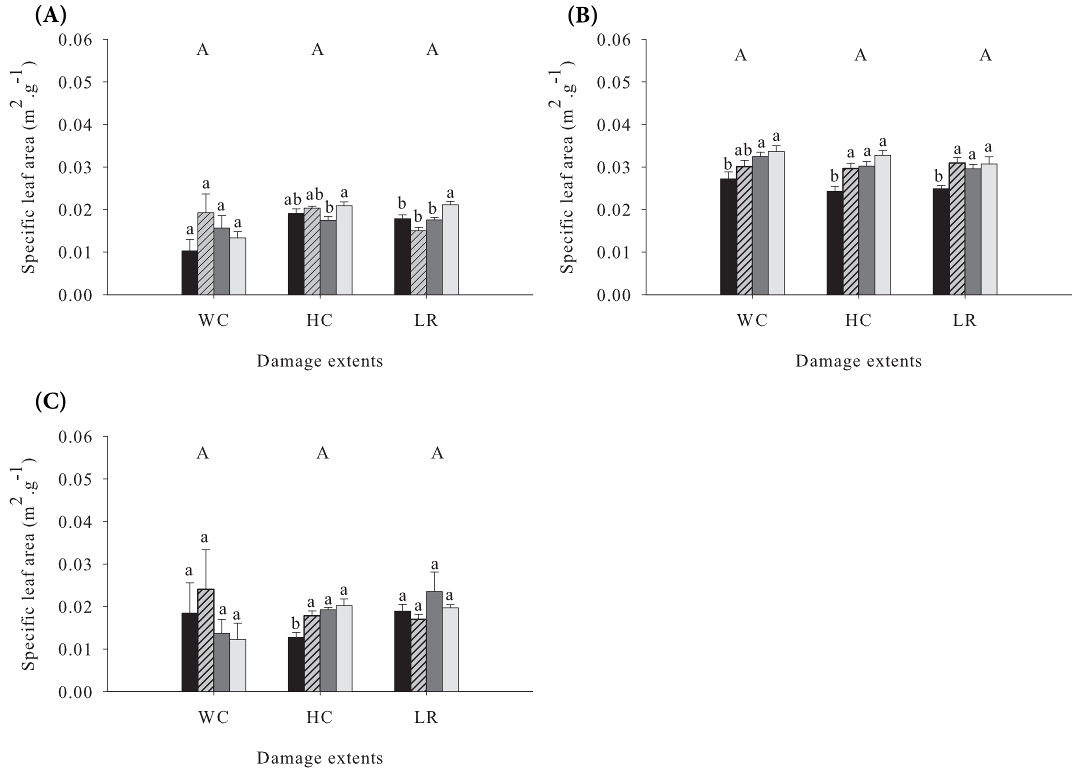

Fig. 5 Specific leaf areas (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

at 10/20°C and 15/25°C, while the total biomass in the LR treatment was highest at 12.5/22.5°C and 17.5/27.5°C. The total biomass was highest at 15/25°C in the WC and HC treatments, while the total biomass was highest at 12.5/22.5°C in the LR treatment. For *M. sativa*, the total biomass was highest in the LR treatment at 10/20°C, 12.5/22.5°C, and 15/25°C; the total biomass was highest at 15/25°C in the HC and LR treatments, while the total biomass was highest at 17.5/27.5°C in the WC treatment. For *A. sphaerocephala*, the total biomass was highest in the HC treatment at the three lower temperatures; the total biomass was highest at 12.5/22.5°C in the WC and HC treatments, while the total biomass was highest at 17.5/27.5°C in the LR treatment (Fig. 6).

Dry matter allocation

The BAMRs of *M. sativa* (0.68–0.94:1 g g^{-1}) were higher than those of the two *Artemisia* species (0.32–0.61:1 g g^{-1}). In the WC treatment, the BAMR (0.34:1 g g^{-1}) was the lowest at 17.5/27.5°C for *A. ordosica*. For *M. sativa*, the BAMRs were lower at higher temperatures (15/25°C and 17.5/27.5°C) than at lower temperatures (10/20°C and 12.5/22.5°C) in each damage extent. For *A. sphaerocephala*, the BAMR (in the WC treatment) tended to increase with increasing temperature, reached the highest value at 12.5/22.5°C and later tended to decline; the BAMR (in the HC and LR treatments) tended to decline with increasing temperature (Fig. 7).

The LMRs for *M. sativa* (0.07–0.26 g g^{-1}) were higher than those for the two *Artemisia* species (0.003–0.15 g g^{-1}) in each damage extent and at each temperature. The LMRs were higher at higher temperatures (15/25°C and 17.5/27.5°C) than at lower temperatures (10/20°C and 12.5/22.5°C) in all damage extents for the three species. For *A. ordosica*, the LMR was the highest in the LR treatment, followed by the HC and WC treatments at all temperatures; the LMRs increased with increasing temperature in the HC and LR treatments. For *M. sativa*, the LMR was highest in the HC treatment at all temperatures. For *A. sphaerocephala*, the LMRs were highest in the HC treatment, followed by the LR and WC treatments at 12.5/22.5°C and 15/25°C, while the LMRs were the highest in the LR treatment followed by the HC and WC treatments at 10/20°C and 17.5/27.5°C (Fig. 8).

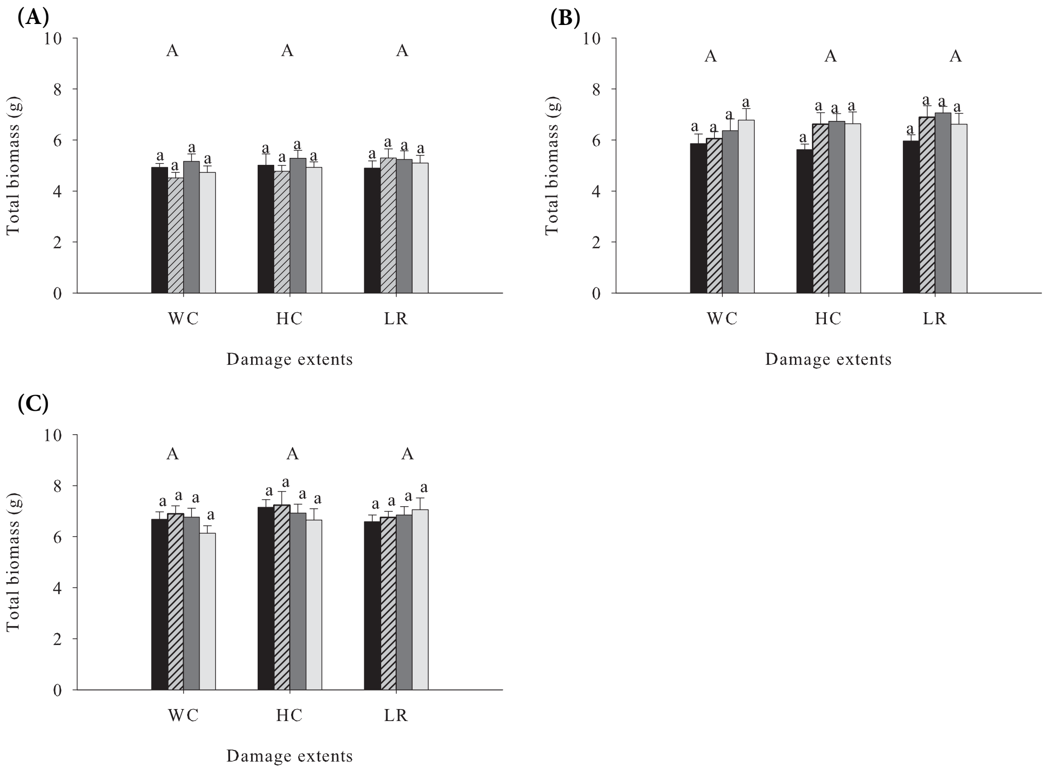

Fig. 6 Total biomasses (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

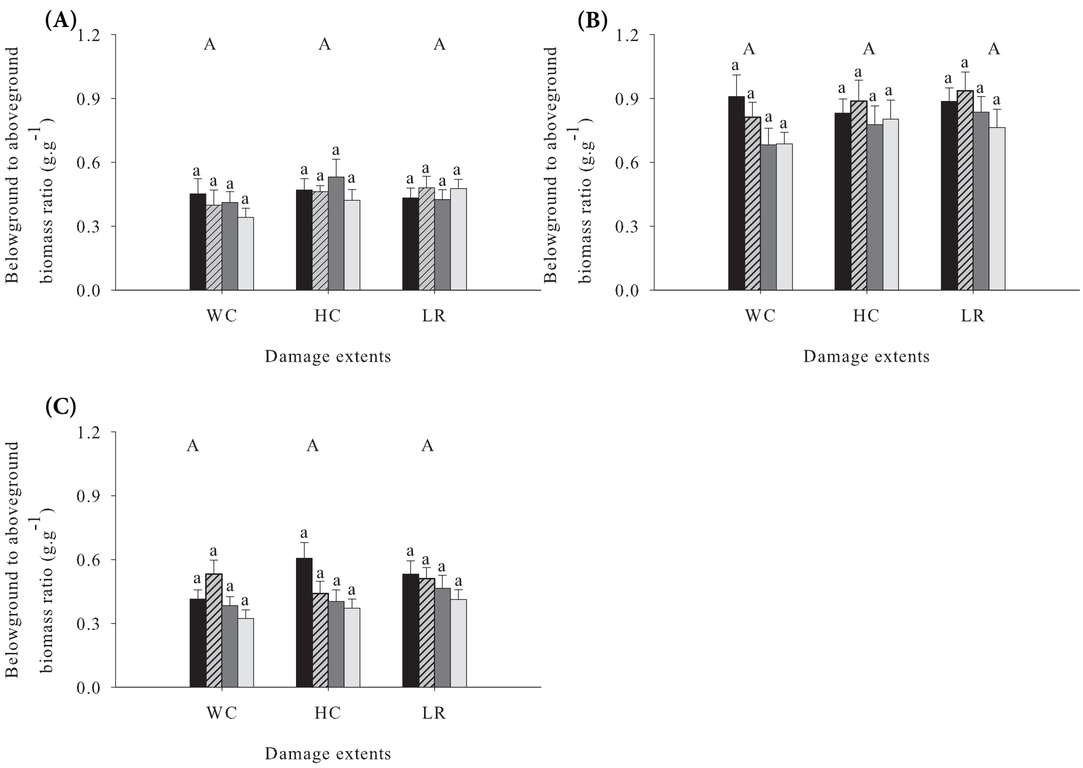

Fig. 7 The ratios of belowground to aboveground dry matter (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

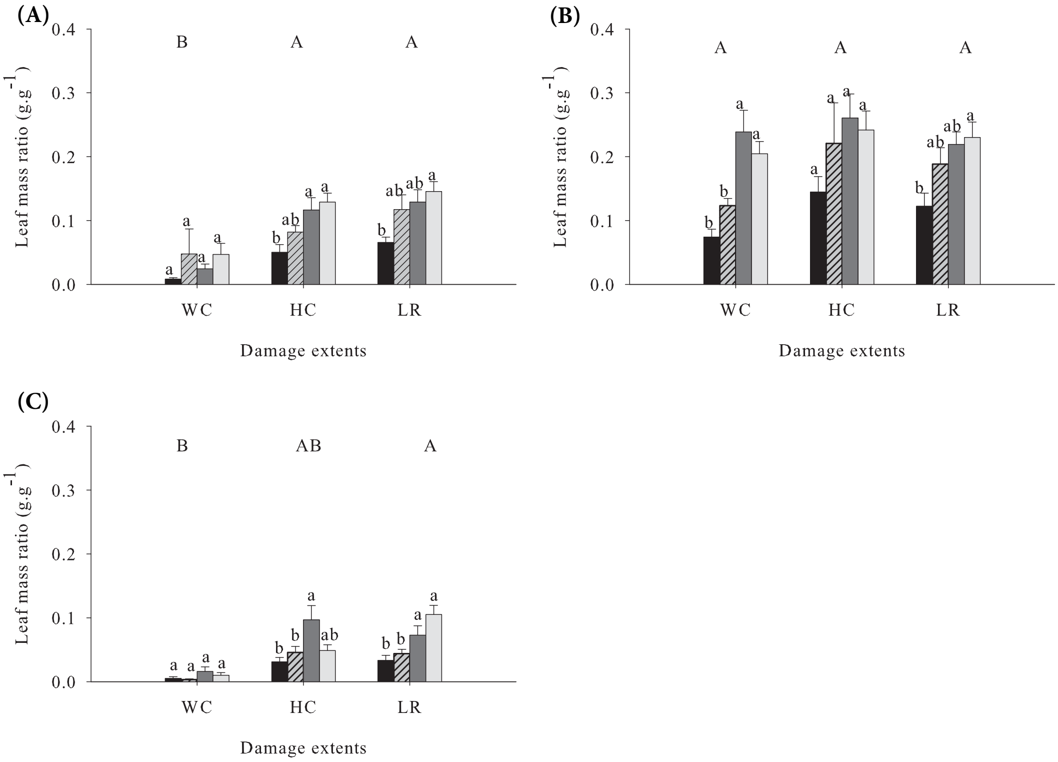

Fig. 8 Leaf mass ratios (±*SE*) of three species. Other descriptions are the same as in Fig. 1.

Discussion

Resprouting of grasses and shrubs

Our studied species inhabit a semiarid ecosystem. Grass-fed sheep are the most intense cause of disturbance, which are not threatening *Artemisia* because of their effective chemical defense. However, no individual died during the experiment, and all individuals had the ability to resprout under different clipping methods and temperatures. In another hypothesis, resprouting is an ancestral trait that is more likely to exist universally, it is affected by the type of ecosystem species inhabits, it does not arise from a specific disturbance regime, and the differences in resprouting ability across different ecosystems are quite limited [28].

In our results, the effects of temperature on resprouting were different among the three species, which belong to different lifeforms, and two of them were in the same genus. The regrowth of *M. sativa* was more sensitive to temperature than the regrowth of the two *Artemisia* semishrubs.

Resprouters usually allocate a large amount of biomass to roots and are thus more tolerant to water stress [29]. However, after aboveground biomass losses, water stress would mitigate due to the elevated root to shoot ratio; however, damaged plants would be more sensitive to water stress than undamaged plants. The storage in roots would be used to form aboveground structures; thus, their nutrient and water absorbing functions would be weakened [30]. Furthermore, biomass allocation is also sensitive to environmental factors [8]. In several studies, species with different resprouting abilities were found to have no significant difference in RGR, and the hypothesis of the trade-off between resprouting ability and RGR might be overly simplistic [31].

Shrubs with high resprouting ability easily inhabit grasslands, and resprouters exhibit improved performance when interacting with grasses [8]. The growth of shrubs was reduced regardless of the resprouting characteristic when competing with grasses, but resprouters were less affected by grasses than nonresprouters [8]. The strong resprouting ability of semishrubs in semiarid ecosystems may be derived from the advantage against grass competitors but may not be directly selected by disturbance.

Resprouting and growth characteristics

Suitable stubble height and cutting frequency are important to sustain the growth of plants [32]. The ability of plants to resprout depends on many factors, including disturbance [33,34], habitat [35,36], and species [1,34]. However, the combined effects of disturbance, habitat and species on resprouting remain unclear.

Shoot removal stimulates plant regrowth [33] due to resprouting, and moderate clipping treatments improve seed production, whereas the most intensive clipping treatments, with the removal of most or all potential flower buds, reduced the reproduction tolerance compared with that in the control [33]. Our results indicated that shoot numbers in the HC and LR treatments were significantly higher than those in the WC treatment for all species (Fig. 1), and the LARs and LMRs in the HC and LR treatments were significantly higher than those in the WC treatment, for all species except *M. sativa* (Fig. 4, Fig. 8).

The RGR and NAR are important values for evaluating the growth of plants. These values represent biomass growth per unit plant biomass (RGR) and biomass growth per unit leaf area (NAR) [26]. The RGR and NAR can increase or decrease with increasing temperature, and these differences depend on species and temperature regimes [21,22]. In our study, the RGR and NAR increased with increasing temperature, reaching their highest values and then declining in most conditions (Fig. 3, Fig. 4). Temperature might be the primary reason for these differences; the temperature was low in the study by Xiong et al. [25], moderate in our study, and high in the study by Zheng et al. [24].

Resprouting and vegetation restoration

The Mu Us Sandland, which is an ecosystem type that covers a majority of the Northern China, is characterized by sand dunes, and vegetation is necessary to fix dunes [12]. Species with higher RGR and NAR values are able to grow quickly and stabilize sand dunes. A high BAMR means more efficient water uptake from the soil and better ability to stabilize the sand dunes [24]. A small leaf area can save water by reducing transpiration, especially in a desert environment where water is limited. High SLA, LMR, and LAR values indicate large leaf areas per unit leaf mass, increased leaf mass per total mass, and large leaf areas per total mass, respectively [26].

The HC and LR treatments significantly increased the number of shoots, LAR, and LMR for the three species in most conditions (Fig. 1, Fig. 4, Fig. 8). To promote the growth of the three species, removing aboveground plant tissue (HC and LR) can be a promising method. However, cutting at half the plant height (HC) can be easier than removing all leaves (LR) because HC requires low labor costs. Thus, HC is the best treatment among the three damage extents to promote the growth of the three species. The shoot number, LMR, and LAR values were higher at higher temperatures (15/25°C and 17.5/27.5°C) than at lower temperatures (10/20°C and 12.5/22.5°C) in most conditions (Fig. 1, Fig. 4, Fig. 8). The temperature of the main growing season from mid-June to mid-August in the Mu Us Sandland ranges from 12.5/22.5°C to 15/25°C [12]. Accordingly, the aboveground plant tissue can be cut before the beginning of the main growing season (end of May or early June). In this case, plants can grow quickly because of the suitable temperature. The shoot number, BAMR, SLA, LAR, and LMR values were highest for *M. sativa*, followed by the two *Artemisia* species in most conditions. Thus, based on these results and the principle of native species priority, the two *Artemisia* species should be used for vegetation restoration in the Mu Us Sandland, and the *M. sativa* could be used as a forecrop or an important species in soil formation and soil improvement in some unimportant conservation areas, such as wastelands, settlements, degraded lands far apart the hotspots of biodiversity, or protected areas.

Conclusions

Suitable disturbance could benefit plant regrowth. This study showed that high temperatures (15/25°C and 17.5/27.5°C) (night/day) and the removal of aboveground plant tissue (HC and LR) resulted in fast regrowth of the three species. Because there were no significant effects of different damage extents on the total biomass, the cutting position should be higher than ground level but lower than half of the plant height for the easy of operation and to ensure increased cutting biomass. Considering the climate in the Mu Us Sandland, it is suggested that plants be clipped before the beginning of the main growing season (end of May or early June) to ensure rapid growth, and the use the two *Artemisia* species will effectively promote vegetation restoration, and the *M. sativa* species can be used for fertilizing or vegetation restoration in unimportant conservation areas in the Mu Us Sandland.

Acknowledgments

The National Institute for Environment Studies supplied all necessary equipment and is deeply appreciated.

Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/asbp/rt/suppFiles/asbp.3612/0:

Tab. S1 Growth parameters of *Artemisia ordosica*, *Medicago sativa*, and *A. sphaerocephala* under different temperatures and different damage extents.

References

1. Bond WJ, Midgley JJ. Ecology of sprouting in woody plants: the persistence niche. Trends Ecol Evol. 2001;16(1):45–51. https://doi.org/10.1016/s0169-5347(00)02033-4
2. Lortie CJ, Aarssen LW. Fitness consequences of branching in *Verbascum thapsus* (Scrophulariaceae). Am J Bot. 2000;87(12):1793–1796. https://doi.org/10.2307/2656831
3. Keeley JE, Pausas JG, Rundel PW, Bond WJ, Bradstock RA. Fire as an evolutionary pressure shaping plant traits. Trends Plant Sci. 2011;16(8):406–411. https://doi.org/10.1016/j.tplants.2011.04.002
4. Canadell J, Lopez-Soria L. Lignotuber reserves support regrowth following clipping of two Mediterranean shrubs. Funct Ecol. 1998;12(1):31–38. https://doi.org/10.1046/j.1365-2435.1998.00154.x
5. Poorter L, Kitajima K, Mercado P, Chubina J, Melgar I, Prins HHT. Resprouting as a persistence strategy of tropical forest trees: relations with carbohydrate storage and shade tolerance. Ecology. 2010;91(9):2613–2627. https://doi.org/10.1890/09-0862.1
6. Zeppel MJB, Harrison SP, Adams HD, Kelley DI, Li G, Tissue DT, et al. Drought and resprouting plants. New Phytol. 2015;206(2):583–589. https://doi.org/10.1111/nph.13205
7. Ramírez DA, Parra A, Resco dDV, Moreno JM. Differences in morpho-physiological leaf traits reflect the response of growth to drought in a seeder but not in a resprouter Mediterranean species. Funct Plant Biol. 2012;39(4):332–341. https://doi.org/10.1071/FP11232
8. Clarke PJ, Knox KJE. Trade-offs in resource allocation that favour resprouting affect the competitive ability of woody plants in grassy communities. J Ecol. 2009;97(6):1374–1382. https://doi.org/10.1111/j.1365-2745.2009.01556.x
9. Pausas JG, Pratt RB, Keeley JE, Jacobsen AL, Ramirez AR, Vilagrosa A, et al. Towards understanding resprouting at the global scale. New Phytol. 2016;209(3):945–954. https://doi.org/10.1111/nph.13644
10. Keeley JE, Bond WJ, Bradstock RA, Pausas JG, Rundel PW. Fire in Mediterranean ecosystems: ecology, evolution and management. Cambridge: Cambridge University Press; 2012.
11. d'Oliveira MVN. Artificial regeneration in gaps and skidding trails after mechanised forest exploitation in Acre, Brazil. For Ecol Manage. 2000;127(1–3):67–76. https://doi.org/10.1016/s0378-1127(99)00117-6
12. Qi, J. Aerial sowing for sand control in China. Beijing: Science Press; 1998.
13. Pelc BD, Montgomery RA, Reich PB. Frequency and timing of stem removal influence

Corylus americana resprout vigor in oak savanna. For Ecol Manage. 2011;261(1):136–142. https://doi.org/10.1016/j.foreco.2010.09.043

14. Kruger EL, Reich PB. Coppicing alters ecophysiology of *Quercus rubra* saplings in Wisconsin forest openings. Physiol Plant. 1993;89(4):741–750. https://doi.org/10.1111/j.1399-3054.1993.tb05280.x
15. Wirthensohn MG, Sedgley M. Effect of pruning on regrowth of cut foliage stems of seventeen *Eucalyptus* species. Aust J Exp Agric. 1998;38(6):631–636. https://doi.org/10.1071/EA98053
16. Matula R, Svatek M, Kurova J, Uradnicek L, Kadavy J, Kneifl M. The sprouting ability of the main tree species in Central European coppices: implications for coppice restoration. Eur J For Res. 2012;131(5):1501–1511. https://doi.org/10.1007/s10342-012-0618-5
17. Zheng W, Li G, Huang Y, Zhang H, Luan Z, Wang P, et al. Compensatory growth responses of plants of *Pharbitis purpurea* (Convulvulaceae) to tissue removal at different seeding depths of seeds. Ecol Res. 2012;27(3):569–576. https://doi.org/10.1007/s11284-011-0922-4
18. VanderKlein DW, Reich PB. The effect of defoliation intensity and history on photosynthesis, growth and carbon reserves of two conifers with contrasting leaf lifespans and growth habits. New Phytol. 1999;144(1):121–132. https://doi.org/10.1046/j.1469-8137.1999.00496.x
19. Haukioja E, Koricheva J. Tolerance to herbivory in woody vs. herbaceous plants. Evol Ecol. 2000;14(4–6):551–562. https://doi.org/10.1023/a:1011091606022
20. Vesk PA, Westoby M. Sprouting ability across diverse disturbances and vegetation types worldwide. J Ecol. 2004;92(2):310–320. https://doi.org/10.1111/j.0022-0477.2004.00871.x
21. Moreira B, Tormo J, Pausas JG. To resprout or not to resprout: factors driving intraspecific variability in resprouting. Oikos. 2012;121(10):1577–1584. https://doi.org/10.1111/j.1600-0706.2011.20258.x
22. Hijioka Y, Lin E, Pereira JJ, Corlett RT, Cui X, Insarov GE, et al. Asia. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, et al., editors. Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Cambridge: Cambridge University Press; 2014. p. 1327–1370.
23. Schwilk DW, Brown TE, Lackey R, Willms J. Post-fire resprouting oaks (genus: *Quercus*) exhibit plasticity in xylem vulnerability to drought. Plant Ecol. 2016;217(6):697–710. https://doi.org/10.1007/s11258-016-0568-y
24. Zheng YR, Rimmington GM, Xie ZX, Zhang L, An P, Zhou GS, et al. Responses to air temperature and soil moisture of growth of four dominant species on sand dunes of central Inner Mongolia. J Plant Res. 2008;121(5):473–482. https://doi.org/10.1007/s10265-008-0172-x
25. Xiong FS, Mueller EC, Day TA. Photosynthetic and respiratory acclimation and growth response of antarctic vascular plants to contrasting temperature regimes. Am J Bot. 2000;87(5):700–710. https://doi.org/10.2307/2656856
26. Poorter L. Growth responses of 15 rainforest tree species to a light gradient: the relative importance of morphological and physiological traits. Funct Ecol. 1999;13(3):396–410. https://doi.org/10.1046/j.1365-2435.1999.00332.x
27. Kabacoff RI. R in action: data analysis and graphics with R. 2nd ed. Beijing: Posts & Telecom Press; 2016.
28. Ickes K, Dewalt SJ, Thomas SC. Resprouting of woody saplings following stem snap by wild pigs in a Malaysian rain forest. J Ecol. 2003;91(2):222–233. https://doi.org/10.1046/j.1365-2745.2003.00767.x
29. Nzunda EF, Griffiths ME, Lawes MJ. Sprouting by remobilization of above-ground resources ensures persistence after disturbance of coastal dune forest trees. Funct Ecol. 2008;22(4):577–582. https://doi.org/10.1111/j.1365-2435.2008.01405.x
30. Pratt RB, Jacobsen AL, Ramirez AR, Helms AM, Traugh CA, Tobin MF, et al. Mortality of resprouting chaparral shrubs after a fire and during a record drought: physiological mechanisms and demographic consequences. Glob Chang Biol. 2014;20(3):893–907. https://doi.org/10.1111/gcb.12477
31. Shibata R, Shibata M, Tanaka H, Iida S, Masaki T, Hatta F, et al. Interspecific variation in the size-dependent resprouting ability of temperate woody species and its adaptive significance. J Ecol. 2014;102(1):209–220. https://doi.org/10.1111/1365-2745.12174
32. Iptas S, Brohi AR. Effect of nitrogen rate and stubble height on dry matter yield, crude

protein content and crude protein yield of a sorghum–sudangrass hybrid *Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf. in the three-cutting system. J Agron Crop Sci. 2003;189(4):227–232. https://doi.org/10.1046/j.1439-037X.2003.00001.x

33. Fang XW, Wang XZ, Li H, Chen K, Wang G. Responses of *Caragana korshinskii* to different aboveground shoot removal: combining defence and tolerance strategies. Ann Bot. 2006;98(1):203–211. https://doi.org/10.1093/aob/mcl088
34. de Figueiroa JM, Pareyn FGC, Araujo EDL, da Silva CE, dos Santos VF, Cutler DF, et al. Effects of cutting regimes in the dry and wet season on survival and sprouting of woody species from the semi-arid caatinga of northeast Brazil. For Ecol Manage. 2006;229(1–3):294–303. https://doi.org/10.1016/j.foreco.2006.04.008
35. Kabeya D, Sakai A, Matsui K, Sakai S. Resprouting ability of *Quercus crispula* plants depends on the vegetation cover of their microhabitats. J Plant Res. 2003;116(3):207–216. https://doi.org/10.1007/s10265-003-0089-3
36. Gracia M, Retana J. Effect of site quality and shading on sprouting patterns of holm oak coppices. For Ecol Manage. 2004;188(1–3):39–49. https://doi.org/10.1016/j.foreco.2003.07.023