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Effects of harvest intensity on the marketable organ yield, growth and reproduction of non-timber forest products (NTFPs): implication for conservation and sustainable utilization of NTFPs

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Abstract

Background: Non-timber forest products (NTFPs) are an important part of forest biodiversity, and the subsistence and trade of local people, especially in less developed countries. Because of the high ecological and economic value, NTFPs have faced the problem of over-exploitation, and the key to solve this problem is to determine the feasible way of sustainable utilization of NTFPs. Harvest intensity is one of the most important and easily controlled utilization factors, which can greatly influence the plant individual survival, growth and reproductive performances, and even the population structure and dynamics. Therefore, we chose two common and important NTFPs species with different marketable parts (i.e., *Acanthopanax senticosus* with tender leaves and *Aralia elata* with tender buds) as our study objects. Aiming to determine the optimum harvest intensity for sustainably utilizing both NTFPs species, five levels of harvest intensity treatments (i.e., control, light, medium, high and severe) were designed to assess the effects of harvest intensity on their marketable organ yield, plant growth and reproductive performances.

Results: The biomass growth rates of marketable organ and plant growth of *A. senticosus* under light harvest intensity treatment were significantly higher than those under other harvest intensities. The plant height growth and 1000-seed weight of *A. elata* under severe harvest intensity treatment were significantly lower than those under control treatment.

Conclusions: The light harvest intensity with 25% leaf removal and the high harvest intensity with all terminal buds harvested are the optimum harvest intensity to maintain the sustainable utilization of *A. senticosus* and *A. elata*, respectively. These findings could provide managers with basic but practical guidance for making decisions about the sustainable harvest management plan for the cultivated NTFPs species, and further provide a theoretical basis for managers to establish the harvest regulations for wild NTFPs species. Consequently, the local residents or communities can improve their income while ensure the sustainable development of wild NTFPs.

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Background

Non-timber forest products (NTFPs) are defined by Global Forest Resources Assessments (FRA) 2020 as "goods derived from forests that are tangible and physical objects of biological origin other than wood" (FAO 2020a). NTFPs are an important part of forest biodiversity and the subsistence and trade of local people (Ros-Tonen 2000). According to FRA 2020, information on NTFPs is reported in 124 countries and territories, which account for 73% of the global forest area and have about 6.2 billion urban and rural people (FAO 2020a). Thus, millions of households around the world depend heavily on NTFPs for livelihoods, and approximately 80% of the people from developing countries takes advantage of NTFPs for health and nutritional needs (FAO 2020b). In addition, the NTFPs also contribute to subsistence needs and cash income of rural and urban residents (Wahlén 2017; Nguyen et al. 2021). Moreover, NTFPs also can be seen as important export commodities, and at least 150 kinds of NTFPs play a significant role in the international trade (FAO 2020b). Thus, the importance of NTFPs for rural and urban residents' livelihood, especially in developing countries, has been widely recognized (Chou 2019).

The history of human beings harvesting valuable NTFPs has been lasting for thousands of years. Harvesting of NTFPs plays an important role for local people in improving cash income and providing subsistence needs in less developed countries (Stanley et al. 2012). Compared with timber harvest, the NTFPs harvest does less damage to forest ecosystems and contributes more to conserve biodiversity and ecosystem function (Gaoue and Ticktin 2008; Hernández-Barrios et al. 2014). Because of the high ecological and economic value, the problem of NTFPs being over-exploited has begun to show up in recent years (Belcher and Schreckenberg 2007). Concerns over the NTFPs overexploitation has led to a growing number of studies on the sustainable utilization of NTFPs (Stanley et al. 2012; Hernández-Barrios et al. 2014; Zhu et al. 2019a).

Generally speaking, sustainable harvest of NTFPs refers to NTFPs harvest in such a way that it is not depleted (Lázaro-Zermeño et al. 2011). At present, few generalized rules on the response of NTFPs to harvest have been summarized due to the widely various harvest effects (e.g., species life forms, harvested parts and harvest intensity) (Schmidt et al. 2011; Rist et al. 2012; Hernández-Barrios et al. 2014). For example, heavy rates of foliage harvest could decrease rates and patterns of reproduction in *Khaya senegalensis* (Meliaceae), but the impact of debarking or combined debarking and pruning on reproductive performance was not significant (Gaoue and Ticktin 2008). *Pentadesma butyracea* Sabine (Clusiaceae) seedling and sapling densities were high in low fruit harvest intensity treatment but very low in high fruit harvest intensity treatment (Avocèvou-Ayisso et al. 2009). All these studies were used to provide guidance for the development of sustainable utilization of local NTFPs. Therefore, Ticktin (2004) has put forward in his review that the NTFPs harvest can directly affect the plant individual survival, growth and reproduction, and further has an impact on the population structure and dynamics. Thus, the reasonable harvest manner is considered as the key to determine the sustainable utilization of NTFPs and preserve the NTFPs store.

According to Hernández-Barrios et al. (2014), the sustainable utilization of target NTFPs can be defined as the harvest intensity at which the marketable organs yield is maximized under the constraint that plant regeneration process of each plot is not significantly affected (i.e., compared with control treatment, the growth and reproductive performances are not significantly reduced). Thus, any problem in the process of plant regeneration may affect the successful regeneration of plant. Many previous studies have focused on the effects of harvest intensity (e.g., harvest frequency and harvest proportion) on the plant regeneration processes (e.g., plant marketable organ yield, survival, growth and reproductive performance) (Endress et al. 2006; Gaoue and Ticktin 2008, Hernández-Barrios et al. 2014) and even population structure (Guedje et al. 2007; Schumann et al. 2011). However, most of them only concentrated on the effect of harvest intensity on a certain process of plant regeneration, and lack of the comprehensive analysis on the impact of the whole process of plant regeneration. This may limit our understanding of the sustainable management of NTFPs.

A wide variety of NTFPs distributes in a montane region of Northeast China. The *Acanthopanax senticosus* (Rupr. Maxim.) Harms and *Aralia elata* (Miq.) Seem., two species of Araliaceae family with different marketable organs, are recognized as two kinds of the common and dominant NTFPs species in this region. The roots, stems and leaves of *A. senticosus* can be used as medicine to treat a variety of diseases (e.g., coronary heart disease, diabetes, and nervous system diseases, etc.) (Zhou et al. 2018). Moreover, the buds and leaves of *A senticosus* are valuable wild vegetables with delicious

taste and high nutritional value, and have been sold in South Korea, Japan and some other countries (Fujikawa et al. 2005). *A. elata* is known as the "king of wild vegetables" in Northeast China. The buds of *A. elata* are rich in nutrition, and its roots, stems, bark and leaves also can be used as medicine to treat various diseases (e.g., neurasthenia and rheumatoid arthritis, etc.) (Hao et al. 2018). Thus, the *A. elata* is the main wild vegetable for earning foreign exchange through export (Sun et al. 2009; Geng et al. 2013). Therefore, we selected these two kinds of edible and medicinal NTFPs species with high economic value as the objects of our study. However, as two important wild resources for both medicine and food use in China, *A. senticosus* and *A. elata* have to face the problems of increasing demand and diminishing storage due to the over-exploitation with disorderly harvest, poor management, and their poor seed regeneration ability (e.g., low seed setting rate, congenital seed dormancy, and low seed germination rate) (Wang and Duanmu 2009; Zhang and Shen 2011). Thus, to improve the marketable organ yield while protecting wild resources, more and more local people and forest managers have tried to develop artificial cultivation and utilization techniques of the two NTFPs species understory (Liu et al. 2011; Hao et al. 2018). At present, the researches on two kinds of NTFPs are mainly focused on cultivation and utilization technology (Luo 2003; Hao et al. 2018), rapid propagation (Han et al. 2008; Qi et al. 2015) and pharmacological action (Zhao et al. 2016). However, few studies have reported the effects of harvest intensity on the complete regeneration processes of wild resources (i.e., including both the subsequent growth and reproduction of NTFPs) (Endress et al. 2006; Hernández-Barrios et al. 2014). Therefore, we took these two Araliaceae species with different harvested parts (leaves and tender buds) to test the influence of harvest intensity (harvest proportion and frequency), and further to find out the optimum harvest intensity to maintain the marketable organ yield and the successful growth and regeneration. We expect that this study can propose practical recommendations (e.g., the optimum harvest intensity) applied in the sustainable utilization and management plan for the Araliaceae species, and further provide supports for the biodiversity conservation by maintaining sustainable utilization of NTFPs worldwide.

Methods
Study area description
The field experiment was conducted in Qingyuan Forest CERN, Chinese Academy of Sciences, located within a montane region in Northeast China (41°50′ N, 124°47′ E, 500–1100 a.s.l.). The climate of study area is temperate continental monsoon type. The mean annual air temperature is 4.7 °C and mean annual precipitation is

810.9 mm, with a rainy summer (80% falls in this season) from June to August (Zhang et al. 2018). The growing season lasts from early April to late October with the frost-free period of 130 days (Lu et al. 2018a; Yan et al. 2019). The soil is a typical brown forest soil, and consists of 25.6% sand, 51.2% silt, and 23.2% clay (Yang et al. 2013).

Secondary forests have become the major forest resources, accounting for 60% and 72% of forest area in the entire world and Northeast China, respectively (Longworth and Williamson 2018; Zhu et al. 2019b). In Northeast China, to meet the high demand for timber production, natural secondary forests have gradually been replaced by plantations (*Larix gmelinii* (Rupr.) Kuzen., *Pinus koraiensis* Sieb. and *Picea koraiensis* Nakai) since the 1950s (Lu et al. 2018b), and the temperate secondary forest ecosystem (i.e., mosaic plantation/ natural secondary forest landscapes) has been established. This study area is covered with the typical temperate secondary forest ecosystem (Lu et al. 2018a). The dominant tree species in the secondary forest include *Fraxinus rhynchophylla* Hance, *Juglans mandshurica* Maxim., *Quercus mongolica* Fisch. and *Acer mono* Maxim. etc. (Lu et al. 2018b). There are abundant wild NTFPs in the secondary forest ecosystem, such as *Pimpinella brachycarpa* (Kom.) Nakai, *Aegopodium alpestre* Ledeb., *A. senticosus*, and *A. elata.* Since 1998, Chinese government has fully implemented the China Natural Forest Protection Project (NFPP) by protecting forests without any management measures and deforestation for natural forests (including primary and secondary forests) (Yu et al. 2011). Local people, who used to make a living by only harvesting timber from the secondary forest ecosystem, must harvest wild NTFPs from forests for livelihood since then. Furthermore, local people also have begun to plant valuable NTFPs (e.g., *P. brachycarp*, *A. senticosus*, *A. elata*, etc.) within larch plantations (*L. gmelinii*) after thinning to raise their revenue, while ensuring the growth of large-diameter timber for larch.

Species description
Both *A. senticosus* and *A. elata* belong to Araliaceae family, and can regenerate from seeds and sprouts. *A. senticosus* is a deciduous perennial shrub species usually occurring in the understory of mixed broadleaf-conifer forests or broadleaf forests, cutting land and forest edge in Northeast China. According to the local standard, the leaves of *A. senticosus* with the length of 3–5 cm are marketable, and the harvest period is lasting from May to August. *A. elata* is a deciduous perennial dungarunga species, mainly distributed in Northeast China. According to the local standard, the tender buds of *A. elata* with the length of 8–15 cm are marketable. The harvest

period of terminal buds is from late April to early May, and the harvest period of lateral buds is in mid-May.

Experiment design

We selected two larch plantation stands with *A. senticosus* (LP1) and *A. elata* (LP2) planted understory, respectively in this study, and the basic information of these two experimental stands were shown in Table 1. A complete randomized design was used in each plantation stand. In April 2017, fifteen 5 m × 5 m plots were established in LP1 and LP2, respectively. Each plot was assigned to one of five harvest intensity treatments (control, light, medium, high and severe). For each species, each harvest intensity treatment had three replicates. The sketch map of study site and experimental design was shown in Fig. 1.

The *A. senticosus* in LP1 was planted in 2010 with the planting density of 7000 clumps·ha^{-1}, and present density was 6500 clumps·ha^{-1} (1–3 individuals/clump). With the management measure of *A. senticosus*, only the tender leaves on the telome were harvested in spring every year, and the interval of fruit harvest was 1–2 years. We defined five harvest intensity treatments of *A. senticosus* in each plot as follows: 1) the control treatment with 0% leaf removal; 2) the light harvest intensity treatment with 25% leaf removal; 3) the medium harvest intensity treatment with 50% leaf removal; 4) the high harvest intensity treatment with 75% leaf removal; 5) the severe harvest intensity treatment with 100% leaf removal (Hernández-Barrios et al. 2014).

The *A. elata* in LP2 was planted in 2003 with the planting density of 6000 individuals·ha^{-1}. The management of *A. elata* was that only tender bud harvest was conducted during the harvest period. In this study, the harvest interval between terminal buds and lateral buds was 10 days. According to the growth characteristics of *A. elata* (i.e., terminal buds and lateral buds), we defined

five harvest intensity treatments in each plot as follows: 1) the control treatment with no tender buds harvested; 2) the light harvest intensity treatment with only 50% terminal buds harvested; 3) the medium harvest intensity treatment with 50% terminal buds and 50% lateral buds harvested; 4) the high harvest intensity treatment with only 100% terminal buds harvested; 5) the severe harvest intensity treatment with 100% terminal buds and 100% lateral buds harvested.

Measurement of marketable organs

The initial mean height and basal diameter (in April 2017) of *A. senticosus* and *A. elata* were 128 and 1.51 cm, and 126.50 and 1.70 cm, respectively. The tender leaves of *A. senticosus* and buds of *A. elata* were harvested in each plot according to the harvest intensity treatments in May 2017 and 2018, respectively. The samples were transported to laboratory, and then were dried at 65 °C for at least 72 h until a constant weight was achieved. The biomass of *A. senticosus* tender leaves per unit area was calculated as the dry mass of tender leaves in each plot divided by each plot area. The biomass of *A. elata* tender buds per plant was calculated as the dry mass of buds in each plot divided by the number of *A. elata* in each plot. Biomass growth rate (BGR) of tender leaves or buds was calculated as follows:
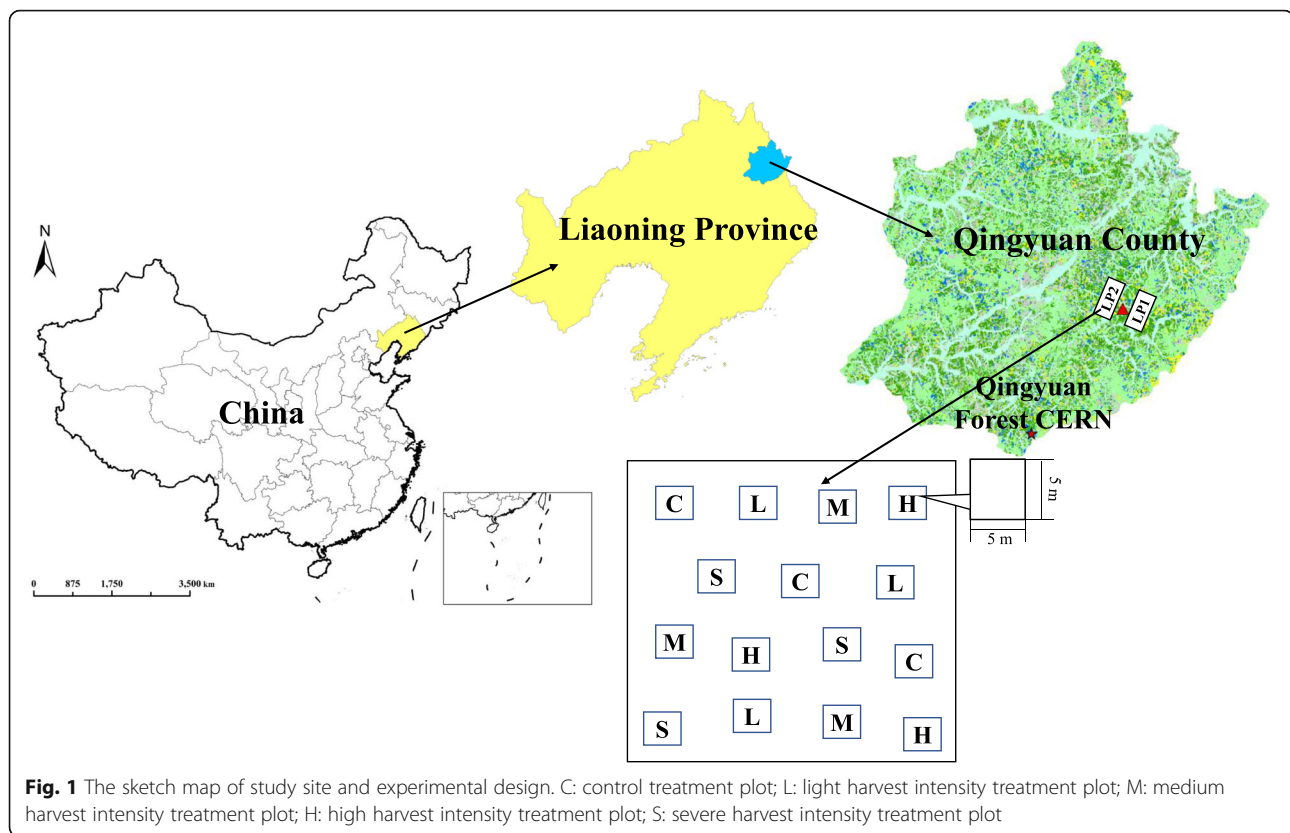
$$\mathrm{BGR}(\%) = \frac{B_2 - B_1}{B_1} \times 100\% \qquad (1)$$

where B_1 and B_2 are the biomass of *A. senticosus* tender leaves per unit area or the biomass of *A. elata* tender buds per plant in 2017 and 2018, respectively.

All individuals in these plots were labeled for the following measurements.

Table 1 Basic information of two experimental stands of larch plantations. DBH: diameter at breast height. LP1: Larch plantation with *Acanthopanax senticosus* planted understory; LP2: Larch plantation with *Aralia elata* planted understory

Characteristics	LP1	LP2
Forest type	Larch plantation	Larch plantation
Slope (°)	15–20	10–25
Stand age (year)	48	49
Stand density (per ha)	150	250
Canopy density (%)	50	50
Mean height (m)	22.4	22.4
Mean DBH (cm)	39	35
Species planted understory	*Acanthopanax senticosus*	*Aralia elata*
The total number of plots	15 (3 replicates of each harvest intensity)	
Measurement cycle for each harvest intensity treatment	Two cycles for harvest and growth One cycle for reproduction	

Fig. 1 The sketch map of study site and experimental design. C: control treatment plot; L: light harvest intensity treatment plot; M: medium harvest intensity treatment plot; H: high harvest intensity treatment plot; S: severe harvest intensity treatment plot

Growth measurement

In October 2017 and 2018, we measured the height and basal diameter of each individual plant of *A. senticosus* or *A. elata* in each plot. The height growth (HG) and basal diameter growth (BDG) were calculated as follows:

$$HG~(cm) = H_2 - H_1 \qquad (2)$$

$$BDG~(cm) = D_2 - D_1 \qquad (3)$$

where H_1 and D_1 are the height and basal diameter of individual plant in 2017; H_2 and D_2 are the height and basal diameter of individual plant in 2018.

The measurements of each plant within the same plot were averaged to represent the status of mean height growth and basal diameter growth.

Reproduction measurement

In June 2018, we distinguished the sprouts and seedlings in each plot after experiment treatment conducted, and then counted and recorded the number of sprouts and seedlings in each plot, respectively. This survey was conducted only once in June 2018. Sprouts regenerated from plant root and grew rapidly, with a height ranging from 10 to 80 cm. Compared with the sprouts, the growth of the seedlings from seeds was slower, with a height ranging from 5 to 30 cm. And then, in October 2018, we harvested the fruits of two species. All the

harvested fruits were transported to laboratory, and then soaked in water and scrubbed off the pericarp and pulp (Tian et al. 1999). The processed fruits were naturally dried. 1000 seeds were randomly selected and weighed. The 1000-seed weight data of each plant within the same plot were averaged to represent the 1000-seed weight of each plot.

Data analysis

A one-way analysis of variance (one-way ANOVA) was used to test the effect of harvest intensity treatment on biomass growth rate, height growth, basal diameter growth, number of sprouts and seedlings, and 1000-seed weight for *A. senticosus* and *A. elata*. Tukey's post hoc tests were used to examine the differences among the harvest intensity treatment levels. All of the statistical tests were performed using R version 3.5.3, and significance was examined at the level $P < 0.05$. For each variable in the same plot, the average values (±S.E.) for each species were presented in the figures and tables.

Results

Biomass growth rate of marketable organs

The biomass growth rate (BGR) of *A. senticosus* tender leaves was significantly affected by the harvest intensity ($P = 0.003$), but the BGR of *A. elata* buds was independent of the harvest intensity ($P = 0.212$) (Table 2). The

Table 2 One-way ANOVA test for the effects of harvest intensity on the biomass growth rate of marketable organs, height growth, basal diameter growth, the number of sprouts and seed weight of *Acanthopanax senticosus* and *Aralia elata*. Significant effects ($P < 0.05$) are bolded

Parameters	df	*Acanthopanax senticosus*		*Aralia elata*	
		F	P	F	P
Biomass growth rate	3	11.520	**0.003**	1.878	0.212
Height growth	4	21.260	**< 0.001**	3.939	**0.036**
Basal diameter growth	4	127.300	**< 0.001**	2.016	0.168
Number of sprouts	4	2.571	0.103	3.016	0.071
Seed weight	4	0.863	0.518	3.685	**0.043**

BGR of *A. senticosus* tender leaves was significantly promoted by the light harvest treatment (BGR = 163.33% ± 21.18%), but greatly decreased with the increase of harvesting intensity (Fig. 2).

Plant growth

The harvest intensity significantly affected the height growth (HG) ($P < 0.001$) and basal diameter growth (BDG) ($P < 0.001$) of *A. senticosus* (Table 2). Both HG and BDG of *A. senticosus* showed significantly decreased with the increase of harvest intensity (Fig. 3). Compared with control treatment, the height growth under light, medium, high and severe harvest intensities decreased 10.85%, 18.06%, 23.32% and 31.30%, respectively; and the basal diameter growth under light, medium, high and severe harvest intensities decreased 9.76%, 26.83%, 39.02% and 48.78%, respectively (Fig. 3). The HG of *A. elata* was significantly affected by the harvest intensity ($P = 0.036$), but the BDG showed no significant

difference among five harvest intensity treatments ($P = 0.168$) (Table 2). The HG of *A. elata* in the control treatment was significantly higher than that in the severe harvest intensity treatment (Fig. 3a).

Plant reproduction

No seedlings regenerated from seeds were found during the investigation after harvest treatments. Thus, only the results of sprouts were shown in this part. The number of sprouts ($P = 0.103$) and the 1000-seed weight ($P = 0.518$) of *A. senticosus*, and the number of *A. elata* sprouts ($P = 0.071$) showed no significant difference among five harvest intensity treatments (Table 2, Fig. 4). Only the 1000-seed weight of *A. elata* was significantly affected by the harvest intensity ($P = 0.043$) (Table 2), and the 1000-seed weight of *A. elata* in the control treatment was significantly higher than that in the severe harvest intensity treatment (Fig. 4b).

Discussion

A. senticosus tender leaves and *A. elata* tender buds are well-known as two of the wild vegetables with high marketability, and are harvested heavily by local people in the montane region of Northeast China. Our results showed that the response of marketable organ yield, plant growth and reproduction of these two species with different harvested parts to harvest intensity varied significantly. These findings illustrated that although the *A. senticosus* and *A. elata* belong to the same family (i.e., Araliaceae), the different harvested parts also led to different responses of plant characteristics to harvest intensity. Based on the summary of many previous studies, the review of Ticktin (2004) has also reported that the
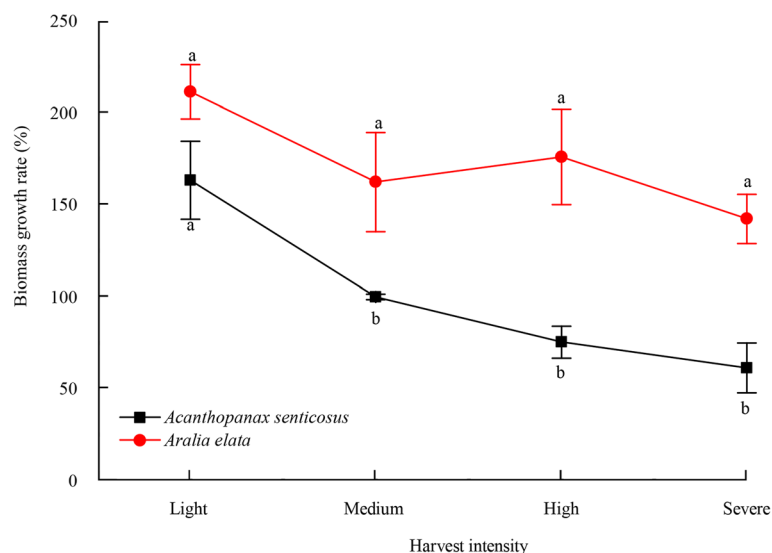

Fig. 2 Biomass growth rate of *Acanthopanax senticosus* tender leaves and *Aralia elata* buds in different harvest intensities. The data are presented as the mean ± S.E.. Different lowercases indicate significant differences ($P < 0.05$) among harvest intensities for the same species

Fig. 3 The height growth (**a**) and basal diameter growth (**b**) of *Acanthopanax senticosus* and *Aralia elata* in different harvest intensities. The data are presented as the mean ± S.E.. Different lowercases indicate significant differences ($P < 0.05$) among harvest intensities for the same species
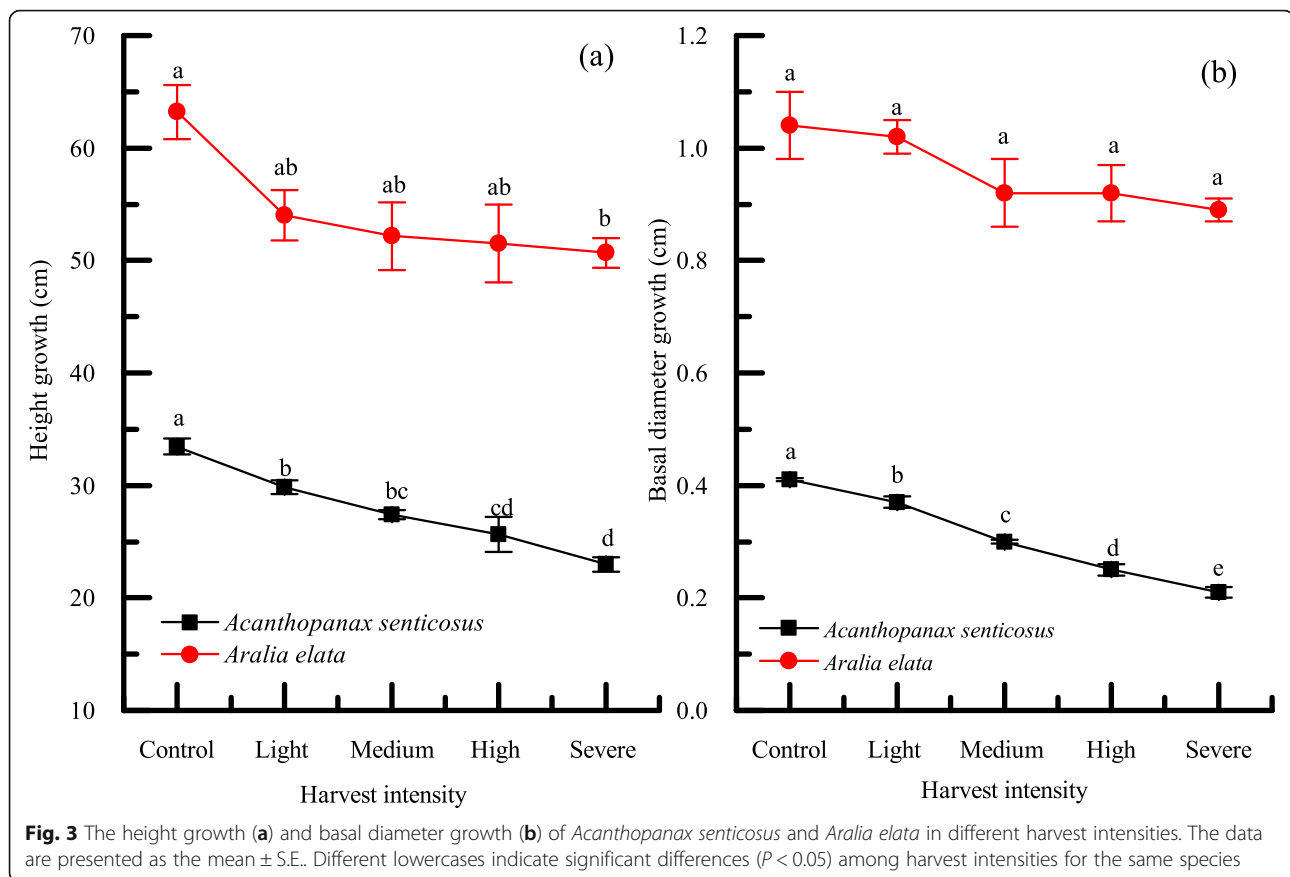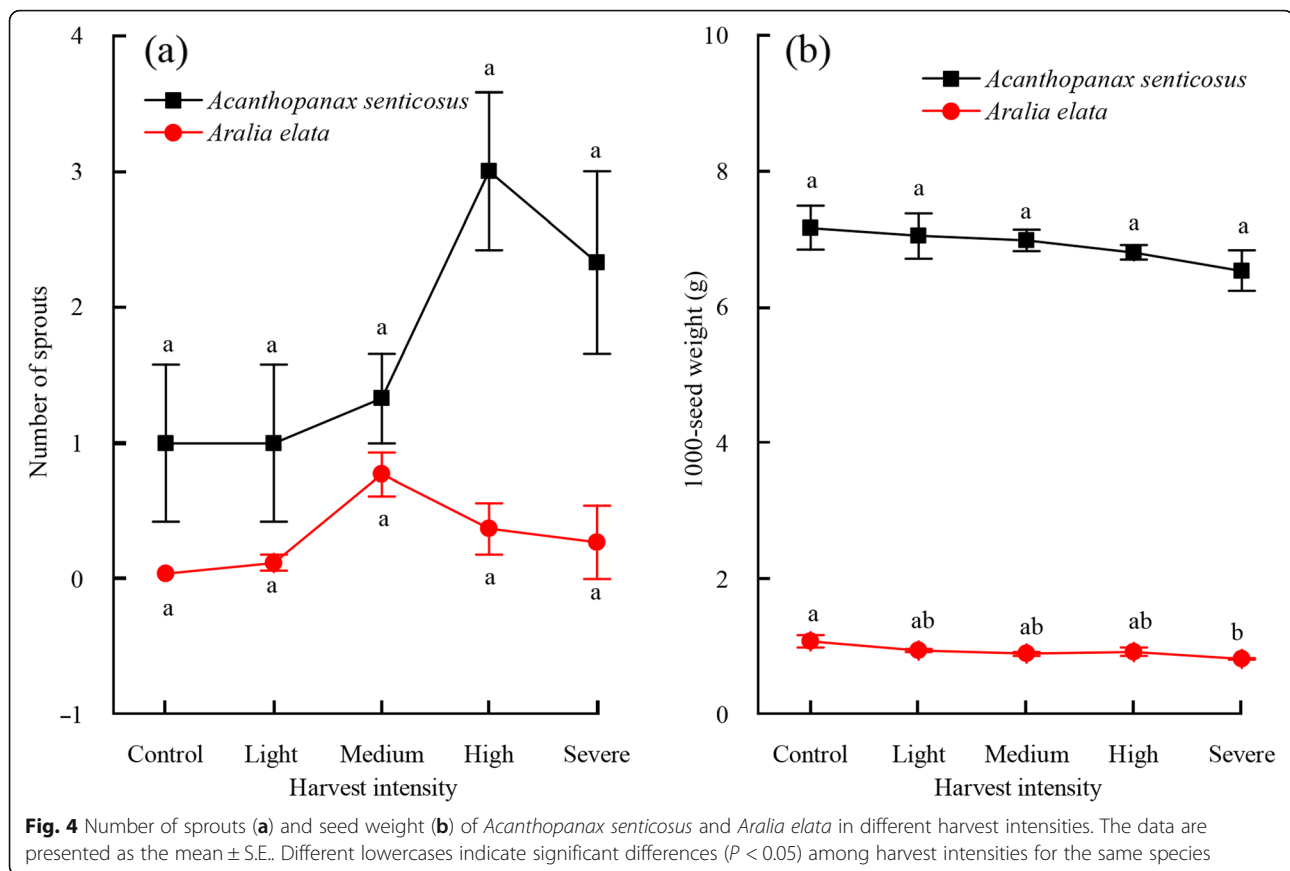
impact of harvest intensity would change with the various harvested parts. Thus, the influence of harvest intensity on plant characteristics should be discussed by specific species.

In this research, harvest activities can lead to the increase of marketable organs yield of both the two Araliaceae species (all BGRs > 0). However, compared with the harvest of *A. elata* tender buds, the effect of harvest intensity on BGR of *A. senticosus* tender leaves is more significant. This may be because leaves are important organs for plant photosynthesis, and the harvest of leaves can directly affect the plant photosynthetic capacity and further affect leaf production, plant growth and reproductive performance (Ticktin 2004; Lázaro-Zermeño et al. 2011; Hernández-Barrios et al. 2014). Our results illustrate that the light harvest intensity (25% of all tender leaves removed) was most beneficial to the promotion of *A. senticosus* marketable organ yield, but the promotion showed significantly decrease when the harvest intensity was greater than 25% of all tender leaves. Hernández-Barrios et al. (2014) had explored the sustainability of palm leaves harvesting, and found the palms tolerated up to 50% leaves harvesting, but higher harvest levels could reduce the leaf production. Our results are partly consistent with theirs because of the

interspecies difference. The effect of tender bud harvest on the plant growth and reproduction of NTFPs have hardly been studied so far. We harvested the tender buds of *A. elata* with different intensities, but finally found that there was no significant effect of harvest intensity on the tender bud biomass growth of *A. elata*. This suggests that compared with foliage harvest, bud harvest shows slight influence on the marketable organ growth in subsequent year.

Both horizontal and vertical growth of *A. senticosus* had significant responses to various harvest intensities, and showed a dramatically trend of decreasing with the increase of harvest intensity. These effects may be because the removal of more leaves can decrease photosynthetic capacity of *A. senticosus*, and further decrease its growth (Endress et al. 2006). Compared with no harvest treatment, the *A. senticosus* plants tolerated up to 25% tender leaf removal (light harvest intensity) showed a slightest effect on the plant growth among all four harvest intensity levels. The tender buds of *A. elata* are the parts which plant uses for the subsequent height growth in the growing season (Jonsson 2006), and harvesting of terminal buds can stimulate the generation and growth of lateral buds. Therefore, the effect of harvest intensity on the growth of *A. elata* is not so significant as that on

Fig. 4 Number of sprouts (**a**) and seed weight (**b**) of *Acanthopanax senticosus* and *Aralia elata* in different harvest intensities. The data are presented as the mean ± S.E.. Different lowercases indicate significant differences ($P < 0.05$) among harvest intensities for the same species

the growth of *A. senticosus*. The height growth of *A. elata* under severe harvest intensity treatment (100% terminal buds and 100% lateral buds per plot harvested) was significantly lower than that under no harvest treatment. This fact suggests that harvesting of all tender buds can lead to poor plant growth. The study on the short *A. elata* in the poor condition also has reported the similar result that the increase of harvest intensity could severely weaken the tree vigor and lead to poor plant growth (Geng et al. 2013). Therefore, to maintain the *A. elata* growth while maximizing marketable organ yield (i.e., tender bud yield), the severe harvest intensity with all terminal and lateral tender bud removal should be avoided in the early spring. Moreover, our results also indicated that harvest intensity was more easily to affect the subsequent growth of plant with tender leaves as marketable organs than those with buds as marketable organs.

There has not reached a consensus in the existing studies for the harvest intensity effects of marketable organs on plant productive performance. In present study, the number of sprouts and seed weight of *A. senticosus* and the number of sprouts of *A. elata* were not affected by harvest intensity, but the seed weight of *A. elata* only under the severe harvest intensity treatment was

significantly lower than that under the no harvest treatment. Thus, the severe harvest intensity was not conducive to *A. elata* reproduction. Taking both market value of terminal buds and lateral buds and influence of harvest intensity on the growth and reproduction into consideration, the high harvest intensity with all terminal bud removal and all lateral buds reserve was the optimum harvest intensity for *A. elata* to maintain plant growth while maximizing bud yield. Previous researches also have studied on the effect of marketable organ harvest on the plant reproduction, and results such as the heavy rates of leaves harvest could decrease rates and patterns of reproduction in *Khaya senegalensis* (Gaoue and Ticktin 2008), leaf-harvesting had a significant impact on the fruit production of *Adansonia digitata* L. (Schumann et al. 2011) and could reduce the growth and reproductive activity of *Chamaedorea radicalis* (Endress et al. 2006), and the sprouting ability of *Anogeissus leiocarpa* significantly increased with higher chopping intensity (Schumann et al. 2011) have been reported. Our results were only partly consistent with these previous studies, this may be due to the interspecies difference and observation interval. The effects of NTFPs harvest in our study are only assessed over 2 years, but the cumulative effects of harvest over

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sufficiently long time are also necessary to assess the effect of harvest on the plant production (Hernández-Barrios et al. 2014).

Conclusions

The sustainable utilization of target NTFPs in our study are considered as the harvest intensity at which the yield/biomass of marketable organs is maximized under the constraint that growth and reproduction of each plot are not significantly reduced (compared with control treatment). According to this definition, we found that the light level of leaf harvesting (25% leaf removal) for *A. senticosus* and the high level of tender bud harvesting (only 100% terminal buds per plots removal) for *A. elata* are the optimum harvest intensity to maintain the sustainable utilization, respectively. Our results can provide NTFPs managers with basic but practical guidance for making decisions about the sustainable harvest management plan for the cultivated NTFPs species. Furthermore, these findings can also play an important role in the harvest intensity management of these two wild NTFPs species. Local harvesting of the two wild NTFPs is usually disorderly and unregulated, but this harvesting pattern will lead to over-exploitation of NTFPs. Our findings on the optimum harvest intensity of these two NTFPs can provide a theoretical basis for managers to establish the harvest regulations for wild NTFPs species. The managers can supervise the harvesting of wild NTFPs by local communities or residents based on harvest regulations, so that the local residents or communities can improve their income while ensure the sustainable development of wild NTFPs. However, our study only conducted in consecutive 2 years, the sufficiently long-time study should be conducted in the future to assess the long-term effect of harvest on the sustainable utilization of especially the plant production. Moreover, in the further study, a comprehensive perspective in the ecological, economic, social and political analysis for designing sustainable NTFPs harvesting regimes is needed to provide more scientific basis for the biodiversity conservation and development of management regulations for reasonable sustainable utilization of NTFPs.

Abbreviations

NTFPs: Non-timber forest products; BGR: Biomass growth rate; HG: Height growth; BDG: Basal diameter growth

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Authors' contributions

LZY conceived the ideas and designed the study. YM conducted the field experiments. TZ analyzed the data and led the writing of the first draft of the manuscript. QLY and LZY contributed to revising the manuscript. All authors contributed to the drafts and gave final approval for publication.

Availability of data and materials

Please contact the author for data requests.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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