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Ramp (*Allium tricoccum* Ait.) weight differs across the harvest season: implications for wild plant stewardship and forest farming

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Abstract A ramp or wild leek (*Allium tricoccum* Ait.) is a perennial forest plant indigenous to midwestern and eastern North America. Throughout this range, ramps are a popular non-timber forest product collected for edible bulbs and leaves. Regarded as a cultural keystone Appalachian wild food in the United States, demand has increased in recent years outside of this region resulting in the development of commercial collection and forest farming. Accordingly, there is a need to identify harvest and stewardship practices that can lessen harvest impacts on wild populations and improve forest farm production. One important component of ramp production is harvest timing, which typically occurs between March 1 and May 30. This study examined the influence of harvest timing on yields, using seven recognizable phenological stages. Total ramp and bulb weight increased 250% and 400%, respectively, between early season and late season stages. This trend was observed regardless of leaf number; three-leaved ramps were significantly larger than two-leaved ramps at each phenological stage. Based on these results, two ways to promote ramp conservation are to delay ramp harvests until ~ 30 days after emergence in the spring to ensure that the late season stage has been attained and to restrict harvesting to three-leaved plants. Because ramps are mostly sold by weight, both actions will lessen harvest impacts by significantly reducing the number of individual plants being removed from a population to achieve a desired weight. However, this must be balanced against the greater contribution of three-leaf plants to seed and clone production.

Keywords Agroforestry · Non-timber forest products · Ramps · Wild leeks · Wild plant stewardship

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Introduction

Ramps or wild leeks (*Allium tricoccum* Ait., Alliaceae) are a slow growing, perennial plant indigenous to forestlands in the Appalachian and Great Lakes regions of the United States and Canada (Weakley 2022). Ramps have been an important North American wild food item for First Nations people and among European settler descendant communities (Baumflek and Chamberlain 2019; Moerman 1998). The species has been referred to as an Appalachian cultural keystone species (Baumflek and Chamberlain; Rivers et al. 2014) owing to the important role it plays in the spring diet and tradition in rural communities. In recent decades, increasing consumer demand for ramps outside of the rural areas has been observed (Baumflek and Chamberlain 2019; Pugh 2022). Ramps can now be found on the menus of urban upscale restaurants (Burkhart, pers. obs.; Pugh 2022) and in grocery stores and farmers markets in the eastern United States with prices averaging $24.00–26.00 per kilogram paid to harvesters (Pugh 2022).

Wild ramp populations are increasingly sought after by food enthusiasts and commercial harvesters, which can have negative consequences for local populations. Matrix modeling suggests that sexual reproduction contributes minimally to the population growth rate and that asexual reproduction via bulb division is the primary mode of population maintenance (Nault and Gagnon 1993). Larger genets and flowering plants are most likely to undergo bulb division forming two or three ramets, a process that can take five to eight years (Nault and Gagnon 1993). Models estimate maximum sustainable harvests range from 8 to 0% of the population annually (Nault and Gagnon 1993; Nantel et al. 1996) to 10% of the population once per decade (Rock et al. 2004). Some have recommended leaf-only harvests to help address conservation concerns (Dion et al. 2016; UPS 2022).

Declines in wild populations due to overharvesting have been reported at both ends of the natural range (Nantel et al. 1996; Rock et al. 2004). The cultivation of ramps is an alternative to collection from wild populations, and in situ cultivation using agroforestry is especially attractive (Bernatchez et al. 2013; Chamberlain et al. 2014; Davis and Persons 2014). The agroforestry practice of forest-based cultivation, or forest farming as it is called in the United States (NAC 2022), involves two general approaches: the first, "woods-cultivated," is more intensive using tillage and/or raised beds; while the second, "wild-simulated," attempts to replicate wild conditions with minimal site preparation (Burkhart 2009; Davis and Persons 2014; NAC 2022). Forest farming approaches may not be clearly categorized, however, since some forest farmers manage existing wild populations as crops or establish "wild" populations using non-local or commercial stock (Burkhart et al. 2021; Pugh 2022).

Whether wild harvested or forest farmed, ramp harvesting begins at emergence during the spring harvest season, and plants may be referred to as "sprouts" at this stage (Burkhart, pers. obs., Pugh 2022). Ramp bulbs can also be gathered during the dormant stage outside of the spring harvest season (Cool 2013; Facemire 2010; Pugh 2022). Significantly, it has been observed that ramp bulbs change in both size and shape over the spring harvest season as nutrients are allocated to the bulb (Facemire 2010; Nault and Gagnon 1988). Although there is a variety of ramp stages collected, the economic significance and conservation impact of harvest timing has not been examined. Accordingly, this study asked the following questions:

1. How does harvest timing (phenology) impact harvest weight and thus the number of plants removed from a population or forest farm?
2. How does leaf number impact harvest weight, and thus the number of plants removed from a population or forest farm?

Materials and methods

Study location

Sampling was conducted at three sites located in Cambria County, Pennsylvania (Fig. 1). Population 1 was on private property and located on a sloped forest bench with a seasonal run-off stream. Populations 2 and 3 were located on public lands on upland ridgetops along moisture seeps. All populations originated as wild (i.e., spontaneously occurring) but one was managed for ~ 10 years as a forest farm. The forest farmer at this site followed a "wild-simulated" approach (Davis and Persons 2014) with

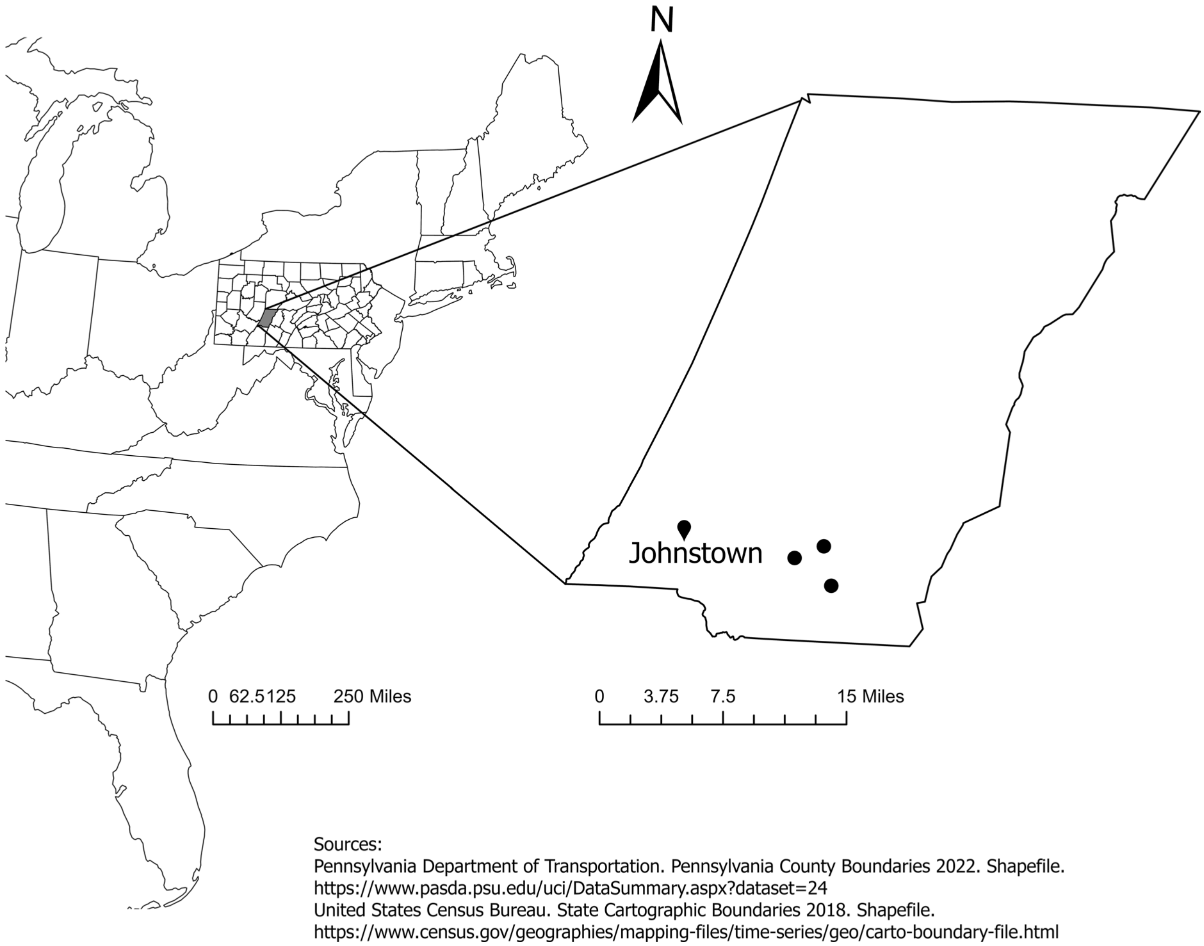

Fig. 1 Sample locations for ramps (*A. tricoccum*) included in this study. Three populations were sampled on forestlands located east of Johnstown in Cambria County, Pennsylvania

no site improvements or manipulation. Production practices were limited to propagation and thinning of populations.

All locations are within the Allegheny Mountain Section of the Appalachian Plateaus physiographic province with an elevation of 609–640 m and 105 cm average annual precipitation. Associated soils were silty loam textured, slightly acidic (pH 4.6–6.1 ($\bar{x}=5.2$)), and mostly low in macronutrients: (phosphorous 5–13 ($\bar{x}=9$) ppm; potassium 58–186 (x = 99) ppm; magnesium 48–239 ($\bar{x}=127$) ppm; calcium 404–3196 ($\bar{x}=1115$) ppm). Sites were forested with sugar maple (*Acer saccharum* Marshall) as the dominant canopy overstory species. Occasional stems of American beech (*Fagus grandifolia* Ehrh.), black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), hickory (*Carya cordiformis* (Wang.) K. Koch, *C. ovata* (Mill.) K. Koch), and elm (*Ulmus americana* L., *U. rubra* Muhl.) were interspersed. Common herbaceous flora found within plots across all sites included Jack-in-the-pulpit (*Arisaema triphyllum* (L.) Schott), blue cohosh (*Caulophyllum thalictroides* (L.) Michx.), yellow trout-lily (*Erythronium americanum* Ker Gawl.), mayapple (*Podophyllum peltatum* L.), hairy Solomon's-seal (*Polygonatum pubescens* (Willd.) Pursh), and toothwort (*Cardamine concatenata* ((Michx.) Sw.), *C. diphylla* (Michx.) Wood).

Sampling methods and identification of stages

At each field site, sampling occurred using four rectangular plots (7.3 m × 3.7 m) placed within populations in a stratified random approach to capture any size/weight differences resulting from micro-site conditions. Entire plants were carefully excavated with hand tools and soil was removed to avoid damaging plant tissue and prevent moisture loss, which would influence final weight. Since ramps are clonal, only plants not actively in the process of bulb division were sampled. When sampling, we targeted plants using above ground leaf number to determine whether the specimen was a single plant and selected individual plants not in proximity to adjacent plants to minimize any weight differences due to plants being recent clonal offsets.

Ramp phenology can be divided into seven stages annually using field traits (Jordan 2020). Ramps have an unusual phenology in which plants emerge from perennial bulbs in early spring before the forest canopy leaf-out occurs and photosynthesize for approximately 12 weeks (~84 days) before leaves senesce. Concurrent with leaf senescence, a scape will emerge on reproductive plants and continue to develop through mid-summer when it will bear an umbel inflorescence. Fruit and seeds mature in late summer and fall and persist on an otherwise leafless stem.

Samples were harvested at these seven visible phenological stages over an eight-month period (Fig. 2). Sampling was initiated in early spring (April 14) as plants began to emerge from overwintering bulbs and when the leaves had only just begun to elongate (early season, stage 1) often referred to as the "shoot" stage by commercial harvesters). Mid-season (stage 2) samples were collected two weeks later (May 2) when leaves were fully extended from the bulb and the bulb was visibly thin or narrow and not yet swollen (i.e., "shaft" stage found commonly in commerce and on social

Stage:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Description:	Early season "Shoot"	Mid-season "Shaft"	Late season "Peak leaf/bulb"	Leaf senescence, Early flowering "Scape"	Flowering	Fruiting	Dormant
Approximate calendar dates: (This study)	March 1-April 15 (April 14)	April 1-May 5 (May 2)	April 15-May 30 (May 10-17)	May 15-June 15 (May 17)	June 15-July 15 (July 12)	July 15-August 30 (August 29)	May 15-April 1 (November 11)
Appearance:	**Leaves:** beginning to expand (<3"). **Bulb:** swelling of bulb may be visible depending on how much "shoot" has been produced.	**Leaves:** mostly to fully expanded. **Bulb:** cylinder shaped, with no or slight swelling of the saft to form a bulb.	**Leaves:** fully expanded. **Bulb:** formed, teardrop shaped, with definite visible separation of the shaft from bulb.	**Leaves:** fully expanded, yellow, and/or beginning to wither. **Bulb:** fully formed, teardrop shaped, with definite visible separation of shaft from bulb. **Scape:** emerging.	**Leaves:** none present. **Bulb:** fully formed, teardrop shaped, swollen. **Scape:** visible on reproductive plants. Flowers visible.	**Leaves:** none present. **Bulb:** fully formed, teardrop shaped, swollen. **Scape:** visible on reproductive plants. Capsules visible.	**Leaves:** none present. **Bulb:** fully formed, teardrop shaped, swollen. **Scape:** visible on reproductive plants. Withered and dry.
Illustration:							

Fig. 2 Seven field phenological stages in ramps (*A. tricoccum*) used in this study and traits for distinguishing each. Terms in quotes are commonly used by harvesters to describe the stages. The emergence and senescence dates vary between years and by location but generally occur between March 1 and May 30 (~84 days)

media). Late season (stage 3) harvesting was conducted when plants had achieved a "peak leaf/bulb" stage (May 10–17) which was characterized by the leaf blades being fully expanded and the bulb being swollen and formed (often described as "teardrop" shaped by harvesters). The remaining four stages (stages 4–7) were visible as senescence ("scape" stage to harvesters), flowering, fruiting, and post-reproductive dormant stages.

Ramps typically accumulate a greater amount of biomass over multiple years as both leaf area and the number of leaves increase (Nault and Gagnon 1988, 1993). To examine differences in weight as a function of leaf number, ramps with one, two, and three leaves (Supplemental Fig. 1) were collected at each of the first three stages. Stages 4–7 had decomposing or absent leaves so only bulb and total weighs were recorded for these stages.

Post-harvest processing and weighing

Collected ramps were kept in an iced cooler in the field and during transport. Once in the laboratory, they were refrigerated for up to 36 h until they could be weighed. While refrigerated, they were kept in sealed plastic bags to prevent moisture loss. Samples were rinsed of soil and the basal plate, roots, and papery sheaths surrounding bulbs were carefully trimmed off and discarded before weighing. This was done to replicate how ramps are sold to buyers and consumers. Additionally, this was done because sheaths are typically found in various stages of decomposition during the spring months as soil temperatures warm and plants begin growth and are an insignificant contribution to bulb weight.

The fresh weight of the ramps was first measured and recorded as a whole plant (e.g., bulb, leaves, and reproductive structure if present). Subsequently, the fresh weight of the individual parts was measured and recorded. For consistency, ramps were cut at the top of the outer bulb sheath to differentiate between bulb and either leaves or reproductive structure (Fig. 3). During the early season stage (stage 1), the leaves were not always fully extended past this point of division and so any extended leaves were simply cut, at the point of emergence from the bulb, and weighed.

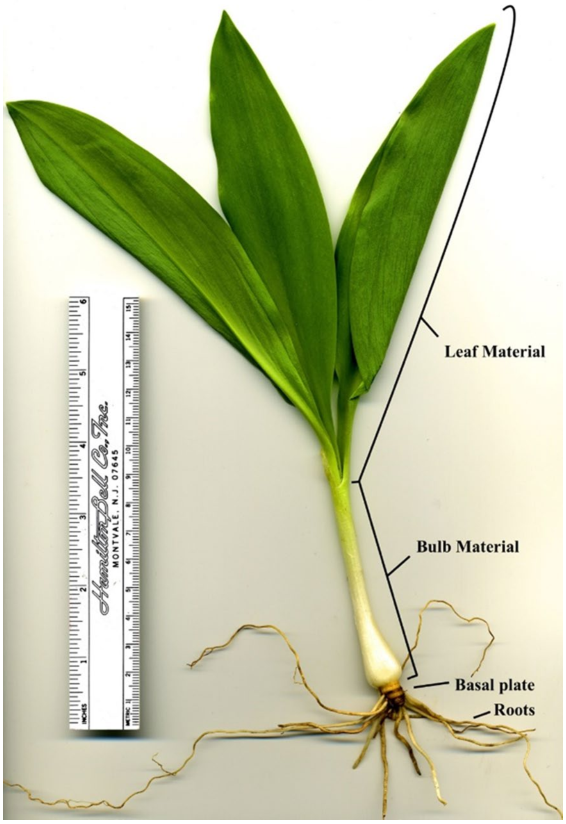

Fig. 3 Ramps were cut and separated at the top of the sheath of the outermost bulb scale where leaves extend outward from the bulb for laboratory weighing. The basal plate (rhizome) and roots were trimmed off and discarded

Taxonomic confirmation and voucher specimens

There is lack of consensus regarding the number of varieties or species of ramps in North America (Bell 2007; Sitepu 2018; Weakley 2022). The traditional interpretation divides ramps into two varieties or subspecies: *Allium tricoccum var. tricoccum,* and *Allium tricoccum var. burdickii* Hanes (Hanes 1953; Jones 1979), while others consider there to be two separate species: *Allium tricoccum* and *A. burdickii*, (NatureServe 2022; Weakley 2022). We confirmed all ramp samples in this study were *A. tricoccum* with Dr. Harvey Ballard of Ohio University (2021, personal communication) who has been studying ramp taxonomy using common garden experiments and morphology (Sitepu 2018).

Herbarium voucher specimens were made of ramp populations included in this study and deposited at PAC and CMNH.

Data analysis

Sample size for phenological stage by site varied (n = 23–73); the total sample size was n = 1077. Total and bulb weight data were log—normally distributed so values were log transformed to allow for parametric analysis. The log transformed data approached the normal distribution for each mean with Shapiro-Wilkes test for normality > 0.05. Analysis of boxplots showed 12 outliers for total weight and 13 outliers for bulb weight present. Separate analyses were run with the outliers removed from the data set, and this did not alter main effect or contrast significance, so outliers were not omitted. Analysis of Variance (ANOVA) was performed on the total weight and bulb weight data, with phenological stage included as a fixed effect and site included as a random effect. After the models were run, studentized residuals were plotted against predicted mean values which showed that the homogeneous variance assumption was met for both variables. Repeated contrasts, based on the a priori hypothesis that mean weights would differ between sequential phenological stages, were performed.

ANOVA was used to test the effect of leaf number (2 or 3 leaves) on ramp total weight and bulb weight for stages 1–3 (early season, mid-season, and peak season stages) only, since these are three phenological stages that have intact leaves. ANOVAs were run separately for each phenological stage on log-transformed total and bulb weight data. Site was modeled as a random effect and leaf number was a fixed effect. The log transformed data were normally distributed for each group mean with Shapiro-Wilkes test for normality > 0.05. No outliers were present, and the homogenous variance assumption was met for all variables. Sample sizes for each group (phenological stage by leaf number) ranged from 70 to 121 with an overall n = 552. For all analyses the means and 95% confidence interval bounds presented in the figures are back transformed for more relevant interpretation. SPSS Statistics version 26 was used for all statistical analyses.

Results and discussion

Harvest timing impact on weight and yield

Both ramp total weight (i.e., leaf and bulb weight combined) and bulb weight change over the growing season (Fig. 4). Both phenological stage ($p < 0.0005$) and site ($p < 0.0005$) were significant sources of variation in total (Supplemental Table 1) and bulb weight (Supplemental Table 2). Mean ramp total weight was the lowest at the dormant stage (stage 7, 2.15 g) and highest at the late season stage (stage 3, 8.53 g) and declined once the leaf began to senesce (Figs. 2, 4). For total weight, all mean contrasts between adjacent stages were significant except senescence (stage 4) versus flowering (stage 5, Table 1). Mean ramp bulb weight was the lowest at the early season stage (stage 1, 1.04 g) and increased over the season, peaking at the senescence stage (stage 4, 4.80 g) before declining during flowering, fruiting, and dormant stages (stage 5–7). For bulb weight, all mean contrasts between adjacent stages were significant except for late season (stage 3) versus senescence (stage 4) stages (Table 1).

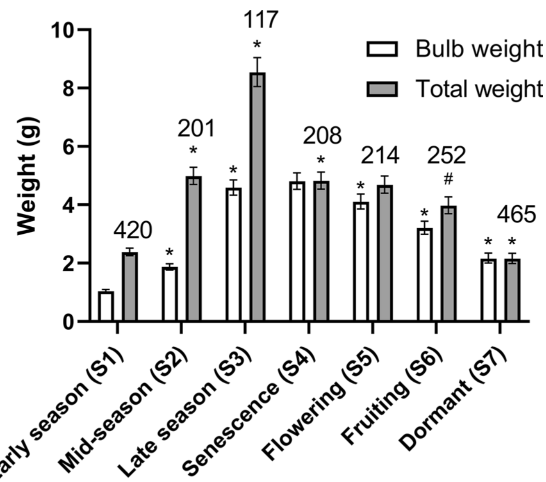

Fig. 4 Back transformed mean total weight and bulb weight by phenological stage. S = stage number, error bars represent the back transformed 95% mean CI. Asterisks indicate that the mean is significantly different from previous phenological stage mean at $p < 0.0005$, pound sign indicates the mean is significantly different at $p = 0.001$. The number above the bars represents the number of individual ramps in one kg fresh weight ramps calculated from total weight back-transformed means for each phenological stage

Table 1 Mean contrasts between adjacent phenological stages for log-transformed ramp total and bulb weight, S = stage

Contrast	Total weight contrast estimate (p-value)	Bulb weight contrast estimate (p-value)
S1 Early season versus S2 mid-season	– 0.321 (**< 0.0005**)	– 0.256 (**< 0.0005**)
S2 Mid-season versus S3 late season	– 0.234 (**< 0.0005**)	– 0.390 (**< 0.0005**)
S3 Late season versus S4 senescence	0.248 (**< 0.0005**)	– 0.020 (0.0270)
S4 Senescence versus S5 flowering	0.012 (0.520)	0.068 (**< 0.0005**)
S5 Flowering versus S6 fruiting	0.071 (**0.001**)	0.108 (**< 0.0005**)
S6 Fruiting versus S7 dormant	0.266 (**< 0.0005**)	0.170 (**< 0.0005**)

Bold values are significant contrasts, $p < 0.0005$

Mean weights and confidence intervals can be viewed in Supplemental Table 3.

These results are consistent with Nault and Gagnon (1988), who documented changes in ramp bulb size and shape in Southern Quebec as nutrients were allocated from leaves to bulbs. The practical significance of this finding is that the increase in weight from early season (stage 1) to late season (stage 3) stages reduces the number of plants required per kg of ramps from 420 individuals at the emergent early season stage to 117 at late season stage (Fig. 4). Therefore, delaying ramp harvesting until the late season stage (~30 days after emergence) would reduce harvest impact on wild and forest farmed populations while maintaining a consistent harvest weight. Ramp harvests during early season (stage 1) and mid-season (stage 2) stages would require significantly more individuals to achieve the same harvest weight.

Harvesting at the late season stage (stage 3, Fig. 2) could be used in combination with "harvesting to a fixed density" (Dion et al. 2016) to improve harvest yield and population viability. Ramp patch density can vary considerably in wild populations and has been reported to be as high as 400 plants m^{-2} (Dion et al. 2016). High patch density can lead to crowding, increased competition, and mortality (Nault and Gagnon 1993; Dion et al. 2016). Dion et al. (2016) reported that ramps grown in plots at lower bulb densities showed increased bulb growth and reproduction (seed production and bulb division). Benefits were also observed in wild plots and researchers recommended harvesting to a density of 44–88 bulbs m^{-2} to maximize patch health and regeneration (Dion et al. 2016).

Pugh (2022) found that the most popular time to harvest ramps in Pennsylvania is during spring months, during the first six weeks following emergence (stages 1 and 2 in Fig. 2), which is consistent with observations elsewhere in the wild range of the species (Cool 2013; Facemire 2010; Rivers 2013). Our study results suggest that encouraging a shift towards harvesting and purchasing ramps during the latter half of the season (~30 days after emergence) would improve weights, yields, and thus conserve plant numbers in both wild populations and forest-farmed crops. For forest farmers, adopting a late harvest window would be economically beneficial in the long term as it would significantly reduce the amount of population or crop impacted by destructive harvesting each year and reduce the amount of labor invested in planting and harvesting. Anecdotally, we found general support for a delayed harvest window when we shared the results of this study with producers in PA and North Carolina, since it is already recognized among many experienced harvesters that ramp bulbs are much smaller earlier in the season and therefore more raw material and labor are needed to meet buyer demand (Steve Schwartz, pers. comm.; Craig Hastings, pers. comm). One producer (Steve Schwartz, pers. comm.) already refuses to harvest early season ramps for New York City clients for this reason.

For commercial harvesters, a shorter harvest window may not be desirable, especially since much of the demand (and higher pricing) occurs early in the season as consumers are excited and eager to consume ramps (Pugh 2022). One way to promote a shift to mid or late (~30 days after emergence and later) season consumption is to educate consumers who encourage early harvesting. There is growing concern and awareness amongst many stakeholders, including consumers, over sustainability in wild harvests as ramp consumption has grown in popularity (Pugh 2022). Some advocate for a "leaf only" harvest as a result (UPS 2022). Recognizing that many consumers will still likely prefer to consume the entire plant, because of preferences and uses, encouraging consumers to wait until bulbs "size up" could be used as a sustainability pitch. Catchy slogans such as "fewer ramps per pound means more ramps in the ground" could be shared on social media, in culinary circles, and at points of sale as part of this effort.

Conscientious consumers might also be more inclined to wait if they knew that delaying ramp harvests could result in a more healthful product by allowing time for seasonal phytochemical development. Relatively few phytochemicals have been measured in ramps, but of those measured seasonally, all have been shown to accumulate in ramps as they develop across the spring stages. For example, ramps contain the organosulfur compound allicin (Calvey 1997) which is believed to be responsible for many allium health benefits including improved cardiovascular health, reduced LDL cholesterol and anti-inflammatory, antimicrobial, and antioxidant effects (Salehi et al. 2019). Ramps also contain phenolic compounds (Jordan 2020; Dabeek 2019) which can have antimicrobial, antioxidant, and anticancer properties (Hedges and Lister 2007). Jordan (2020) determined that while concentrations of allicin and total phenolic compounds varied by stage on a per gram basis, the total accumulation of these compounds per individual plant increased with ramp weight. The average individual whole ramp harvested at the peak spring stage (equivalent to stage 3 late season stage in Fig. 2) had 850% more allicin and 240% more total phenolic compounds than a ramp at the emergent "shoot" stage (equivalent to early season or stage 1 in Fig. 2, Jordan 2020). Although garlic represents an abundant source of dietary allicin and polyphenols, ramps differ in important sensory characteristics which may contribute to some consumers' preference for ramps as a local source of phytochemicals (Calvey 1997). Therefore, to capitalize on the healthful compounds from each individual ramp harvested, harvesters and consumers should wait until ramps have reached their peak size.

Harvest impact of leaf number

Leaf number was a significant effect ($p < 0.0005$) for log total ramp weight and log bulb weight for all marketable phenological stages examined (Supplemental Table 4). Three-leaf ramps were significantly larger than two-leaf ramps at each stage (Fig. 5, Supplemental Table 3). At the late season stage (stage 3), the mean total weight per ramp was 4.03 g for two-leaf ramps and 5.42 g for three-leaf ramps. One hundred and thirty-seven ramps were required to make one kg using two-leaf plants versus 98 for three-leaf plants. Therefore, preferential harvesting of three-leaf ramps over two-leaf ramps would allow for more individuals to remain in the patch per weight harvested.

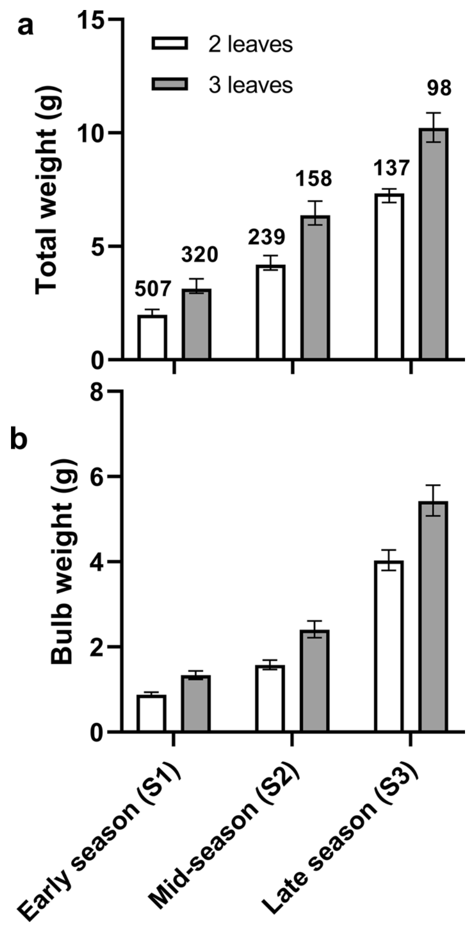

Fig. 5 Back transformed mean total ramp weight (**a**) and bulb weight (**b**) for 2-leaved ramps and 3-leaved ramps by phenological stage. S = stage number, error bars represent the back transformed 95% mean CI. For all phenological stages leaf number was a significant effect ($p < 0.0005$). The number above the bars represents the number of individual ramps in one kg fresh weight ramps calculated from total weight back-transformed means for each phenological stage by leaf number

While delaying the harvest of ramps until the late season stage (stage 3) may have conservation and health benefits, the long-term impact of selective harvesting of larger, three-leaf ramps over two-leaf ramps on ramp population maintenance is unknown.

Larger ramps tend to have more seed and bulb division reproductive potential (Dion et al. 2016; Nault and Gagnon 1993). Therefore, selective harvesting using leaf number as a target could have negative consequences for patch regeneration and genetic diversity if the three-leaf ramps are the individuals primarily producing new ramets or seed in a population or area. For example, McGraw (2001) found that wild-harvested American ginseng (*Panax quinquefolius* L.) declined in stature over a 186-year period and hypothesized that this might have been due to harvesters consistently removing the largest plants from populations. Additional studies on the long-term impact of selective harvesting of the largest ramps on population regeneration, genetic diversity, and plant size are therefore needed to ensure that unintended consequences do not result from consistent targeting of large ramps.

In wild populations and forest farms, seed production may not contribute much to ramp population growth since bulb division has been observed as contributing more to maintenance and expansion in the wild (Dion et al. 2016; Nault and Gagnon 1993). Given the predominance of clonal growth, genetic diversity within ramp populations may be low, as was found in Quebec (Vasseur et al. 1990). Protecting ramp genetic diversity is important given climate change (Bernatchez and Lapointe 2012) and the growing cultural and economic importance of ramps as a forest-farmed crop (Chamberlain et al. 2014; Pugh 2022). A harvest strategy that focuses on thinning a population or area (Dion et al. 2016) could lessen competition and create openings in the herbaceous layer that better promotes seed germination and seedling survival. This, in turn, could contribute to increased genetic diversity.

Conclusions

In commerce, ramps are mostly sold by weight. Total ramp and bulb weight were found to significantly increase from spring emergence (early season, stage 1) to senescence (stage 4), with a late season "peak leaf/bulb" stage (stage 3) occurring about 30–35 days after emergence. When considering the number of individuals needed to attain a target weight, delayed harvesting (toward the latter half of the spring harvest season) results in significantly fewer plants being removed from a population. Wild and forest farming harvest practices should be shifted to mid-late season (~ 30 days and thereafter) to encourage delayed harvesting of ramps until this more fully developed stage is attained. Higher early season prices and demand attract early harvesters, but this must be balanced against the amount of labor and raw materials required to obtain a pound of raw materials. Consumer education can play a role in reducing early season harvest because many producers feel compelled to supply early season markets (Steve Schwartz, pers. comm.).

Additionally, three-leaf ramps weigh more than two-leaf ramps, so targeting of this stage will further reduce the number of plants required to attain a given weight. Thinning these larger three-leaf ramps could be beneficial to long-term ramp population management by creating herbaceous layer gaps where seedlings can establish, thereby facilitating sexual reproduction and resulting in increased genetic diversity. However, this must be balanced against the greater contribution of three-leaf plants to seed and clone production.

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References

Baumflek M, Chamberlain JL (2019) Ramps reporting: what 70 years of popular media tells us about a cultural keystone species. Southeast Geogr 51(1):77–96. https://doi.org/10.1353/sgo.2019.0006

Bell RA (2007) A reexamination of species boundaries between *Allium burdickii* and *A. tricoccum* (Liliaceae). Thesis, West Virginia University

Bernatchez A, Lapointe L (2012) Cooler temperatures favour growth of wild leek (*Allium tricoccum*), a deciduous forest spring ephemeral. Botany 90(11):1125–1132. https://doi.org/10.1139/b2012-089

Bernatchez A, Bussières J, Lapointe L (2013) Testing fertilizer, gypsum, planting season and varieties of wild leek (*Allium tricoccum*) in forest farming system. Agrofor Syst 87(5):977–991. https://doi.org/10.1007/s10457-013-9613-1

Burkhart EP, Jacobson MG (2009) Transitioning from wild collection to forest cultivation of indigenous medicinal forest plants in eastern North America is constrained by lack of profitability. Agrofor Syst 76(2):437–453. https://doi.org/10.1007/s10457-008-9173-y

Burkhart EP, Nilson SE, Pugh CV, Zuiderveen GH (2021) Neither wild nor cultivated: American ginseng (*Panax quinquefolius* L.) seller surveys provide insights into in situ planting and trade. Econ Bot 75(2):126–143. https://doi.org/10.1007/s12231-021-09521-8

Calvey EM, Matusik JE, White KD, Deorazio R, Sha D, Block E (1997) Allium chemistry: supercritical fluid extraction and LC-APCI-MS of thiosulfinates and related compounds from homogenates of garlic, onion, and ramp. Identification in garlic and ramp and synthesis of 1-propanesulfinothioic acid S-allyl ester. J Agric Food Chem 45(11):4406–4413. https://doi.org/10.1021/jf970314e

Chamberlain J, Beegle D, Connette K (2014) Forest farming ramps. Agroforestry notes. Web: https://www.fs.usda.gov/nac/assets/documents/agroforestrynotes/an47ff08.pdf. Accessed 17 June 2022

Chamberlain J, Emery M, Patel-Weynand T (2018) Assessment of nontimber forest products in the United States under changing conditions. Gen Tech Rep SRS-232. https://doi.org/10.2737/SRS-GTR-232

Cool B (2013) Ramps or how to take a leek in the woods. CreateSpace Independent Publishing Platform, Scotts Valley, California

Dabeek WM (2019) Characterization of major flavonols in ramps. MS Thesis, West Virginia University. http://researchrepository.wvu.edu/etd/4020/

Davis J, Persons WS (2014) Growing and marketing ginseng, goldenseal, and other woodland medicinals. New Society Publishers, British Columbia

Dion P, Bussières J, Lapointe L (2016) Sustainable leaf harvesting and effects of plant density on wild leek cultivation plots and natural stands in Southern Quebec. Can Agrofor Syst 90(6):979–995. https://doi.org/10.1007/s10457-015-9878-7

Facemire G (2010) Having your ramps and eating them too. McClain Printing Company, Parsons, West Virginia

Hanes C (1953) *Allium tricoccum* Ait var *burdickii*. Rhodora 55(655):243–244

Hedges L, Lister C (2007) The nutritional attributes of Allium species. Crop and Food Research Confidential Report No. 1814, New Zealand Institute for Crop and Food Research Limited. pp 1–48. https://doi.org/10.13140/2.1.4265.4402

Jones AG (1979) A study of wild leek, and the recognition of *Allium burdickii* (Liliaceae). Syst Bot 4(1):29–43. https://doi.org/10.2307/2418663

Jordan RT (2020) Allicin and total phenolic content in ramps (*Allium tricoccum* Ait.) in relation to phenology, location, and morphology in Pennsylvania. MS Thesis, the Pennsylvania State University. https://etda.libraries.psu.edu/catalog/17718rtj5

McGraw, (2001) Evidence for the decline in stature of American ginseng plants from herbarium specimens. Biol Conser 98(1):25–32. https://doi.org/10.1016/S0006-3207(00)00138-5

Miean KH, Mohamed S (2001) Flavonoid (myricetin, quercetin, kaempferol, luteolin, and apigenin) content of edible tropical plants. J Agric Food Chem 49(6):3106–3112. https://doi.org/10.1021/jf000892m

Moerman DE (1998) Native American ethnobotany. Timber Press, Portland, Oregon

NAC - National Agroforestry Center (2022) Forest farming. https://www.fs.usda.gov/nac/practices/forest-farming.php. Accessed 17 June 2022

Nantel P, Gagnon D, Nault A (1996) Population viability analysis of American ginseng and wild leek harvested in stochastic environments. Conserv Biol 10(2):608–621. https://doi.org/10.1046/j.1523-1739.1996.10020608.x

NatureServe (2022) *Allium burdickii*. NatureServe explorer: an online encyclopedia of life. Version 7.1 Web: http://explorer.natureserve.org/servlet/NatureServe?searchName=Allium+Burdickii. Accessed 17 June 2022

Nault A, Gagnon D (1988) Seasonal biomass and nutrient allocation patterns in wild leek (*Allium tricoccum* Ait.), a spring geophyte. Bull Torrey Bot Club 115(1):45–54. https://doi.org/10.2307/2996565

Nault A, Gagnon D (1993) Ramet demography of *Allium tricoccum*, a spring ephemeral, perennial forest herb. J Ecol 81(1):101–119. https://doi.org/10.2307/2261228

Pugh C (2022) Ramp/leek "culture" in Northern Appalachia: a study of attitudes, behaviors, and knowledge surrounding a non-timber forest product. Thesis, the Pennsylvania State University

Ritchey KD, Schumann CM (2005) Response of woodland-planted ramps to surface-applied calcium, planting density, and bulb preparation. HortScience 40(5):1516–1520. https://doi.org/10.21273/hortsci.40.5.1516

Rivers B, Oliver R, Resler L (2014) Pungent provisions: the ramp and Appalachian identity. Mater Cult 46(1):1–25

Rivers BC (2013) Merging symbols, space, and identity in Appalachia: an examination of the ramp. Thesis, Virginia Polytechnic Institute and State University

Rock J, Beckage B, Gross LJ (2004) Population recovery following differential harvesting of *Allium tricoccum* Ait. in the southern Appalachians. Biol Conserv 116(2):227–234. https://doi.org/10.1016/S0006-3207(03)00193-9

Salehi B, Zucca P, Orhan IE, Azzini E, Adetunji CO, Mohammed SA, Banerjee SK, Sharopov F, Rigano D, Sharifi-Rad

J, Armstrong L, Martorell M, Sureda A, Martins N, Selamoğlu S, Ahmad Z (2019) Allicin and health: a comprehensive review. Trends Food Sci Technol 86:502–516. https://doi.org/10.1016/j.tifs.2019.03.003

Sitepu BS (2018) An integrative taxonomic study of ramps (*Allium tricoccum* Aiton) complex. Thesis, Ohio University. https://etd.ohiolink.edu/pg_10?0::NO:10:P10_ACCESSION_NUM:ohiou1534064390052709

UPS - United Plant Savers (2022) Species-at-risk list: ramps. https://unitedplantsavers.org/species-at-risk-list/ramps-allium-tricoccum/. Accessed 17 June 2022

Vasseur L, Gagnon D (1994) Survival and growth of *Allium tricoccum* Ait. transplants in different habitats. Biol Conserv 68(2):107–114. https://doi.org/10.1016/0006-3207(94)90340-9

Vasseur L, Gagnon D, Simon JP (1990) Iso- enzymatic variability among populations and varieties of wild leek (*Allium tricoccum*). Biochem Syst Ecol 18(5):321–324. https://doi.org/10.1016/0305-1978(90)90004-Y

Weakley AS (2022). Flora of the southeastern United States: Pennsylvania. University of North Carolina Herbarium, North Carolina Botanical Garden. Web: https://ncbg.unc.edu/research/unc-herbarium/floras/. Accessed 17 June 202