The potential for sustainable harvest of Common Persimmon (*Diospyros virginiana* L.) fruits at Pea Ridge National Military Park

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Research

Abstract

Background: The large, sweet fruits of the Common Persimmon (*Diospyros virginiana* L.) have a long history as a wild-harvested food in the eastern United States, by both Indigenous people and European settlers. However, little is known about the sustainability of persimmon fruit harvest. Persimmon fruits are a culturally important food for the Osage Nation. Pea Ridge National Military Park (hereafter PERI) is within the Osage ancestral territory

Methods: We examine the sustainability of persimmon fruit harvest through field surveys of fruit production and the application of the United Plant Savers "At-Risk Assessment Tool", which assesses the risk of overharvesting wild plants. Our field work to determine persimmon fruit yield was conducted at PERI in response to a National Park Service's (NPS) 2016 rule which provides a pathway for Native American tribes, the Osage Nation in our case, to collect culturally important plants from NPS land if harvest is sustainable.

Results: Combining our field surveys of fruit production with NPS data on persimmon tree density and potential persimmon habitat at PERI, we estimate annual fruit production of about 143,000 persimmon fruits, or about 1,990 kg (4100 lbs.) at PERI. Persimmon fruit harvest has a low risk of overharvest, with an At-Risk score of 19 on a scale with a max score of 96 (highest risk).

Conclusions: An annual harvest of 9-15 kgs (~20-30 lbs.) of persimmon fruit by the Osage at PERI (< 1% of total estimated yield), would be sustainable and help promote traditional Osage practices of collecting, preserving, and eating persimmons.

*Keywords***:** persimmon, sustainable harvest, At-Risk assessment, Pea Ridge, ethnobotany

Background

The large, sweet fruits of the Common Persimmon (*Diospyros virginiana* L.), hereafter persimmon, have long been a food staple of Indigenous people in the eastern United States (Fritz 2000, La Flesche 1923). Seeds of the persimmon fruit are common, sometimes abundantly so, at archeological sites of Indigenous villages in the southeastern U.S. (Hammett 2000, Fritz 2000), and there is evidence that trees were planted near Indigenous communities (Hammett 2000). The earliest European settlers quickly adopted the fruits as a food source and to

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brew beer and make brandy (Briand 2005). Today persimmons are still locally popular in custards, pies, jams, and puddings. Native persimmon trees have not been commercially cultivated, as their tender ripe fruits are easily crushed and bruised and are not suitable for shipping. Although local markets may sell persimmons as a specialty item in the autumn, most are either garden grown or wild-harvested (Collins *et al.* 1993, Goodell 1982).

With any wild-harvested species, sustainable harvest is critical for maintaining healthy, future populations, allowing for continued economic benefits (Chamberlain *et al.* 2019) and preserving cultural and social practices (Lake *et al.* 2018, Watson *et al.* 2018). Sustainable harvest practices also promote healthy ecosystems, ensuring plant resources are available to wildlife and other species (Ticktin 2004). Estimating the amount of plant material that can be sustainably harvested, (e.g., our work with oshá [*Ligusticum porteri* J.M. Coult. & Rose]), requires detailed demographic data (Kindscher *et al.* 2013, 2019) which is research intensive and time consuming to collect. The challenge is even greater for long-lived trees (Castle *et al.* 2014). For the vast majority of plant species, we lack the resources for such in-depth demographic studies. To fill this gap, rapid and easily used assessment methods have been developed. The At-Risk Assessment Tool, which we helped create (Castle *et al.* 2014), is one such method. It allows allowing land-managers, harvesters, and conservationists to quickly assess the risk of overharvest of a species based on basic ecological and plant-use knowledge. Specifically, a plant species is scored in five areas: life history characteristics, effects of harvest, species abundance and range, habitat vulnerability, and market demand. The plant is given a numeric score in each area to provide an overall "at-risk" score. In this study, we applied the At-Risk Assessment Tool to persimmon fruit at Pea Ridge National Military Park (PERI).

The persimmon is a sun-loving tree, native to forests and woodlands of the southeastern one-third United States (Figure 1). It flourishes in early successional woodlands, and along roadsides, fencerows, and railroads (Reich 1991; Steyermark 1940). Persimmon trees are dioecious with male and female flowers produced on separate trees (Eckenwalder 2009). Flowering occurs March through June, with later blooming times at higher latitudes. Rarely are flowers damaged by a late freeze. Trees in the Lawrence, Kansas area have produced fruit every year for the past 40 years (Kindscher, personal observation). The nectar-rich flowers attract bees and other pollinators (Fletcher 1942, Troop & Hadley 1896). The sweet, fleshy fruits (Figure 2), yellow to red-orange in color, ripen in September to October. The edible flesh clings to six or more seeds. Fruits tend to remain on the tree until ripe, often being retained until after leaf fall. The fruits are eaten by many animals, including raccoons, opossums, coyotes, foxes, white-tailed deer, wild turkey, and quail (Glasgow 1977, Rebein *et al.* 2016, Roehm & Moran 2013). Propagation also occurs asexually through root suckers, often producing small groves with all trees of a single sex (Eckenwalder 2009). The the persimmon tree has a unique, deeply furrowed, blocky bark (Figure 2), which helps protect it from fire (Hammond *et al.* 2015).

The persimmon tree has also been used as medicine by both Indigenous peoples and European settlers. There is surprisingly little recorded ethnobotany on the use of persimmon as food and medicine by Indigenous people. The Cherokee utilized persimmon bark to treat a wide variety of ailments including gastrointestinal issues, toothache, hemorrhoids, and venereal disease (Cozzo 2004, Hamel & Chitoskey 1975). Both the Cherokee and the Rappahannock treated thrush and sore throats with persimmon bark (Hamel & Chitoskey 1975, Speck *et al.* 1942). European Americans also used parts of persimmon to treat a variety of ailments from dysentery to hemorrhoids (Briand 2005). The large, hard persimmon seeds were used to make buttons during the American Civil War. The dense, hard wood from the persimmon tree has been used to make gunstocks, shoe lasts, chisel handles, and loom shuttles, among other things (Briand 2005).

Our interest in the sustainable harvest of persimmon fruit relates to a larger, collaborative ethnobotany project among the Osage Nation, the Kansas Biological Survey, and Pea Ridge National Military Park (PERI) that began when the Osage Nation and PERI both expressed an interest in working towards a preliminary collecting agreement under the "Gathering of Certain Plants or Plant Parts by Federally Recognized Indian Tribes for Traditional Purposes" rule by the NPS (U.S. Federal Register 2016). This rule, established in 2016, supports Indigenous peoples harvesting plants for food, medicine, and other uses in their ancestral homelands within NPS holdings by providing guidelines for creating collecting agreements with federally recognized tribes. For a preliminary agreement to be made, there must be interest by tribal members in collecting plants on NPS lands and there must be a historical relationship between the tribal nation, the land, and the plant(s) being harvested. Equally important is the demonstration that the plant(s) can be harvested sustainably, without damaging the plant populations or ecosystems on NPS land. With the rule in place and with adequate studies and review, the Eastern Band of the Cherokee are now harvesting Sochan (*Rudbeckia laciniata* L.) at Great Smoky Mountains National Park (National Park Service 2018a) and members of the Tohono O'odham Nation are harvesting Saguaro (*Carnegiea gigantea* (Engelm.) Britton & Rose) and Cholla (*Cylindropuntia* spp. (Engelm.) Kreuzinger) in Saguaro National Park (National Park Service 2018b). Our study provides the documentation that persimmon fruits could be sustainably harvested at PERI, should the Osage and the park choose to enter into such an agreement.

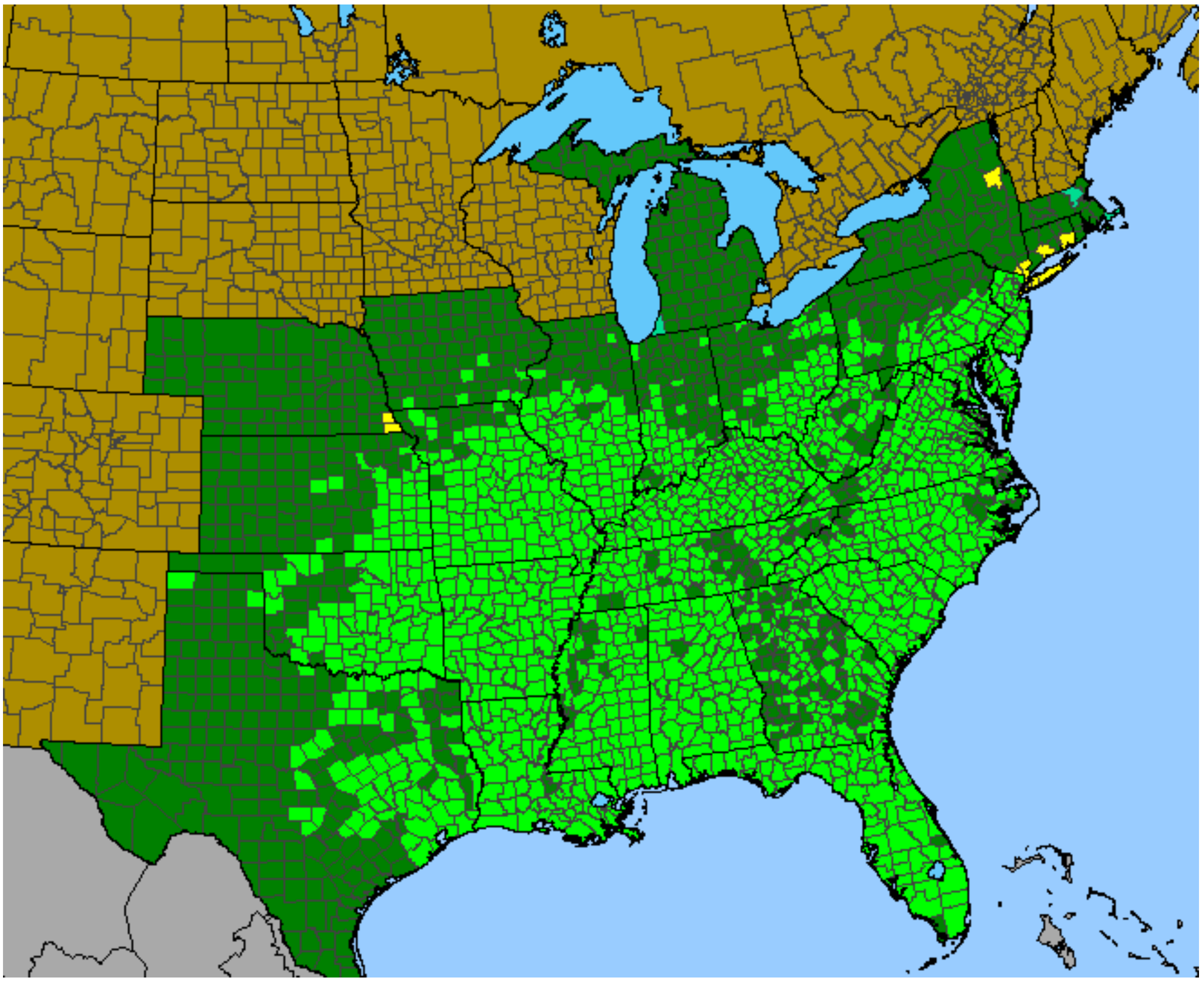

Figure 1. Geographical Distribution of Common Persimmon (*Diospyros virginiana* L.) in the United States. Dark green represents states where persimmon is found. Bright green counties are where persimmon has been recorded. Tan represents states and territories where persimmon has not been found (Kartesz 2021).

The ancestral lands of the Osage Nation spread across the central U.S., encompassing what is currently Oklahoma, Kansas, Missouri, and most of Arkansas, reaching north into Wisconsin, south into Louisiana, and as far east as Pennsylvania. The Osage are part of the Dhegiha Siouan lineage (Hunter *et al.* 2013), which emerged from in the Ohio Valley. Around 1300 AD, the Osage moved westward (Hunter *et al.* 2013), where they settled in numerous villages and settlements throughout present-day Missouri, Oklahoma, Arkansas, and Kansas (Burns 2004). Forced land cession by European colonizers throughout the 1800's greatly reduced Osage lands (Burns 2004). In the late 1870's, the Osage Nation uniquely purchased over 1.4 million acres of land in northeastern Oklahoma for their reservation (Burns 2004, Chapman 1938). Today, Pawhuska, Oklahoma is the governmental seat of the modern Osage Nation, as well as the county seat for Osage County, Oklahoma.

PERI, located in northwest Arkansas, is situated in the center of the Osage Ancestral Territory, approximately 270 km (167 m) from Pawhuska, Oklahoma. PERI was established in 1956 to preserve the history of the 1862 Pea Ridge Civil War Battlefield and surroundings (National Park Service 2014) and includes more than 1700 hectares (4200 acres) of both human-created environments such as hay fields, and native ecosystems, including forest and restored grasslands (Table 1, Dale & Gibbons 1979, Diamond *et al.* 2013).

Figure 2. Ripe fruit (left) and characteristically blocky bark of persimmon trees (right).

To facilitate the potential creation of a preliminary collection agreement between the Osage Nation and the NPS, we first researched the recorded historical ethnobotany of the Osage. In consultation with the Tribal Historical Preservation Office of the Osage Nation, and our Osage colleagues, the fruit of persimmon was chosen as a culturally important plant that could be collected at PERI. Traditionally, the Osage collected a large quantity of persimmon fruits in the fall after fruits ripened. The seeds would be removed from the pulp. The pulp was then flattened and preserved as dried cakes. Francis La Flesche, who was Omaha, studied Osage culture while working as the first professional Native American ethnologist at the Smithsonian Institution. He wrote the first Osage Dictionary (La Flesche 1932), as the Omaha and Osage languages are closely related. Through his work he observed and described the making persimmon cakes (La Flesche 1923):

> The *çta-i*^{n}*-ge* (persimmon) is a fruit that is gathered in large quantities for winter use. In preparing the fruit for preservation, the seeds are first separated from the pulp, with a rude screen made of small saplings. The pulp of the fruit is then moulded (sic) into cakes, put on wooden paddles and held over live coals to bake. After baking the cakes are dried in the sun and stored. A specimen which was furnished by *Mo*$^{s'}$*-çi-tse-xi* is now in the National Museum.

The yearly gathering of persimmons was a social endeavor, as La Flesche (1923) describes:

> The process of preparing the persimmon for preservation is called *Çta-i*^{n}*-ge ga-ze*, making *çta-i*^{n}*-ge*. In autumn the people go out in groups and camp in the woods to gather persimmons for preserving.

During his travels up the Missouri River with the Pacific Fur Companies expedition, John Bradbury visited the Osage Village near Fort Osage in 1811 and recounts his experience being fed persimmon as a guest of Osage Chief Waubuschon (Thwaites 1904):

> On our return through the town, we called at the lodge belonging to a chief named Waubuschon. . . The floor was covered with mats, on which they sat; but as I was a stranger, I was offered a cushion. A wooden bowl was now handed round, containing square pieces of cake, in taste resembling gingerbread. On inquiry I found it was made of the pulp of the persimmon, (*Diospyros virginiana*) mixed with pounded corn. This bread they called *staninca*.

Given the importance of persimmons as a food source to the Osage it would be appropriate for the Osage to enter into a collecting agreement with the NPS at PERI, but only if persimmon fruits could be harvested sustainably. To demonstrate that sustainable persimmon fruit harvest is possible, we estimated persimmon fruit production at PERI based on a combination of field surveys and vegetation mapping, and we applied the At-Risk Assessment Tool (Castle *et al.* 2014) to determine if there was risk of overharvesting persimmon fruit.

Materials and Methods

Assessing Sustainable Harvest of Persimmon

Our central hypothesis is that a limited yearly harvest of persimmon fruits would not have negative short- or long-term consequences to the persimmon population at PERI. In consultation with the Osage, we proposed an annual harvest of 9-15 kgs (20-30 lbs.) of persimmon fruit from PERI. This is a substantial amount of fruit for use by the Osage and could be collected in a single trip to PERI. To demonstrate short-term sustainability, we estimated the yield of persimmon fruits at PERI. This was done through combining our field surveys with NPS data to estimate persimmon density and habitat acreage. Collecting the long-term data required to demonstrate long-term sustainability using population models was beyond the scope of this project. Instead, we took another approach, applying knowledge of the ecology and biology of persimmons to the At Risk of Overharvest Assessment Tool (Castle *et al.* 2014). Both approaches are described in more detail below.

Estimating Total Fruit Yield

To estimate persimmon fruit yield at PERI, we needed an estimate for the following variables:

1.) the average number of fruits produced per tree (*Fruits/Tree*),
2.) the percentage of trees producing fruit (*Percent Fruiting*),
3.) the number of persimmon trees per hectare (*Stem Density*), and
4.) the number of hectares of persimmon habitat at PERI (*Habitat*).

Having these estimates allowed us to estimate total fruit yield at PERI as:
Fruits/Tree x *Percent Fruiting* x *Stem Density* x *Habitat* = *Estimated Fruit Yield*

Data were collected in two separate years (Oct 11-12, 2019; Oct. 12-13, 2020) to see if there was inter-annual variation. At this time of the year, persimmon fruits are just beginning to get ripe, and most persimmon trees have dropped their leaves, making the ripening persimmon fruits easily seen on the upper branches.

To estimate fruit production per tree, we established nine belt transects (100 x 20 m) in 2019 throughout PERI (Figure 3). We chose to place our transects where persimmon trees were abundant and easily accessible for harvest. We began each transect at a persimmon tree. For each persimmon tree within the transect we measured diameter at breast height (DBH), estimated height (modified stick method, Leverett & Bartolette 2014) and crown spread (average of the widest and narrowest crown diameters (Leverett & Bartolette 2014). We also recorded whether each tree was fruit-bearing or not. We measured 117 trees, recording the location of each using a handheld GPS unit.

In 2019, we found that out of the 117 trees, 63 were fruit-bearing. On each fruit-bearing tree, we counted the number of branches per tree, defining branches as coming off the main trunk and larger than 2 cm in diameter. On trees with more than six branches, we counted fruit on two lower, two middle, and two upper branches. We then estimated the number of fruits by multiplying the average number of fruits per branch by number of branches. For trees with six or fewer branches we counted all fruits on the tree. We also counted all fruits on trees with fewer than 20 fruits, regardless of the number of branches. For five trees, foliage prevented us from seeing and counting fruits. These trees were not included in our calculations.

In 2020 we re-visited our belt transects to determine if there was substantial inter-annual variation in fruit production. We successfully relocated all nine transects and found 71 of the 117 trees were fruit bearing. In 2020, leaf-fall had progressed further than when we sampled in 2019 and fruits were easily seen on the top-most branches. We counted all fruits on each tree, regardless of the number of branches, instead of estimating based upon a subset of six branches. This method was more efficient than determining which fruits come from which branches. This decision was made after a comparison of both methods on 10 trees indicated no difference in our estimates. Using GPS locations and DBH measurements, we were able to confidently match 2020 data to the 2019 data for 25 trees, or 35% of fruiting trees in 2020. This low percentage was due to low GPS location accuracy (3 - 5 m) and trees were often close together and similar in size. We did not observe any tree mortality during our two-year sampling period. Using a paired t-test on this subset of trees, we compared fruit production in 2019 to 2020.

Persimmon trees are dioecious, with male and female flowers produced on separate trees, although male persimmon trees are known to occasionally produce female flowers and fruits (Ross *et al.* 2014; Spongberg 1979). We are not sure if we observed this phenomenon at PERI. We found that percentage of fruiting persimmon trees was well over 50% (53% in 2019 and 60% in 2020). This could be due to local conditions, vegetative propagation, or "leaky dioecy" where otherwise male trees produce a few fruits (Ross et al. 2014). Thus, to conservatively estimate persimmon fruit production we used 50% of trees fruiting in our calculations, which represents a 1:1 sex ratio.

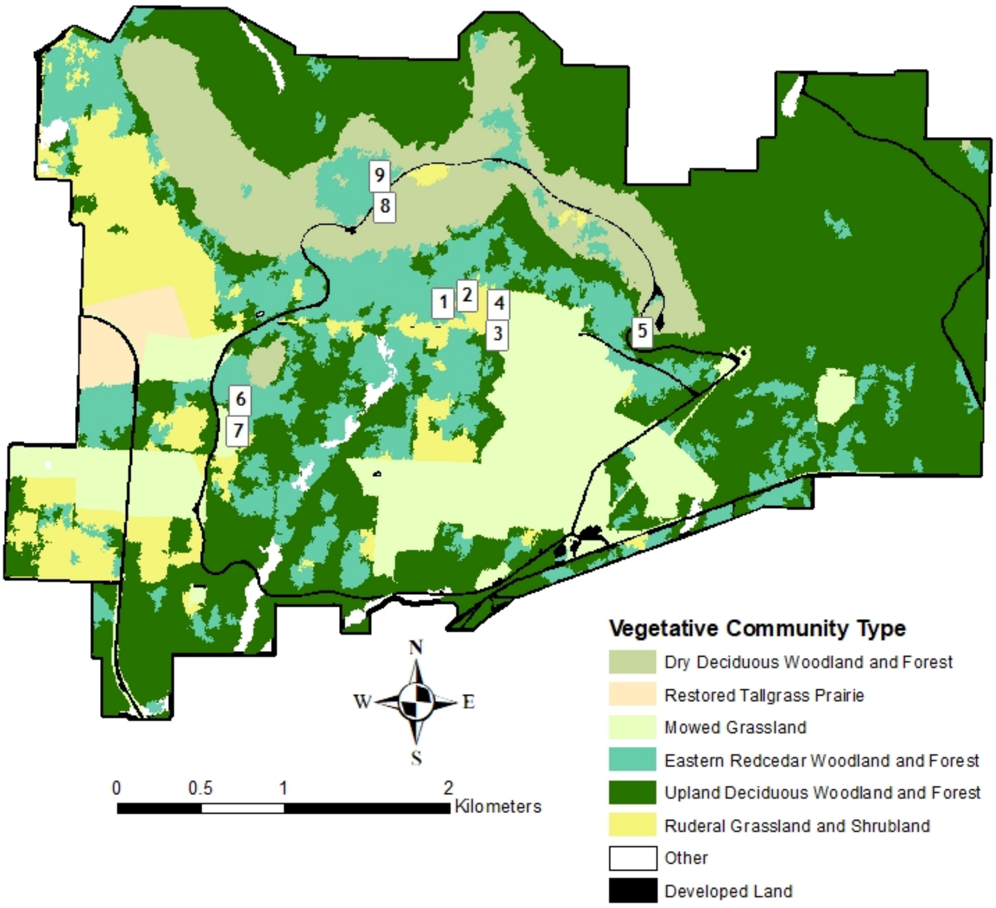

Figure 3. Map of Pea Ride National Military Park showing the location of sampling transects (numbered) and extent of estimated persimmon habitat (Diamond *et al.* 2013), defined as Upland Woodland and Forest, Dry Deciduous Woodland and Forest, Ruderal Grassland and Shrubland, and Eastern Red Cedar Woodland and Forest. Not considered as persimmon habitat: Restored Tallgrass Prairie, Mowed Grasslands, and Other (Marsh, Bottomland Deciduous Forest, Silver Maple Forest).

Since each transect intentionally started on a persimmon tree, rather than being randomly located, using persimmon tree density estimates from our transects could potentially overestimate the number of persimmon trees throughout the park. Thus, to generate a more conservative estimate of persimmon fruit yield, we turned to a published NPS Vegetation Monitoring Report (Leis 2018), in which the density of overstory trees, including persimmon, was monitored in 2006 and 2017. It should be noted that the seven 0.1-hectare plots of Leis (2018) were located in mature Upland Deciduous Forest, with all plots intentionally placed away from the forest edge.

Leis (2018) found persimmon stem density ranged from 8.6 stems per hectare in 2006 to 4.3 stems per hectare in 2017. Her study plots were located in closed canopy forest, leading to the decrease in persimmon stem density over time, a pattern that has been found in other mature forests (Christensen 1977, Skallerup 1953). Our sampling plots were located along forest edges and in open forest habitat, better habitat for persimmon trees, habitat in which persimmon densities have been shown to increase through time (Adams 1982, Barcus *et al.* 1978, Twedt & Wilson 2002). However, to provide the most conservative estimate of persimmon fruit available to PERI, we used the lower stem density of 4.3 in our calculations, although this likely underestimates persimmon fruit production, as discussed below.

Persimmon is an early successional species, thriving in open, early successional woodlands and forests, and commonly found along fencerows, roadsides, and other forest edges (Adams *et al.* 1982, Lashley *et al.* 2014, Steyermark 1940, Trammel & Carriero 2011). It can also be found in more mature forests (Christensen 1977, Skallerup 1953). Our estimates of persimmon habitat at PERI were based on published NPS data. Diamond *et al.* (2013) mapped nine vegetative community types at PERI. In their sampling plots, they found persimmons most frequently in four community types: Upland Deciduous Woodland and Forest (10 of 12 plots), Dry Deciduous Woodland and Forest (4 of 4 plots), Ruderal Grassland and Shrubland (6 of 8 plots), and Eastern Red Cedar Woodland and Forest (8 of 13 plots, Table 1). In our initial surveys at PERI, we also found persimmon trees most commonly in these four vegetative communities. We used the area of these four community types, which covers 82% of the park, to estimate persimmon habitat at 1423 hectares (3516 acres). Excluded from our estimate of persimmon habitat: Developed Land, Marsh, Bottomland Deciduous Woodland and Forest, Silver Maple Forest, Restored Tallgrass Prairie, and Mowed Grassland.

Table 1. Area (in hectares) of each vegetative community type at PERI, showing the mean % cover of persimmon in each community type. Data from Diamond et al. 2013.

Vegetative community type	Hectares	% of park	Mean % cover of persimmon
Included as persimmon habitat			
Eastern Red Cedar Woodland and Forest	273	15.8	1.6
Upland Deciduous Woodland and Forest	810	47.0	4.51
Ruderal Shrubland and Grassland	147	8.5	6.12
Dry Deciduous Woodland and Forest	194	11.2	0.67
Excluded as persimmon habitat			
Mowed Grassland	230	13.3	0.5
Restored Tallgrass Prairie	24	1.4	3.0
Silver Maple Forest	3	<1	0
Bottomland Forest	22	1.3	0
Marsh	<1	<1	3.0
Developed Land and Water	23	1.3	0

At-Risk Assessment

The At-Risk Assessment tool generates scores from five broad categories: life history, effects of harvest, species abundance and range, habitat vulnerability, and market demand (Castle *et al.* 2014). These sub-scores are then added together to generate a final score. Lower scores indicate a relatively lower risk of overharvest than higher scores. Because the tool uses standardized questions, scores can be compared between species to assess which are most at risk. The scores are relative, with no threshold number representing "at-risk" of overharvesting (Castle *et al.* 2014).

To assess whether persimmon tree populations would be at risk of overharvesting, we (Kindscher and Moody) each scored harvest of persimmon fruit independently based upon our knowledge of persimmon ethnobotany and ecology. Results were compared and discussed until consensus was reached for each of the sub-section scores. These sub-scores were added together to get the final "at-risk" score. Our scores were also reviewed by the lead author of the At-Risk Assessment Tool (Castle *et al.* 2014).

Results

Persimmon Fruit Yield Estimate

In 2019, we counted 117 trees in our nine belt transects. The average tree height was 8.9 m, with an average DBH of 11.5 cm. Fifty-three percent of all the trees produced at least one fruit. The average number of fruits per tree was 50.6, and the maximum was 676. In 2020, the average fruit production per tree was 43 fruits, with a range of 3 to 300 fruits being produced on a single tree. In both 2019 and 2020, over two-thirds of the trees produced more than 10 fruits. Fruits per tree is calculated across all trees, not just fruit bearing trees.

We specifically compared fruit production of the 25 trees that were matched between 2019 and 2020. A paired t-test indicated there was no difference in per tree fruit yield between years (mean 2019 = 94.22, mean 2020 = 86.72, $t = 0.196$, $p = 0.846$). This indicated no significant interannual variation in fruit production. Thus, we averaged mean per-tree fruit production from all trees in 2019 and 2020 (48.6 fruits per tree) to use in our estimate of total persimmon fruit production at PERI.

Using a combination of our field collected data on fruit production (48.6 average fruit per tree), estimate of percentage of trees producing fruit (50%), published records of persimmon stem density (4.3 stems per hectare, Leis 2018) and estimates of persimmon habitat (1,423 hectares, Diamond *et al.* 2013), we calculated a conservative estimate of 143,182 persimmon fruits produced annually at PERI. We weighed 100 persimmon fruits at 1.39 kg/100 fruit. Thus, the total estimated yield of persimmon fruit at PERI is approximately 1,990 kgs of persimmon fruits/year. In consultation with the Osage, we estimated that they would likely collect between 9-15 kgs (20-30 lbs.) of persimmon fruit each fall during a collecting trip by youth and elders. This amount represents between 0.5% and 0.8% of the total estimated persimmon yield at PERI, an amount which could be sustained without harm to the persimmon population or the ecosystems.

At-Risk Assessment

Based on the At-Risk Assessment Tool (Castle *et al.* 2014), we scored persimmon at 19 out of a maximum of 96, indicating a low risk of being overharvested, as high scores indicate a greater risk of over-harvest. Below we discuss, in detail, the scoring of each category and sub-category of the assessment with scores reported in Table 2. Note that negative scores are possible for some sub-sections, which subtracts from the overall score (Castle *et al.* 2014).

Scoring Category 1: Life History

Life history traits such as life-span and reproductive strategy have a large impact on the risk of a species being overharvested. For example, long-lived species that do not reach sexual maturity for many years are at high risk, especially when the whole plant is harvested. In contrast, species that reach sexual maturity rapidly and/or produce many seeds have a lower risk of being overharvested. Risk of overharvest increases for species that depend upon specialized animal relationships for pollination or seed dispersal but decreases for species that reproduce asexually or that can withstand some level of disturbance.

While persimmon trees are long-lived, with optimal fruit bearing age between 20-50 years (Glasgow 1977, Halls 1990), younger trees can produce fruit (Godell 1982, Iverson 1999), and fruit harvest is not destructive to the maternal plants (sub-section 1.0). At optimal fruit bearing age, a large female tree can produce several hundred fruits, each containing six or more seeds (sub-section 1.1, Reich 1991). Seed germination ranges between 45-88%, and seeds do not require passage through animal gut for germination (Rebein *et al.* 2016, Roehm & Moran 2013). Seedlings can be found in the wild (Leis 2018) but are not common (sub-section 1.4). Persimmons can also reproduce asexually through root suckers (Reich 1991), often resulting in groves with all trees of the same sex (sub-section 1.3). As an early successional species, persimmon tolerates high light levels and some level of disturbance (Baskin & Baskin 2000, Nelson *et al.* 2008, Wade 1989), though frequent or high intensity disturbance can be detrimental (sub-section 1.2, Nelson *et al.* 2008). Persimmons do not rely on specific animal species for seed dispersal. Bees are found abundantly on trees when flowering (Fletcher 1942), and there are no reports of specialized pollinators for persimmon (sub-section 1.5). For the Life-History section, we scored persimmon a 6, out of a possible range from -6 to 22 (low to high risk, Table 2).

Scoring Category 2: The Effect of Harvest

The effects of harvest on individual plants and their populations could have a large impact on the risk of overharvest. Harvesting of roots or whole plants is more destructive than harvest of only above-ground parts. Risk of overharvest is increased with either the length or frequency of the harvest season.

While collecting persimmon fruits does not damage the maternal plant, it does remove seeds from the population, potentially reducing recruitment of new persimmon seedlings in subsequent years (sub-section 2.0). Persimmon fruits ripen in the fall, and they are harvested once a year, typically in October and November. Not all fruits ripen at the same time and some fruits can remain on the tree all winter (sub-sections 2.2 and 2.3). There is no indication that harvesting fruits one year will reduce fruit production the following year (sub-section 2.1). We scored the collection of persimmon fruits a 6 out of a possible range of -2 to 18 (low to high risk) in this section (Table 2)

Table 2. Assessment Scores for Common Persimmon (*Diospyros virginiana* L.) using the At-Risk Assessment Tool (Castle et al. 2014), compared to the minimum and maximum possible score for each section and sub-section.

	Persimmon score	Min score	Max score
1. Life History			
1.0 Life Span	4	4	12
1.1 Age at First Reproduction	2	-2	2
1.2 Disturbance Tolerance	0	-2	2
1.3 Vegetative Reproduction	-2	-2	2
1.4 Seed Reproduction	0	-2	2
1.5 Interactions	-2	-2	2
Life History Total	2	-6	22
2. Effect of Harvest on Plant			
2.0 Plant Part Harvested	8	4	12
2.1 Post-Harvest Recovery	-2	-2	2
2.2 Harvest Interval	0	-2	2
2.3 Length of Harvest Season	0	-2	2
Effect of Harvest Total	6	-2	18
3. Abundance and Range			
3.0 Natural Abundance	8	4	12
3.1 Range - Current Population Size	-2	-2	2
3.2 Changes in Population Size	0	-2	2
3.3 Habitat Specialization	-2	-2	2
Abundance and Range Total	4	-2	18
4. Habitat			
4.0 Habitat Vulnerability	4	4	12
4.1 Habitat Acreage	-2	-2	2
4.2 Habitat Fragmentation	-2	-2	2
4.3 Soil Type	0	0	2
4.4 Threats to Habitat	0	0	2
Habitat Total	0	0	20
5. How Much is Needed			
5.0 Annual Demand	8	4	12
5.1 Yield per Acre	-2	-2	2
5.2 Alternatives	2	-2	2
5.3 Cultivation Status	-1	-2	2
Demand Total	7	-2	18
Overall Total	**19**	**-12**	**96**

Scoring Category 3: Species Abundance and Range

Widespread plant species are at lower risk for overharvest than those found in a narrow geographic range. Likewise, species that have a broad ecological range, with the ability to survive and grow in many different environments, are at a lower risk for overharvest than species that require a specialized environment. The risk is also lower for species with large, stable populations.

Persimmon trees are found throughout the east-central and southeastern United States (Figure 1) and have been naturalized outside their native range in California, Utah, and Arizona (Burge 2018). Within this broad range, populations can be scattered but locally dense. Thus, persimmons are neither rare nor incredibly abundant (sub-section 3.0). Persimmon has a broad ecological range and does not require specialized habitat (sub-sections 3.1 and 3.3), being found in long-leaf pine forests (Addington *et al.* 2015, Gilliam *et al.* 1993), abandoned agricultural fields (Barcus *et al.* 1978), bottomland forests (Brown & Peterson 1983, Nixon *et al.* 1977), upland forests (Hoff *et al.* 2018), along grassland edges (Adams *et al.* 1982), and in urban woodlands (Trammel & Carreiro 2011). The effect of harvest on persimmon populations is unknown, however, given that harvesting fruits does not destroy the tree, it seems unlikely that harvest would result in a significant decrease in population size (sub-section 3.2). Overall, we scored the harvest of persimmon fruits a 4 in the Abundance and Range section which ranges from a possible -2 to 18 (low to high risk, Table 2).

Scoring Category 4: Habitat

Species limited to vulnerable habitats are at higher risk of overharvest and plant species are safe from overharvest only to the degree that their habitat is protected. In addition to outright habitat destruction due to human activity, habitat can be threatened due to fragmentation, invasive species, disease, and climate change. The presence of these threats increases the risk of overharvest.

Persimmons can grow in a wide range of habitats, and while a specific habitat type may be vulnerable (i.e., high-quality forest), overall, persimmon habitat is not vulnerable, as it is widespread (sub-section 4.0 score = 4). Furthermore, some common persimmon habitat such as roadsides and old fields, are expected to continue to increase (sub-section 4.1) and persimmons may benefit from habitat fragmentation of large swaths of forest (sub-section 4.2). Persimmons are not confined to a specific soil type (sub-section 4.3) and human activities such as mining or grazing do not pose a specific threat to persimmon habitat (sub-section 4.4). We scored the harvest of persimmon fruit 0, out of a possible range of 0 to 20 (low to high risk) for the Habitat section (Table 2).

Scoring Category 5: Market Demand

Plant species with greater market demand will be at higher risk of overharvest, as economic pressures increase the amount harvested from the wild. This risk will be reduced by the availability of cultivated varieties or alternative species.

Currently, persimmon has a negligible local market, and there is no global market. We estimated that total demand in the U.S. would be between 1 and 10 tons (dry weight) per year, a relatively low amount (sub-section 5.0). Though if persimmon fruit are popularized as a superfood, the demand could change, impacting this score. For the purposes of the At-Risk Assessment, we estimated the yield per acre to be over 10 pounds (sub-section 5.1). The flavor and texture of persimmons are unique. The Asian persimmon (*Diospyros kaki* L. f.) is a cultivated species that is similar, but it is not easily and widely accessible (sub-section 5.2), and for many reasons not a suitable substitute. Although efforts have been made through the years to encourage cultivation (Goodell 1982, Troop & Hadley 1896), widespread cultivation has not occurred (sub-section 5.3). We scored the harvest of persimmon fruits 7 out of a range of -2 to 18 (low to high risk, Table 2).

Combined Total Score

Overall, based on the sums of scores above of the At-Risk Assessment Tool (Castle *et al.* 2014), we scored persimmon at 19 out of a maximum of 96, indicating a low risk of being overharvested, as high scores indicate a greater risk of overharvest.

Discussion

The Osage Nation is interested in reviving the traditional practice of collecting persimmon fruit. Recently, the Osage Nation Historical Preservation Office sponsored a project in which tribal members collected persimmon fruit to make persimmon 'cakes' using the traditional methods described by La Flesche (Polacca 2013). Given the historical importance of persimmon, and the current interest by the Osage, there is strong justification for the Osage to return to their traditional practice of harvesting persimmons on traditional territorial lands at PERI under the NPS's 2016 "Gathering of Certain Plants or Plant Parts by Federally Recognized Indian Tribes for Traditional Purposes" rule. Our data and analysis provide evidence that the traditional gathering of persimmon fruits could be sustainable if the Osage are interested in entering into such an agreement.

We estimated the persimmon trees at PERI would produce approximately 143,000 persimmon fruit (1,990 kgs) annually. Estimating fruit production of a tree species across a large area is a challenge, made more difficult with limited time and resources. We were fortunate that there were published NPS data for PERI on both persimmon tree densities (Leis 2018) and a map of vegetative community types (Diamond *et al.* 2013) from which we could estimate persimmon habitat. We were able to integrate this information with our field surveys of fruit production to obtain a relatively conservative estimate of fruit yield.

We developed scientifically sound methodology that we hoped would engage Osage youth and elders in a citizen science outreach project through data collection on persimmon fruit production. However, due to scheduling conflicts in 2019 and the restrictions imposed by the Covid-19 pandemic on travel in 2020, we were unable to include Osage youth and elders in data collection. We placed our transects in good persimmon habitat that was also easily accessible, the types of locations where the Osage could easily collect persimmon fruit in the future. Fruits were counted after leaf-fall began when fruits were ripe and easily visible. We saw little evidence of fruit fall and no evidence animal scat containing persimmon seeds, indicating that most fruits were still on the trees at the time of counting.

Persimmon tree density varies across its geographic and ecological range, and 4.3 trees/hectare is at the low end of published persimmon tree densities (Table 3). Using Leis' lowest estimate of persimmon trees density (4.3 per hectare Leis 2018), leads to a conservative estimate of persimmon tree density across all of PERI. Her data were taken from plots located in the Upland Deciduous Forest type. They were specifically placed away from edge habitat, where persimmon trees thrive. While persimmons can be found in mature upland forests, they are also found in many other forested ecosystems (Barcus *et al.* 1978, Hoff *et al.* 2018, Lashley *et al.* 2014, Nixon *et al.* 1977, Wall & Darwin 1999), including as a pioneer species in successional woodlands (Baskin & Baskin 2000, Steyermark 1940), and even along the borders of grasslands (Palmer 1921). Our fruit-counting transects were mainly located in areas mapped as Ruderal Grassland and Shrubland by Diamond *et al.* 2013. Since our goal was to determine a sustainable level of harvest, we felt this conservative approach to estimating fruit yield was appropriate, and it is likely that there are more persimmon fruits available at PERI than our estimate suggests.

The vegetative management at PERI will favor continued persimmon habitat. The management plan for PERI is to maintain the land close to its appearance during the 1862 U.S. Civil War Battle (National Park Service 2014). During that time, the landscape was a combination of agricultural fields, open woodlands, and Arkansas Highlands Forest (National Park Service 2014). Since 1862, fire suppression and disturbance have led to an increase in density of oak-hickory forest. The vegetative management plan for PERI calls for thinning 140 hectares of open woodlands and 1062 acres of forest. Eastern Red Cedar (*Juniperus virginiana*) has become prominent in many post-1862 agricultural fields and disturbed woodlands at PERI; in 2014 there were 759 acres of red cedar compared to the 4-10 acres in 1862. The vegetation management plan calls for the removal of red cedar through prescribed burns and cutting to reduce cover to only 4-10 acres of the park (National Park Service 2014). Opening of forest through the thinning of overstory trees and removal of red cedar will promote persimmon habitat and fruiting. Persimmon trees in long-leaf pine forests had higher fruit production when located near fire breaks (within 25 m) (Lashley *et al.* 2014). Although intense fires can, in the short term reduce persimmon stem density (Taft 2003), persimmon trees easily resprout and are relatively fast growing and the reduced density of trees in the forest will create better persimmon habitat (Adams *et al.* 1982, Boyer & Carter 2011, King & Antrobus 2005, Nelson *et al.* 2008, Twedt & Wilson 2002).

We proposed that 9-15 kgs (20-30 lbs.) of persimmon fruit can be harvested sustainably each year at PERI, without harm to the persimmon populations or other plants or wildlife at PERI. The total At-Risk Assessment score of 19 (range -12 to 96) indicates there is very little risk of persimmon fruit being overharvested. This low risk of overharvesting persimmon fruits is due, in part, to ample persimmon fruit production, the harvest of which is not destructive. The wide geographic and ecological range of persimmons and weak demand for persimmon fruit also contribute to the low At-Risk score. In a review of 40 plant species, Castle *et al.* (2014) found At-Risk scores to range from 9 for common nettles (*Uritca dioca*) to 75 for sandalwood (*Santalum* spp), a long-lived, slow-growing tree harvested for its wood. Harvesting persimmon fruit does not destroy the parent tree, which is left to produce more fruit in future years. In a review of five studies of sustainable harvest of fruit from tree species, Ticktin (2004) found 80-95% of fruits could be harvested without influencing future population growth. The proposed harvest of 9-15 kg (20-30 lbs.) is less than 1% of our estimate of total persimmon fruit yield at PERI. Persimmon trees can also propagate asexually, providing another mechanism for maintaining population size. While foxes, raccoons, opossums, and coyotes are all known to eat persimmon fruit (Glasgow 1977, Rebein *et al.* 2016, Roehm & Moran 2013), none are dependent upon it as their only food source. Removal of less than 1% of the fruit production would ensure copious amounts of persimmon fruit are still available to wildlife at PERI.

Table 3. Estimates of persimmon tree (*Diospyros virginiana* L.) stem density for different habitats extracted from published studies. Ranges are given for studies that examined stem density through time or for different treatments. Where noted, stem density was converted to stems per hectare (ha). Note that the Leis (2017) values are taken at PERI. AR – Arkansas, GA – Georgia, IL – Illinois, KY – Kentucky, LA – Louisiana, MS – Mississippi, NC – North Carolina, TX – Texas.

Stems/ ha	Life Stage	Habitat Type	Comments	Source
0.5	> 2.5 cm dbh	Immature Oak-Hickory Forest, NC	1977	Christensen 1977
1.9	Overstory Trees > 10 cm dbh	Cross Timbers Forest, OK		Hoff et al. 2018
4.1	> 2.5 cm dbh	Immature Oak-Hickory Forest, NC	1952	Christensen 1977
4.3	> 5 cm dbh	Upland Deciduous Forest, AR	2016	Leis 2018
6.7	21-30 cm dbh	Old-Growth Floodplain Forest, TX		Nixon et al. 1977
7.1	> 5 cm dbh	Upland Deciduous Forest, AR	2012	Leis 2018
8.6	> 5 cm dbh	Upland Deciduous Forest, AR	2007	Leis 2018
12	>2.54 cm dbh	Old-Growth Bottomland Forest, IL		Brown and Peterson 1983
25	> 61 cm tall, < 5.1 cm dbh	Bottomland Hardwood Forest, IL	One year after tornado	Nelson et al. 2008
38.3	> 4.5 feet tall	Mixed Pine and Hardwood, GA	Average in unburned forest	Wade et al. 1989
38.5	at least 0.5 m tall	Reforested Agricultural Land, MS	Before reforestation	Twedt and Wilson 2002
58.7	> 4.5 feet tall	Mixed Pine and Hardwood, GA	Average in burned forest	Wade et al. 1989
100	> than 61 cm tall and < 5.1 cm dbh	Bottomland Hardwood Forest, IL	Two years after tornado	Nelson et al. 2008
141.5	at least 0.5 m tall	Reforested Agricultural Land, MS	After reforestation	Twedt and Wilson 2002
150	>2.54 cm dbh	Forested Verges of Interstate Corridors, KY	I- 64 near Louisville, KY	Trammell and Carreiro 2011
178	> 61 cm tall, < 5.1 cm dbh	Bottomland Hardwood Forest, IL	Three years after tornado	Nelson et al. 2008
281.5	> 2 m tall	Bottomland Forest, LA		Wall and Darwin 1999
350	>2.54 cm dbh	Forested Verges of Interstate Corridors, KY	I-65 near Louisville, KY	Trammell and Carreiro 2011
2,000	> 10 cm DBH	Mature Upland Pine Forest, GA	Scaled up from stems/m^2	Addington et al. 2015
12,000	Reproductively Mature	Long-Leaf Pine Forests, NC	Scaled up from stems/m^2	Lashley et al. 2014

Conclusion

Our work demonstrates that the use of the At-Risk Assessment tool, in conjunction with field data on persimmon fruit production, and NPS data on persimmon tree density at PERI provided evidence for the sustainable harvest of persimmon fruits. Importantly, these methods allow for such an assessment in a relatively time- and cost-effective manner. Our process outlined here can be used for other sustainable harvest analysis. In this work, the information we provided to the NPS about the sustainability of persimmon fruit harvest at PERI was necessary to potentially develop a collecting agreement between the Osage Nation and the NPS for harvesting persimmon at PERI.

Declarations

List of Abbreviations: PERI - Pea Ridge National Military Park, NPS - National Park Service
Ethics Approval and Consent to Participate: No human participants were involved in this study
Consent for Publication: Not applicable
Availability of Data and Materials: Original data are available through the corresponding author.
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