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Producers, production, marketing, and sales of non-timber forest products in the United States: a review and synthesis

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Abstract Non-timber forest products (NTFPs) are derived from natural populations of plants or fungi, or farmed in forests. Harvesters and producers often benefit from NTFPs by selling them to generate income. This article explores research on the producers, production, marketing, and sales of NTFPs in the United States, including the continuum of production from wild-harvesting to forest farming of NTFPs, and their costs and benefits. Specific examples are presented, but the concepts and generalizations are broadly applicable to many NTFPs throughout the U.S. and other parts of the world. Integrating NTFPs into forest management can enhance economic opportunities but also will increase complexity, and will entail balancing multiple and potentially conflicting objectives among a diverse community of stakeholders. We identify information gaps including the need for inventories and yield models of NTFPs, understanding the effect of silvicultural activities on NTFP survival and yield, time series and trends in collection of NTFPs by U.S. households, identification of vulnerable and marginalized communities associated with NTFP harvest, and harvesters' motivations and drivers.

Keywords Forest farming · Wild-harvest · Stewarding · Conflicts · Economics

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Introduction

The term "non-timber forest product" (NTFP) has many definitions around the world, depending on region, country, institution, and author (Belcher 2003). In the United States, NTFPs include a broad class of plant and fungi-derived products, originating from forests (Chamberlain et al. 2018a) (see Table 1 for a list of some common NTFPs from the U.S.). In the U.S., animal products from forests (e.g., from hunting or trapping) are generally grouped into a separate category as game/wildlife/fish. NTFPs may be produced along a continuum of production intensity from harvesting of natural populations (wild-harvest), to stewarding natural populations, to managing forests for NTFPs, to intentional forest farming. Often, NTFPs are classified based on their purpose, including: (1) edible/culinary, (2) medicinal/supplement, (3)

Table 1 Some common nontimber forest products from the United States. This list is not comprehensive, but is indicative of the breadth and diversity of the group of products. *Source*: Adapted from Chamberlain et al. (2018b, appendix 4)

Scientific name	Common name	Harvested organ	Use/market segment	Region[a]
Abies spp.	Fir	Bough and whole plant	Decorative	GP, MW, NE, NW, SE, SW
Acer saccharum	Sugar maple	Sap	Edible	NE
Actaea racemosa	Black cohosh	Root	Medicinal	NE, SE
Allium tricoccum	Ramp; leek	Whole plant	Edible	NE, SE
Asimina triloba	Pawpaw	Fruit	Edible	NE, SE
Betula papyrifera	Paper birch	Bark	Decorative	MW, NE
Boletus spp.	Bolete	Fruiting body	Edible	NW
Cantharellus spp.	Chanterelle	Fruiting body	Edible	GP, MW, NE, NW, SE, SW
Dioscorea spp.	Wild yam	Tuber	Edible; medicinal	GP, MW, NE, P, SE
Echinacea spp.	Coneflower; echinacea	Root; leaf; stem	Medicinal	GP, MW, NE, SE, SW
Fraxinus spp.	Ash	Wood	Crafts	NE, SE
Galax urceolata	Galax	Leaf	Decorative	SE
Gaultheria shallon	Salal	Leaf	Decorative	NW
Gaylussacia spp.	Huckleberry	Fruit	Edible	NW
Hamamelis virginiana	Witchhazel	Bark	Medicinal	GP, MW, NE, SE
Hydrastis canadensis	Goldenseal	Root and leaf	Medicinal	GP, MW, NE, SE
Juglans nigra	Black walnut	Fruit	Edible; medicinal	GP, MW, NE, SE, SW
Ligusticum porteri	Osha	Root	Medicinal	GP, SW
Matteuccia struthiopteris	Ostrich fern "fiddlehead"	Leaf	Edible	GP, MW, NE
Morchella spp.	Morel	Fruiting body	Edible	C, GP, MW, NE, NW, P, SE, SW
Muhlenbergia spp.	Sweetgrass, deergrass	Leaf	Crafts	SE
Panax quiquefolius	American ginseng	Root	Medicinal	MW, NE, SE
Pinus spp.	Pine	Needle; cone	Landscaping; decorative	MW, NW, SE
Pinus spp.	Pinyon	Seed	Edible	SW
Rubus spp.	Raspberry; blackberry; salmonberry	Fruit	Edible	GP, MW, NE, NW, SE, SW
Sambucus canadensis	American elderberry	Fruit	Medicinal; edible	GP, MW, NE, SE, SW
Sanguinaria canadensis	Bloodroot	Root	Medicinal	NE, SE
Serenoa repens	Saw palmetto	Fruit	Medicinal	SE
Taxus spp.	Yew	Bark	Medicinal	NW
Tricholoma magnivelare	American matsutake	Fruiting body	Edible	NW
Trillium spp.	Trillium	Whole plant	Decorative; landscaping	MW, NE, SE
Vaccinium spp.	Blueberry; cranberry; huckleberry	Fruit	Edible	GP, MW, NE, NW, SE
Xerophyllum tenax	Beargrass	Leaves	Decorative	NW

[a]Regions refer to areas where the products are commonly harvested: C = Caribbean; GP = Great Plains; MW = Midwest; NE = Northeast; NW = Northwest (including Alaska); P = Pacific Islands (including Hawai'i); SE = Southeast; SW = Southwest

decorative/floral, (4) nursery/landscaping, and, (5) arts/craft products (Chamberlain et al. 2017). The variety of species used to produce these products is vast; more than 350 plant and fungus species have been identified as providing NTFPs in the United States (Chamberlain et al. 2018a). Each species has its own life cycle, habitat requirements, and phenological characteristics to consider in production (Ticktin 2015).

NTFPs contribute to farm and household economies through non-market and market channels. Non-market channels include subsistence and home consumption of products, collection for cultural or recreational purposes, and giving of gifts (McLain et al. 2008). NTFP production, marketing, and sale through market channels, and the people that undertake these activities, are the focus of this manuscript. The total wholesale market size of NTFPs in the United States has been estimated to range from approximately \$800 million to \$1 billion annually (for the years 2004–2013) (Chamberlain et al. 2018b).

Comprehensive and consistent scientific information about NTFP production and sale in the United States is scarce. The objective of this manuscript is to consolidate and synthesize knowledge about NTFP producers, production, marketing, and sales, and identify research needs focusing on NTFP harvest for income generation. Examples from the U.S. Southeast, Pacific Northwest, and Northeast are presented, but the concepts and generalizations are broadly applicable throughout the U.S. and other parts of the world. We hope that such synthesis will inform producers, land managers, and decision-makers, and stimulate more research, to improve integration of these products into forest management and valuation.

A few notes are in order. Throughout the text, we use the terms "harvest," "collect," and "gather" interchangeably. We use the terms "harvest" and "harvester" in connection to collection of NTFPs from natural populations, whereas "produce," "producer," and "production" are umbrella terms that include forest farming and collection from natural populations. When the two are used together, produce/producer/production can be understood to refer to forest farming. When discussing economics and profitability, we use the financial indicators net present value (NPV) and soil expectation value (SEV), which are common in forest resource economics literature, and are mathematically related. Both indicators discount future dollars relative to present dollars, but NPV is calculated over a finite time horizon, whereas SEV is over an infinite time horizon. In either case, a positive value indicates profitability at a rate higher than the stated discount rate (Mercer et al. 2014). Such discounting is fundamentally important in forest resource economics, to account for the opportunity cost of time needed generate products over many years, but discounting is not common in NTFP literature.

Wild-harvest

Frequently, NTFPs are harvested from natural populations of plants and fungi in intact forests with little or no management of the resource, which is considered "wild-harvesting." Some people who consider themselves wild-harvesters may practice minimal management, which is discussed more below in the section on Stewarding of Natural Populations.

Wild-harvesting takes place on private and public forests, with and without permission from the landowner or manager. About one quarter of private family forest landowners report NTFP harvest on their property (Butler et al. 2016), but little is known about which species, with what frequency, or quantity of harvest. With regard to public lands, most National Forests and Bureau of Land Management lands allow harvesting of some NTFPs, but few have management plans or specific prescriptions for maintaining or enhancing these resources (Chamberlain et al. 2002, 2018a; Jones et al. 2004). State policies and regulations on harvesting NTFPs vary widely. Some states, such as Idaho have no regulations for managing harvests, while others, such as Arizona and Washington have specific rules concerning harvest of these products (De Angelis et al. 2018). Many, but not all, states allow NTFP harvest in State Forests (Frey and Chamberlain 2016; Jones et al. 2004).

In general, wild-harvesting can be an attractive way to earn income, particularly for low-income individuals, as it is a low cost endeavor, with little planning required and few expensive inputs. It requires some ecological knowledge, perhaps a permit or contract to access the forest, labor, transportation to and from the harvest site, and often little or no equipment (Chamberlain et al. 2017). Ecological knowledge, the wisdom and experience about ecological communities passed down within communities or through generations, is a key input to wild-harvesting (Ballard and Huntsinger 2006; McLain et al. 1998), but is extremely difficult to quantify or estimate its value (Frey et al. 2020a). Harvesters may need a permit to collect on public lands (Alexander and Fight 2003; Ballard and Huntsinger 2006; Carroll et al. 2003; Schlosser and Blatner 1997), but this requirement is not universal across all districts or forests and may depend on the purpose or volume of the harvest. "Free-use" (a.k.a. "personal-use" or "recreational") permits may have limits on volumes collected but no fee, whereas "charge-use" ("commercial") permits allow collection of larger volumes for a fee (Alexander and Fight 2003; Hansis 1998). Also, some Native American tribes do have treaty rights to harvest on certain public lands without a permit. Access to private forest lands often is through an informal agreement based on a social relationship (Hembram and Hoover 2008), although pay-for-access contracts or leases are common for some particular products such as pine straw for landscaping mulch, edible mushrooms, or floral products (Casanova 2007; Schlosser and Blatner 1997).

Labor and transportation are the other major expenses of wild-harvesting, which are seldom incorporated in valuing the resource (Chamberlain et al. 2017; Frey et al. 2020a). Some NTFP businesses hire individuals or crews of harvesters, as described in more detail in the section on producers, but labor costs frequently are the opportunity costs of unpaid self- or family-employment. Although the amount of time involved in wild-harvesting can be high, in many cases there are few alternative income-generating opportunities, meaning the opportunity cost per hour is relatively low (Chamberlain et al. 2017). As the costs of wild-harvesting are generally the harvesters' time, more common plants tend to be harvested in larger amounts than rare species that are challenging to find (Chamberlain et al. 2019). However, some rare species are subject to intense harvesting pressure when there is high demand, harvesting that causes mortality, and slow reproduction (Frey et al. 2018).

Economic values of wild-harvesting activities have rarely been estimated, as accurate estimates require detailed and nuanced understanding not just of species population characteristics, but also harvester behaviors (Frey et al. 2020a). A few estimates of the SEV of wild-harvested mushrooms in the Pacific Northwest ranged from about $17/ha to $2,500/ha at 4% discount rate, depending on site and species, as well as numerous assumptions, underscoring the highly variable nature of the enterprise (Alexander et al. 2002; Pilz et al. 1998, 1999). Estimates also would vary depending on the amount of time and resources allocated by harvesters to stewarding or managing natural populations.

Stewarding of natural populations

The wide range of plant and fungi components that are harvested for NTFPs from natural populations creates challenges for stewardship or management (Chamberlain et al. 2019). The species' life history traits and the specific component harvested are important for the population's resilience and the potential for sustainable management (Ticktin 2015). Harvest that causes adult mortality, change the population structure, or reduce genetic diversity, such as taking whole plants, bark, roots, or other below-ground components, is more challenging to manage, and have higher potential of unsustainable harvests. Conversely, species that grow rapidly and have high reproductive rates usually recover from harvests more rapidly.

Often, wild-harvesters "steward" natural populations by nurturing reproduction. Some harvesters may limit harvest to a portion of the populations; propagate seeds, spores, or vegetative material; limit site disturbance; or take other actions (Ballard and Huntsinger 2006; Burkhart et al. 2012; Pilz and Molina 2002). Such stewardship approaches are often guided by local ecological knowledge, which can come from years or generations of experience, and in some cases influenced by policy. In the case of American ginseng (*Panax quinquefolius*), wild-harvesters may be required to adhere to harvest seasons, and re-plant seeds from harvested plants. Rotating gathering sites, regulating harvest intensity and frequency, replacing immature bulbs and corms and pieces of rhizome are reportedly techniques used by wild-harvesters to encourage sustainability (Anderson 2013). Native American communities frequently have approaches for promoting natural plant and fungus populations, such as fires used to promote berry and root production, based on traditional ecological knowledge (Carroll et al. 2003). "Rules of thumb" for use and management derived from local or traditional ecological knowledge may or may not align with conventional scientific knowledge (Ballard and Huntsinger 2006; Hummel and Lake 2015). The scale of this type of management has received insufficient research to verify impacts on sustainability of the resources. Silvicultural prescriptions designed for timber may enhance the impacts of stewardship by wild-harvesters.

Management and joint management with timber

Management of natural populations of NTFP species entails a broad range of activities. Fundamentally, knowledge is needed on what is in (inventory) and going into (reproduction) the ecosystem, and what is going out (harvest and mortality). The potential for sustainable harvest is greatest as long as what is going into the ecosystem exceeds what is going out. An inventory of the product is a starting point to determine how much can be harvested. Trees that produce NTFPs, such as slippery elm (*Ulmus rubra*) for its bark or sugar maple (*Acer saccharum*) for syrup, are typically included in forest inventories and the stock of NTFP can be estimated (Kauffman et al. 2015); however, understory plants and fungi are generally not monitored. In an effort to address this challenge, Chamberlain et al. (2013a) created a model to estimate the relationship of above-ground vegetation to the harvestable stock of below-ground rhizome of black cohosh (*Actaea racemosa*). Small and Chamberlain (2018) found recruitment of black cohosh new cohorts inadequate for sustainable management after moderate rates of harvest. Estimates of black cohosh growth rates, however, are elusive at this time.

Jointly managing forests for multiple uses is widely accepted practice (Ellum 2007). Forests can be managed for joint production of NTFPs with such goods as timber, fuelwood, and forage as well as services such as watershed protection and biodiversity conservation. Silvicultural practices designed for timber production can be applied to co-manage forest resources for nontimber (Chamberlain et al. 2018a). As an example, thinning to improve timber production can change the overstory in such a way as to favor certain understory NTFP plants (Kerns et al. 2004). Managing for species that grow best in mature forests with dense shade, more consistent soil moisture, lower pH, etc., may require limiting thinning regimes and/or extending the rotation length for commercial timber harvest (Chamberlain et al. 2013b; Kranabetter et al. 2005; Pilz and Molina 2002). Other species may thrive under modest thinning regimes (Minore et al. 1979; Pilz et al. 1999). Harvesting systems that limit soil compaction may also mitigate negative impacts (Pilz and Molina 2002). Harvesting timber in the winter, when understory plants are 'dormant' allows for them to acclimate to changes in light and moisture regimes (Ellum 2007). Keys to integrated forest management include recognizing the ecological and economic importance of the products, and considering how silviculture can impact production. Four examples of joint management of forests for timber and NTFPs illustrate this: pines (*Pinus* spp.) for straw, noble fir (*Abies procera*) for boughs, sugar maple for syrup, and hardwood forests for American ginseng.

Pine straw, which are needles raked from the forest floor while the trees grow to timber size, to be used as landscaping mulch, is a major contributor to economies of southern states (Casanova 2007). The common practice is for companies to pay landowners an annual lease fee to harvest, with yields increasing as trees mature (Casanova 2007). The impacts of raking pine straw on production of timber, and site productivity is debatable. Removing the needles reduces fuel loads and the risk of wildfires, and may have long-term effects on carbon and nutrient balance, impacting site productivity (Gonzalez-Benecke et al. 2014). Fertilization is possible to mitigate nutrient loses, but the added costs must be compared to changes in productivity (Susaeta et al. 2012). With proper management, pine straw may be harvested with little or no impact to growth potential of trees (Dyer et al. 2015) but monitoring impacts to soils and productivity is essential. Susaeta et al. (2012) estimated that pine straw sales, including fertilization costs, increased SEVs from \$700/ha to \$5,100/ha at 4% discount rate, relative to timber sales alone.

The contribution of noble fir to the floral greenery industry of the Pacific Northwest, because of its colorful foliage, symmetrical branching and needle retention, has been recognized for decades (Douglass 1975; Murray 1988). Murray (1988) found that a noble fir plantation could provide annual bough harvest and produce timber volume within about 5 percent of that estimated for the favored Douglas-fir (*Pseudotsuga menziesii*). Using a variety of forest inventory biometrics and software, researchers developed methods to estimate the weight of harvestable boughs and assess the feasibility of jointly managing for sawtimber and boughs (Blatner et al. 2005, 2010; Fight et al. 2005). The estimated SEVs at 4% discount rate ranged from $325/ha to $4,650/ha, demonstrating potential profitability. Little is known about the long-term impact of bough harvest on tree growth, but any modest reduction in wood volume or quality would be more than offset by increased financial returns from the sale of boughs (Blatner et al. 2010).

Sugar and other maple species (*Acer* spp.) have been tapped for the sap and valued for their wood for hundreds of years (Whitney and Upmeyer 2004). However, managing to produce the highest possible yield of the sweetest sap per hectare, often necessitates that timber becomes subordinate (Lancaster et al. 1974; Sendak et al. 1982). Even though average loss in timber value due to tapping is less than 5% (Farrell 2012; Sendak et al. 1982), silvicultural prescriptions for tapping generally require reducing the number of trees, and increasing the rotation length (Lancaster et al. 1974). Mitigating these conflicts is part of the management decision process. Managing stands with these characteristics may not be conducive to timber production, although they may be more compatible with forest farming understory nontimber forest species, such as American ginseng.

American ginseng is a slow-growing plant that prefers undisturbed intact forests (Chamberlain et al. 2013b). Roots with characteristics that appear wild are highly preferred in the market, and in general, product with those characteristics is wild-harvested, although some landowners forest farm it using methods to simulate wild characteristics (see section on Forest Farming). Evidence indicates that harvesting timber from hardwood forests of eastern United States has impacted the survival, growth and reproduction of this important medicinal plant (Chandler and McGraw 2015). As American ginseng is one of a suite of medicinal plant species that grow in similar forest habitats, the other species may have been similarly impacted. Extending the rotation length and restricting entry timing into the stand when the understory species are dormant could improve production. Additional forest farming of ginseng and other medicinal forest plants may lead to better forest management.

Forest farming

Farming of NTFPs in forests is an alternative to harvesting natural populations. Forest farming is an agroforestry practice in which plants and fungi are cultivated in the unique microclimate created by an existing forest canopy (Chamberlain et al. 2009). Forest farming is advocated potentially to produce forest products in an ecologically sustainable way and to bring economic diversity to rural areas (Chittum et al. 2019). Forest farming involves establishing, managing, and harvesting an NTFP crop, and encompasses approaches with a spectrum of management intensities, from "wild-simulated" to "woods cultivated" and "woods grown" (some authors also consider management of natural populations to be a form of forest farming, but we keep them separate for purposes of this review) (Beyfuss 1999; Frey et al. 2020a). Intuitively, greater intensity of management leads to higher costs, but also larger yields per hectare. On the cost side, forest farming requires more labor and equipment than wild-harvesting, but generally utilizes less equipment and no artificial shade, and is therefore less expensive than field-based cultivation (Burkhart and Jacobson 2009).

Forest farming can generate products with similar qualities to those harvested from natural populations, in some cases providing a marketing advantage. The prime example is American ginseng, which has a unique international market in which consumers prefer "wild" characteristics (Davis and Persons 2014). The wild-simulated approach to forest farming American ginseng uses minimal inputs to mimic the "wild" product, thus deriving a significant price premium over field-cultivated product. Other forms of ginseng forest farming, such as woods-cultivated, involve more intensive practices such as tilling the soil, which yield greater quantities of a product that less-closely resembles wild and thus obtains a lower price (Beyfuss 1999). Although American ginseng is unique with this type of market that favors wild characteristics, growing forest plants in their native habitats may eliminate or reduce disease problems and potentially facilitate access to "organic" and other niche markets. Causative links have been made between choice of growing site and disease incidence and severity in some species (Albrecht and McCarthy 2006; McGraw et al. 2003; Thomas et al. 2006). There also may be differences in chemical constituent levels associated with where and how plants are grown (Bennett et al. 1990; Lim et al. 2005; Salmore and Hunter 2001). Finally, forest farming has the potential to increase income while maintaining forest integrity (Chamberlain et al. 2009). Income derived from forest farming is received at shorter intervals than timber, giving private forest landowners more revenue options, enabling them to pay annual taxes and other costs. It can also produce income from woodlots that are of marginal quality for timber or too small for economical timber harvest.

A number of studies have demonstrated the potential for commercial forest farming of edible mushrooms (Bruhn et al. 2010, 2009; Grace and Mudge 2015), and wild onions (*Allium tricoccum*; a.k.a. ramps, leeks) (Bernatchez et al. 2013), as well as medicinal plants such as American ginseng, and to a lesser extent black cohosh, goldenseal (*Hydrastis canadensis*), and bloodroot (*Sanguinaria canadensis*) (Beyfuss 1999; Burkhart and Jacobson 2009; Davis 1999; Davis and Persons 2014). However, studies rarely have incorporated opportunity costs for producers' labor or for the time between investment and return by use of a discount rate. Further, very few studies incorporate sensitivity analysis for key variables such as length of cropping period, material and labor costs, final yield, or prices (Burkhart and Jacobson 2009).

Burkhart and Jacobson (2009) showed that, considering these relevant opportunity costs, forest farming of American ginseng could be highly profitable—the equivalent of an SEV of $1,051,000 /ha at 4% discount rate (NPV of $152,610 /ha in a four-year period, grown from root transplants, at mean prices)—but seven other Appalachian medicinal plants would be unprofitable at mean prices. Goldenseal was the only other NTFP studied that could be potentially profitable, but only under the most optimistic scenarios of price, yield, and number of years to harvest (Burkhart and Jacobson 2009). Likely, the relatively large volume of low-cost wild-harvested product undercuts the price that would be necessary to generate a profit for these medicinal species (Burkhart and Jacobson 2009). Given the diminished wild populations of ginseng, profits are possible but risky, since that theft is common (Frey et al. 2018), and an investment in security (fencing, cameras, etc.) to eliminate theft would greatly reduce the returns.

Forest farming of certain edible and craft products, may be more likely to generate a profit, because the consistency of quality and production, and more local nature of markets. As an example, Frey et al. (2020b) found that a 500-log shiitake mushroom (*Lentinula edodes*) forest farming operation could generate equivalent to an SEV of $6,750, when converted to a 4% discount rate. Producers of forest farmed edible or craft products may be able to avoid transaction costs and realize greater product differentiation through more flexible marketing and sales strategies.

Marketing and sales

An essential first step for producers who want to sell their products is to determine what product to sell, and to whom. Market chains, or value chains, describe how products move from producers, through various levels of aggregation, value-adding, and distribution, to the final consumer (Frey et al. 2019). Participants in market chains include individuals and organizations of varying sizes. The types and sizes of the participating individuals and organizations, as well as the overall structure of the market chain depends on numerous factors relating to biology and ecology of the species, land ownership patterns, as well as demand for the product (Frey et al. 2019). In many cases, there are degrees of vertical integration in the market chain; that is, harvesters may work directly for an aggregating/processing company, or processors may manage retail outlets (Cernusca et al. 2012; Schlosser et al. 1991). Some aggregating/processing companies may work with harvesters and producers in an educational or marketing capacity. In other cases, the individuals and organizations that make up the market chain are independent and only loosely and informally connected (McLain et al. 2008). Finally, many government agencies (e.g., state cooperative extension services), non-profit organizations, and trade associations do not participate directly in the market chain, but assist producers through research, education, marketing, and advocacy. Some organizations fill various roles (e.g., educating, processing, marketing).

Once a plant or fungus is harvested, the harvester may choose to sell it unprocessed, or first perform some processing. Common simple first processing steps by harvesters include cleaning and/or drying (Frey et al. 2020a). Other producers may take the step of crafting wild-harvested materials into a final product such as baskets or wreaths, for sale at local craft fairs or shops, or mass-marketed online (Greene et al. 2000).

Often, market chains are determined by product and species characteristics, which in turn determine how producers interact with buyers (Frey et al. 2019). Market chains also depend on the source of demand for the product; for instance, many medicinal herbs are highly sought-after in Europe or Asia, whereas crafts or edibles may be sold more locally (Greene et al. 2000). For example, products that are relatively dispersed throughout large areas of forest, and/or are destined for distant markets, such as many medicinal forest products, may require harvesters to interact with regional dealers who aggregate quantities from numerous harvesters (Greene et al. 2000). On the other hand, products that are concentrated in smaller areas and relatively bulky and consumed locally, such as pine straw, may allow harvesters to deliver product directly to wholesale or retail markets (Casanova 2007).

Forest-farming may generate larger quantities of product per area of forest, on a more consistent schedule. Producers have more opportunities to bring product directly to retail markets like restaurants, farmers markets, or health shops, as well as to market value-added final products. For example, wild-harvested mushrooms often are sold to an aggregator/dealer (Schlosser and Blatner 1995), whereas forest farmed specialty mushrooms may be marketed direct to restaurants (Gold et al. 2008). These opportunities, however, require greater investment of time and resources in market identification and targeting, branding, quality control, and product consistency. Forest farming also entails more research and understanding of external factors including competition with existing producers and new entrants, similar products, and the market power of buyers (Cernusca et al. 2012; Gold et al. 2008). Aggregators and processors of wild-harvested products deal with similar marketing pressures (Schlosser et al. 1991).

Markets for many NTFPs are volatile and sometimes ephemeral, generating highly variable prices. Individual NTFP markets are fairly small, so modest short-term changes in supply or demand due to environmental (e.g., weather), social (e.g., unemployment), or policy (e.g., regulation) factors can affect price in unanticipated ways (Blatner and Alexander 1998; Frey et al. 2018). In the longer term, however, certain products have shown a trend for increasing prices, potentially due to limitations in potential supply of the resource, increasing demand for natural products, or both (Frey et al. 2018; McConnell and Graham 2016).

Certification is used as a messaging tool to inform consumers as to a product's origin, production method, or contents, and may relate to health benefits, ecological sustainability of production, quality and administrative standards, or socio-economic benefits for otherwise marginalized people, which serves to brand and differentiate products (Chittum et al. 2019; Pierce et al. 2008). Certification of wild-harvested NTFPs for sustainable forest management or ethical harvesting techniques pose significant technical and social challenges, including the sparse and ephemeral populations of NTFP species, lack of inventories and management science, difficulty of restricting access, shifting human harvester populations and product supply and demand, and dependence on NTFPs among vulnerable communities (Emery 2002; Pierce et al. 2008; Pierce 1999). The Forest Stewardship Council (FSC) certifies sustainable forest management for NTFPs on a case-by-case basis, but there are few experiences in the U.S. (Pierce et al. 2008).

Burkhart and Jacobson (2009) suggested that a certification mechanism for forest farming might signal to consumers a more sustainable production method for botanicals and generate an economic incentive through price premiums; in 2014 a "Forest Grown Verification Program" was established to certify sustainable forest farming practices (Chittum et al. 2019). If experiences with sustainable forest management certification for timber are any guide, price premiums may prove elusive. On the other hand, timber markets in the U.S. generally are more oriented towards commodity lumber production, which is not necessarily a favorable environment for product differentiation.

Organic certification and labeling has had branding and price premium success in the U.S., including for some NTFPs (Cernusca et al. 2012). Indeed, an experience with both sustainable forest management (under FSC) and organic certifications of maple syrup in the state of Vermont demonstrated a ready market for organic, but little economic benefit of FSC (Pierce et al. 2008). However, the costs of implementation can be substantial and out of reach for many producers.

Producers and conflicts

Mirroring the diversity in products, uses, and management of NTFPs, a wide variety of people harvest or produce NTFPs. These range from casual harvesters who occasionally may pick berries on the road-side or trail-side, to farmers who sell intensively forest-farmed mushrooms at weekly farmers' markets or direct to restaurants, to seasonal wild-harvesters who generate income for the holiday season (Bailey 1999; Carroll et al. 2003; Hembram and Hoover 2008; Jones et al. 2004; Robbins et al. 2008). The majority of all people who at least occasionally harvest NTFPs, which may include about one quarter of the general population across all parts of various demographic spectra, apparently do so for motivations such as home consumption; however, many of these are infrequent, casual harvesters (Bailey 1999; Butler et al. 2016; Jones et al. 2004; Robbins et al. 2008). Most of those who are identified by themselves or others as NTFP producers/harvesters harvest more frequently than these casual harvesters and likely have at least a partial motivation to sell for income (Jones et al. 2004).

Many wild-harvesters who depend on NTFPs for income are among the poorest and most vulnerable populations in their respective communities (Hembram and Hoover 2008; Schlosser and Blatner 1995). Full-time harvesters do exist in certain regions including the Pacific Northwest, and many collect or produce multiple types of products and/or travel to different regions throughout the course of the year; these are the minority of commercial harvesters but may collect the majority of certain products (Carroll et al. 2003; Cernusca et al. 2012; Hembram and Hoover 2008; Love et al. 1998; Schlosser and Blatner 1995, 1997). Larger, more well-established NTFP aggregating and processing businesses may hire or contract with these full-time harvesters (Schlosser et al. 1991). Full-time harvesters frequently include immigrants (Anderson et al. 2000; Emery et al. 2006; Hansis 1998).

Most NTFP producers only work part time or seasonally in the industry (Bailey 1999; Hinrichs 1998; Robbins et al. 2008). Income from NTFP wild-harvest usually is not large in these cases; typical seasonal part-time wild-harvesters generate income on the order of a few hundred up to a few thousand dollars per harvest season (Cernusca et al. 2012; Hembram and Hoover 2008; Love et al. 1998). Seasonal harvesters may undertake NTFP collection or production during seasons when there is a low opportunity cost of time, such as when their main line of work (e.g., construction, agriculture) has a slack period (Emery et al. 2006; Hinrichs 1998), or when there is a need for additional income, such as the holiday season (Bailey 1999).

Forest farming as a full-time business in the United States is not widespread, although 14 percent of forest landowners in the U.S. South have reported some form of management of forests for NTFP production (Workman et al. 2003). To our knowledge, no research has studied adopters of forest farming in the U.S. specifically; however, research on the broader groups of agroforestry adopters and those interested in forest farming suggests that they may tend to be more educated, younger, higher income, and nontraditional landowners with multiple objectives (McLain and Jones 2013; Valdivia and Poulos 2009).

Different harvester types and social groups frequently develop ecological knowledge and unwritten cultural norms for NTFP management and harvest over time (see Section on Stewarding of Natural Populations). NTFP harvesting norms can become strongly linked to individuals' identity and sense of connection to those social groups (Hinrichs 1998). Perhaps unsurprisingly, Native American groups, who have the longest history of NTFP management and harvest in the area now known as the U.S., generally have the most developed ecological knowledge and cultural norms, although these have been influenced by and in some cases suppressed by other groups (Carroll et al. 2003; Richards and Creasy 1996). Other social groups, such as African-, Asian-, European-, or Hispanic-Americans have less length of NTFP tradition in the U.S., but may tap heritage of NTFP harvesting from their countries of ancestry (Hansis 1998; Hurley and Halfacre 2011).

Among individuals with long personal NTFP experiences, common personal values are respect for nature, stewardship of the resource, and independence (Emery 2001; Love et al. 1998). Perhaps due to the value of ecological knowledge in the production practice, the desire for independence, and historical interactions with landowners/managers resulting in restriction or revocation of access, secrecy has become a norm in many NTFP wild-harvest communities (Love et al. 1998; McLain 2008). The combination of

NTFPs being linked to social connectedness within groups, and the desire for secrecy and independence, can generate a perspective of viewing "insiders" and "outsiders" differently and lead to occasional conflicts between different harvester groups. Full-time, commercial harvesters may use more intensive methods that are sometimes seen as destructive by harvesters with household, subsistence, or supplemental income motivations (Carroll et al. 2003). User types or harvest approaches may correlate with social groups (e.g., harvesters from different ethnicities or local communities), creating a situation where larger resentments or conflicts become tied to NTFP harvest (Carroll et al. 2003; Emery et al. 2006; Hansis 1998; Love et al. 1998; Richards and Creasy 1996).

Conflicts also occur between harvesters and landowners/managers. As a point of law, private landowners have the right to manage or restrict access; managers of public lands have similar authority in most cases, particularly for commercial harvesters (Alexander and Fight 2003; McLain 2008). Land ownership or other relatively secure land access/tenure arrangements can allow potential NTFP producers to invest in management of resources, including forest farming. However, many forest resources, including NTFPs and wildlife, have traditionally been viewed as open-access resources in the U.S., and the difficulty of excluding outsiders can create de facto open access (Alexander and Fight 2003; Frey et al. 2018; McLain 2008). Open access generates a context for unauthorized harvest, or poaching (Ballard and Huntsinger 2006; Frey and Chamberlain 2016). On private lands, resource poaching can translate into potentially tense encounters between landowners and harvesters and a barrier to investment in management of the resource. On public lands, the interaction between land manager and users can be more complicated since different user groups may have different access rights and requirements (Alexander and Fight 2003). Land managers may feel an obligation to monitor and limit harvest, which harvesters may view as unnecessary and intrusive (McLain et al. 2008). Further, despite common interest in sustainable use, there may be differences between what land managers view as appropriate management based on scientific approaches, and harvesters' stewarding based on ecological knowledge (Carroll et al. 2003; Love and Jones 2001). Allowing harvesters to participate directly in monitoring and management can be time-consuming and challenging to find common ground among land managers and various user groups, and can be fraught if there are unequal power balances, but if done appropriately may reduce some of these tensions (Hummel and Lake 2015; McLain et al. 1998; McLain and Jones 2001; Pilz and Molina 2002).

Key findings and information needs

There is great variety of native plants and fungi that are harvested for their nontimber values, and the sale of which contribute significantly to the U.S. economy. Integrating these products into forest management can enhance economic opportunities but also will increase complexity, and will entail balancing multiple and potentially conflicting objectives with a diverse community of stakeholders.

These key findings demonstrate opportunities and challenges:

- Managing production of NTFPs from natural populations or forest farming will often require balancing multiple and often conflicting land use objectives.
- Silvicultural practices designed for timber can be effective for NTFP production; however, changes in soil moisture and temperature dynamics can impact growth and resilience of some species.
- NTFP producers, particularly wild-harvesters, are frequently from underserved or limited-resource communities.
- Wild-harvesting is a low cost endeavor. Moving on the production intensity spectrum from wild-harvesting, to managing natural populations, to forest farming, will generate higher yields per hectare, but higher yields do not necessarily lead to higher profits.
- To have an incentive to manage or farm NTFPs, producers depend on engaging in markets that can be thin or volatile Forest farming can potentially benefit from accessing local and niche markets. Investment of time into marketing, branding, education, and understanding competitive forces is necessary. Use of certification as an NTFP branding tool has been relatively limited to date.
- Historical user groups, including some vulnerable and marginalized communities, are often not large landowners, yet historically have been able to

access NTFPs, through informal relationships or traditional cultural norms. At the same time, private landowners view their rights to the resources as exclusive, and public land managers have an obligation to ensure resources are managed sustainably. Power imbalances, differing cultural norms, and challenges in managing access can create misunderstandings and tensions, and conditions for unauthorized harvest, which impedes investment in NTFP management.

The knowledge needed to integrate NTFP species into forest management is a challenge faced by managers and landowners. In general, knowledge about the plants and fungi harvested for nontimber products is limited. But, knowledge about managing forests for timber may be appropriate for NTFPs. Equally, to manage natural populations, knowledge is needed about how much is being harvested, and how much is being lost to mortality. Monitoring harvest rates across populations, localities and ecoregions provides information needed to manage at different scales. This information provides what is needed to understand how much biomass is leaving the system.

Managing access and conflicts between user groups and landowners/managers is a challenge. Some households and communities may be particularly reliant on NTFPs for their well-being. A proper accounting of utilization of and dependence on NTFPs by United States households would allow economic policymakers, educational institutions, and nonprofits to determine vulnerabilities to potential future shocks and possible future reliance on safety-net programs if vulnerabilities are not addressed.

Information is lacking on:

- Forest inventories that include NTFP species.
- Growth and yield models of NTFP species.
- Extent and impact of NTFP stewarding practices, based on ecological knowledge.
- Effect of management and sivilcultural activities on NTFP survival and yield.
- Time series and trends of collection and use of NTFPs by United States households.
- NTFPs' role in advancing the standard of living of those engaged in their harvest, processing, and sale.
- Identification of communities (geographic, cultural) that are particularly vulnerable to NTFP species loss/change in distribution.
- Motivations and influences of people to undertake wild-harvesting and forest farming.

Conclusions

NTFPs are a diverse set of products from forests, and harvested by a diverse set of producers. These products may be wild-harvested with little management, harvested from managed populations, or forest farmed. Harvesters and producers often enjoy the connection to nature and cultural heritage, and sense of independence that NTFP harvesting or producing provides. In most cases, NTFPs are only a seasonal or supplemental income source; for harvesters who depend on them as their primary income source, NTFPs likely only provide a minimal livelihood, at best. Increased economic opportunities and impacts from sustainable utilization of the NTFP resource are possible through greater management, but many ecological, economic, and social complexities impede progress. A better understanding of silvicultural management approaches, market forces, and NTFP-dependent communities is necessary to move beyond the current paradigm.

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