# Growing hickories (*Carya* spp.) for roost trees

## A METHOD TO SUPPORT CONSERVATION OF DECLINING BAT POPULATIONS

**Tara Luna, Daniel L Lindner, and R Kasten Dumroese**

ABSTRACT

Bats (Vespertilionidae and Phyllostomidae) are a critically important component of North American ecosystems. These insectivorous mammals provide largely unrecognized ecosystem services to agriculture and forest health and sustain bat-dependent native plant populations. The decline of North American bat populations reflects the recent emergence of the fungal disease white nose syndrome (WNS); susceptibility to pollutants; and rapid changes occurring in the North American landscape, such as energy development and associated forest fragmentation and loss. Hickories (*Carya* L. spp. [Juglandaceae]) are an important roost tree for bats in the eastern US, and we describe how to propagate them in bareroot nurseries.

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KEY WORDS

bat conservation, Juglandaceae, propagation, bareroot, white nose syndrome, Vespertilionidae, Phyllostomidae

NOMENCLATURE

Bats and plants: ITIS (2013)
Fungus: Minnis and Lindner (2013)

Bats favor shagbark hickory (*Carya ovata*) as a roost tree because they can hide under its loose-plated bark that curls away from the trunk at the ends and gives this species its name. Photo courtesy of Jay Heritage Center, Rye, New York

Many biologists emphasize that bats, like amphibians, are important, sensitive indicators of ecosystem health and integrity. Bats are, however, largely unrecognized for their contributions and benefits to ecosystems and human welfare. In habitats around the world, bats play critical ecological roles that contribute to insect control, plant pollination, and seed dissemination (Kunz and others 2011). Whitaker (1995) estimated that a single colony of 150 Big Brown Bats (*Eptesicus fuscus* Beauvois [Vespertilionidae]) in Indiana can consume 1.3 million pest insects each year. A single Little Brown Bat (*Myotis lucifugus* LeConte [Vespertilionidae]) can consume nearly their body weight of insects every night (Brunet-Rossini and Wilkinson 2009), 4 to 8 g (0.14–0.28 oz) total (Kurta and others 1989). When extrapolated to a million bats, between 660 to 1320 metric tons (725–1450 tons) of insects are consumed annually in the Northeast and Mid-Atlantic region (Frick and others 2010). Boyles and others (2011) estimated the value of bats to the US agricultural industry in terms of pest control is US$ 23 to 54 billion/year. These estimates do not factor in other “hidden” economic benefits, such as protection of water quality, which may be gained through reductions in pesticide applications.

Most bat-pollinated plant species occur in the tropical and subtropical regions of the world. More than 150 New World plant genera are pollinated by bats, and notable New World plant families containing a large number of species dependent on bats for pollination and seed dispersal include the Cactaceae and Asparagaceae in the American Southwest and Bromeliaceae in Florida, Puerto Rico, and Mexico. Other familiar bat-pollinated North American genera include *Acacia* Mill. (Fabaceae), *Arbutus* L. (Ericaceae), *Oenothera* L. (Onagraceae), *Mirabilis* L. (Nyctaginaceae), and *Passiflora* L. (Passifloraceae) (Fleming and others 2009). Commercial agricultural species dependent on bats in the Americas include bananas (*Musa* L. [Musaceae]), mangoes (*Mangifera indica* L.) and cashews (*Anacardium occidentale* L. [Anacardiaceae]), dates (*Phoenix* L. [Arecaceae]), figs (*Ficus carica* L. [Moraceae]), peaches (*Prunus* L. [Rosaceae]), guava (*Psidium guajava* L. [Myrtaceae]), avocado (*Persea americana* Mill. [Lauraceae]), and agave (*Agave* L. [Asparagaceae]) (Fleming and others 2009).

Flowers pollinated by bats are large, nocturnal, white, dull yellow or green in color, and (or) produce copious amounts of nectar and pollen. Bats tend to pollinate plants that are typically present in low densities. Bats are regarded as long-distance pollinators and play important roles in maintaining genetic diversity in fragmented habitats and in plant species that naturally occur in low densities (Fleming and others 2009). In both fragmented and intact habitats, bats play a critical part in maintaining the genetic stability of existing or remnant plant populations.

Unfortunately, populations of bats are declining because of disease, pollution, energy development, and loss of habitat.

*Figure 1.* Scientists are monitoring bat populations for white nose syndrome (WNS), a disease caused by the newly described fungus *Pseudogymnoascus destructans*. This Big Brown Bat (*Eptesicus fuscus*) is being sampled to better understand how WNS has caused serious declines in bat populations in the eastern US since 2006. Photo by Daniel L Lindner

## White Nose Syndrome

White nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus* (=*Geomyces*) *destructans* (Blehert & Gargas) Minnis & D.L. Lindner (Pseudeurotiaceae) (Minnis and Lindner 2013), was first documented in 2006 near Albany, New York (Blehert and others 2009), and has since spread rapidly. WNS affects hibernating bats and is named for the white fungal growth sometimes observed on the muzzles of infected bats, although the fungus can colonize almost all exposed areas, including ears and wing membranes. This fungus was named and described in 2009 (Gargas and others 2009) and since that time has been discovered in multiple locations throughout Europe (Wibbelt and others 2010). European bats, however, are not suffering declines, which suggests that the fungus is a recent introduction to North America and an invasive pathogen (Puechmaille and others 2011). The fungus grows best in high-humidity, low-temperature environments (Verant and others 2012), conditions that bats favor for hibernation.

WNS now occurs throughout the northeastern and Mid-Atlantic regions in the US as well as in Ontario and Québec provinces in Canada, and has recently been documented from Virginia, Tennessee, eastern Missouri, and north-central Oklahoma (Dzal and others 2011) and Arkansas and Illinois (see USGS 2013). Following the initial detection of the disease, bat surveys (Figure 1) described a population decline in excess of 75% from 2006 to 2008 (Blehert and others 2009). Within a relatively short period of time, more than a million bats representing 7 species have died from WNS in eastern North America, and as a result, several bat species may become endangered or extinct (Frick and others 2010; Foley and others 2011). One species, the Little Brown Bat, was the most widely distributed species in North America but now is facing regional extinction because of the high incidence of WNS in hibernacula (Dzal and others 2011). In general, large colonies tend to be the first to exhibit high mortality rates (Wilder and others 2011). Although WNS is a major concern for bat populations, analyses by Ingersoll and others (2013) suggest that bat populations are being affected by multiple threats and that population declines may have preceded the arrival of WNS.

### Pollution

Bats require fat reserves to sustain them during winter hibernation. Unfortunately, many persistent organic pollutants (POPs) are lipid soluble and accumulate in fat tissues of bats through biomagnification in the food chain (Allinson and others 2006). During hibernation these fat deposits are used for energy, and the contaminants can be mobilized and reach high concentrations in the blood, brain, and liver (Swanepoel and others 1999). Kannan and others (2010) found elevated concentrations of PCBs, PBDEs, DDT, and chlordanes in fat tissues of bats afflicted with WNS in New York, although non-afflicted bats in Kentucky also had elevated levels of these chemicals. Moreover, sublethal exposure to POPs, such as lindane, have been shown to elevate the metabolic rates in bats (Swanepoel and others 1999). The concern is that exposure to these chemicals leads to immunosuppression that would make bats more susceptible to WNS, and increases in metabolism would further weaken bats by reducing their fat reserves during hibernation (Kannan and others 2010; Quarles 2013).

### Impacts from Energy Development

Forest fragmentation and degradation of habitat in brood-rearing sites, roosting sites, and along migratory paths create additional, magnified risks to bat populations. For example, in Pennsylvania and other mid-Atlantic states, recent development of natural gas well sites has expanded rapidly and is projected to remain high for the next 20 y (Hein 2012). Many of the well sites occur in forests. In Pennsylvania, an average of 3.6 ha (8.8 ac) of habitat is required for each well pad and associated infrastructure. With the projected number of wells estimated at 15,000 by 2030, and two-thirds of those expected to be within forests, upwards of 37,000 ha (83,000 ac) of forests will be directly lost in Pennsylvania alone (Johnson 2010). The impact is, however, far greater. Removal of forest habitat creates an associated "edge effect" ranging from 100 to 300 m (330–985 ft) into the remaining forest stand (Flaspohler and others 2001; Lee and others 2011). Increasing light and wind exposure and changes in humidity and temperature can alter vegetation dynamics at least 50 m (164 ft) into an eastern forest interior (Matlack 1993), thereby contributing to the loss of favored bat roost tree species and brood-rearing sites. The cumulative result is drastic landscape-level fragmentation, which has serious implications for bat populations, as well as other animal and native plant species.

Contaminated water is a by-product of oil and gas wells and is often stored on-site in open-air impoundments or evaporation ponds. These open wastewater pits and evaporation ponds usually contain flowback water produced during drilling and made up of drilling mud and the residues of diesel, oil, and gas. Open-air impoundments attract insects, which in turn attract insectivorous bats and songbirds (Trail 2006). Even small quantities of oil associated with this wastewater can entrap bats (Ramirez 1999, 2009, 2010). Several endangered bat species occur in the oil and gas production states that commonly use open pits for wastewater, including the Gray Bat (*Myotis grisescens* A.H. Howell [Vespertilionidae]), Indiana Bat (*Myotis sodalis* Miller and Allen [Vespertilionidae]), Ozark Big-eared Bat (*Plecotus townsendii ingens* Handley [Vespertilionidae]), Lesser Long-nosed Bat (*Leptonycteris curasoae yerbabuenae* Martinez and Villa [Phyllostomidae]), and Mexican Long-nosed Bat (*Leptonycteris nivalis* Saussure).

In the northeastern US, even "green" energy can be harmful to bats. Wind turbines kill bats (Boyles and others 2011), and some estimate that the annual toll may be as high as 111,000 bats by 2020 in the Mid-Atlantic Highlands (Kunz and others 2007).

## CONSERVATION AND RESTORATION OF IMPORTANT DAY ROOST TREE SPECIES

An important component of the life history of bats is their use of favored day roost trees. A common feature of such trees, whether they are in urban landscapes, deciduous forests, bottomland forests, or western coniferous forests, is their large diameter (Vonhoff and Barclay 1996; Brigham and others 1997; Callahan and others 1997; Hutchinson and Lacki 2000; Mager and Nelson 2001; Yates and Muzika 2006). Living and dead trees can serve as day roost sites (Humphrey and others 1977; Callahan and others 1997; Yates and Muzika 2006). For Red Bats (*Lasiurus borealis* Müller [Vespertilionidae]), day roosts in Kentucky were well within contiguous forests (Hutchinson and Lacki 2000), but they were also found roosting within urban areas in large deciduous trees in Illinois (Mager and Nelson 2001).

Many species of trees are used. In the Pacific Northwest states, bats roost in western white pine (*Pinus monticola* Douglas ex D. Don [Pinaceae]), and to a lesser extent in ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) and western larch (*Larix occidentalis* Nutt. [Pinaceae]) (Vonhoff and Barclay 1996). In the Midwestern states, bats have been

TABLE 1

*Fresh seeds of* Carya *species require stratification, ranging from zero to 150 d.*

| Species | Stratification duration (d) | Source |
|---|---|---|
| **True-hickory** | | |
| *glabra* | 90 to 120 | WPSM (1948) |
| *laciniosa* | 120 to 150 | WPSM (1948) |
| *ovata* | 30 to 150 | Barton (1936) |
| | 90 to 150 | WPSM (1948) |
| **Pecan-hickory** | | |
| *aquatica* | 30 to 150 | Bonner and Maisenhelder (1974) |
| | 90 to 150 | WPSM (1948) |
| *cordiformis* | 90 to 120 | WPSM (1948) |
| *illinoinensis* | 60 to 90 | van Staden and Dimalla (1976) and Adams and Thielges (1978) |
| | 30 to 90 | WPSM (1948) |
| | 0 to 90 | Southern sources to northern sources; Madden and Malstrom (1975) |
| *tomentosa* | 90 to 150 | WPSM (1948) |

WPSM = Anonymous, Woody-Plant Seed Manual.

observed roosting on sweetgum (*Liquidambar styraciflua* L. [Altingiaceae]) and oaks (*Quercus* L. [Fagaceae]) (Mager and Nelson 2001) and tulip tree (*Liriodendron tulipifera* L. [Magnoliaceae]) (Hutchinson and Lacki 2000). In Kentucky, Red Bats most commonly used smooth bark hickories, such as mockernut (*Carya tomentosa* (Lam. ex Poir.) Nutt. [Juglandaceae]), bitternut (*C. cordiformis* (Wangenh.) K. Koch), and pignut (*C. glabra* (Mill.) Sweet) (Hutchinson and Lacki 2000). Moreover, the endangered Indiana Bat favored shagbark hickory (*Carya ovata* (Mill.) K. Koch) as a roost tree, selecting it most frequently because of its loose-plated bark that curls away from the trunk at the ends (Britzke and others 2006). Thus, hickories, regardless of their bark habit, smooth or shaggy, are an important roost tree species.

Given that bats prefer larger diameter trees, ensuring that suitable hickories are available for future roosting sites requires ongoing outplanting of seedlings. Unfortunately, hickory seedlings are slow-growing and challenging to produce as typical bareroot stock. Here we provide some details on how hickories are being grown in bareroot nurseries in the midwestern US.

## PROPAGATION OF HICKORY

Hickories are native to the eastern half of the US, ranging from Florida north to Maine as well as the southern portions of Quebec and Ontario and west to grasslands of the Great Plains. Hickory species can be divided into 2 main groups: true-hickory and pecan-hickory. Leaves of true-hickories have 3 to 9 leaflets (mostly 5–7), whereas pecan-hickories have 5 to 17 leaflets (mostly >7) (Harlow and others 1979). The 4 primary species in the true-hickory group are shellbark (*Carya laciniosa* (Michx. f.) G. Don), pignut, mockernut, and shagbark, whereas the 4 primary species of pecan-hickories include water (*C. aquatica* (F. Michx.) Elliott), nutmeg (*C. myristiciformis* (F. Michx.) Elliott), bitternut (*C. cordiformis* (Wangenh.) K. Koch), and pecan (*C. illinoinensis* (Wangenh.) K. Koch), for which this group gets its name. Hickories are consistently found in broad association with oaks, the oak-hickory forest type, as well as with other hardwood species (Graney 1990).

Hickories are monoecious and flower during spring. The fruits turn from green to brown at maturity (September to November) and can be harvested by hand off the ground or by shaking the tree or flailing the limbs. For all species, good crops are expected every 1 to 3 y (Anonymous 1948). The husks are easily removed by hand, but large quantities could be processed with a macerator or a commercial Jessee walnut huller (Jessee Equipment Manufacturing, Chico, California). In Missouri, they pass nuts through a Jessee aspirator to separate viable and nonviable seeds (Hoss 2005a,b,c). Seeds are orthodox and can be stored for only 2 y when dried to a moisture content <10%, placed in sealed containers, and kept at 3 °C (37 °F). Between 3 and 4 y of storage, half to two-thirds of the viability can be expected to be lost (Bonner 2008). All hickory seeds have physiological dormancy and require stratification (cold, moist treatment) before germination can occur (Baskin and Baskin 2001). In general, 30 to 150 d is suggested (Table 1) but with some caveats: seeds stored for a year generally require a shorter stratification duration (Bonner 1976), and, at least for pecan, the most southerly sources may not need stratification, with the stratification duration increasing as the seed sources move northward (Madden and Malstrom 1975). Most state nurseries simply fall sow their hickory crops and allow for stratification to occur naturally; artificial stratification is possible but could require substantial space for these large-seeded species.

### Growing Bareroot Hickories

In general, all bareroot hickories are grown in a similar fashion. Here we report on the techniques used at the George O White State Nursery in Licking, Missouri (Hoss 2005a,b,c); the Vallonia State Nursery in Vallonia, Indiana (Hawkins 2014); and the Wilson State Tree Nursery in Boscobel, Wisconsin (Vande Hey 2014). All 3 nurseries grow shagbark hickory; Missouri and Indiana also grow shellbark, and Indiana produces pecan, too. Within nurseries, the same methods are used for all *Carya* species in production, suggesting these techniques would also work for other *Carya* not currently in production. The hickories are a finicky, demanding, slow-growing species. Generally a 2+0 crop, and occasionally a 3+0 crop, the key to growing high-quality hickory seedlings is developing a good root system. Achieving that, however, is challenging.

A year or two before sowing, nurseries prepare their fields in the typical manner. Fields are either fallowed or planted with a cover crop. Missouri uses "Roundup Ready" crops because weeds can be controlled with glyphosate without damaging the cover crop. Indiana prefers wheat whereas Wisconsin uses winter wheat, Sudex, or soybeans. Regardless, in late summer, cover crops are plowed in with a disc harrow and the fields are worked a few more times to provide a smooth area. In fall, fields are fumigated according to the product label, beds are formed, and fresh, non-stratified nuts are sown 2 to 10 cm (0.75–4 in) deep. Wisconsin and Indiana sow shallower (4–5 cm [1.5–2 in] and 2 cm [0.75 in] deep, respectively) because they further protect the nuts from deer, squirrels, and birds with a cover crop and (or) mulch, whereas Missouri sows deeper because it does not use a cover crop. Target seedling density is about 85 to 110 per $m^2$ (8–10 seedlings/$ft^2$) as recommended by Williams and Hanks (1976). As mentioned, Wisconsin and Indiana sow a cover crop of winter wheat or rye at the same time as the nuts, as described by Hawkins (2004), to protect the beds from erosion and predation. In spring, the cover crop is killed with glyphosate, paraquat, or fluazifop just prior to germination of the hickory seeds, which is easily monitored by excavating a few nuts regularly and looking for hypogeal germination. Hawkins (2004) also described adding a thick layer of straw mulch (5 cm [2 in]) to further protect the seeds (the cover crop grows up through it), and this mulch is removed with fire during early spring (late February or early March) before the seeds germinate (Figure 2). Hickory is generally the last species to germinate in the spring.

In Wisconsin, at the time of germination, controlled-release urea (either $40N{:}0P_2O_5{:}0K_2O$ or $44N{:}0P_2O_5{:}0K_2O$ available from local farm fertilizer companies) is applied at 49 kg of nitrogen (N) per ha (44 lb/ac), similar to the technique used at the nursery for applying controlled-release fertilizer to conifer crops (Vande Hey 2007). At about 4 to 6 wk after emergence, Missouri and Wisconsin apply ammonium sulfate ($21N{:}0P_2O_5{:}0K_2O$) at rates of 22.5 to 28 kg N per ha (20–25 lb/ac) for a total of 90 to 112 kg N per ha (80–100 lb/ac) for the 1+0 season. Total number of applications, applied about every 2 wk, depends on weather and the state of the crop. No additional N is added after the end of July. Indiana makes the same number of applications at the same frequency during the same time frame, but uses a liquid form of N (ammonium nitrate + urea; 28% N) applied with a tractor-pulled spray tank. Indiana applies the fertilizer with a modified exponential regime, increasing from 34 kg N per ha (30 lb/ac) to a final application rate of 94 kg N per ha (84 lb/ac). This application technique better matches the amount of N applied with the amount of N required by seedlings and was shown to improve the overall

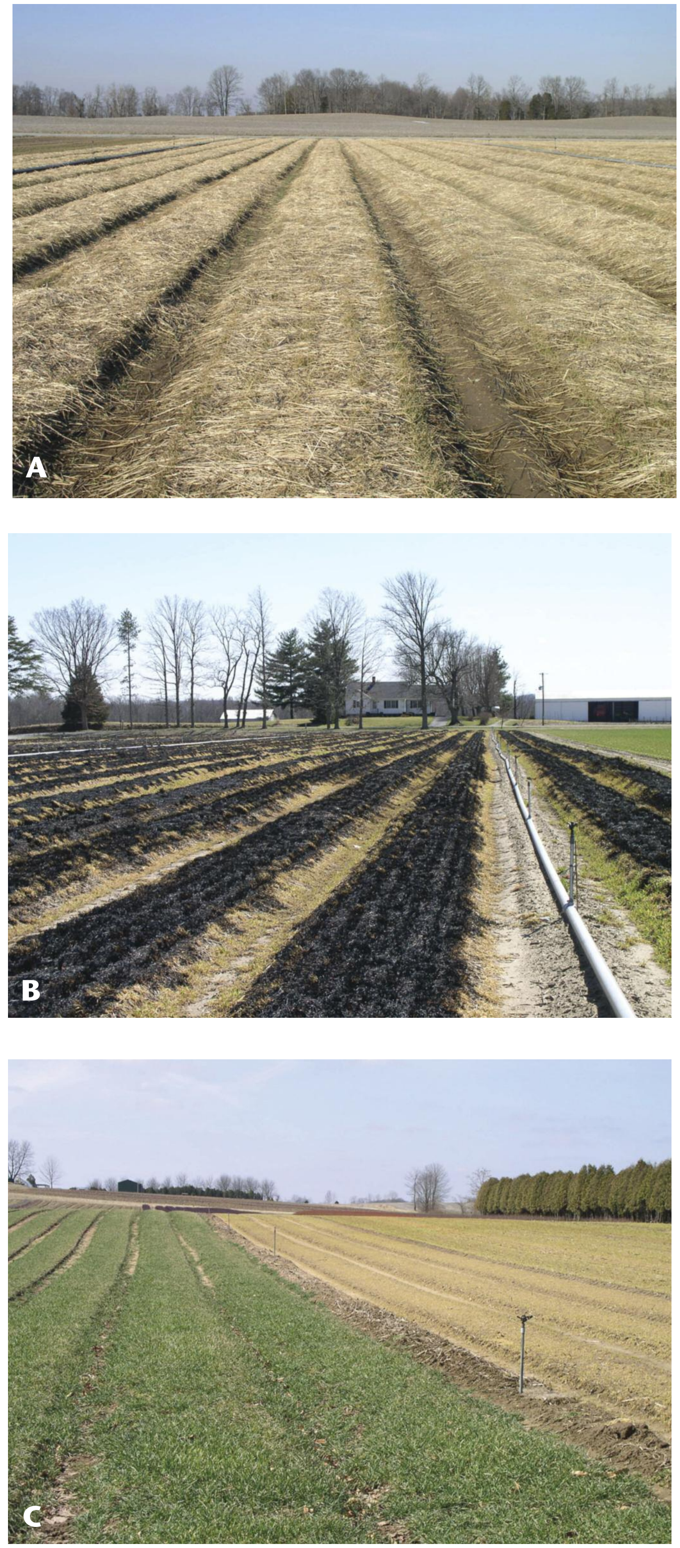


*Figure 2.* Bareroot beds of shellbark hickory (*Carya laciniosa*) at Vallonia Nursery in Indiana in midwinter. Note the cover crop is beginning to green up (A). The thick layer of straw mulch used to protect nuts from the weather and predation is burned off in late winter (B). The cover crop (left portion of photo) can be sprayed with herbicide (right portion of the photo) to release the hickory seedlings (C). Photos by Bob Hawkins

nutrient uptake efficiency and quality of oak seedlings (Birge and others 2006) as well as their outplanting performance (Salifu and others 2009).

Regardless of fertilization technique, shoot height at the end of the 1+0 season is only about 10 cm (4 in). Hickory generates a long, thick taproot without much taper (it resembles a pencil), and attempts to root prune with a non-reciprocating bar during the first growing season have not yielded acceptable results. In Wisconsin, the foliage is very susceptible to leaf blights so a fungicide is applied according to the product label, generally every 2 wk, but sometimes as often as once per wk if it has been cool and rainy and the seedlings are flushing. Thiophanate-methyl (Cleary 3336 WP, Cleary Chemicals, Dayton, New Jersey) is alternated with mancozeb (Dithane, Dow AgroSciences, Indianapolis, Indiana) throughout each growing season. Even so, most leaves have succumbed to disease by early fall. In Indiana, foliar disease symptoms rarely occur; seedlings are sprayed every 14 or so d, alternating thiophanate-methyl, myclobutanil (Eagle 20, Dow AgroSciences), and propiconazole (Banner Maxx, Syngenta Professional Products, Greensboro, North Carolina), among others.

During germination as well as during the second and third growing seasons, seedlings in Wisconsin are extremely susceptible to frost damage, much more so than other species. If the seedlings have leaves and even a hint of frost is in the forecast, frost-prevention irrigation is employed to protect the crop. In Wisconsin, in the second growing season before bud break, they again receive controlled-release urea at 49 kg N per ha (44 lb/ac). At Wisconsin and Missouri, from mid-May through late July seedlings receive ammonium sulfate ($21N:0P_2O_5:0K_2O$) in 6 to 8 applications of 22.5 to 28 kg N per ha (20–25 lb/ac) for a total of 135 to 180 kg N per ha (120–160 lb/ac). Missouri may apply much less depending on the way the crop is growing. As soon as the first flush of new growth is complete, the nursery beds are well watered and the seedlings root pruned with a stationary blade at a depth of 15 to 18 cm (6–7 in) in Wisconsin and to a depth of at least 25 cm (10 in) in Missouri. Pruning is best when seedling density is good and uniform, and beds must be at field capacity prior to pruning. On Wisconsin's loamy fine sand soils, beds must be well-watered (about 7.5 cm [3 in] of irrigation even when timed with a heavy rain event) just prior to pruning; and on Missouri's heavier silty clay loam soils, beds are irrigated 2 or 3 d prior to root pruning to ensure the root zone is well-watered but sufficiently drained for tractor access. Missouri irrigates for at least 2 h after pruning to settle the soil, and then heavily the next 2 or 3 d to reduce shock. If done under these conditions, the seedlings generate prolific lateral branching. Dormant, root-pruned seedlings are easily harvested in late fall through early spring when conditions allow.

During the second growing season, Indiana follows the same fertilizer regime as they used for 1+0 plants but they do not root prune. Instead, they lift at a much deeper depth (30–33 cm [12–13 in]) than the other nurseries (18–25 cm [7–10 in]). Lifted stock can be stored under refrigeration (0.5–3 °C [33–37 °F]). Target heights are generally 20 to 25 cm (8–10 in) regardless of species (Figure 3). In Indiana, anecdotal reports from the field indicate that outplanted *Carya* seedlings fail to develop much new shoot for a year or two, presumably as further root development occurs.

*Figure 3.* 2+0 shagbark hickory (*Carya ovata*) seedlings. Photo by Bob Hawkins

## SUMMARY

Conservation of larger diameter trees (either living or snags), which are favored by bats for roosting and rearing, along with reductions in forest fragmentation are needed to help conserve rapidly disappearing bat populations. Outplanting hickory seedlings can assist in restoring bat populations by providing the next generation of roost and rearing trees, as well as being used to connect fragmented forests. Bareroot production of hickory seedlings is demanding; this slow-growing, tap-rooted species provides cultural challenges.

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## AUTHOR INFORMATION

**Tara Luna**
Botanist
PO Box 447
East Glacier Park, MT 59434
tluna@3rivers.net

**Daniel L Lindner**
Research Plant Pathologist
USDA Forest Service, Northern Research Station
One Gifford Pinchot Drive
Madison, WI 53726
dlindner@fs.fed.us

**R Kasten Dumroese**
Research Plant Physiologist / National Nursery Specialist
USDA Forest Service, Rocky Mountain Research Station
1221 South Main Street
Moscow, ID 83843
kdumroese@fs.fed.us