

# Home and Horticultural

# PESTS

## Borers

### Common Kansas Species

The term “borers” applies to a wide range of insects whose immature stages generally develop within host plants. Although insects feeding on foliage pose a minimal threat to health and vigor of woody plants (because auxiliary buds can produce new foliage), borers feed unseen beneath bark, destroying irreplaceable cambial and wood tissues. Insect borers are commonly classified according to taxonomic families within larger orders. Orders with the most borer species are Coleoptera (beetles) and Lepidoptera (moths). Hymenoptera (bees and wasps) and Diptera (flies) each have borer species, but they are few and rarely cause major damage.

When the term “trees” is used in this publication, it should be understood to include woody shrubs.

### Coleopterans (Beetles)

The two most recognized families of borer beetles are Buprestidae and Cerambycidae, commonly referred to as metallic wood borers and longhorned wood beetles, respectively. Legless larvae distinctively indicate their borer status. Buprestids are sometimes called flatheaded borers for their distinctly enlarged and flattened thoraxes, with abdominal segments that are generally constricted and flattened (see Fig. 1, p. 4). Cerambycid larvae are called round-headed borers for their round thoraxes and abdomens (Fig. 2). A third prominent family of borer beetles are Scolytidae, whose larvae typically create gallery systems beneath bark where mature larvae pupate. Newly emerged beetles bore directly through bark, creating randomly spaced emergence holes ranging from bird-shot-sized to BB-sized and earning the name “shothole borers.”

### Flatheaded Borers (Family: Buprestidae)

Buprestids are especially damaging to newly transplanted trees lacking established root systems. Beetles deposit eggs in bark cracks and crevices and are especially attracted to wound areas (e.g. pruning cuts or mower and string-trimmer damage at tree bases). After boring through bark, young larvae become established in the sapwood, forming broad serpentine galleries (right)



Larval galleries

as they feed on inner bark and sapwood tissues. Destruction of these tissues hinders formation of new wood and essentially girdles branches and trunks, resulting in dead branches and trunks beyond zones of destruction. The most prevalent flatheaded borers in Kansas are the **bronze birch borer** (Fig. 3) and the **flatheaded apple tree borer** (Fig. 4)

### Roundheaded Borers (Family: Cerambycidae)

Cerambycids are a large group of wood-boring beetles. Longhorned beetles vary greatly in size, shape and coloration. Roundheaded borers may initially feed on outer tissues but eventually burrow deeper into wood, where feeding or tunneling activities structurally weaken trees and shrubs. Examining break points in downed limbs often provides evidence of roundheaded borer feeding damage.

Many common Kansas wood borers are roundheaded borers. These include the **cottonwood borer** (Fig. 5) — probably the most widely recognized borer in Kansas because of its imposing size and unusual coloration. The relatively long-lived adults (one month) feed on tender leaf and bark tissues. Most female beetles eventually move to tree bases, forming shallow pits below the soil line. Larvae burrow mainly in roots, but galleries can extend slightly above ground level. Adults emerge through holes in either location. Smaller, younger trees (one to two years) are most susceptible to cottonwood borer damage. Beetles can girdle small branches, giving young trees a scrawny, broken and defoliated appearance. Larger, established trees can absorb more damage but may show leafless, smaller branches high in canopies.

**Poplar borer** (Fig. 6) beetles tend to select larger, established trees. **Elm borers** (Fig. 7) are attracted to weakened trees. Larvae tunnel through bark disrupting the flow of nutrients and water. As larvae grow larger, damage increases, including girdling and dead branches. Attacks usually occur over a period of years, causing gradual decline and eventual death. **Pole borers** (Fig. 8) are indiscriminate feeders that deposit eggs in wound areas (usually around tree bases) or previous galleries. Some beetles emerge in late summer and seek new hosts. Others do not emerge, but rather mate and lay eggs in old galleries. Pole borers seldom attack injury-free trees with healthy bark.

**Mulberry borer** (Fig. 9) beetles emerge from mid-May to mid-June, living for several weeks. **Tilehorned prionus** (Fig. 10) beetles begin appearing in mid-summer. Females deposit eggs in soil at tree bases. Larvae enter roots and feed on outer bark before moving into larger roots. As these are hollowed out, trees' structural integrity is compromised. Smaller roots are also consumed, decreasing anchorage or tree stability and leading to general decline and eventual death. **Ash and privet borer** (Fig. 11) beetles are present from May to August, laying eggs in both healthy and dying hosts. Larvae pack frass behind them as they tunnel into wood, leaving no external signs of their activity.

Despite its name, the **red oak borer** (Fig. 12) also attacks all white oak species. Adults emerge from June through August. Damage in the first year of the two-year life cycle is difficult to detect, but enlarged holes in the bark and stains from oozing sap (right) alert people to borers' presence in the second year.



Red oak borer damage

Established trees seem to tolerate borer activities, and wounds heal over time. However, borer damage downgrades harvested and milled lumber.

The **locust borer** (Fig. 13) is most abundant in September, when it often feeds on goldenrod and ragweed pollen during daylight. As the day ends, beetles return to locust trees and deposit eggs. Damaged trees or trees in nutrient-poor soils or eroded sites tend to be more susceptible to locust borer damage. Trees planted on good sites and thrifty, older, dominant trees usually survive locust borer attacks.

Three borer species are commonly encountered emerging from firewood stored indoors or crawling on stacked outdoor firewood. The **painted hickory borer beetle** (Fig. 14) closely resembles the locust borer beetle, but is active only in spring and has a wider host range. Logs cut the previous winter are their preferred egg-laying sites. **Redheaded ash borer** (Fig. 15) beetles often are attracted to newly transplanted trees struggling to become established, as well as young, stressed trees with minimal sapwood. Usually, borer damage becomes evident when trees are cut into lumber and larval galleries make it unmarketable. The **banded ash borer** (Fig. 16) beetle emerges in early spring. Its normal one-year developmental cycle may lengthen to several years under less than ideal conditions (e.g., if infested materials are sawed, stored and dried out).

The **ivory marked beetle** (Fig. 17), also called the four-marked ash borer, may have a two-year life cycle, but one report claims a prolonged life history in dry wood; one beetle apparently emerged from a 40-year-old birch bookcase.

The **twig girdler** (Fig. 18) is responsible for twigs littering the ground in late September and October. Beetles feed on tender bark prior to mating. Fertile females begin

girdling branches before and during the egg-laying period. After girdling, branches remain attached to the tree by a thin core (below right) until their weight, aided by wind, causes breakage. By the time branches snap off, twig girdlers are no longer present. Although larger mature trees may have a ragged appearance, damage is considered minimal. In smaller nursery trees or developing landscape trees, excessive branch drop may result in unusual forking and tree deformities, rendering trees unmarketable and aesthetically diminished.



Girdled branch

Examining cut ends of branches on the ground helps determine whether squirrels or twig girdlers are causing damage. Squirrels gnaw through branches, leaving ragged edges and causing them to immediately drop to the ground. Twig girdlers do not completely sever branches, but rather make neat "buzz-saw" cuts around central stalks (above right).



"Buzz-saw" cut

## Shothole Borers (Family: Scolytidae)

Some scolytid beetles are designated shothole borers. They are small ( $\frac{1}{16}$  to  $\frac{1}{8}$  inch long) and seldom seen. Close inspection of sick or recently dead trees reveals the small shotholes that confirm their presence. People assume trees are killed by these beetles and their larvae when, in fact, scolytids are attracted to stressed trees with minimal defenses and deliver the final death blow. While most are not considered economically important, some destructive species have a major impact on forests and the lumber industry. A recent report by the Kansas Department of Agriculture listed 52 scolytid species in Kansas. Three species are perhaps the most important and frequently encountered.

**Eastern ash bark beetles** (Fig. 19) create egg galleries in boles, limbs and larger branches of weakened trees. Two generations per season are normal in Kansas. Watersprout growth at tree bases attracts second-generation beetles, which later move to node or bud areas to create overwintering chambers. Damaging outbreaks are historically sporadic and unpredictable, making insecticidal control impractical. Applications after the fact are of little or no value.

**Smaller European bark beetles** (Fig. 20) seek healthy trees to feed or weakened or diseased trees to breed. They are the primary carrier of the fungal pathogen responsible for Dutch elm disease. Beetles carry fungal spores that they transmit when feeding in twig crotches of healthy trees. By midsummer, initial symptoms of Dutch elm disease may be evident on scattered branches. Foliage wilts, turns yellow and eventually dies, leaving foliage on dead branches dry and brown. It may take several years for the tree to reach a dramatically rapid final demise. Communities once fought elm loss by implementing sanitation practices to eliminate

breeding sources, applying insecticide to healthy trees, and destroying underground root grafts. There is, however, little that homeowners personally can do to prevent tree loss. A tree service may apply insecticide against each of two beetle generations, but this may not avert the disease.

The **eastern fivespined ips** (Fig. 21) prefers recently felled pine trees and slash for egg-laying, but also attacks trunks and branches, particularly in stressed and weakened trees. This species likely produces several generations annually in Kansas. Insecticide applications against these beetles are impractical due to their unpredictable occurrences. Sanitation practices, such as removing and disposing of dead trees and debris, will eliminate sources of beetles.

## Lepidopterans (Moths)

Two families of lepidopterans with the most familiar borer species are Sesiidae and Cossidae. Sesiids are commonly called clearwing moths for their transparent wings. Another common name is wasp moths for the wasp-like coloration and patterns of some species, their ability to hover, and their buzzing noises. Sesiid moths are active during daylight and vary in size. Wingspans range from  $\frac{1}{5}$  to  $\frac{3}{4}$  inch. Larvae have a typical caterpillar appearance, are white, and reach  $1\frac{1}{2}$  inches in length. Although several dozen sesiid species are considered pests of trees, shrubs, vines, and herbaceous plants, only a few receive attention in control guides.

A common Kansas species is officially known as both the **ash borer** and the **lilac borer** (Fig. 22) for its primary hosts. Moth emergence and activity typically begin in mid-April and end in late June. Egg-laying moths are attracted to wound sites, but also will deposit eggs on trunks and larger limbs. Initial flight activities can be monitored with traps containing artificial clearwing borer pheromone to attract male moths. Control is best achieved by applying insecticides to trunks and larger branches seven to 10 days after moth capture.

The carpenterworm moth and leopard moth are the two prevalent Cossidae species in Kansas. **Carpenterworm moths** (Figs. 23, 24) are especially common. They likely have a two-year life cycle, emerging from April through July. Each moth may produce up to 1,000 eggs. Galleries may be 6 inches long and quite wide to accommodate larvae, which move back and forth between galleries and tree exteriors, expelling sawdust and frass. Tunneling may cause structural weakening of larger limbs, resulting in breakage. Carpenterworm damage reduces wood quantity and lumber quality.

**Leopard moths** (Fig. 25) attack more than 100 species of trees and woody shrubs if hosts have wood of sufficient diameter to support the large larvae. Moth emergence begins in May and extends through August. Each female produces 400 to 800 eggs, deposited singly or in small clusters in bark crevices or beneath bark scales. Larvae hatch in 10 days. If they initially bore into small stems, they may outgrow their confines and leave to seek another feeding site. The slow-developing larvae overwinter twice before moths emerge.

## Cultural Practices For Borer Management And Prevention

Borers are considered secondary pests. They are often attracted to weakened and stressed hosts. In Kansas, the primary stress factor is drought, especially when coupled with extremely hot weather. Other factors contribute to moisture stress. Around construction sites, excavation may severely damage and reduce root systems of established trees retained for landscaping. Heavily compacted soils restrict re-establishment of pruned or damaged roots, as well as newly transplanted trees' root development. Compacted soils are less able to absorb and store water. Excessive numbers of trees and shrubs can compete for moisture. When adequate moisture is available small borer larvae do not survive water surging through tree vascular elements. They are "sapped out" or "drowned."

### Tips to ensure tree health and vigor

- **Select proper tree varieties.** Extension foresters or local nursery employees can recommend varieties best suited for different areas in Kansas, as well as placement or exposure.
- **Consider buying locally produced trees.** Nurseries know which tree and shrub species do well in their areas.
- **Select trees after noting their general health,** vigor and conformation. Avoid bargain trees, which may have undesirable attributes that decrease prices or marketability.
- **Look for signs of borer activities.** Leafless or dead branches can indicate ongoing problems. Closer inspection, especially at a tree base, can reveal borer exits. Cracked and separated bark also hints at borer damage.
- **Prepare sites** to give transplanted trees the best opportunity to successfully take root and thrive. Extension publications detail steps to prepare trees for transplanting, as well as proper planting procedures and techniques.
- **Give constant attention and care to help transplants** overcome transplant shock. Water for plant uptake is critical. Moist soil allows new roots to gain a foothold and expand, providing additional surface area for water uptake as well as anchorage.
- **Water and fertilize newly transplanted or young trees properly** to stimulate establishment and growth. This is needed beyond initial years of establishment, especially during hot or dry periods (including winter).
- **Place tree wraps around trunks** of transplanted or young trees to protect against egg laying. Replace or repair wraps if tears occur. Use them for several years, but change them intermittently to avoid constricting trunk growth.
- **Prune or remove and dispose of sick, dead, or fallen branches and limbs** to deal with established borers. Consider removing seriously ailing trees, borer-weakened trees and dead trees, all of which could support future borers.
- **Consider insecticides** as a preventative tool against insect borers.



Fig. 1: Flatheaded borer larva



Fig. 2: Roundheaded borer larva



Fig. 3: Bronze birch borer  
*Agrilus anxius* Gory



Fig. 4: Flatheaded appletree borer  
*Chrysobothris femorata* (Olivier)



Fig. 5: Cottonwood borer  
*Plectrodera scalator* (Fabricius)



Fig. 6: Poplar borer  
*Saperda calcarata* Say



Fig. 7: Elm borer  
*Saperda tridentata* Olivier



Fig. 8: Pole borer  
*Parandra brunnea* (Fabricius)



Fig. 9: Mulberry borer  
*Dorcaschema wildii* Uhler



Fig. 10: Tilehorned prionus  
*Prionus imbricornis* (Linnaeus)



Fig. 11: Ash and privet borer  
*Tylonotus bimaculatus* Haldeman



Fig. 12: Red oak borer  
*Enaphalodes rufulus* (Haldeman)



Fig. 13: Locust borer  
*Megacyllene robiniae* (Forster)

(Pictures not to scale)



Fig. 14: Painted hickory borer beetle  
*Megacyllene caryae* (Gahan)



Fig. 15: Redheaded ash borer  
*Neoclytus acuminatus* (Fabricius)



Fig. 16: Banded ash borer  
*Neoclytus caprea* (Say)



Fig. 17: Ivory marked beetle  
*Eburia quadrigeminata* (Say)



Fig. 18: Twig girdler  
*Oncideres cingulata* (Say)



Fig. 19: Eastern ash bark beetle  
*Hylesinus aculeatus* Say



Fig.20: Smaller European elm bark beetle  
*Scolytus multistriatus* (Marsham)



Fig. 21: Eastern fivespined ips  
*Ips grandicollis* (Eichhoff)



Figure 22: Ash/lilac borer  
*Podesia syringae* (Harris)



Fig. 23: Male carpenterworm moth  
*Prionoxystus robiniae* (Peck)



Fig. 24: Female carpenterworm moth



Fig. 25: Leopard moth  
*Zeuzera pyrina* (Linnaeus)

(Pictures not to scale)

<b>Borer name / hosts</b>	<b>Description</b>	<b>Warning Signs</b>	<b>Life Cycle</b>
<b>Bronze birch borer</b> Birch, esp. European white birch	Olive to black-brownish; narrow, flattened, and ¼ to ⅞ inches long.	Dead branches in treetops.	1 year; overwinter as larvae. Wide range of larval stages results in continuous adult presence from late spring through summer.
<b>Flatheaded appletree borer</b> Indiscriminate attacks on many tree species	Broad, oval, flattened beetles, ¼ to ⅝ inches long.	Readily apparent trunk damage to new transplants.	1 year; overwinter as larvae. Pupation in spring and early summer. Most beetle activity in May, but occurs through mid-fall.
<b>Cottonwood borer</b> Cottonwood, poplar	1 to 1½ inches long, black and white coloration. Entirely black long antennae.	Frass exuded on collars and exposed brace roots of mature trees, but damage often only evident after trees fall. Girdling may give scrawny, broken, defoliated appearance to nursery trees.	Varies from 1 year (in young trees) to 2 years (in older trees); but some adults appear every year. Adults emerge from late June through mid-August in Kansas.
<b>Poplar borer</b> Poplar, cottonwood	¾ to 1¼ inches long; grey, speckled by cover of small dark spots. Readily visible, somewhat orange markings.	Oozing sap; frass and woodshavings at gallery entrances.	Reportedly 2 to 5 years, although not known in Kansas.
<b>Elm borer</b> Elm	¾ to ½ inch long; grey fuzz, reddish orange stripe (back ridges and wing covers) and slanted crossbars on outer wings; two black dots on each side of back, two on each wing case and one on each wing end.	Reddish frass exuding from openings in bark crevices; girdling and dead branches as larvae size increases.	1 year. New larvae bore into outer bark and then inner bark and sapwood, where they overwinter. Beetles typically appear from May through July.
<b>Pole borer</b> Indiscriminate attacks on many tree species	Broad and flattened; shiny mahogany color; males ¾ inch long with prominent mandibles, females ½ to ⅝ inch long with smaller mandibles.	Most activity is in heartwood. Frass is packed in galleries, so damage signs generally not evident. Wind damage to weakened trees (including downed trees) may be first evidence.	3 to 4 years. New beetles form in late summer; some emerge and seek new hosts, while others remain in galleries to mate and lay eggs.
<b>Mulberry borer</b> Mulberry, Osage orange	⅝ to ⅞ inch long; cylindrical front thorax gives it "necked" appearance; coat of fine gray hairs conceals dark brown body; small round bare spots give wing covers pitted appearance.	Sap ooze from niches for egg-laying; fine frass from small larvae, coarse and fibrous from older larvae. Dieback on branches and part of crown during initial attacks.	1 year. Larvae overwinter and beetles emerge mid-May to mid-June and live several weeks. Egg-laying continues into early July.
<b>Tilehorned prionus</b> Oak, pecan, hickory, poplar, Osage orange, cottonwood, and tree fruit species (apple, peach, plum, etc.)	Broad, shiny, dark reddish-brown; 1¼ to 1¾ inches long; distinctive tiled antenna extend from one-third to halfway down wing covers.	No direct signs. Excavating around larger roots may expose oval exit holes for larvae.	3 to 5 years. Beetles begin appearing in mid-summer. Females lay eggs in soil at base of trees. Larvae bore into roots but later return to soil to build pupation chambers.
<b>Ash and privet borer</b> Ash, privet, elm, hickory, black walnut, some poplar and birch species	Elongated and somewhat flattened. Mostly brown with three light creamy or yellowish spots along wing covers.	Close inspection may reveal sap oozing from site of larval penetration. First signs may be killing of larger limbs.	2 years. Beetles present May to August.

<b>Borer name / hosts</b>	<b>Description</b>	<b>Warning Signs</b>	<b>Life Cycle</b>
<b>Red oak borer</b> Red oak, white oak	Fine, downy cover of light brown or tan, blotched and darkened as it wears away with age. Females 1 $\frac{5}{16}$ inches long. Males have 1 $\frac{1}{2}$ -inch bodies, with antennae exceeding body length.	Difficult to detect in first year because of small entry-hole size (more enlarged in second year). Staining from oozing sap may signify borer presence (see Fig. 12).	2 years. Adults emerge June-August; larvae overwinter in inner bark, then move into sapwood the following year. Large larvae overwinter twice.
<b>Locust borer</b> Black locust and its cultivars	Bright yellow bands on black background. Straight lines across front of thorax and top of wing covers; W-shaped on wing covers.	Sap oozing from larval entrance holes in spring, along with increasingly evident amounts of frass.	1 year. Beetles appear in late summer, early fall. Larvae overwinter in inner bark, then move into sapwood and heartwood the next year.
<b>Painted hickory borer</b> Ash, black walnut, hackberry, mulberry, oak	Looks similar to locust borer, but active only in spring.	Most often found in firewood in and around homes.	1 year. Beetle emergence and early egg-laying in spring allows larvae to develop quickly and pupate over winter.
<b>Redheaded ash borer</b> Ash, hickory, walnut, oak, birch, maple, dogwood, redbud, hackberry, black locust, honeylocust, Osage orange, lilac, pear, cherry, plum, peach, apple, elm, sweet gum	Elongated, tapered beetle, $\frac{1}{4}$ to $\frac{3}{4}$ inch long. Front of thorax is round and has fine, rusty-reddish hairs. Four distinct lines of fine yellow hairs traverse wing covers. Front legs noticeably shorter.	Young trees may develop slowly, with some branch dieback. Established trees may show some exit holes in trunks, but most attacks are undetectable. Damage is most evident when trees are felled for lumbering.	1 year. Beetle emergence varies from May to September. Larvae enter sapwood within several weeks and enter pupal stage by late winter or early spring.
<b>Banded ash borer</b> Cut ash, hickory and elm logs	$\frac{3}{8}$ to $\frac{3}{4}$ inch long. Dark brown to black with band of cream-colored hairs on front of thorax and four bands on each wing cover, with first two almost circular.	Beetle may emerge from or crawl on firewood, both indoors and out.	1 year to several years (under less-than-ideal conditions). Pupation occurs in fall and beetles overwinter, then emerge in early spring.
<b>Ivory marked beetle</b> Ash, hickory, oak, maple, honeylocust, elm, bald cypress	$\frac{1}{2}$ to $\frac{3}{4}$ inch long. Ivory-colored spots at base and middle of each light-brown wing cover.	No early warning signs.	Not certain. 2 years to perhaps many years in dry wood.
<b>Twig girdler</b> Elm, pecan, hackberry are preferred hosts. Also found in apple, pear, peach, plum, dogwood, oak, honeylocust, poplar, maple	$\frac{5}{8}$ to $\frac{3}{4}$ inch long. Primarily greyish brown, but some specimens have lighter ash-grey band on wing covers. Small, scattered tufts of yellowish or golden bristles on wing covers.	First visual evidence often is branches with dead brown leaves. Snapped-off branches on ground show neat, "buzz-saw" cuts around central stalk.	1 year, with beetle activity from August to October. Slow development means overwintering larvae, but accelerates in spring and summer. Pupation by August and September.
<b>Eastern ash bark beetle</b> Ash	$\frac{1}{16}$ to $\frac{1}{8}$ inch long. Primarily dark brown with flat, grayish white scales. Dark diamond pattern on front of thorax; heringbone pattern across wing covers.	Close inspection reveals small shotholes dotting dead branches.	Rapid larval development (2 months) provides two generations per year. Beetles can overwinter and emerge directly in early spring to start new cycle.

<b>Borer name / hosts</b>	<b>Description</b>	<b>Warning Signs</b>	<b>Life Cycle</b>
<b>Smaller European elm bark beetle</b> Elm	⅛ inch maximum. Black front thorax and dark reddish-brown wing covers. Stout spine projecting beneath abdomen.	No early warning signs; appearance of shotholes after infestation.	6 weeks from egg to adult beetle; two generations per year in Kansas. Larvae overwinter and pupation/ beetle emergence occur in early spring.
<b>Eastern fivespined ips</b> Mostly felled pine trees and slash, but weakened or stressed pines may be affected	⅛ to ⅜ inch long. Dark reddish-brown. Five prominent spines project rearward from wing covers.	No early warning signs; appearance of shotholes after infestation.	Although confirmation is needed, there are apparently several generations per year in Kansas.
<b>Ash borer or lilac borer</b> Ash, lilac, privet	1 to 1½ inch wingspan. Appearance varies; forewings typically opaque and blackish with tinges of red or chestnut brown; newly emerged moths black in front, reddish brown in back with series of yellow hair tufts encircling abdomen. Older moths generally darker.	Sap with a fine frass inclusion oozing from larvae entrance burrows, eventually becoming chunky frass. Moth exit holes above entrances.	1 year. Moth emergence from mid-April to late June. Overwintering larvae.
<b>Carpenterworm</b> Primarily elm and green ash, but also other tree species	Females: 3-inch wingspans with light speckles on grey and black wings; plump, fuzzy, grey abdomens. Males: 2-inch wingspans, darker appearance (black head and thorax, black wings with orange highlights on hind wings).	Sap spots with finely mixed frass early; as infestation advances, sap stains are larger and wood chips and frass are expelled from entrance holes.	2 years in Kansas. Moths emerge April through July.
<b>Leopard moth</b> More than 100 tree and shrub species	Wings and thorax white with black spots. 3-inch wingspan for females, 2 inches for males.	Broken twigs, wilted yellow foliage at first. Dead brown foliage and broken branches in upper canopy later.	2 years. Moths emerge May to August. Larvae overwinter twice.

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All photos by Robert Bauernfeind except "Red oak borer damage" on p. 2 (courtesy of Kim Bomberger, Kansas Forest Service) and Fig. 26 (courtesy of Ashraf El-Sayed, Canterbury Research Centre)

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*Borers: Common Kansas Species, Home and Horticultural Pests, MF-2735.* Kansas State University, October 2006.

### **Kansas State University Agricultural Experiment Station and Cooperative Extension Service**

MF-2735

October 2006

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