The Hidden Beauty of
Stems

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Front cover: Bracken fern (*Pteridium aquilinum*) rhizome
Title page: Blazing star (*Liatris* sp.) stem

Contents

From the Author

As I suspect is the case with many other botanists, most of my experience with stem anatomy involved looking at stained, prepared specimens that are available from science supply companies. Such material is typically preserved ("fixed") to help keep the structures intact, sectioned with a machine (microtome) that cuts very thin sections of uniform thickness, and treated with one or more stains. The resulting stained sections show fine details very nicely but the colors often do not represent those actually present in live plants.

I had occasionally made a "free-hand" section of a live plant using a sharp blade, but only recently—more or less on a whim—began surveying nearly every plant stem I could find in my neighborhood and examining them with compound microscopes using a variety of optical methods. Although not every plant is cooperative in yielding (unfixed) sections that are relatively intact or aesthetically pleasing, a surprising number were dramatic in both their structure and colors. Fresh material may also yield a better view of the fine hairs and other such structures on the stem surface, which can be lost in the processing involved in producing thinner, stained sections. Hand-cut sections were so striking that this book was created to share them. Nevertheless, a number of images that were taken of commercially produced materials are also included here. Typically viewed with brightfield optics (see the Techniques section), these prepared sections often take on a very different appearance when other optics are used and yield finer detail than do free-hand sections.

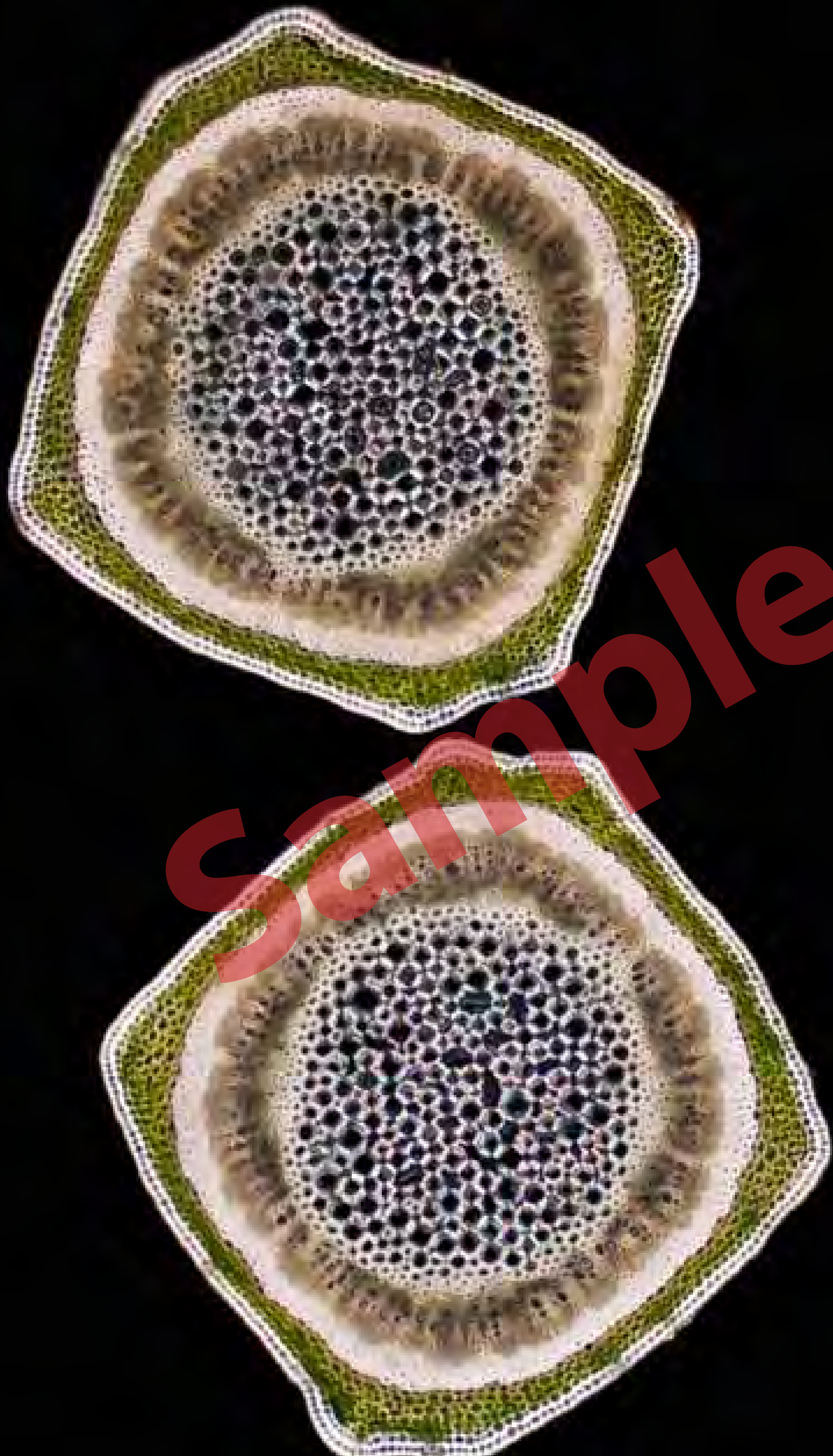
As it turned out, some of the more spectacular specimens I happened to examine were catnip and its relative, motherwort. These two mint species are common and often weedy and it often seemed to be the case, as the project continued, that similarly weedy species frequently made the most striking subjects.

A techniques section at the end of this eBook provides some details of how the anatomical images were acquired and the different types of optics that were used. Most sections examined were of young, narrow stem segments not far from the growing tip that were approximately 2–3 mm (about 1/8 inch) in diamter. At that stage, even stems of woody trees and shrubs can be cut with very sharp razor blades.

Stems can be cut in a variety of orientations (planes of section), which is discussed and illustrated in the Introduction. Cross sections are often easiest to interpret (at least for the nonexpert plant anatomist, a category in which I include myself) and is the view that is arguably the most aesthetically pleasing. To me, these stem cross sections are reminisent of the beautiful snowflake images of Kenneth G. Libbrecht, which can be found online and in a number of printed books. The stem cross sections exhibit a different sort of complexity that is attributable to their biological nature, with myriad different chemical compounds being arranged in a great variety of ways as dictated by the plants' underlying genetics, as well as effects the environment can have on them.

I hope that this brief eBook provides at least a glimpse into the plant wonders that can be found at small scales. A number of botany (plant biology) and plant anatomy textbooks can be easily located, which would undoubtedly better describe the details that are covered in a rather superficial way here.

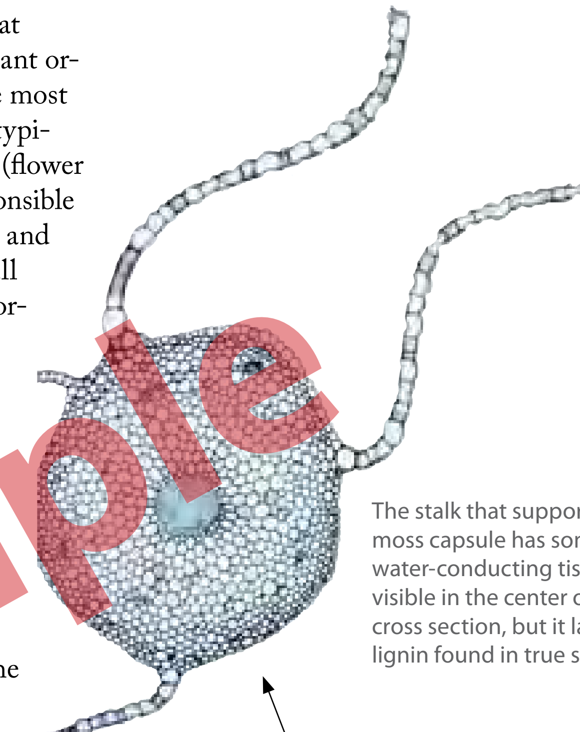
Lee W. Wilcox



Narrow-leaved loosestrife (*Lysimachia quadriflora*) — Myrsine family

INTRODUCTION

The bodies of plants—like our own—are made up of different organs, each of which performs a suite of vital funtions that allows plants to grow and reproduce. Of the three basic plant organs—roots, stems, and leaves—leaves understandably receive the most attention by photographers, painters, and other artists since they typically represent the showiest and most aesthetically striking organ (flower parts are actually modified leaves). In most plants, leaves are responsible for the bulk of photosynthesis—the conversion of sunlight, water, and carbon dioxide into food (sugar)—a process that supports nearly all terrestrial life on Earth, though stems also contribute to this important process. The root is no doubt the least well appreciated plant organ because it's usually found underground and thus is not obvious to us (though we are more familiar with roots we eat). With the possible exception of the bark found on woody plants, the stem is also underappreciated aesthetically because many of its often remarkable details only become apparent when observed with a macro lens or microscope.



The stalk that supports the moss capsule has some water-conducting tissue, visible in the center of this cross section, but it lacks the lignin found in true stems.

WHAT IS A STEM (AND WHAT ISN'T)?

The plant stem is usually found above the ground and supports the leaves and reproductive structures. It contains vascular tissues—analagous to the blood vessels in our bodies—that conduct water, minerals, food, and other substances to and from the leaves and roots (vascular tissues are found all three organs and are interconnected).

Not all plants have stems. Mosses, liverworts, and hornworts—collectively known as bryophytes—have leaflike, stemlike, and rootlike structures (Figure 1) but they differ from the "true" leaves, stems, and roots of more-advanced plants in several ways. One important distinction is that the water-conducting tissues in bryophytes lack lignin, which is a tough material that helps gives wood its strength.

Plant groups with stems include the seedless vascular plants (lycophytes and ferns) and the seed plants, which comprise gymnosperms (e.g., conifers such as pine trees) and the flowering plants (angiosperms).

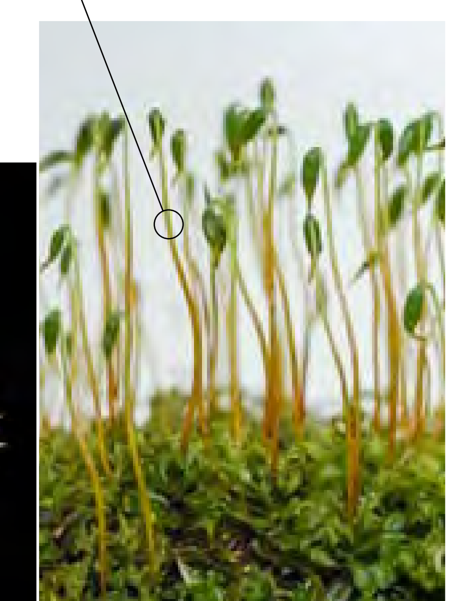


Figure 1 Mosses can have leaflike and stemlike structures

A BRIEF LOOK AT STEM ANATOMY

Botanists or plant biologists—scientists who study plants—are famous (infamous?) for using a great deal of terminology. The number of terms used here will be kept to a minimum but some are helpful in describing, at least superficially, some of the intricate and often beautiful detail that can be found in plant stems.

The major components of a stem are illustrated in a drawing of a stem cross section (Figure 2):

- Like us, plants have a protective skin. This outermost layer of cells is called the *epidermis*.
- Vascular tissue, which can often be found as a ring-shaped cluster of discrete *vascular bundles*, such as drawn here, consists of *xylem* to the inside (which transports water and minerals) and *phloem* to the outside (which carries food). Some plants instead have a more-or-less solid ring of vascular tissue (Figure 3), while yet others, such as corn and its relatives, have discrete vascular bundles that are scattered throughout the stem (Figure 4).
- The so-called "ground tissue" in which the vascular tissue is embedded is divided into the *pith* (in the center) and the *cortex* (between the vascular tissue and the epidermis). In some plants the pith becomes hollow as the stem matures.

Most of the stem images shown in this book are cross sections, but a quick look at stems in longitidinal view is helpful in understanding the overall organization and function of stems.

A longitudinal (vertical) section through the top of a lilac shoot is shown in Figure 5. Young (pre-)leaves, buds, and vascular tissue are all evident. The apical meristem is a region where cells continue to divide throughought the life of a plant to form new cells and tissues that bring about an increase in height ("meristem" is a general term that refers to particular places in plants where cells divide to form new ones; meristems are found in a number of specific locations). The formation of cells and tissues by the apical meristem is referred to as *primary growth*.

Figure 2 Stem cross-section diagram

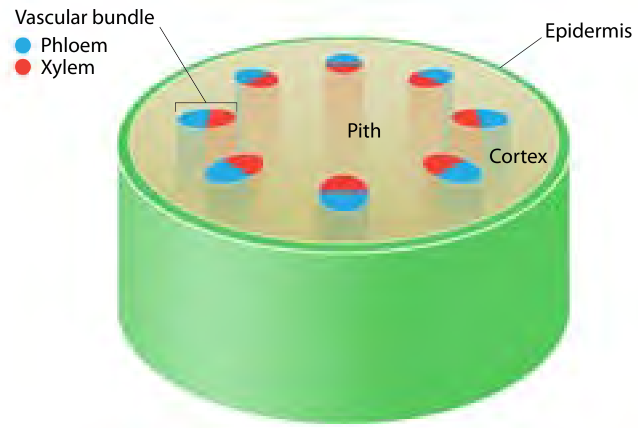


Figure 3 Ring-shaped vascular tissue of young basswood stem

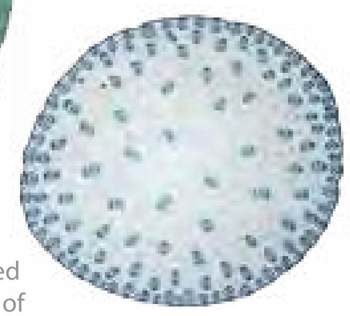


Figure 4 Scattered vascular bundles of corn stem

Figure 5 Lilac shoot tip

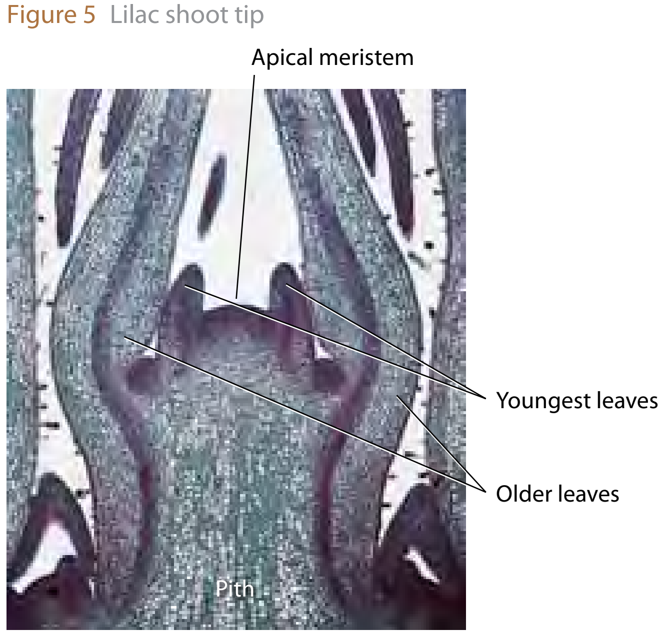
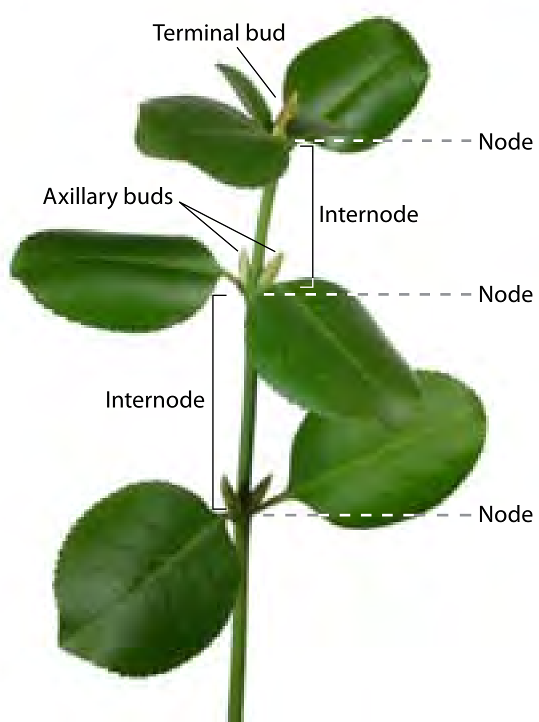


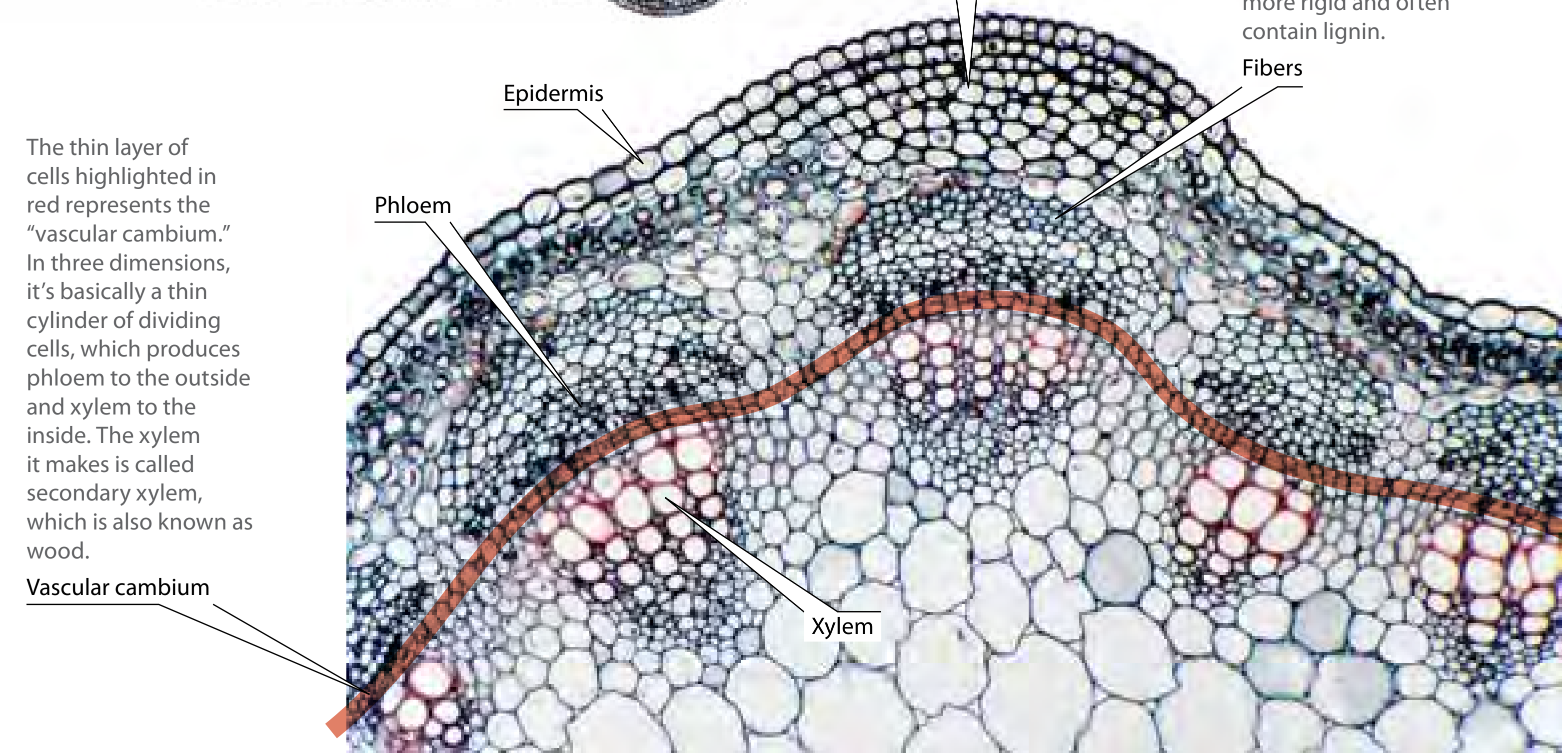
Figure 6 Burning bush shoot



The photo illustration in Figure 6 shows some external features of stems. A *node* is the region where a leaf or leaves are attached (two leaves are attached to each node of this burning bush plant). An *internode* is simply the region between two adjacent nodes. Most of the photos included in this book were taken of stem cross sections cut from internodes. *Axillary buds* are formed in the angle (or "axil") formed between the top of a leaf and the stem. Such a bud can grow into a branch, which is essentially another stem with its own set of leaves and sometimes reproductive organs (flowers or cones).

Some additional details of stem anatomy are illustrated below (Figure 7).

Figure 7 Alfalfa stem cross section at two magnifications



Secondary growth

Trees and shrubs and even some plants we often think of being herbaceous can grow in diameter—sometimes just a small amount and sometimes to a great extent. This type of growth is known as *secondary growth*, to distinguish it from primary growth, which causes a plant to grow vertically (or in length in the case of plants that creep along the ground or on other plants). We've already looked at the tissue responsible for secondary growth—the vascular cambium. The apical meristem, responsible for primary growth, produces cells that mature into the "primary" vascular tissues. Some plants, such as most of the buttercups, rely solely on this type of vascular tissue. In many other (if not most) plants, however, some amount of vascular tissue is also produced by the vascular cambium—the perpetually young ring of tissue that produces (food-conducting) secondary phloem to the outside and (water-conducting) secondary xylem to the inside (Figure 8). Secondary xylem is also known as wood.

Cells of the secondary vascular tissue produced by the vascular cambium tend to occur in rows. Typically, more secondary xylem is made than secondary phloem, which is why the bulk of a tree trunk consists of wood and not bark (everything to the outside of the vascular cambium is considered to be bark). Like the primary vascular tissues, secondary ones consist of different cell types but those involved in conducting materials are mostly long, vertically oriented cells. There are two main types in secondary xylem—tracheids, which are the more ancient type and are found in all vascular plants, and vessels, which tend to be larger and lose their end walls to form long tubes. Vessels are found in the wood of flowering plants but not conifers. Some more-or-less brick-shaped cells in secondary xylem and phloem are oriented horizontally and run along the radius of the stem and are known as "rays" (Figures 9, 10). The rays assist in moving materials laterally. Figure 10 shows sycamore wood in three different views, which gives a better idea of what the vertical conducting cells and rays look like in three dimensions.

Another meristem is present in woody stems and is known as the *cork cambium* (Figure 8). This meristem may actually form multiple times throughout the lifetime of a tree or shrub; the first time typically from cells in the cortex beneath the epidermis. It produces protective cork cells to the outside (which die) and living, more general cells to the inside. The cork cambium, together with the cells it makes to the inside, and the cork cells it produces to the outside, are known as the *periderm*. In the oak slice shown on the following page, there are actually several periderms visible as fine lines in the outer bark. The epidermis and cortex are sloughed off as the periderm(s) form and the plant grows (they can't stretch to keep up as the woody stem expands in diameter). The organization of the periderms is responsible for the patterning of the bark, whether it be the thin, peeling bark of a birch tree, the smooth bark of a beech, or the characteristic shredded bark of the shagbark hickory.

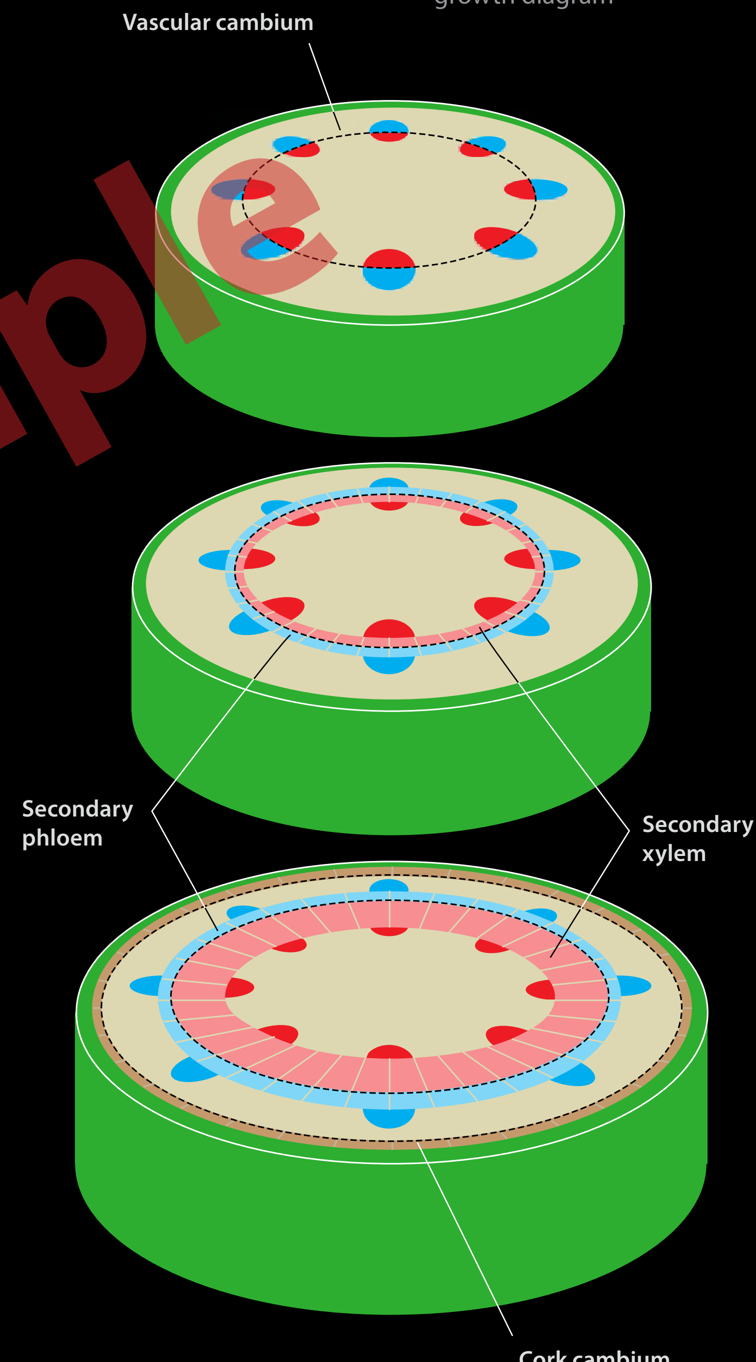


Figure 8 Secondary growth diagram

Figure 9 The woody stem of oak

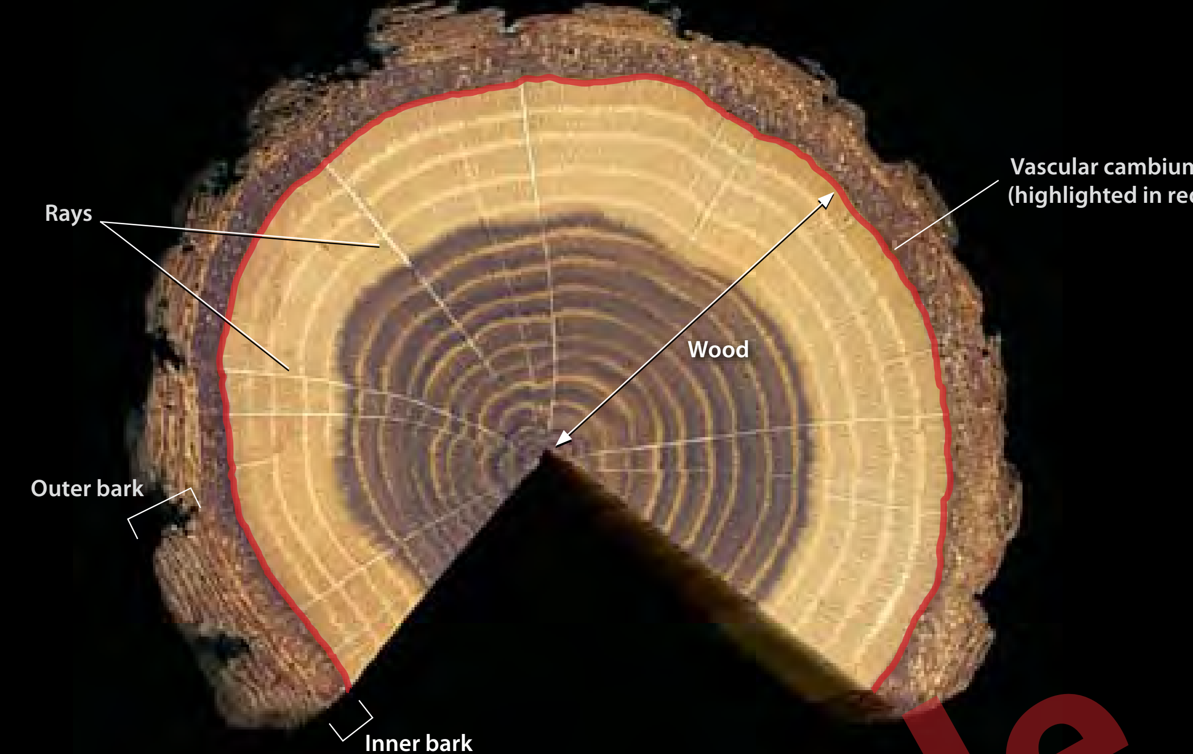
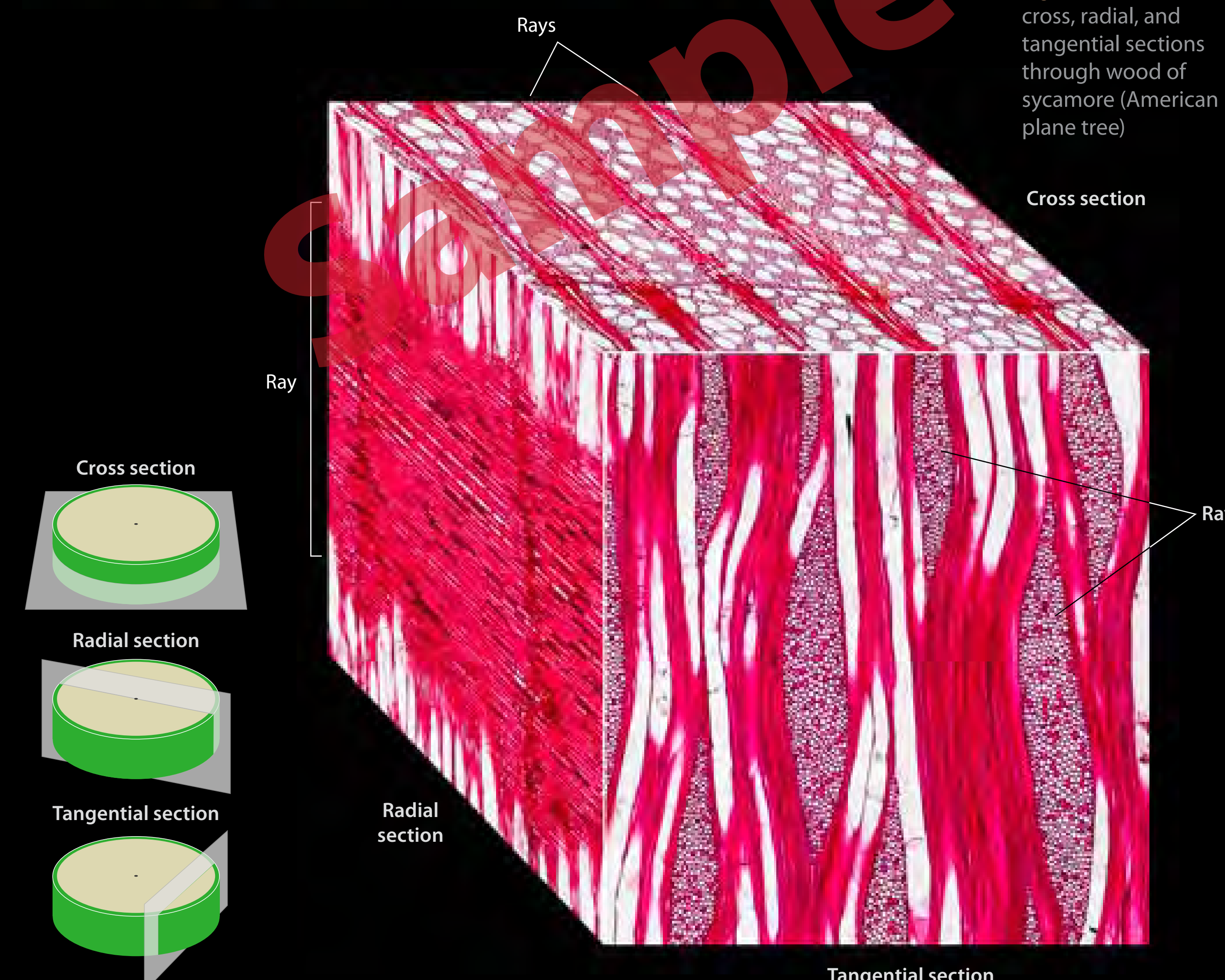


Figure 10 Stained cross, radial, and tangential sections through wood of sycamore (American plane tree)



Unusual stems

Stems come in a variety of forms that don't resemble the "typical" stems we've been considering so far. Some are barely recognizable as stems at all. In plants such as Virginia creeper, portions of the stem are modified as *tendrils*—vining extensions that grab onto nearby plants and structures for support (Figure 11). Not all tendrils are modified stems, however, as in the case of peas, where the tendrils instead represent leaves that have lost some of their flat, bladelike portions.

The familar potato we eat is actually a stem called a *tuber* that is modifed for storage (Figure 12). The "eyes" are buds, which can grow and produce new plants if a piece of a potato tuber with an eye is planted. Notice that the buds are found in a spiral pattern on the potato. In many plants leaves are likewise attached to stems in a spiral fashion.

A type of stem that runs horizontally and typically lies beneath the soil surface is the *rhizome*. Rhizomes of some plants can be quite deep and extend for surprisingly long distances. Vertical stems or leaves periodically emerge from the rhizomes such as in iris plants (Figure 13). Rhizomes are generally not green.

Stolons, or runners, are probably most familiar in strawberries. These horizontal stems "run" along the surface of the ground and can form new plants where they touch down. The example shown here is a species of *Potentilla* called silverweed (Figure 14), which is a relative of strawberries.

In some plants, stems are responsible for the majority if not all of photosynthesis. Cacti are a good example (Figure 15). The stem may be flattened, as here (a "cladode"). In addition to performing the bulk of photosynthesis, it stores water. The leaves are reduced to spines. Once again, as with the eyes on potato tubers, you can see a spiral pattern of the spines on the cactus, which provides a clue as to their leafy origin. Stems in some other groups of plants are also flattened into cladodes but are amazingly similar in appearance to leaves. The example here is a relative of the poinsettia; the flat structures are indeed stems, not leaves (Figure 16).

Figure 11 Stem tendril of Virginia creeper

Figure 12 Tuber (fingerling potato)

Figure 13 Rhizome (iris)

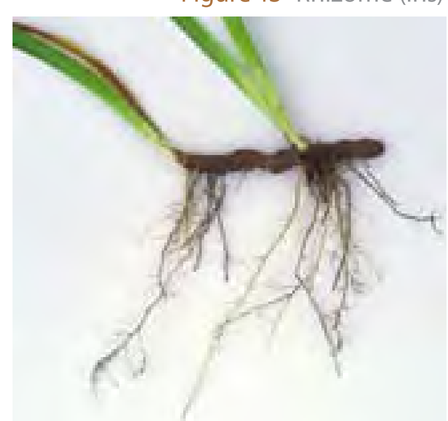


Figure 14 Stolons (silverweed)

Figure 15 Flattened stem (cactus)

Figure 16 Phyllanthus cladodes

Stem ornamentation

Some plants have stems that are smooth but more often there is some sort of surface ornamentation that can take on many forms and serve different purposes.

No doubt we've all encountered plants with *prickles*, such as roses (Figure 17) or raspberries. Prickles represent modified tissues of the epidermis and cortex.

As mentioned earlier, *spines*, such as those found on cacti, represent modified leaves. They are also found on many other plants. In the case of the black locust spines, shown here, they're actually "stipular" spines, because they are derived from the little structures (stipules) that can be found at the base of some leaves (Figure 18).

The honey locust has larger, pointed structures called *thorns*, which are modified branches (Figure 19) (note that, botanically speaking, the "thorns" of roses are actually prickles and not thorns).

All these pointy structures may help protect the plant by deterring herbivores. Other stem modifications play different roles.

Herbaceous plants and young portions of woody ones, often have stems with hairs ("trichomes") on their surface (Figure 20), which are outgrowths of the epidermis. Hairs take on a great variety of shapes and sizes as can seen in this book. Some help insulate the plant and/or help keep it moist while others are tipped by glands, which often contain fragrant oils and other substances that may deter pests.

Woody plants, which eventually are covered by bark, often have *lenticels*, which appear as raised dots, lines, etc. on the surface where localized growth has created a passageway for air to move (bark contains waxy substances and is pretty much impervious to air).

Figure 17 Prickles (rose)

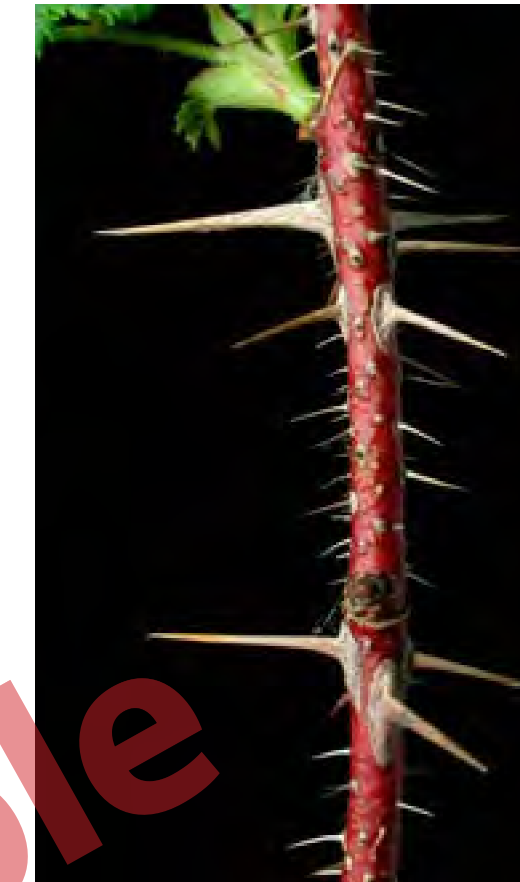


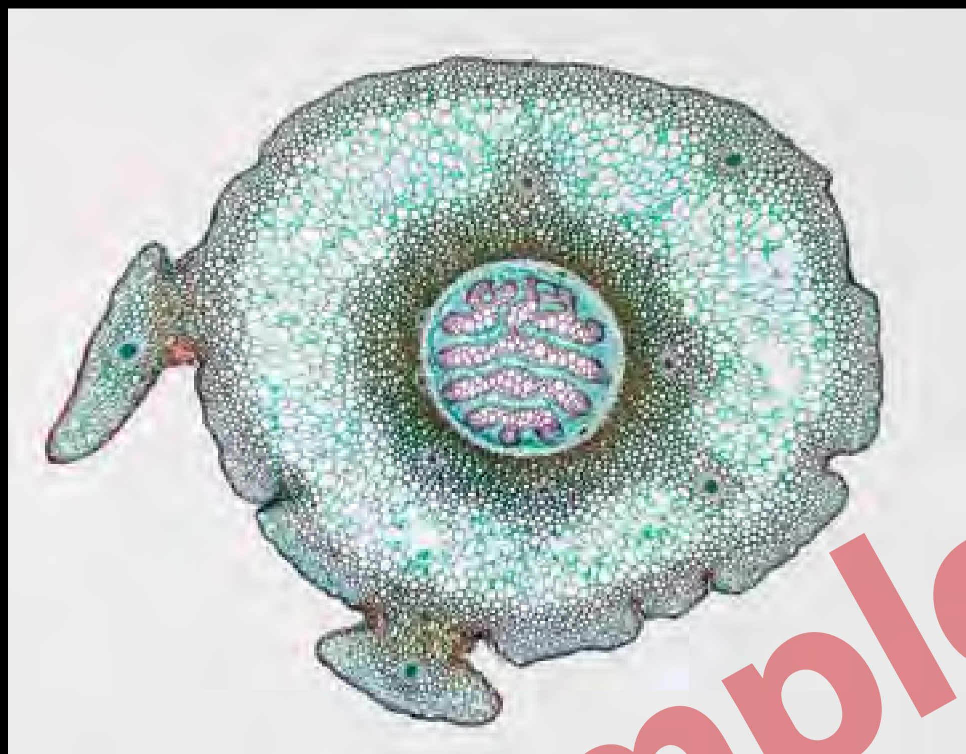
Figure 18 Stipular spines (black locust)

Figure 19 Thorns (honey locust)

Figure 20 Hairs (black-eyed Susan)

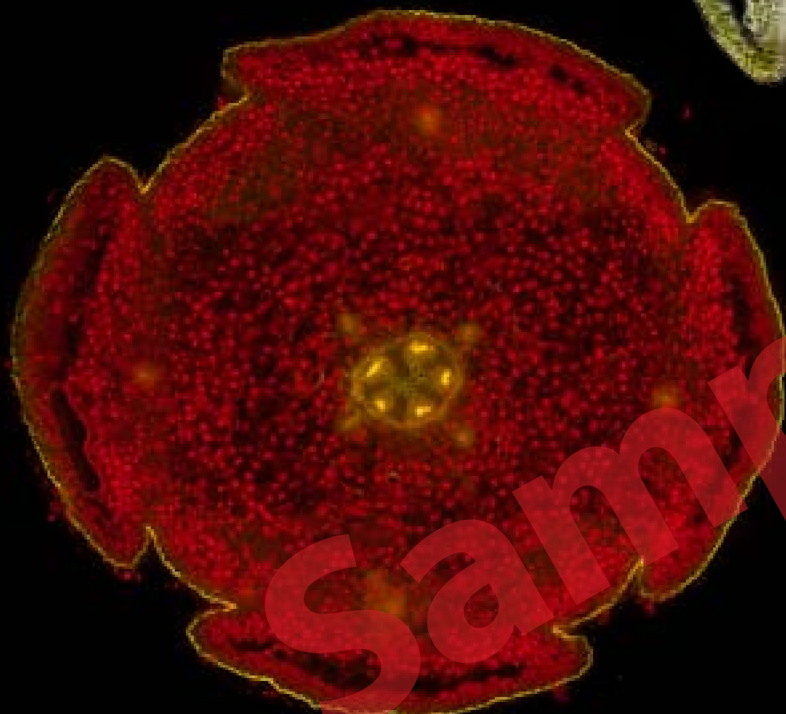
Lycophytes and Ferns

Crowfoot clubmoss
Diphasiastrum digitatum



Clubmosses (*Lycopodium* and closely related plants) — Clubmoss family

Clubmosses are actually not mosses but, rather, seedless vascular plants that have horizontal stems that creep either along the surface of the ground or beneath it, as well as upright shoots. They are evergreen plants, some of which resemble gymosperms, and have common names such as "ground pine" and "Christmas green." Two different species are shown on the opposite page. The treelike species has cones at the top, which produce spores that were used as "flash powder" in the early days of flash photography because they are very fine and burn explosively. The creeping species also makes cones but this particular specimen had not yet produced them. The same stained prepared slide shown above was photographed with (left to right) brightfield, darkfield, and polarized light optics (see the Techniques section at the end of the book for more information). The vascular tissue is located in the center of the stem in this ancient group of plants. Leaves are attached to the stem at 7- and 9-o'clock in this section. Each leaf contains a single unbranched vein, which is characteristic for leaves of clubmosses and other members of the plant group known as lycophytes.



Clubmoss family

This page Shining firmoss (clubmoss) (*Huperzia lucidula*)

Named for its shiny leaves, this lycophyte is a simple plant with a centrally located vascular cylinder in its stem. A cross section is seen here with polarized light (top) and epifluorescence using blue light (bottom) (see Techniques section at the end of the book). The red autofluorescence is due to chlorophyll pigments and the vascular tissue in the center glows yellow, as does the waxy cuticle on the epidermis. The four lobes are leaves about to emerge from the stem. Small strands of vascular tissue can be seen moving through the stem toward other leaves. The white structures on the stem to the immediate right are clam-shaped *sporangia*, in which spores were produced (sporangia on this plant have released their spores). Upright stems were sectioned in both this and the next species (rather than the rhizome).

Next page Crowfoot clubmoss (*Diphasiastrum digitatum*)

This fan-shaped clubmoss is an attractive ground cover plant that bears a particularly strong resemblance to conifers and is sometimes called "ground pine" or "ground cedar." Polarized light and epifluorescence images are once again shown.

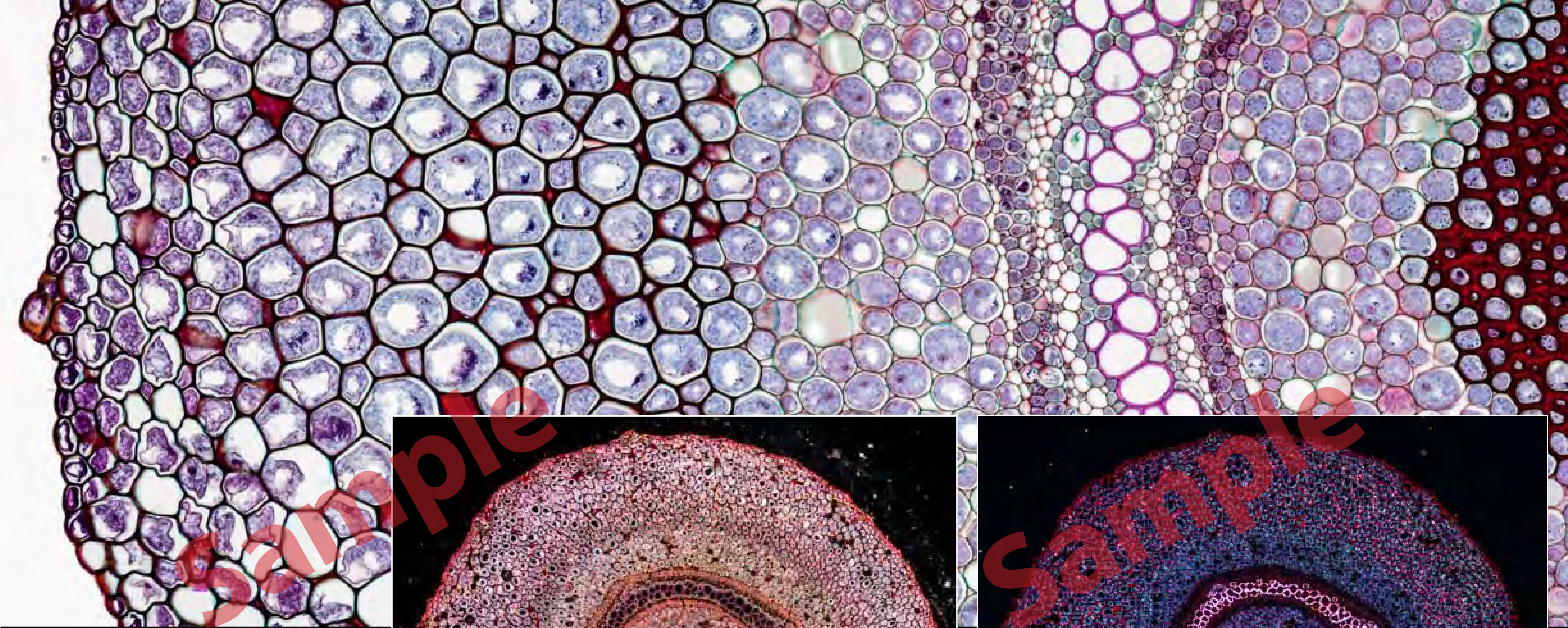
Sample

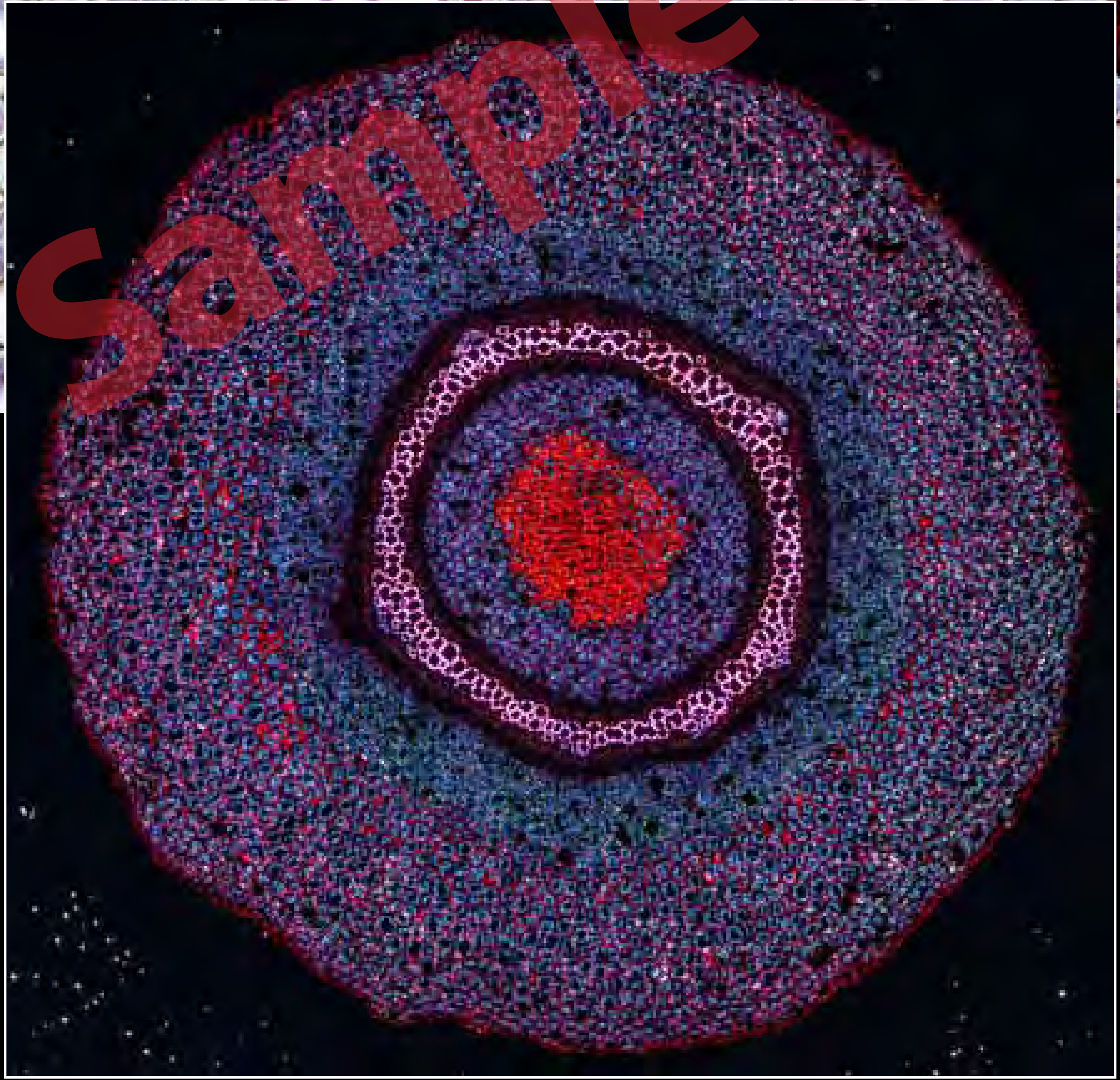
Bracken fern (*Pteridium aquilinum*) — Bracken fern family

The common and often weedy bracken fern is a member of a fern family that is primarily tropical in distribution. As with most other ferns, the main stem is actually a rhizome, in this case one that can be found at considerable depth (up to 3 meters or 10 feet) beneath the ground and can extend over 400 meters in length! The aboveground portion of the plant that is visible is the leaf. The "stalk" is the leaf *petiole* (known as a *rachis* in ferns). It is quite similar to the rhizome when viewed in cross section but is flattened along one side. The ferns are in many ways the champions of complexity when it comes to the arrangement of vascular tissue. The whitish vascular tissue here is separated by patches of red or orange thickened "sclerenchyma" tissue. These specimens are all fresh and the bright colors are real and also show up with brightfield microscopy.

American royal fern (*Osmunda spectabilis*) — Royal fern family

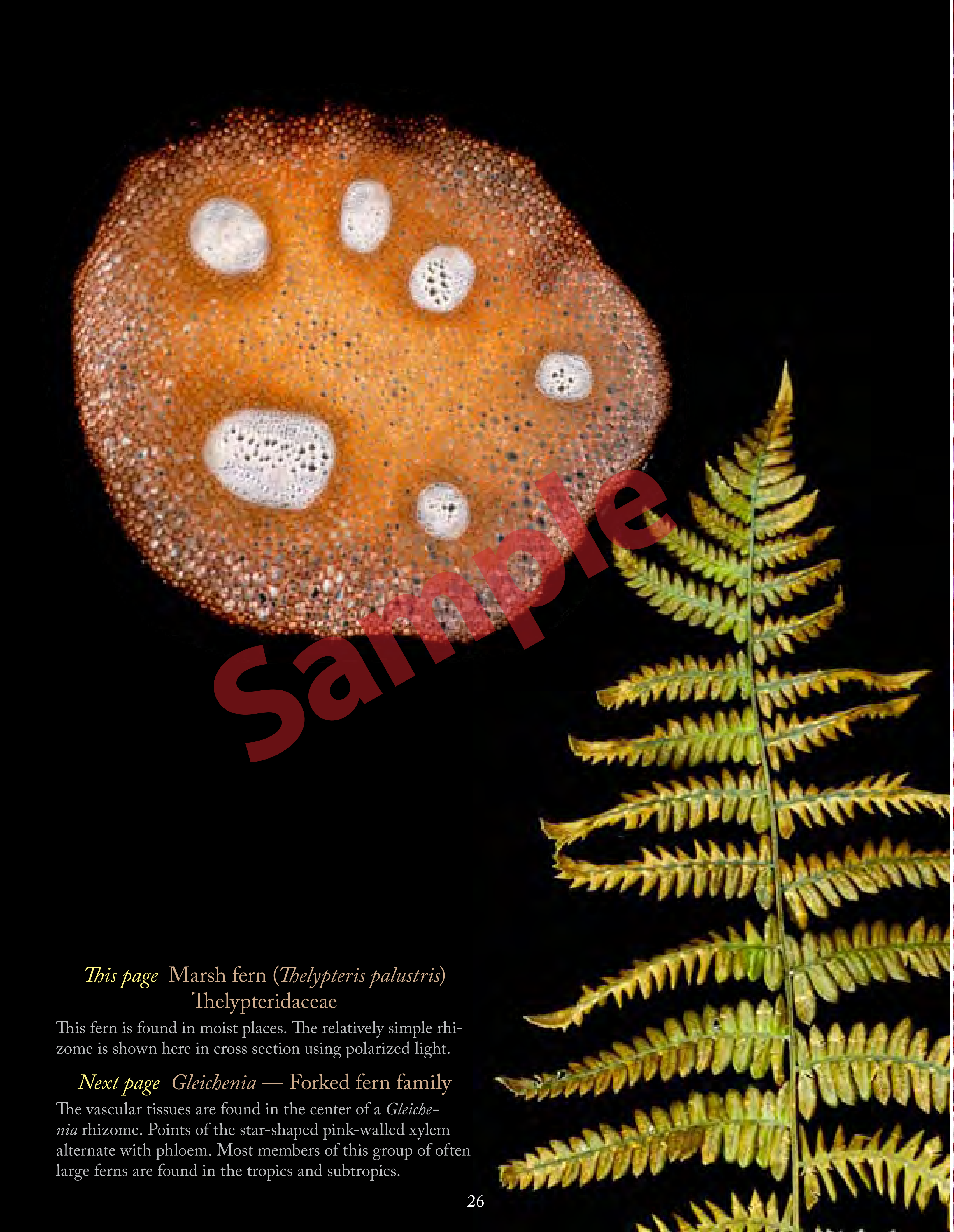
The royal fern prefers damp areas and is distinguished from its relatives in having rather large, separate leaflets or pinnae. A persistent, sizable mass of smaller stems and roots emerge from the rhizome, which doesn't occur as deep as that of the bracken fern. The clump of ferns shown in the upper right was photographed in early spring when green spore-producing portions of the plant contrast with the yellow leaflets, which eventually turn green. Leaves typically turn bright yellow in the fall.





Tree fern (*Dicksonia*) — Dicksoniaceae

This genus of tree fern grows in a variety of Southern Hemisphere locations, including Australia, New Zealand, South America, and Mexico. It is thought to extend back in time to the Jurassic Period. Here, a commercially produced stained specimen of its rhizome is seen with brightfield optics (top) as well as darkfield (bottom left) and polarized light (bottom right). The vascular tissue consists of two rings (actually, cylinders) of phloem sandwiching a ring of xylem (the xylem cells appear hollow with pink cell walls in brightfield and polarized light optics).

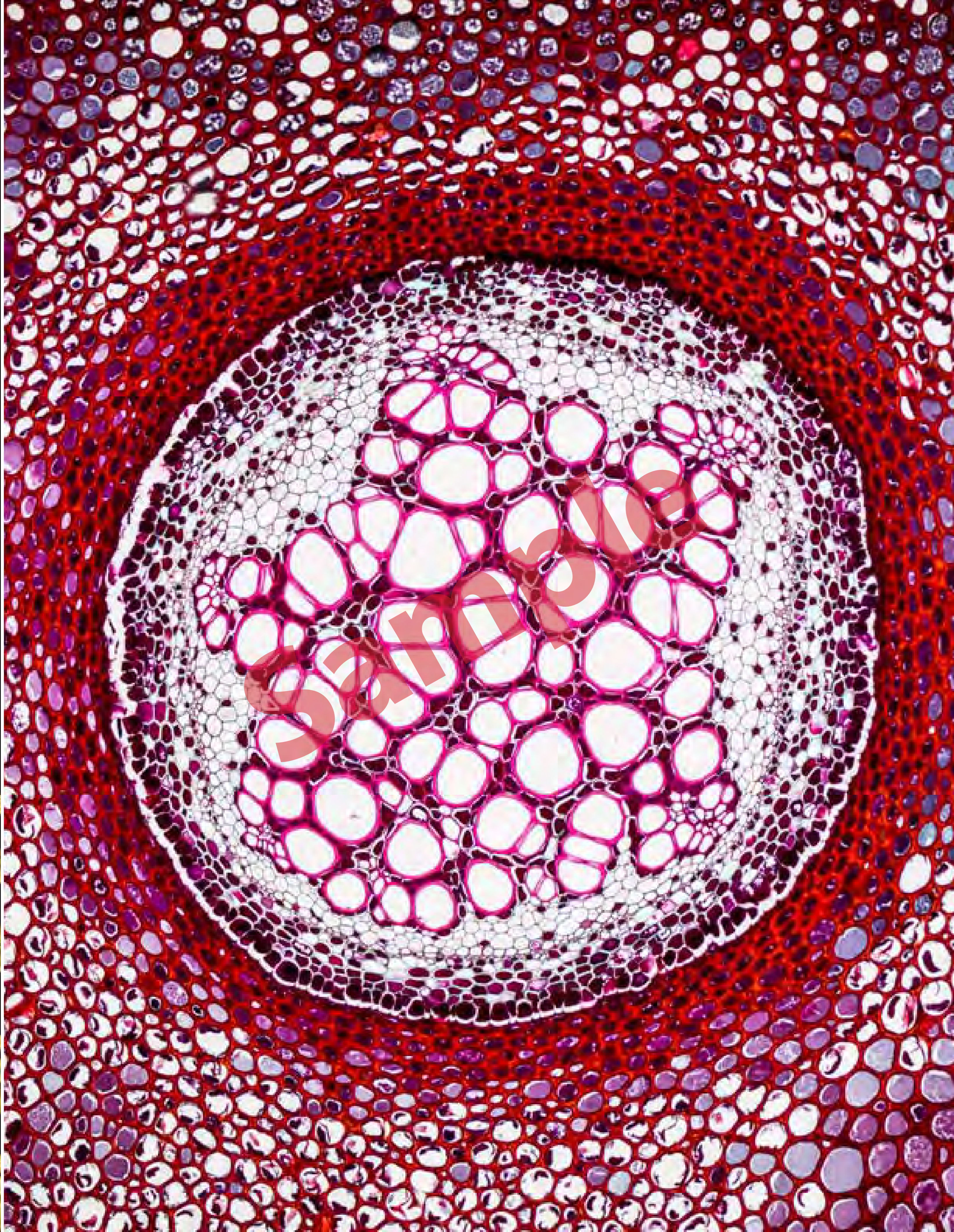


This page Marsh fern (*Thelypteris palustris*)
Thelypteridaceae

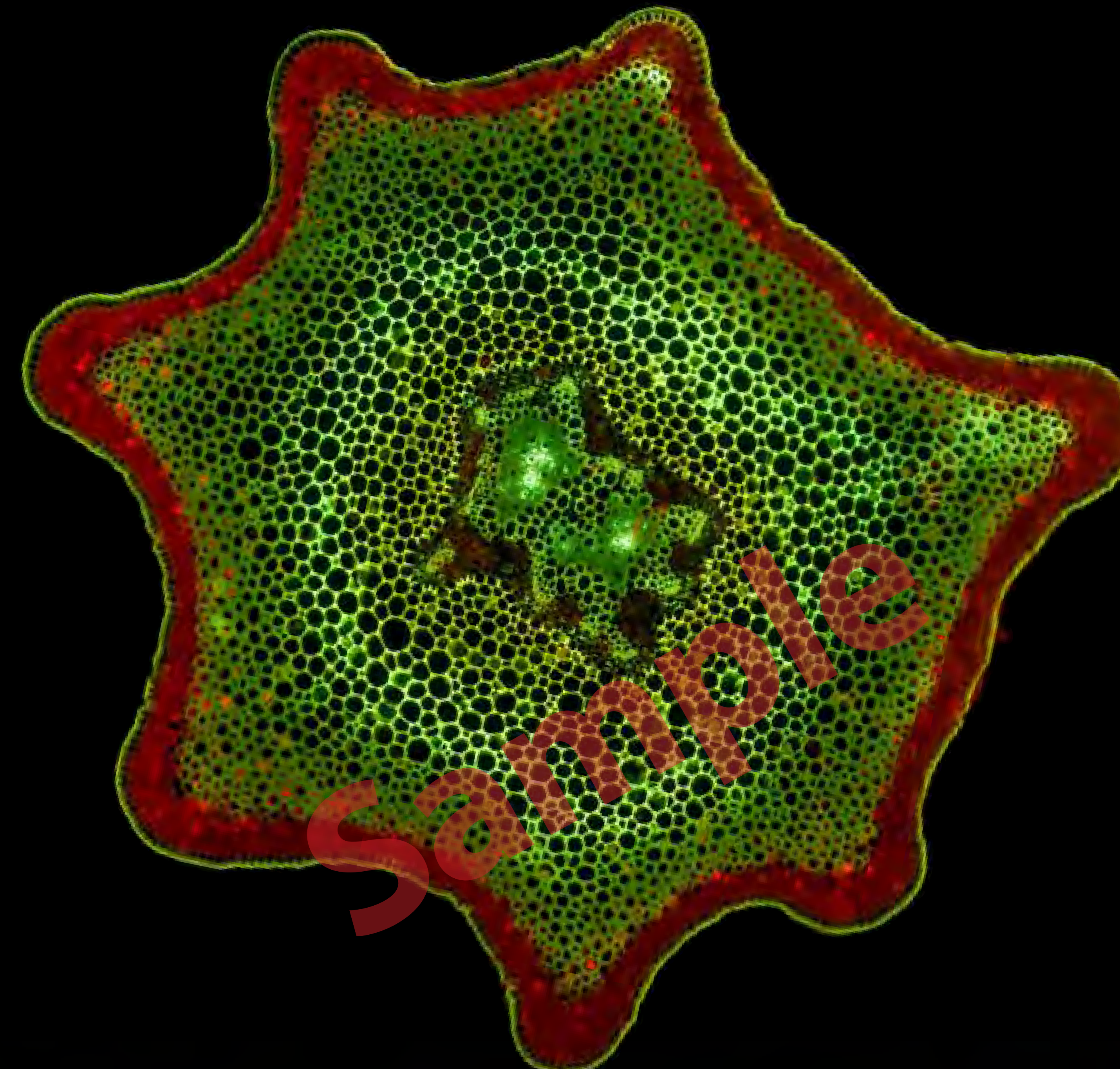
This fern is found in moist places. The relatively simple rhizome is shown here in cross section using polarized light.

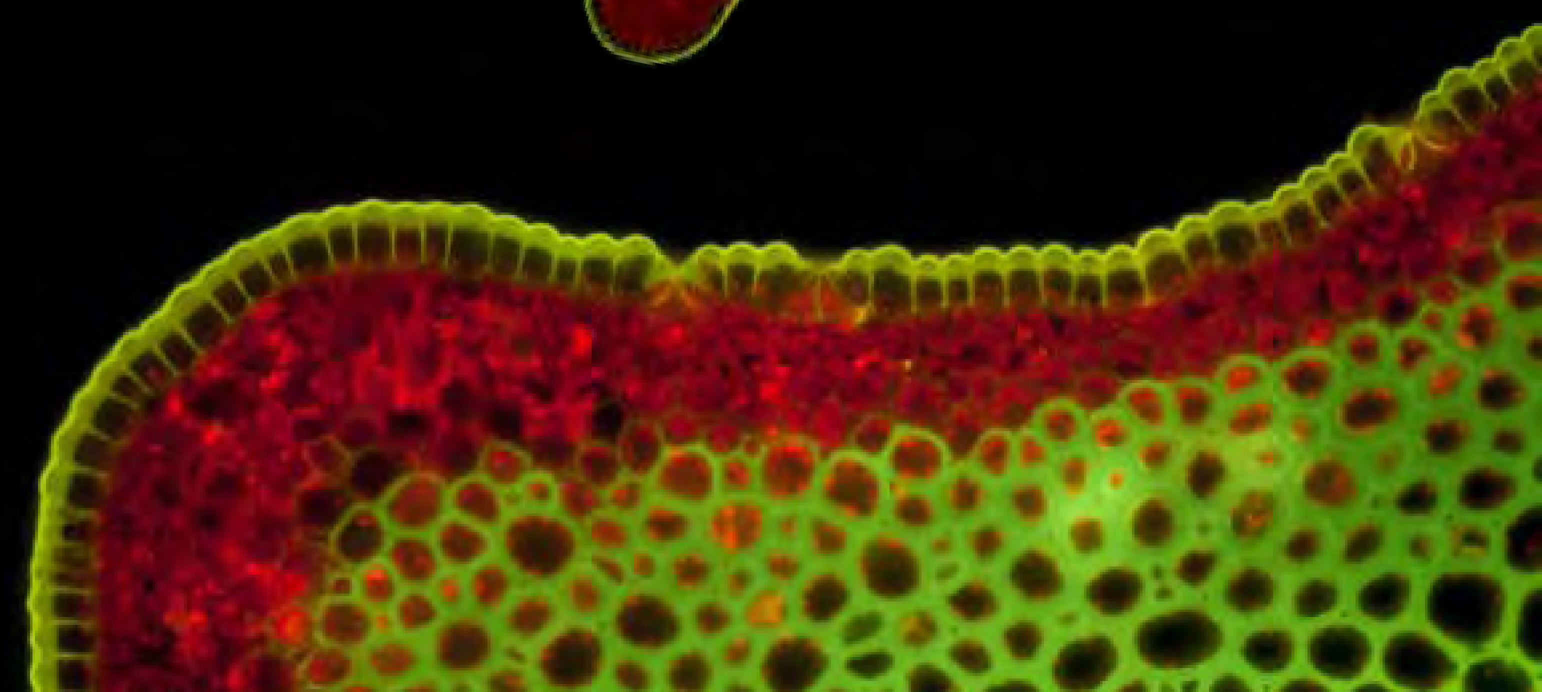
Next page *Gleichenia* — Forked fern family

The vascular tissues are found in the center of a *Gleichenia* rhizome. Points of the star-shaped pink-walled xylem alternate with phloem. Most members of this group of often large ferns are found in the tropics and subtropics.



Sample

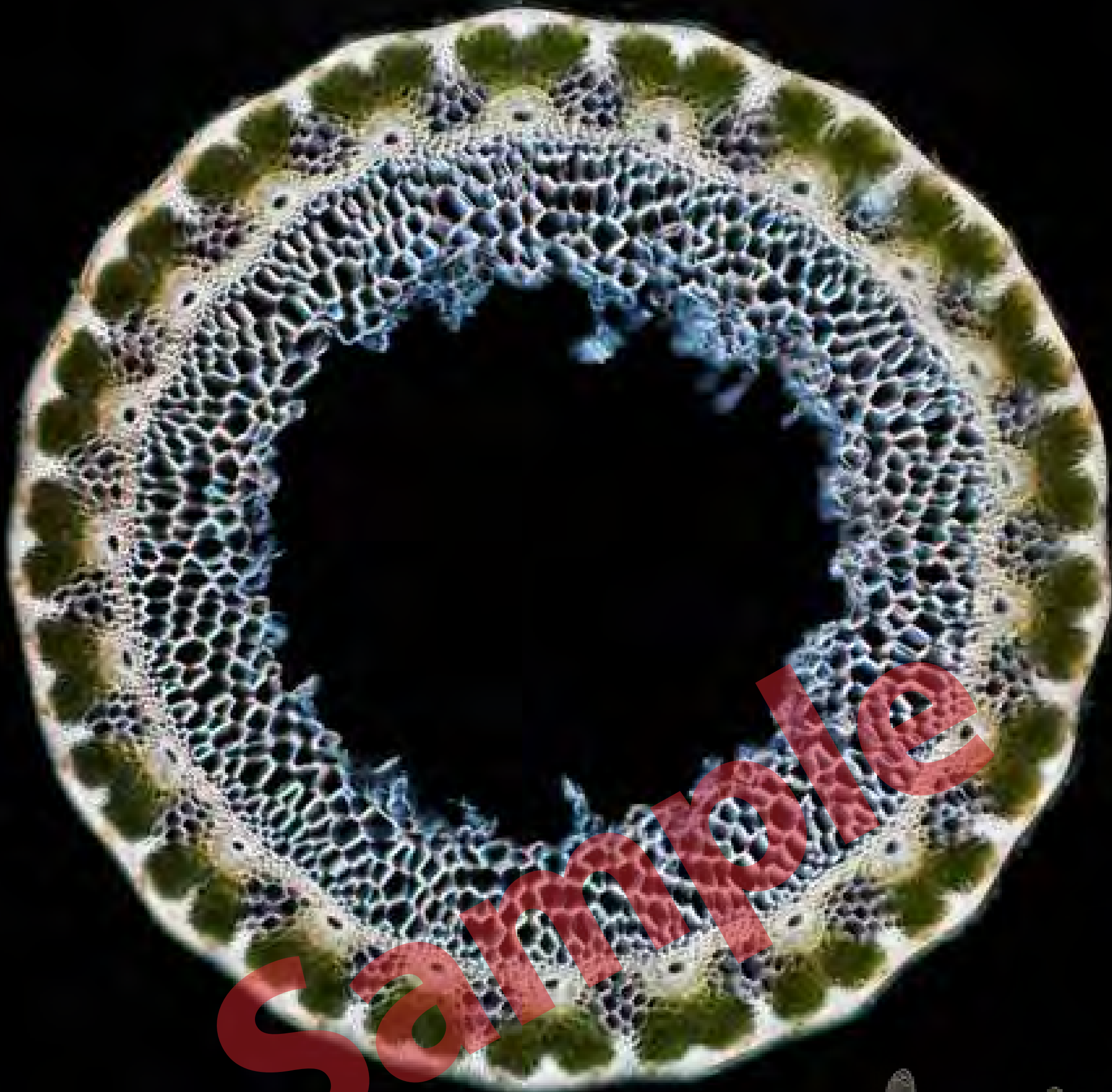




Whisk fern (*Psilotum nudum*) — Whisk fern family

This page The whisk fern is an unusual tropical plant that has no true leaves or roots. It grows on other plants and so the lack of roots isn't detrimental. The green stems take on the job of photosynthesis, whereas in most plants the leaves do the lion's share of the photosynthetic work. At one time separated into its own group, it's now recognized that whisk ferns are related to other types of ferns. The yellow and brown structures are sporangia, which produce the tiny spores by which the plant reproduces.

Next page These images were taken using epifluorescence microscopy and show the red autofluorescence of chlorophyll pigments, while the green color comes from lignin-containing cell walls. The close-up view of the stem surface better shows the thick, waxy *cuticle* coating the epidermis (yellow-green here), which helps the plant stay moist and protects against pathogens. Notice that, like most of the other non-seed plants shown here, the vascular tissue is at the center of the stem.



Horsetail (*Equisetum*) — Horsetail family

Horsetails are also known as scouring rushes (silica is found in the stems, which make them effective in scrubbing pots and pans). These plants have complex, highly symmetrical stems with canals of various sizes. The internodes of mature stems are hollow. The cross sections shown here come from upright shoots, which grow from underground horizontal rhizomes.

This page Smooth horsetail (*E. laevigatum*) is an unbranched species.

Next page Top: Water horsetail (*E. fluviatile*) has branches that, as in all branched species, actually push their way through the fused leaves, which encircle the stem at the nodes. An excised node with branch buds is shown in cross section. There is tissue in the center of the stem at the nodes, as opposed to the internodes. Bottom: Field horsetail (*E. arvense*), a common branched species.

Gymnosperms

Black spruce
Picea mariana

This page Red cedar (*Juniperus virginiana*) — Cypress family

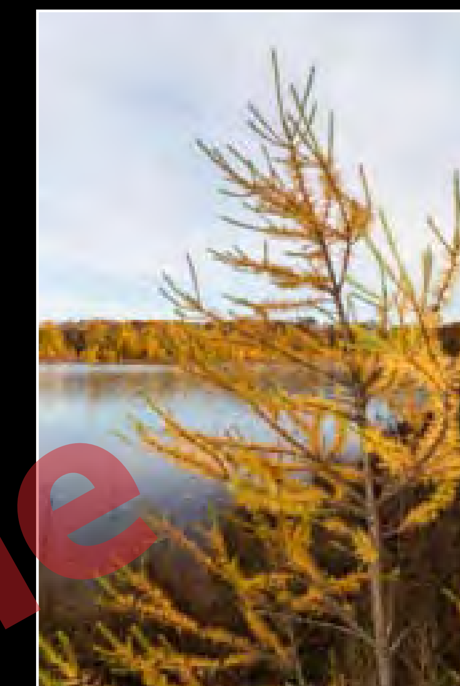
Red cedar is a common and sometimes invasive tree that can often be found in fallow fields. It and the two tree species on the next page are gymnosperms—plants that produce "naked" seeds but no flowers or fruits. More specifically, the plants shown here are among the familiar "conifers" or cone-bearing trees. In each conifer stem section shown here there are resin ducts, through which move the fragrant compounds we associate with these trees. They show up best as the dark circles in the greenish-colored cortex of the Norway spruce stem.

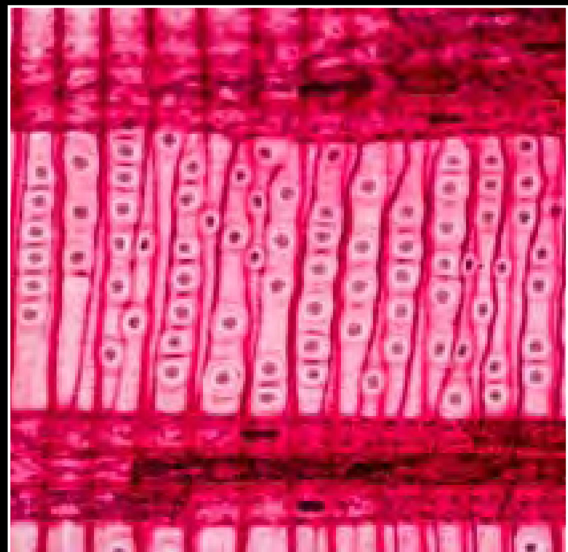
Next page (top) Tamarack (*Larix laricina*) — Pine family

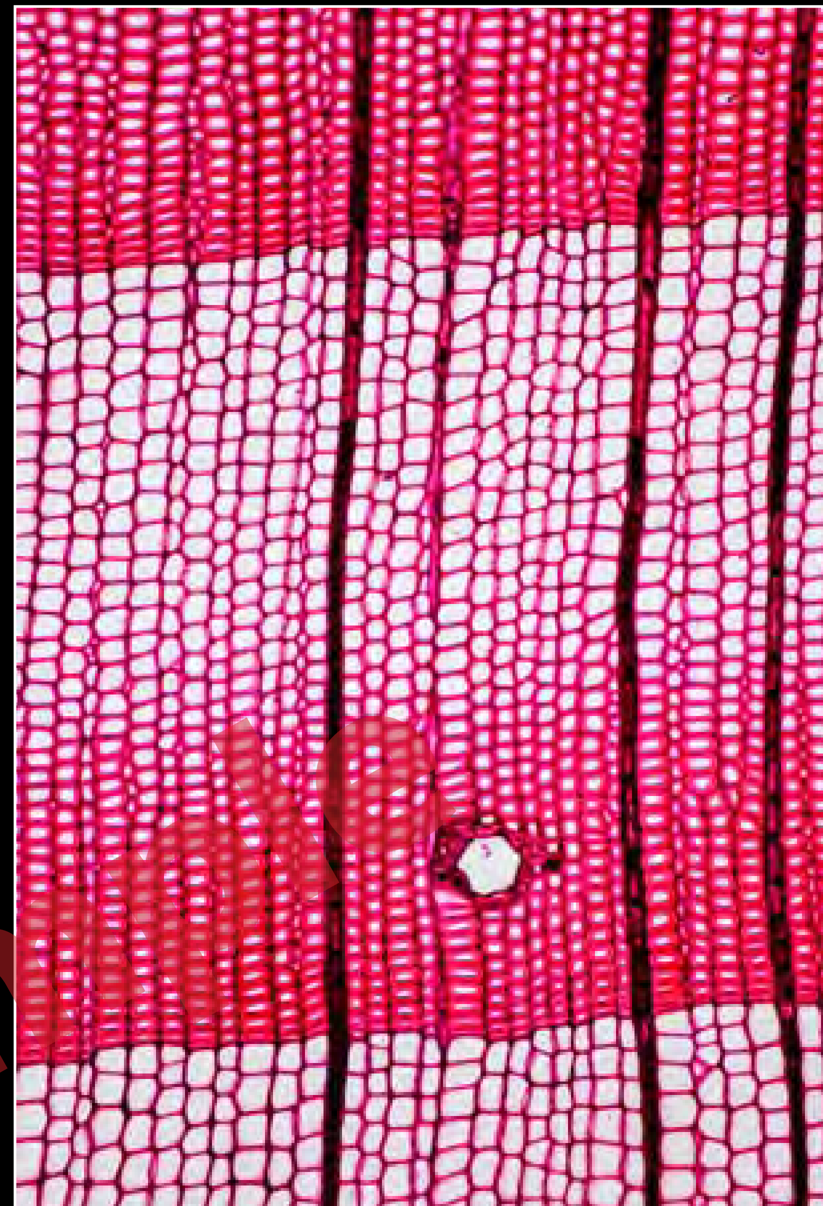
The tamarack is primarily a wetland tree that, unlike most confers, is a deciduous plant, rather than an evergreen. Its soft and slender needles turn a golden yellow in the fall before they drop. The stem section shown has more wood than the other conifer stems shown here. Two growth rings, by which tree age can be determined, are evident.

Next page (bottom) Norway spruce (*Picea abies*) — Pine family

The Norway spruce is a frequently encountered tree in cityscapes that is often planted as an ornamental. It finds its way into homes as a Christmas tree as well. The section shown here is from a very young stem that is at the earliest developmental stage of the three stems on these two pages. The white lobes coming off the stem represent regions where the bases of leaves (needles) are fused to the stem. Barely any wood has been produced to this point.







Douglas fir (*Pseudotsuga menziesii*) — Pine family

Douglas fir wood is shown here in three different planes of section (see Introduction). Like pines and other conifer trees, there are no xylem vessels. Instead, smaller xylem cells called tracheids transport water. Cross section—top right: The center of the stem is toward the top and the vascular cambium, which produces the wood, is toward the bottom (but not seen here). Tracheids in the later portion of a growth ring ("late wood") have thicker cell walls than those of the early wood. The larger opening in the lower center is a resin duct. Radial section—top left: Parts of two rays are evident on the top and bottom of the image. The circular structures are pits (seen here in face view); pits allow water to move between cells. Tangential section—lower left: Several rays are viewed end-on. They are only one cell wide. Pits are seen both in face and side views.

White pine (*Pinus strobus*) — Pine family

A tree familiar to many, white pine can grow to considerable height and is in fact the tallest tree in Eastern North America. A very young stem with only a small amount of wood is shown in cross section in the inset. Resin ducts can be seen outside of the vascular tissue. The background image shows the green autofluorescence of lignified xylem cells (tracheids), along with the red of some chlorophyll still found in the pith of a somewhat older stem. Hints of chlorophyll are also evident in wood rays.

Martha E. Cook

Joint-fir (*Ephedra* sp.) — Ephedra family

Ephedra includes several dozen species but is the only genus in its own family and order. At first glance it appears somewhat similar to horsetails (see earlier) but seeds are produced in its "female" cones (as opposed to spores in the cones of horsetails). Like horsetails, the stem is the photosynthetic organ of the plant. The cortex in this cross section is filled with chloroplasts, giving it a green color.

FLOWERING PLANTS

Buttercup
Ranunculus sp.

Dutchman's pipe (*Aristolochia*) — Dutchman's pipe family

This genus is widespread and contains viny species that may become woody (wood is present in this section) as well as herbaceous perennials. Some of the best examples of lenticels (which allow for gas exchange—see Introduction) are found in these plants. Portions of three lenticels are seen in this prepared specimen. This plant family is thought to be among the more ancient groups of flowering plants.

Waterweed (*Elodea*) — Frog's bit family

The stems of waterweed, like those of most aquatic plants, possess air spaces/canals that help move oxygen to more deeply submerged portions of the plant where the water may contain very little or no oxygen. This common aquatic plant is often used in aquaria as well as in the biology classroom because it has thin leaves in which the cells and chloroplasts are easy to examine. It also has a quite spectacular apical meristem, with very many tightly packed forming leaves.

Carrion flower (*Smilax*) — Greenbrier family

This viny plant is a monocot—that is, it has one *cotyledon* or seed leaf, as do corn and other grasses, lilies, and asparagus. Monocots have scattered vascular bundles, which is an arrangement that does not allow for secondary growth with a vascular cambium. Each bundle looks a bit like an alien face, with two large xylem vessel tubes for “eyes.”

Asparagus (*Asparagus officinalis*) — Lily family

In this well-known food plant, it is the stem that is primarily responsible for carrying out photosynthesis. The little triangular flaps of tissue are the leaves. Branches emerge from the “axil” between the leaf and stem. As with other members of the lily family, and monocots in general, the vascular bundles are scattered throughout much of the stem.

Cattail (*Typha latifolia*) — Cattail family

The common cattail has a modified stem called a rhizome, from which the leaves and flower shoots emerge. This often invasive plant can spread quickly by means of the rhizomes. Cattails have been put to many uses, including the extraction of starch from the rhizomes for use as food.

Corn (*Zea mays*) — Grass family

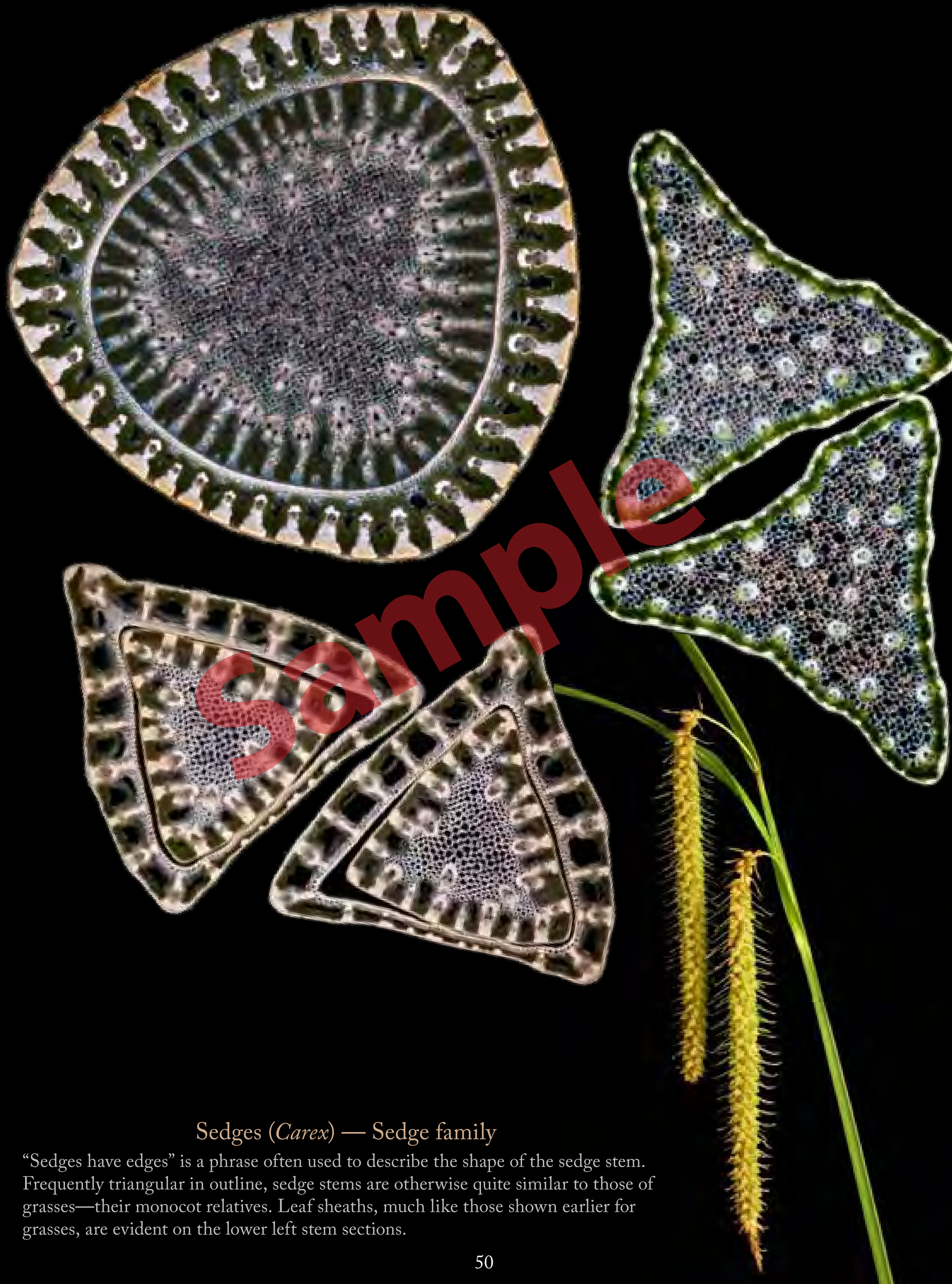
Corn is a typical monocot in having stems with scattered vascular bundles. It is often used in the classroom to demonstrate this feature. Young stems such as the one shown above can be quite hairy.

Reed canary grass (*Phalaris arundinacea*) — Grass family

This grass is terribly invasive in many places, particularly in low-lying areas. It can spread via seeds and by thick rhizomes. As a typical grass, many portions of the stem are at least partially surrounded by the basal part of a leaf—the leaf sheath. The macro shot of the leaf sheath shown here (indicated by the arrow) is of a related grass. In the cross section, a leaf sheath closely wraps the stem, which has a hollow pith.

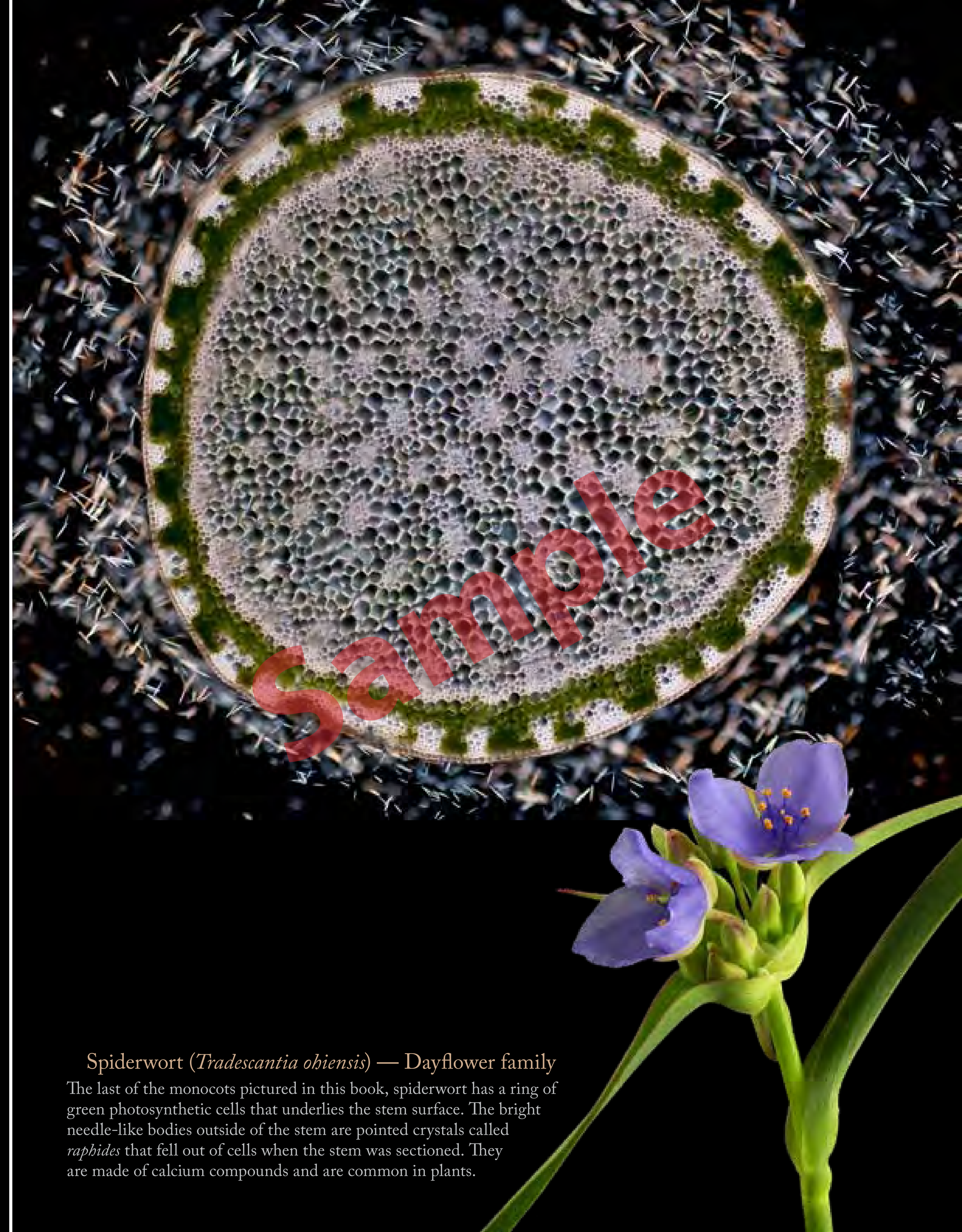
Panic grass (*Dichanthelium*) — Grass family

Another grass, seen above with the main stem and a smaller branch surrounded by leaf sheaths. Basal portions of two large hairs are evident on the outermost leaf sheath.



Sedges (*Carex*) — Sedge family

"Sedges have edges" is a phrase often used to describe the shape of the sedge stem. Frequently triangular in outline, sedge stems are otherwise quite similar to those of grasses—their monocot relatives. Leaf sheaths, much like those shown earlier for grasses, are evident on the lower left stem sections.



Spiderwort (*Tradescantia ohiensis*) — Dayflower family

The last of the monocots pictured in this book, spiderwort has a ring of green photosynthetic cells that underlies the stem surface. The bright needle-like bodies outside of the stem are pointed crystals called *raphides* that fell out of cells when the stem was sectioned. They are made of calcium compounds and are common in plants.

Coon's-tail (*Ceratophyllum demersum*) — Coon's-tail family

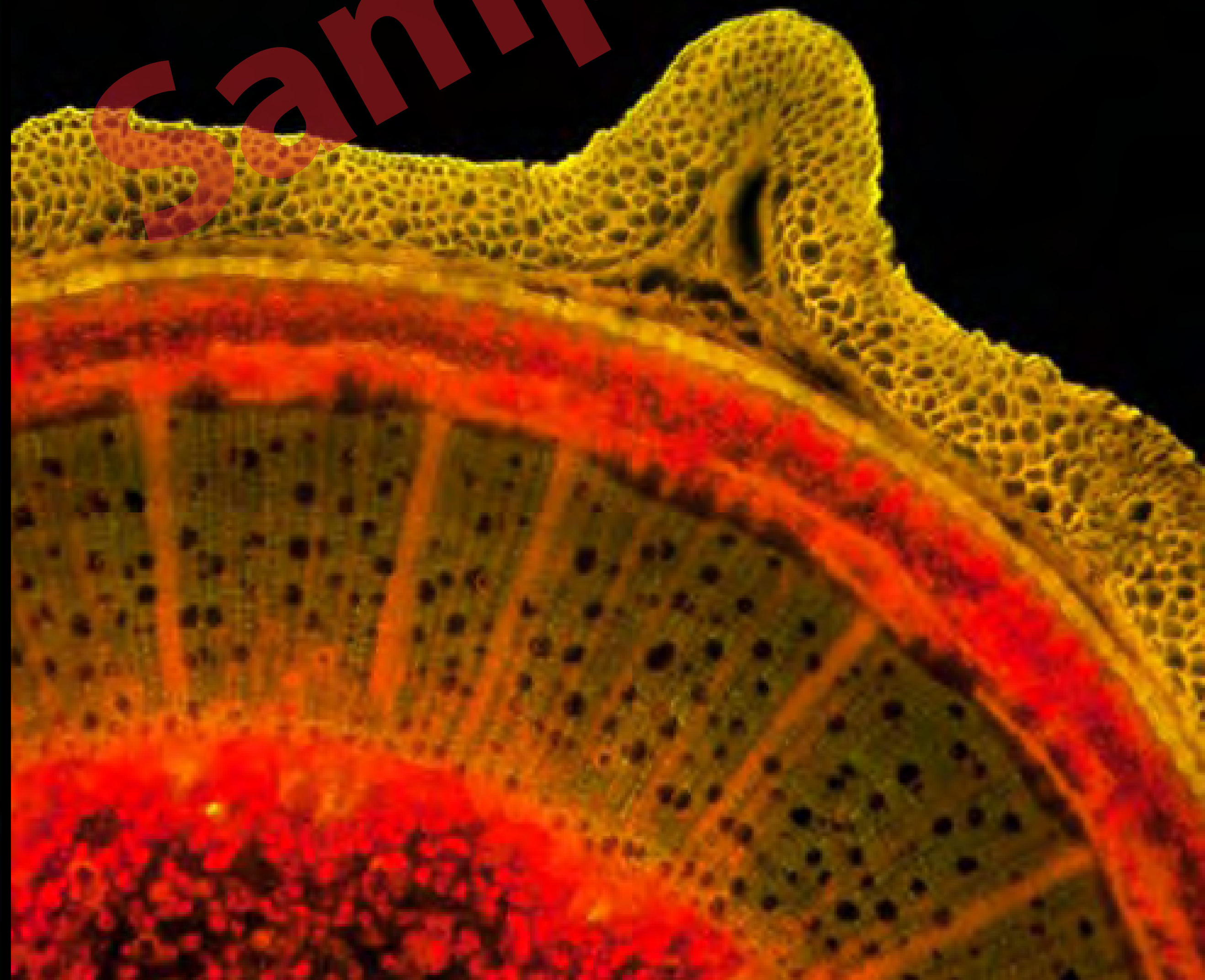
The scientific name of this free-floating aquatic plant comes from the little teeth that are found on the leaves (see inset at left). It's a plant in which a number of leaves are attached in a "whorl" at the same point on the stem. Coon's-tail resemble charophytes, which are green algae that are related to plants and which can be confused with coon's-tail at first glance. This is an unusual group of plants whose relationships are not fully understood. They may fall between monocots and eudicots (plants with two cotyledons or seed leaves) on the plant family tree. Starch grains occur in cortical cells and some contain pink-purple, water-soluble pigments.

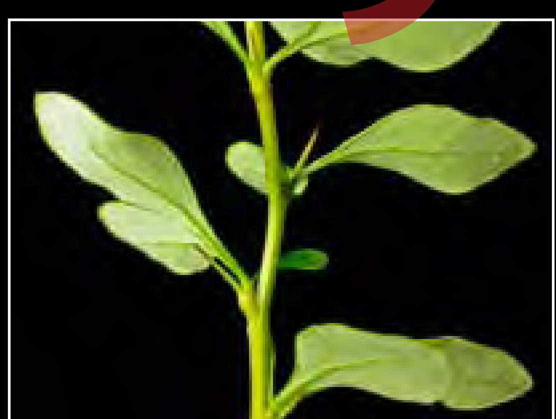
Tall meadowrue (*Thalictrum dasycarpum*) Buttercup family

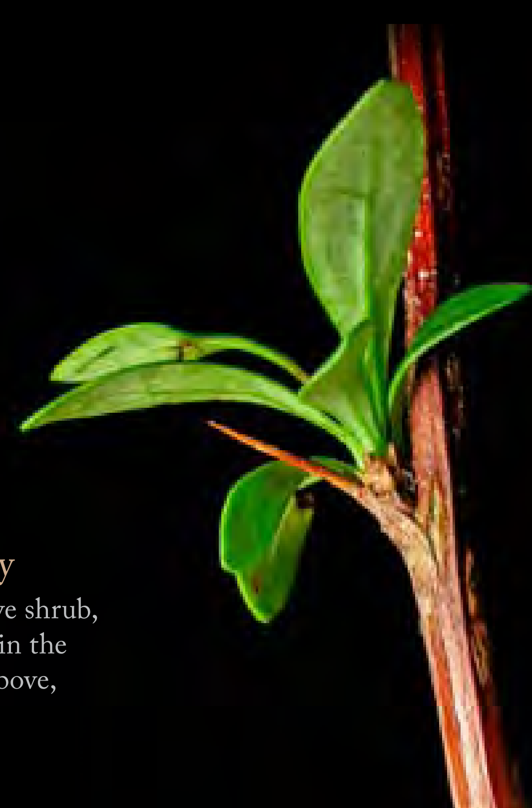
Most members of the buttercup family are annuals, often with tender stems. There are some exceptions, such as *Clematis*, which is a woody vine. Tall meadowrue and the rest of the plants pictured in this book are eudicots.

Gooseberry (*Ribes*) — Gooseberry family

Stems of gooseberry plants are rather fearsome-looking, with a plethora of spines and prickles. Very pronounced lignified supporting cells are found beneath the stem epidermis. The image above and on the top of the next page show them with polarized light, while they autofluoresce yellow under blue light (bottom of next page). The cultivated currant is a member of this genus. The base of a prickle that has broken off is evident at about 10 o'clock in the top image on the next page.





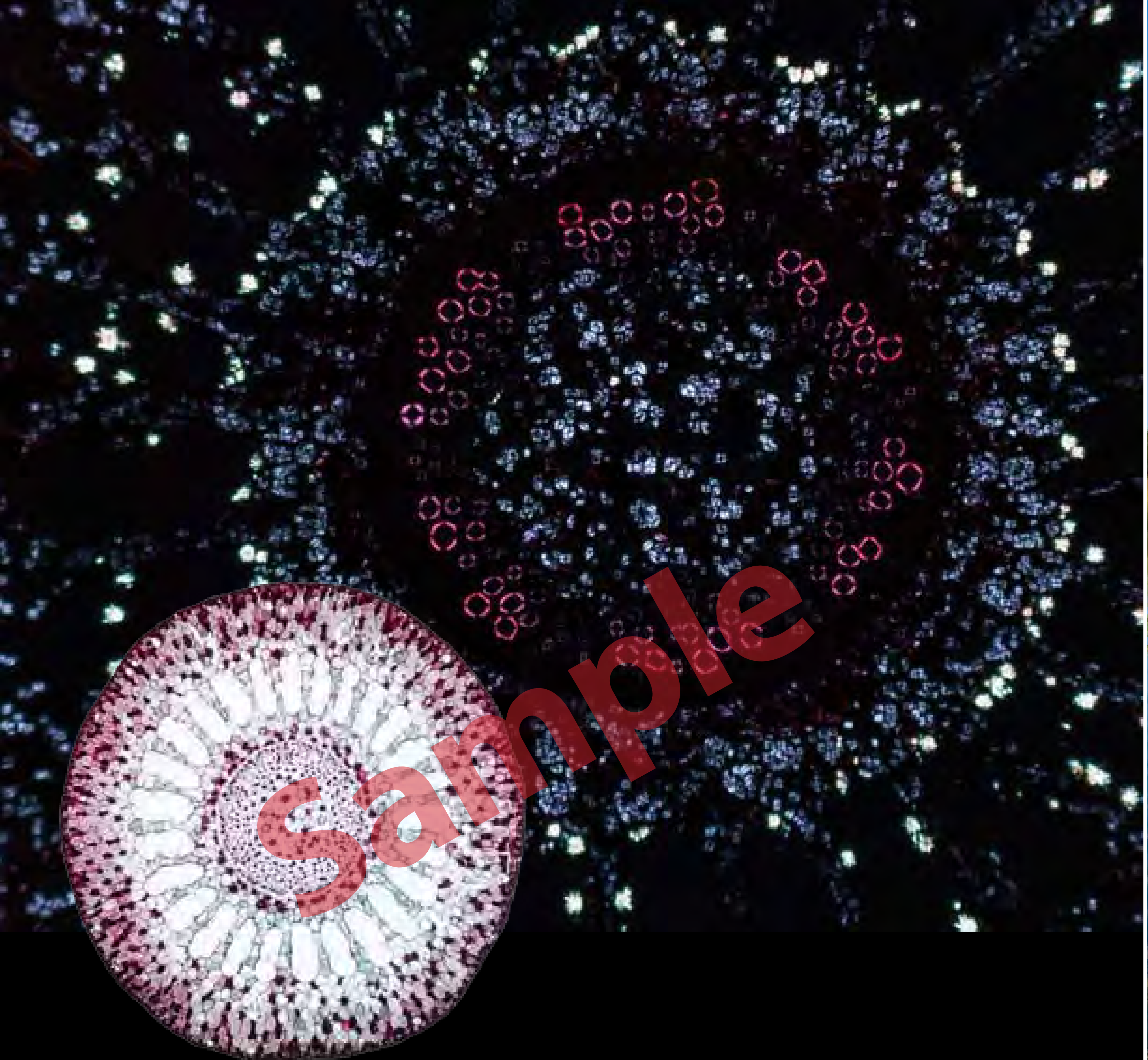


Japanese barberry (*Berberis thunbergii*) — Barberry family

Spines, which are modified leaves, are found on stems of this sometimes invasive shrub, You'll note that short branches with leaves have developed from the bud found in the axils formed by the spines and the stem. Such spines start out soft and green (above, left) but later harden (right).

Showy stonecrop (*Sedum spectabile*) — Stonecrop family

This common ornamental plant can sometimes escape cultivation. The stem has some cells with chloroplasts but the bright pinkish-red pigments stand out.

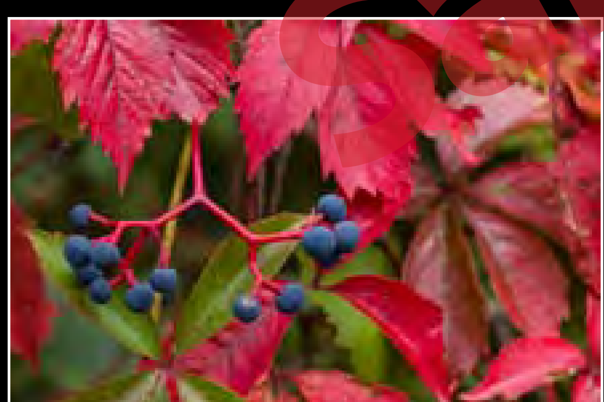


Watermilfoil (*Myriophyllum*) — Watermilfoil family

This common water plant has stem features that are typical of aquatic plants, particularly the large air spaces, which help carry oxygen—often in short supply in aquatic habitats—throughout the plant. The scientific name means "too many leaves to count."

This page A stained section is observed with brightfield (foreground) and polarized light optics (background). Notice the jagged-edged, bright white spots in the latter. These are crystals called *druses*, which can be seen in the stems and leaves of a great variety of plants. They are composed of calcium compounds.

Next page Cross sections of fresh material that once again shows the druses, the majority of which are located in the air spaces. A mass of *Myriophyllum* is visible in the foreground of the photo taken of Ennis Lake, Marquette County, WI, which is the "Fountain Lake" of John Muir's youth.



Virginia creeper (*Parthenocissus quinquefolia*) Grape family

The leaves of this familiar vine have five leaflets, which distinguishes it from poison ivy. The tendrils here are modified stems that grab onto pretty much any nearby plant or structure, helping the plant reach the light and to spread. When a bit older, the tendrils can develop adhesive pads. Virginia creeper can turn a beautiful scarlet color in the fall, which contrasts with its blue fruits.

Riverbank grape (*Vitis riparia*) — Grape family

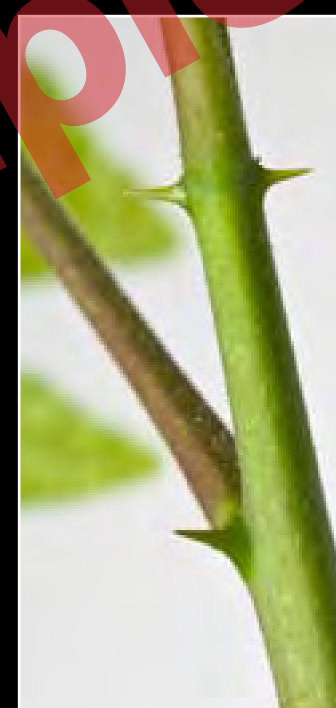
A familar woody vine, riverbank grape has a stem that is similar to that of its cousin, Virginia creeper. It often produces a large number of fruits, which can be used to make grape juice, jams, etc. It is used in wine and table grape breeding programs because of favorable traits, including cold hardiness and resistance to certain pathogens. The small cross section is of a tendril. The typical ring-like arrangment of vascular tissues reveals it to be a modified stem.

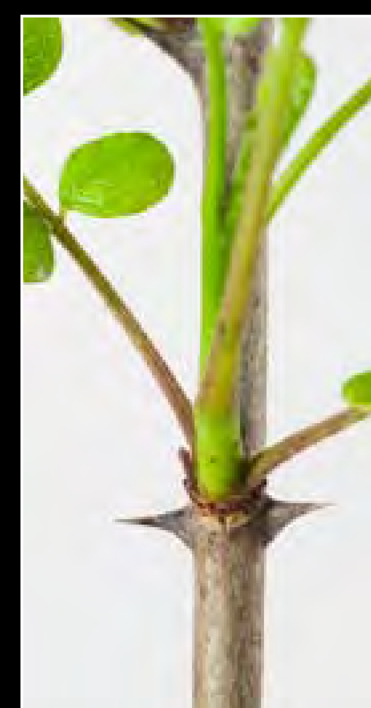
Water willow (*Decodon verticillatus*)
Loosestrife family

Water willow or swamp loosestrife is a shrubby plant that grows near or in water. The stems arch over and may generate new plants where they contact mud. It's a relative of the highly invasive purple loosestrife, which is seen on the opposite page. The squarish stems are quite spectacular in cross section, particularly after some wood has been produced, as is the case here.

Purple loosestrife (*Lythrum salicaria*)
Loosestrife family

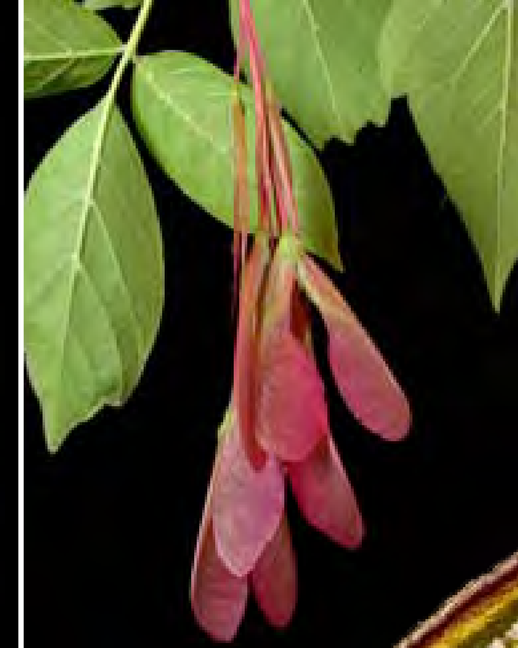
Though an attractive plant, purple loosestrife is a notorious invader of North American wetlands, displacing native species. The stem as seen in cross section bears a family resemblance to its relative, *Decodon*.

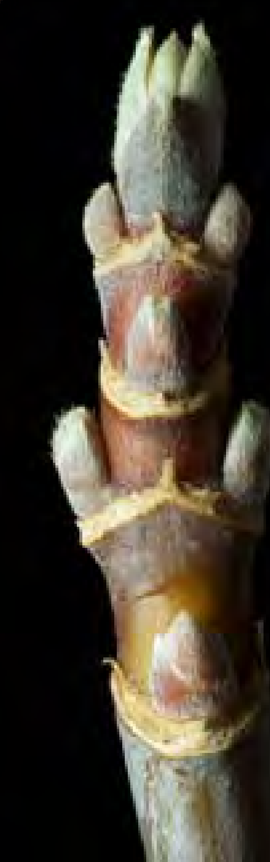




Prickly-ash (*Zanthoxylum americanum*) — Citrus family

This small tree is the northern-most member of the citrus family in North America and produces sharp prickles on both stems and leaves. The twin prickles that are found by each leaf were actually soft and green in the rather fearsome-looking cross section in the upper right. They later harden and make walking through a dense thicket of prickly ash a bit of an adventure. The aromatic leaves, bark, and fruits of *Zanthoxylum* have been used in native medicines and more recent studies have indicated that extracts of various parts of the plant have anti-fungal properties.





Box elder (*Acer negundo*) — Maple family

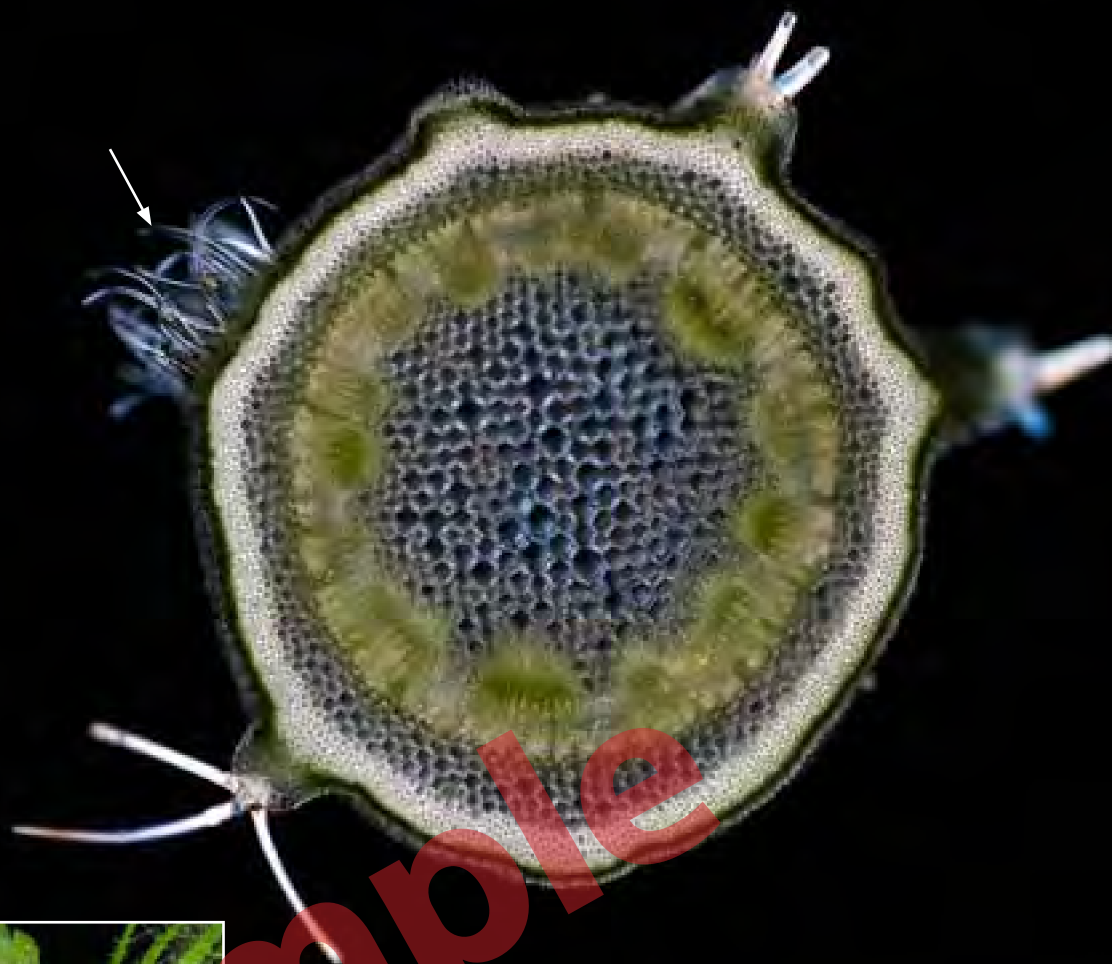
Box elder is in the same genus as sugar, silver, and other maples but differs from other maples in having compound leaves with 3 to 7 leaflets. Box elder is a good example of a plant with opposite leaves, where two leaves are attached to each node. Leaf scars (places where leaves were once attached) are seen on the twig to the right. Buds in the axils of those former leaves may grow to form new branches. Its separate male and female flowers are similar to those of other maples (males flowers are on top right and developing fruits on the top left). Its wood is soft and not of much commercial value.

Sugar maple (*Acer saccharum*) — Maple family

The beautiful fall colors and syrup of sugar maples are much appreciated. The stem, as can be seen here, is very similar to its close relative, box elder. One lenticel is present at 11 o'clock.

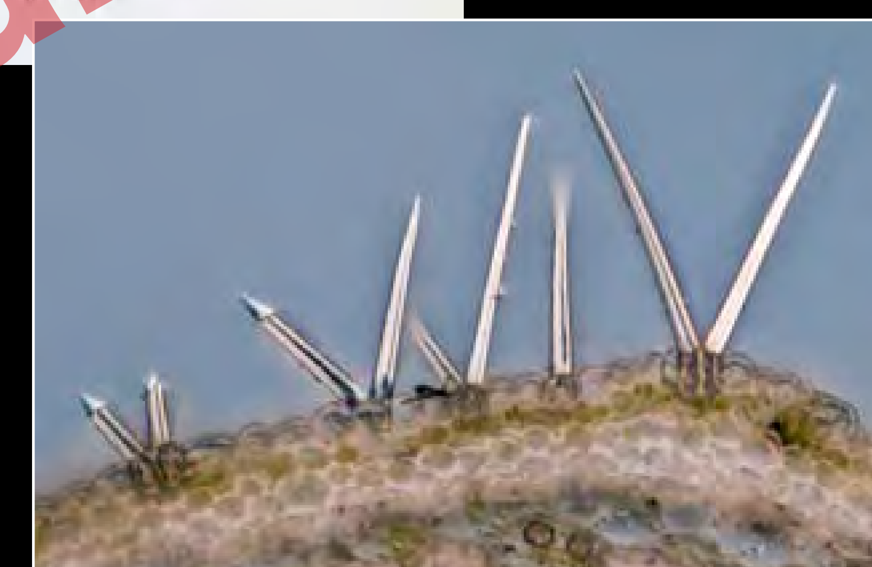
Mouse-ear cress (*Arabidopsis thaliana*)
Mustand family

This small, unassuming mustard family member has become the most intensively studied plant in the entire plant kingdom because of it small genome size and ease of cultivation. Known as a "rosette" plant, the majority of its leaves are packed tightly together on a very short stem near the soil. When the plant "bolts" to produce flowers, longer stems are sent up that are capped by tiny white flowers. Both leaves and stems are covered by unicellular hairs, many of which branch into three parts. As with many other aspects of the plant, the genetics of these hairs has been studied. The number, distritubtion, and architecture of hairs is tightly regulated by the plant's genes.



Flower of an hour (*Hibiscus trionum*) — Mallow family

This weedy plant has a row of small wooly hairs along one side of the stem (arrows) and larger, stiffer hairs elsewhere. The tips of some are broken off in the cross section shown here.

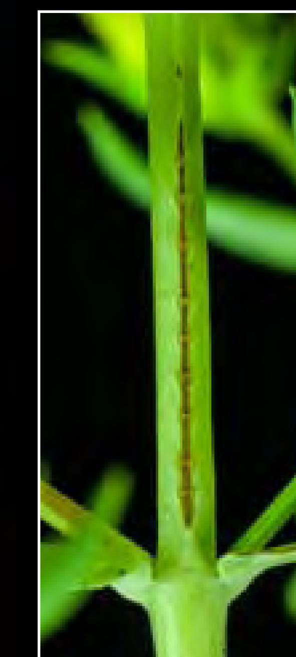


Velvetleaf (*Abutilon theophrasti*) — Mallow family

A common weed in North America that prefers cropland, velvetleaf has a soft-to-the-touch leaf and stem (though the fierce-looking hairs arising in pairs might suggest otherwise). Longer, multicellular hairs, each tipped with a gland, are also present.

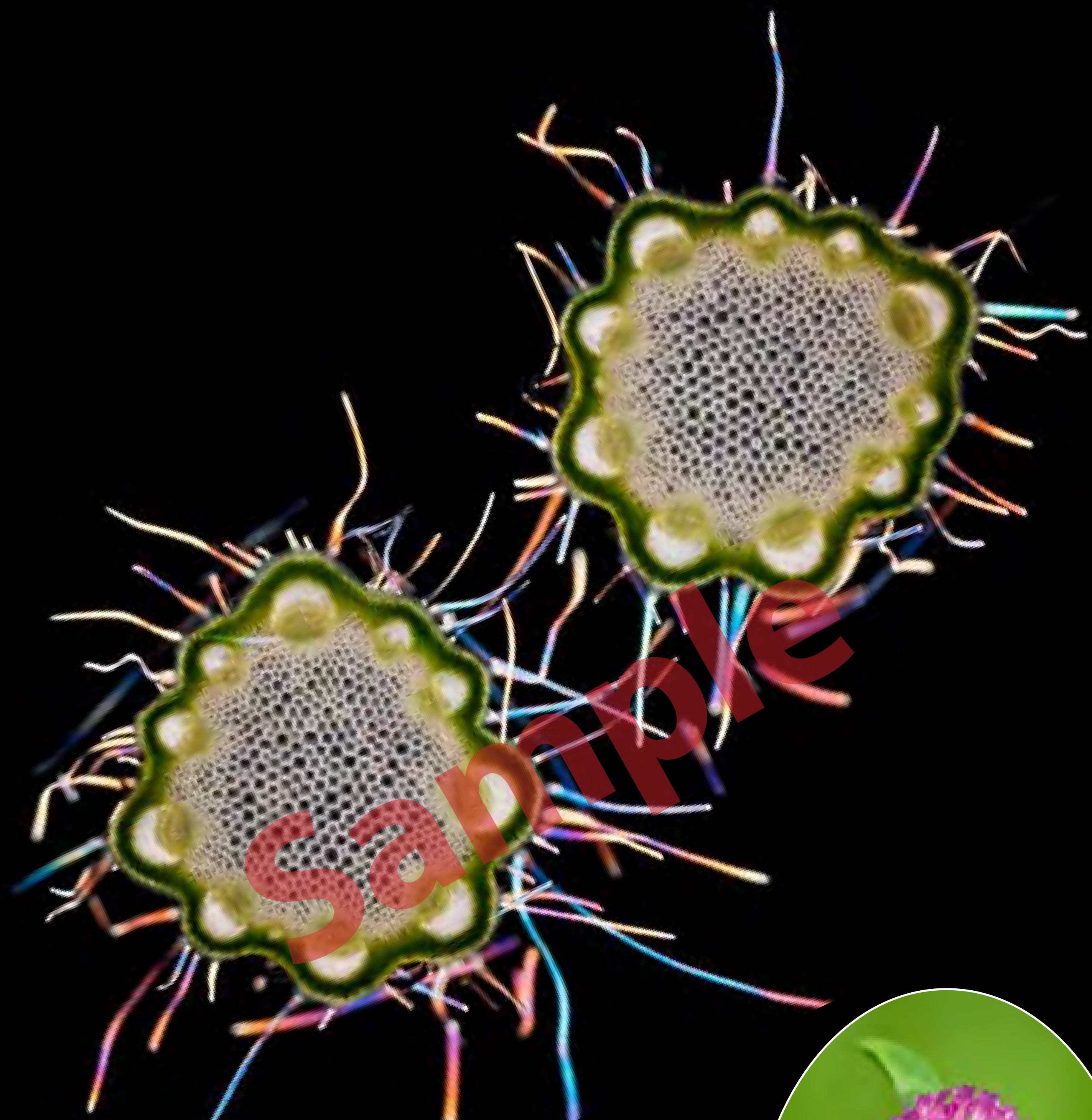
Pussy willow (*Salix discolor*) — Willow family

This familiar shrub or small tree has fuzzy catkins bearing small flowers. The bark varies in color. A fair amount of the first year's wood has formed in the cross section above.



St. John's-wort (*Hypericum*)
St. John'swort family

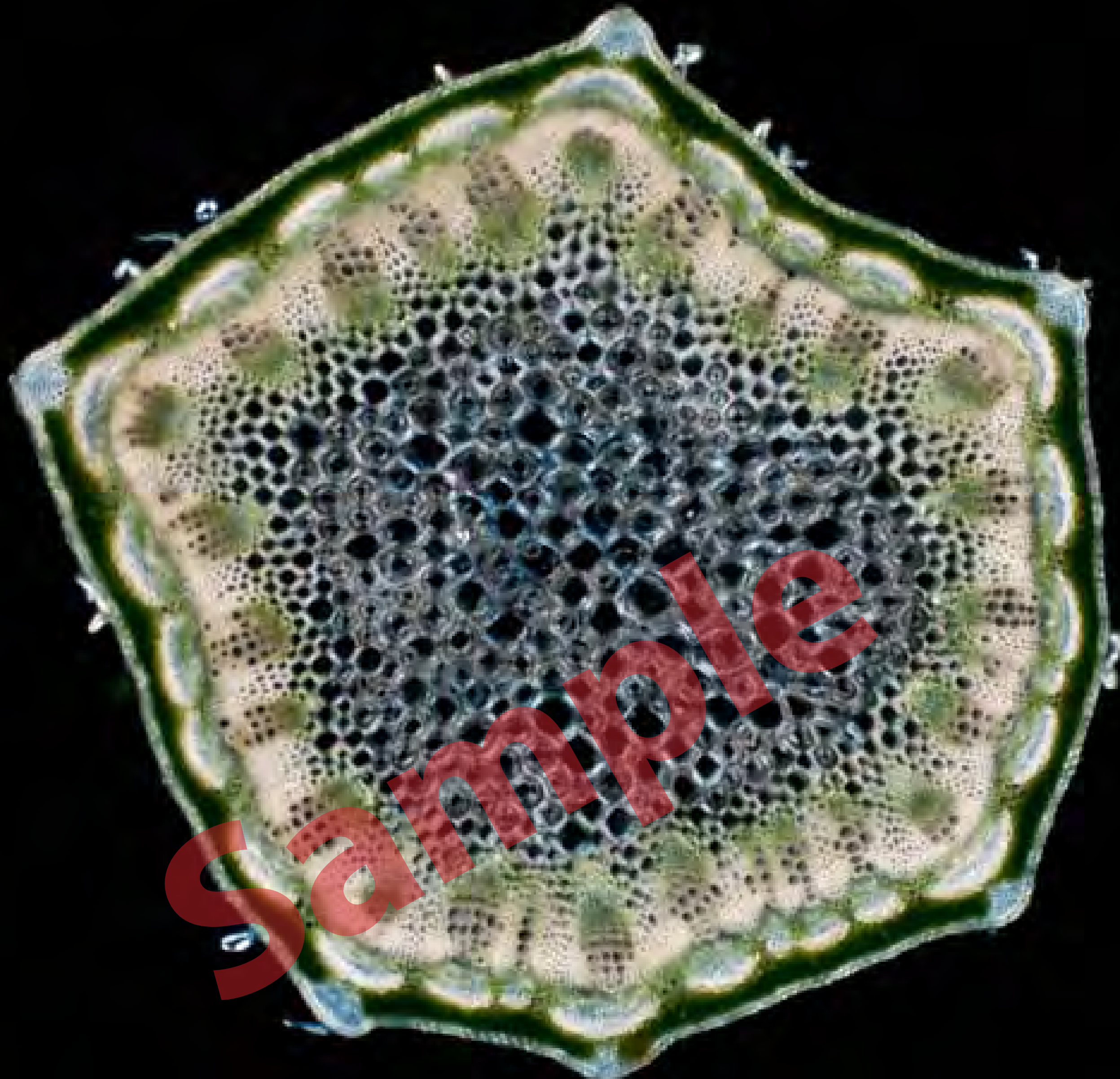
This widespread plant genus contains herbaceous and woody species, some of which can be small trees. The yellow flowers have conspicuous stamens (the pollen-producing part of the flower). The two reddish protrusions seen 180 degrees from each other on the stem cross section are visible as vertical lines that run along opposite sides of the stem when the outside of a stem is viewed close-up.



Red clover (*Trifolium pratense*) — Legume family

This page Looking a bit like firework trails, hairs on red clover stems are multi-colored under polarized light. A very clear ring of discrete vascular bundles is present.

Next page Stem hairs are seen on a red clover stem that was silhouetted against polarized light and photographed with a macro lens plus polarizing filter.



Alfalfa (*Medicago sativa*) — Legume family

This common crop plant is also often encountered in botany classrooms as an example of a stem with discrete vascular bundles (see Introduction). This is a view of a fresh alfalfa stem under polarized light. Compared to the stained, prepared slide, some of the finer details are not as clear but it affords a more natural view of the stem, with the green chlorophyll pigments showing up better, for example. Even though alfalfa and many other plants are called herbs (or herbaceous plants), some secondary xylem or wood can be formed. The wood in this stem section is farther along in its development than the one shown in the Introduction.

Crown vetch (*Securigera varia*) — Legume family

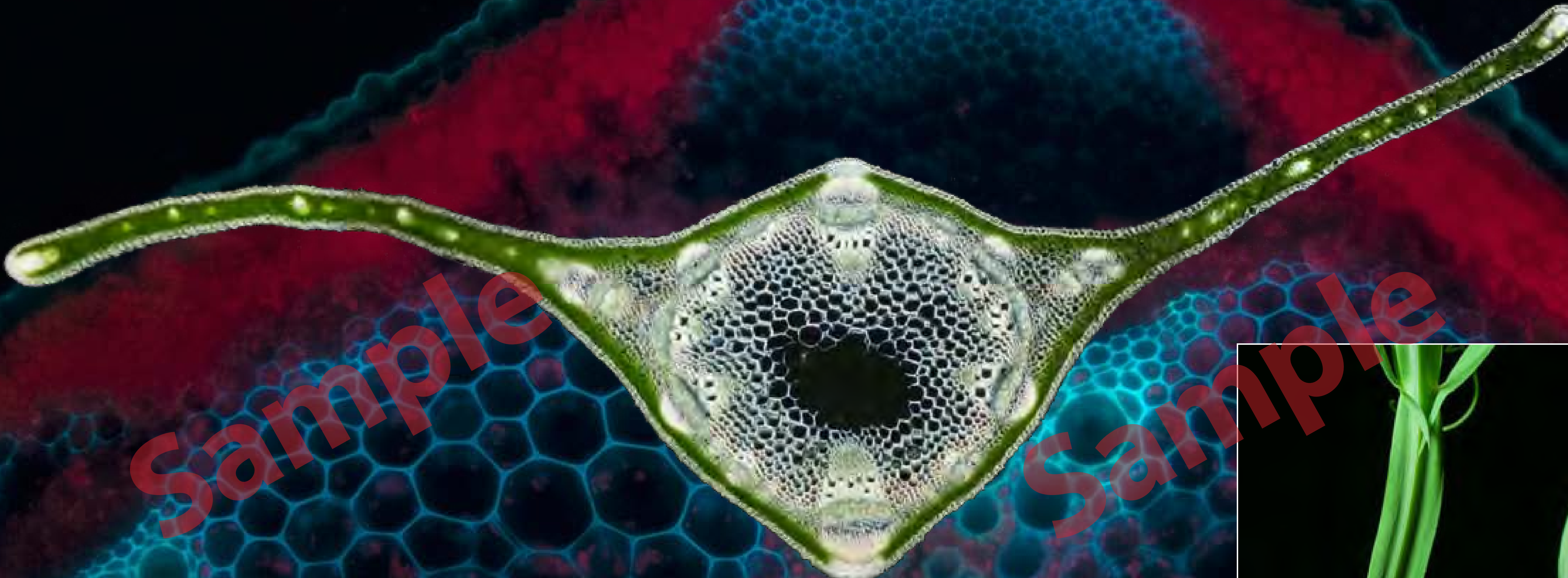
Native to Africa, Europe, and Asia, crown vetch is an attractive legume that is helpful in controlling erosion. It is invasive in many areas, however. The crown of flowers is mirrored by the shape of the stem cross section.

Leadplant (*Amorpha canescens*) — Legume family

This prairie plant is a shrubby member of the legume family and has compound leaves with many leaflets, as opposed to most legumes, whose leaves have just three. The velvety, lead-gray hairs give the plant its color and name, and decorate the stem in cross section. Here they appear multi-colored under polarized light.

Soybean (*Glycine max*) and Garden bean (*Phaseolus vulgaris*) — Legume family

Cross sections of soybean (brightfield image at top) and garden bean (polarized light image with dark background at bottom) are superimposed on an autofluorescence image of soybean. The wavy bright blue line toward the upper left is the waxy cuticle on the stem epidermis and the blue cell walls on the lower right are found in the vascular tissue.

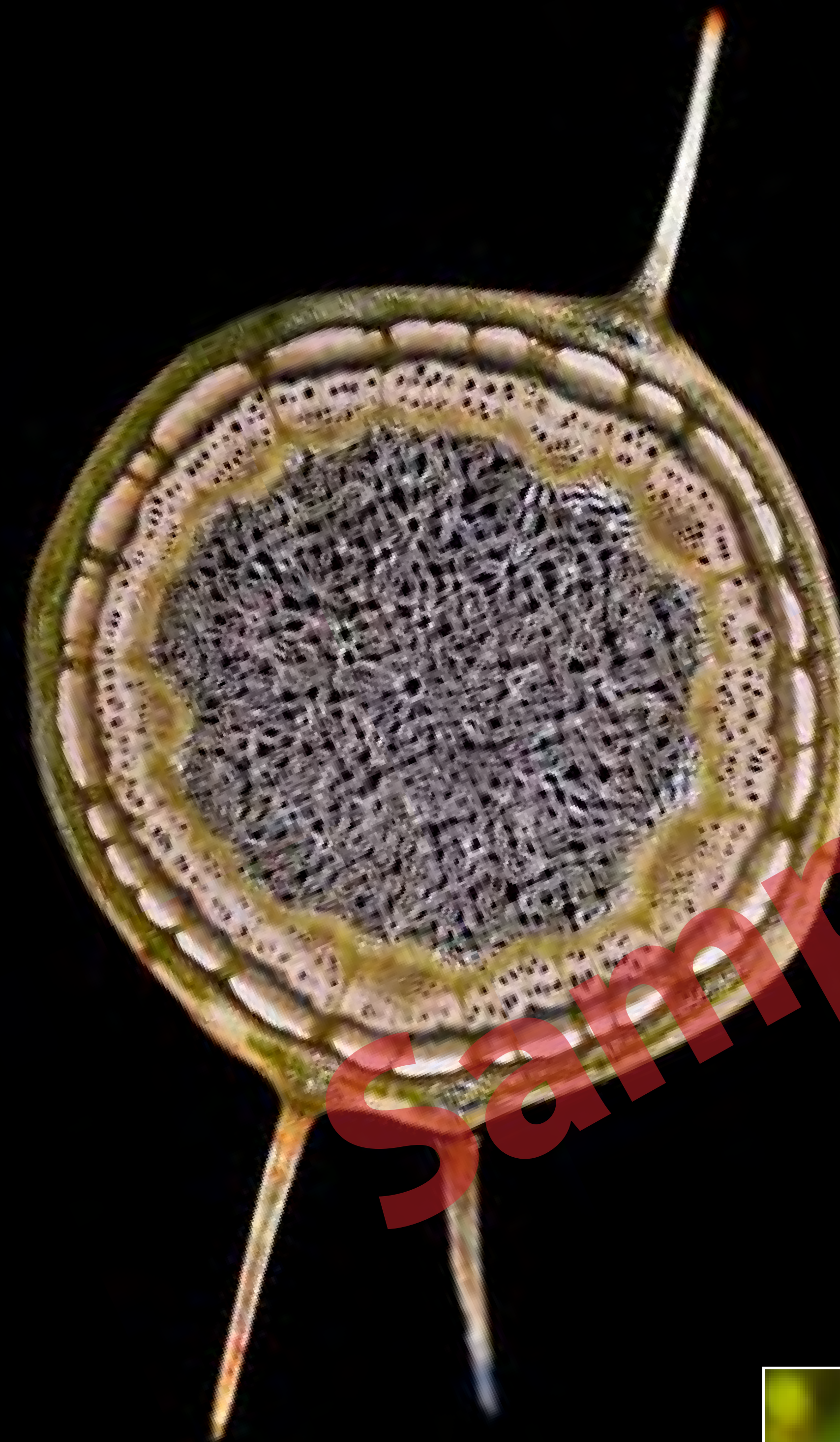


Everlasting pea (*Lathrys latifolius*) — Legume family

This introduced viny pea plant can grab onto adjacent plants with its leaf tendrils or creep along the ground. The stems (the more vertical portion in the next-page inset) have wide wings, as do the leaf stalks (petioles)—one of which angles to the right in the inset. The background image shows autofluorescence of lignin-containing cell walls (blue) and chloroplasts (red). The pink, odorless flowers are about an inch across.

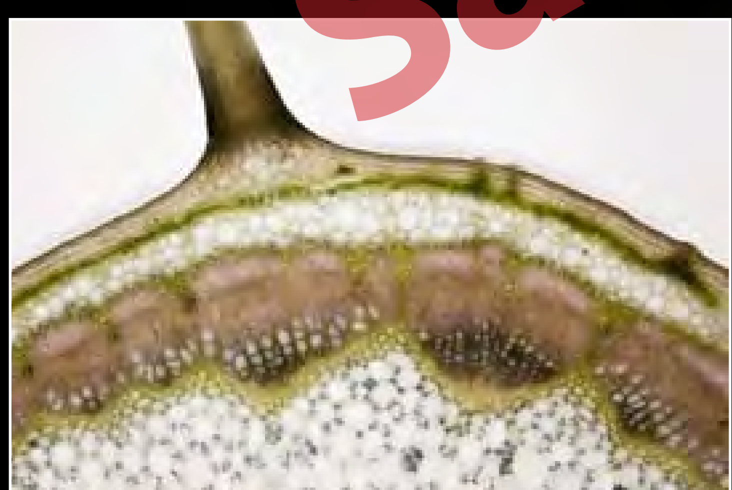
Black locust (*Robinia pseudoacacia*) — Legume family

The black locust is a common tree that can be invasive. It produces pleasingly fragrant blossoms in the late spring. Insets show the fragrant flowers and cells of (or close to) the vascular cambium in tangential section (see Introduction). The long, vertical cells give rise to the water-conducting vessels and tracheids of its wood, while the clusters of smaller cells produce the rays.



Red raspberry (*Rubus idaeus*) — Rose family

This plant is of course known for its tasty fruits but anyone who has picked them is also familiar with the prickles, which start out as soft glandular hairs (upper right photo) that gradually harden.



Blackberry (*Rubus allegheniensis*) — Rose family

Not surprisingly, blackberry stems are quite similar to those of its red raspberry cousin. One prickle was sectioned here.

Stinging nettle (*Urtica dioica*) — Nettle family

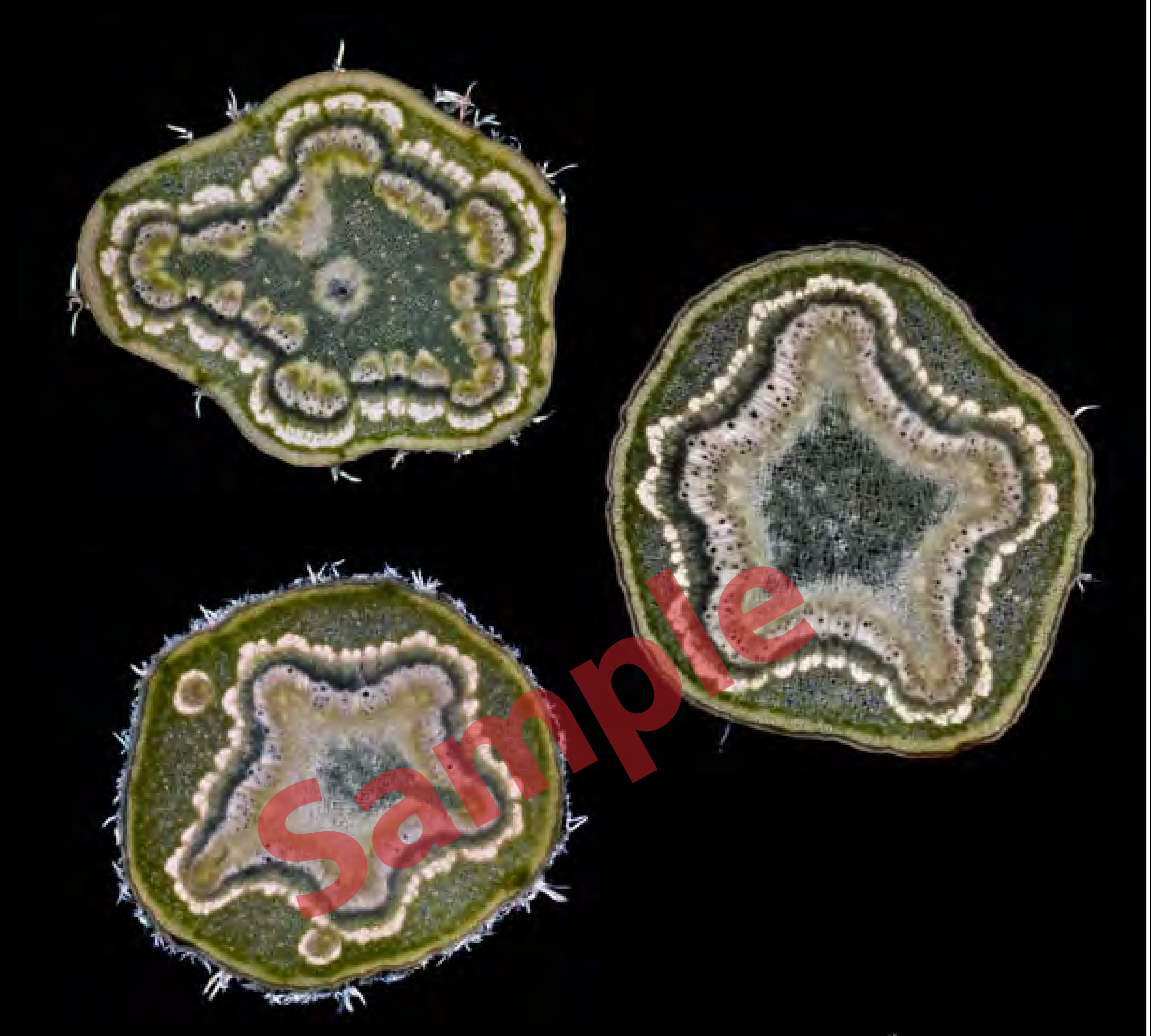
Though it's an unpleasant plant to encounter unwittingly, stinging nettle nevertheless has been used as a nutritious green in the diet and it also has a very impressive stem when seen microscopically. Stinging hairs, which act like tiny hypodermic needles, inject a variety of chemicals that cause a burning sensation; they are found on both leaves and stems.

False nettle (*Boehmeria cylindrica*) — Nettle family

This plant looks much like its stinging nettle relatives but is harmless. Shown here are stems in both cross- and longitudinal section, illuminated with polarized light. Interpreting longitudinal sections is definitely more challenging than cross sections but provides different information. For example, the cells in the pith are more or less cubical in shape, whereas the colorful fibers are long, thin cells.

Oak (*Quercus*) — Beech family

The same commercially produced, stained section is shown here with brightfield (top) and polarized light (bottom) optics. Notice the star-shaped vascular tissue, which is a common feature of all the oak stems shown on the next page.



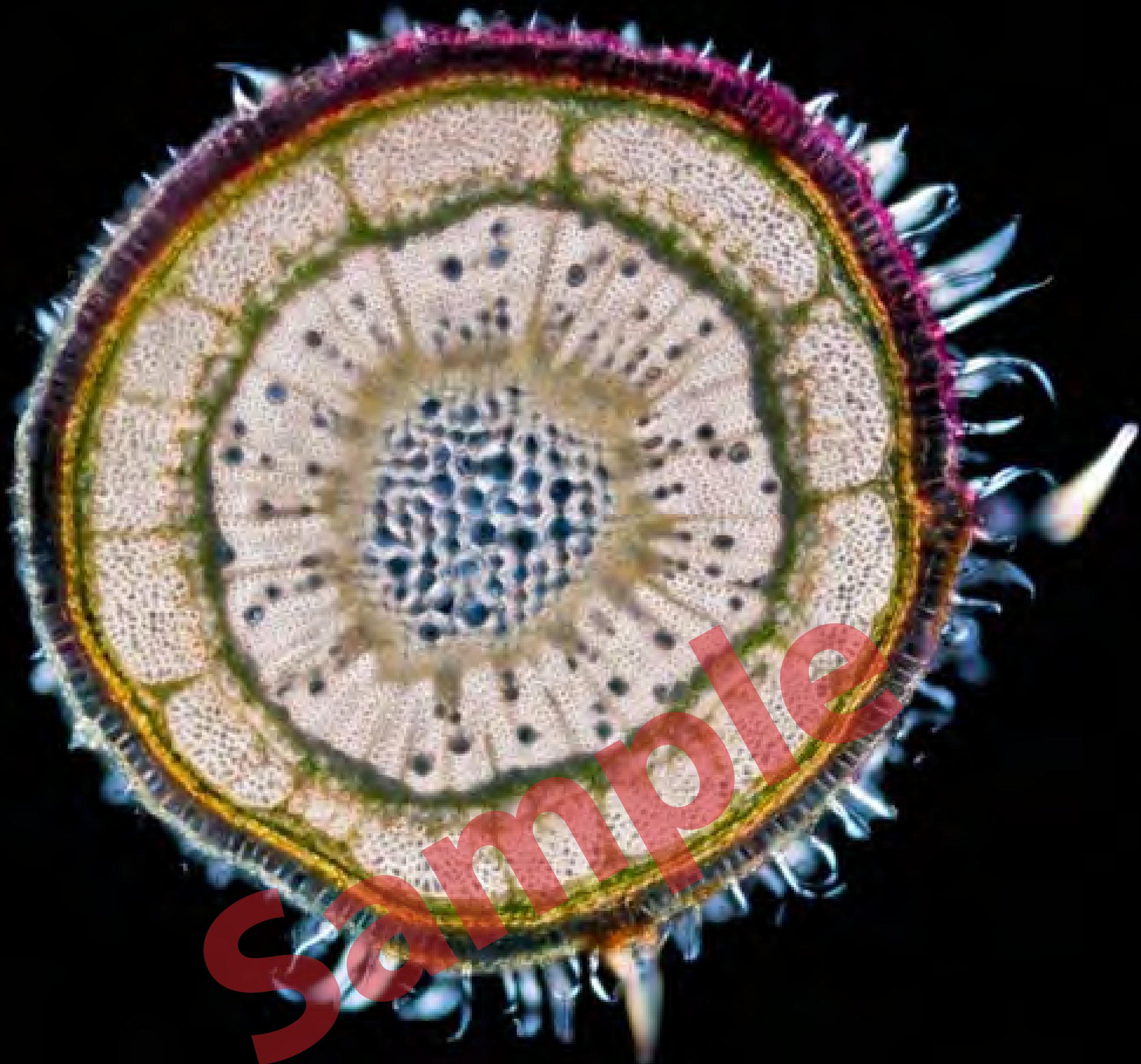
Oak (*Quercus*) — Beech family

This page In these fresh stem sections photographed under polarized light, the similarities among three oak species are obvious. At the top is red oak (*Q. rubra*), at the right is white oak (*Q. alba*), and bur oak (*Q. macrocarpa*) is at the bottom. Notice that two vascular "traces" have diverged from the main vascular tissue of the bur oak stem and are on their way to leaves or buds.

Next page A stained, cross section of a woody oak stem that contains one entire growth ring. Notice that the big xylem vessels occur mostly in the "early" wood (formed in the first part of the growing season). Portions of two rays are present. The inset shows a very smoothly cross-cut oak board, in which the comparable structures are seen without staining.

Early wood

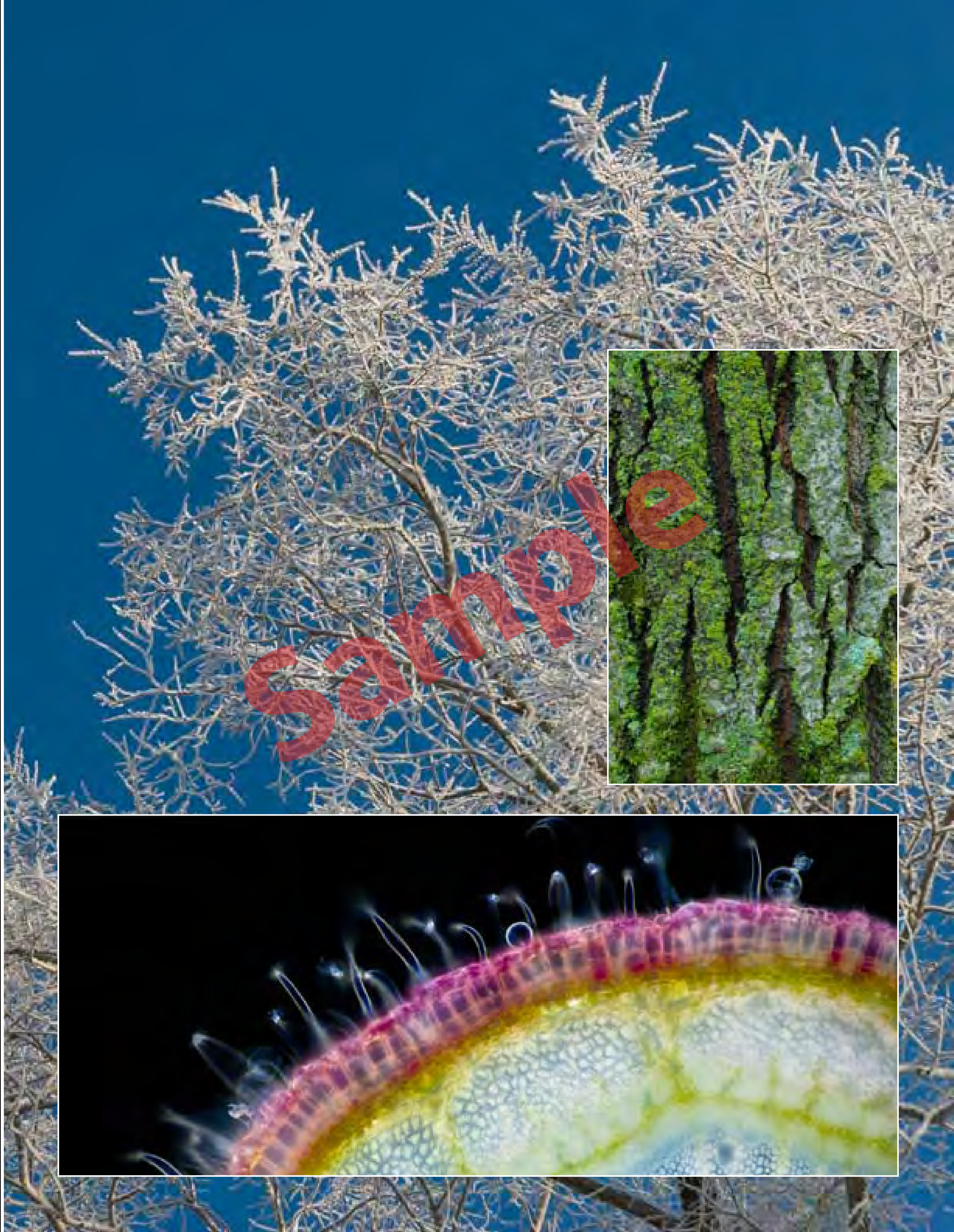
Late wood



Siberian elm (*Ulmus pumila*) — Elm family

This page This elm species is invasive in parts of North America but has some attractive qualities, including colorful and hairy young stems, seen above with polarized light optics.

Next page Stem hairs are shown in the lower inset using darkfield microscopy, while lichen-covered bark of a mature tree is seen in the upper. In the background, hoarfrost decorates a Siberian elm in winter.

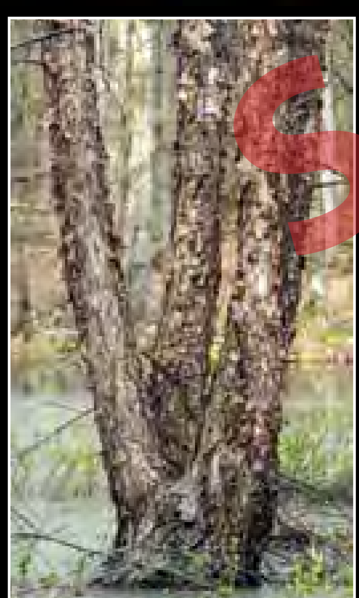


Sample

Black walnut (*Juglans nigra*) — Walnut family

This page Young stems of black walnut are covered by a variety of other worldly-looking hairs, many of which contain a sticky, fragrant substance.

Next page Very young walnut twigs are green and quite tender. In the upper left image, the base of a leaf with the associated axillary bud is present and the white areas in the stem represent developing wood. Eventually, thin membranes separate the pith into chambers. Some twigs, including the buds, can be very hairy for a time but eventually bark forms and the hairs are lost.



River birch (*Betula nigra*) — Birch family

Like that of other flowering plants, the wood of river birch contains larger cells/tubes called vessels but they are scattered throughout each growth ring as opposed to the oak wood shown earlier, where the larger vessels are concentrated in just part (the "early" wood) of each growth ring. The cross section of a living stem (top left) shows three developing lenticels. Eventually, the bark flakes off in sheets.

Bog or swamp birch (*Betula pumila*) — Birch family

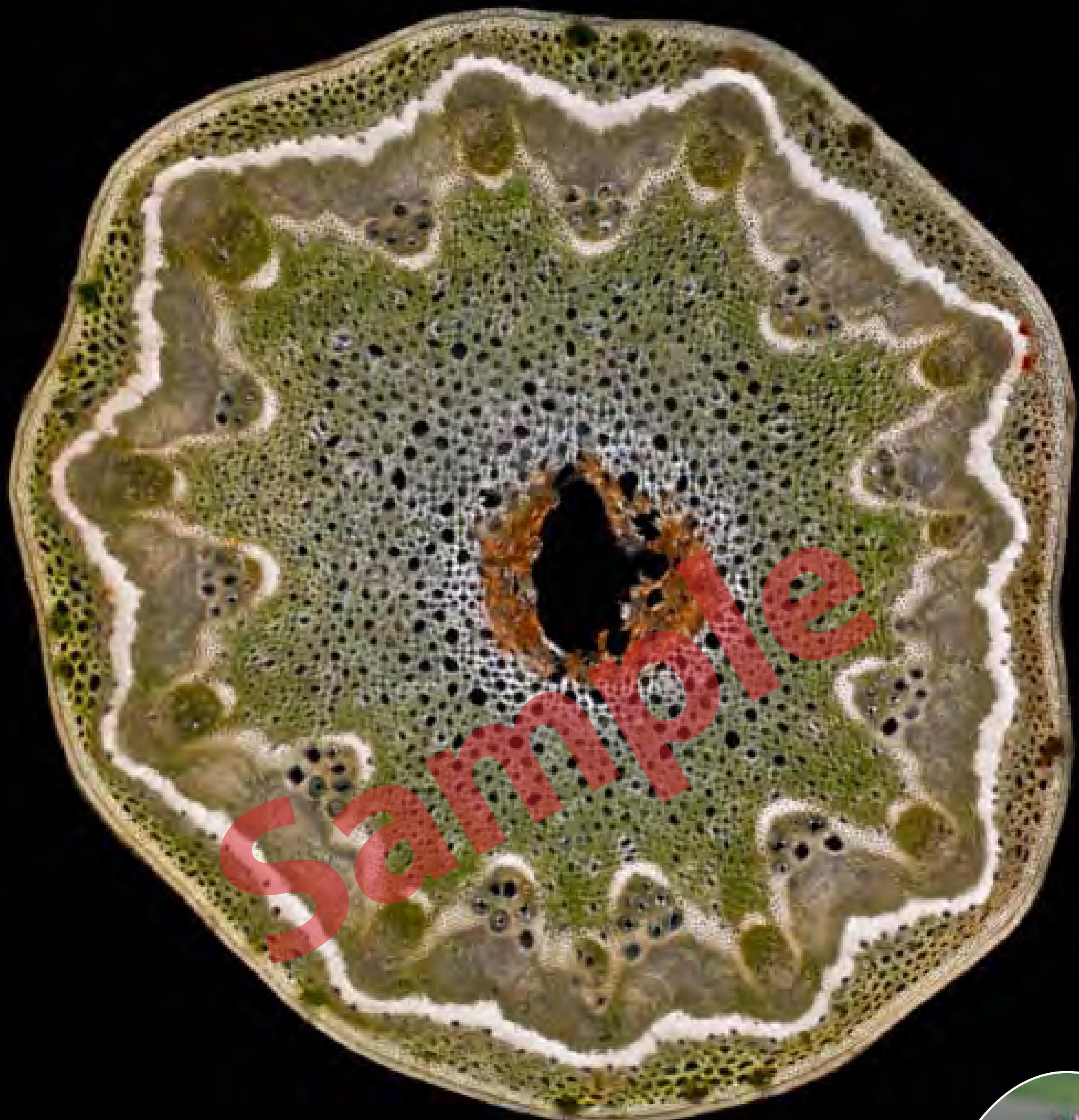
As its name implies, this is a wetland plant that is a shrub or small tree. Young stems have numerous hairs, which appear multi-colored under polarized light.

Wild cucumber (*Echinocystis lobata*) — Gourd family

This viny plant, native to North America, can at times be problematic when overspreading other vegetation. It produces small, inedible melon-like fruits that are covered with prickles.

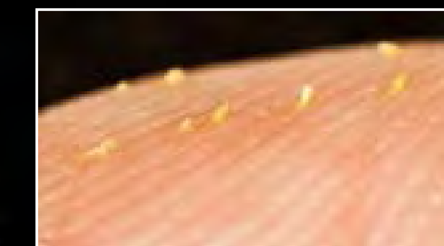
Curly dock (*Rumex crispus*) — Smartweed family

This often weedy plant is probably most recognized by the brownish fruits that adorn the brown, dried floweer stalk at the end of the growing season. Rhubarb is a relative and gardeners familiar with its flower stalk will note the similarities to that of curly dock.



Water smartweed (*Polygonum amphibium* [*Persicaria amphibia*])
Smartweed family

This smartweed species prefers moist-to-wet habitats and has an attractive pinkish-red inflorescence and a striking stem cross section.



Arrow-leaved tearthumb (*Polygonum sagittatum*) — Smartweed family

This spindly plant grabs onto nearby plants for support with the help of a plethora of downward-facing prickles along the corners of the square stems. It can be an unpleasant experience to encounter this aptly named plant as it matures because these prickles can break off and lodge themselves in one's skin. The stem contains a considerable amount of starch (starch granules have a cross-like appearance under polarized light). Starchy roots are common but large amounts of starch in stems is less so.

Pigweed (*Amaranthus retroflexus*) — Pigweed family

This plant has an interesting irregular stem cross section. The arrangement of vascular bundles (many of which are found in the pith) and associated leaf/branch traces has been used as a character to help distinguish among the many *Amaranthus* species.

Wild four-o'clock (*Mirabilis nyctaginea*)
Four-o'clock family

This sometimes weedy plant has flowers that tend to open in the late afternoon (hence the name). The hairy developing fruits are evident in the circular inset. Wild four-o'clock has an impressive squarish stem with an unusual arrangement of vascular tissue. As in pigweed on the facing page, there are a number of vascular bundles ("medullary" bundles—meaning "in the middle") present in the pith as well as a more typical ring toward the outside of the stem.

White campion (*Silene latifolia*) — Pink family

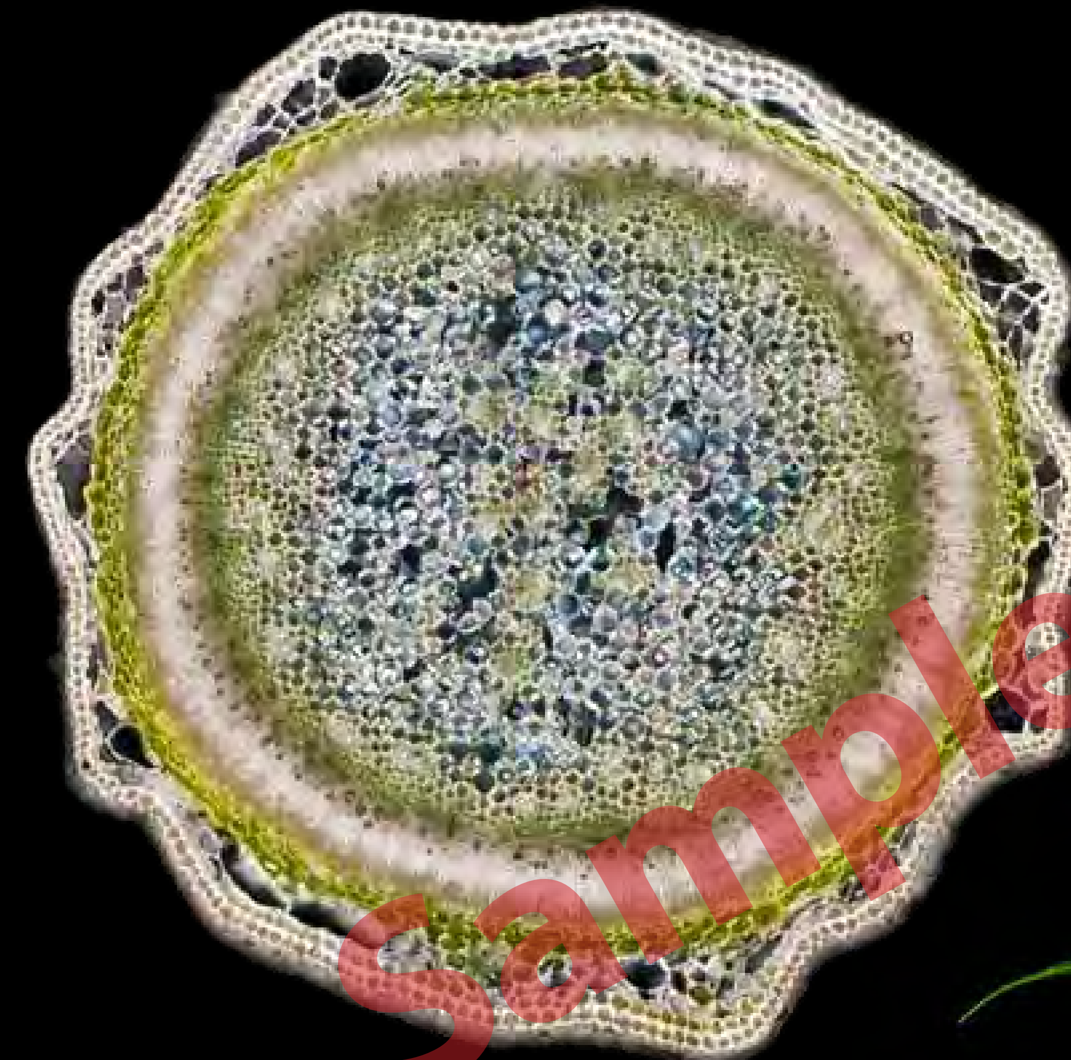
This common plant, with distinctive white male and female (shown here) flowers, also has distinct sex chromosomes, which has not been documented in very many plants. Stems are covered by numerous soft, multicellular hairs.

Red osier dogwood (*Cornus sericea* [*C. stolonifera*]) — Dogwood family

This dogwood species is common in wet areas and is cultivated in part for its bright red stems, which are particularly appreciated in the wintertime. The red pigmentation likewise stands out in the outer cortex when stems are observed in cross section.

Bog rosemary (*Andromeda glaucophylla* [*A. polifolia*])
Heather family

Bog rosemary—like most of its bog-dwelling relatives such as leatherleaf and cranberry—is a relatively small shrubby plant. The narrow leaves look a bit like those of the rosemary plant whose shoots are used as a spice but that plant is a member of the mint family. The bark has started to slough off in the woody cross sections shown above, while the photograph to the right shows a stem tip at an earlier stage of development.



Bottle gentian (*Gentiana andrewsii*) — Gentian family

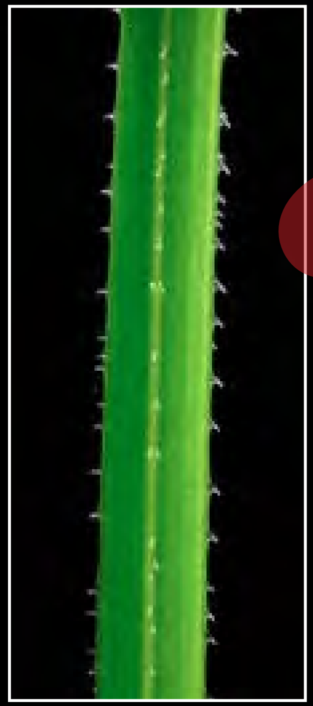
The stem of bottle (closed) gentian has a smooth undulating stem surface. This species is named for the flowers, which remain nearly closed when mature, as opposed to other gentians, such as fringed gentian.

Swamp milkweed (*Asclepias incarnata*)
Milkweed family

This page This attractive, primarily wetland plant has a more vibrant pink flower than the common milkweed but the flowers are very similar structurally. The stem is smooth and has numerous bundles of fibers.

Next page A dried swamp milkweed stem is pictured that was picked long after the growing season had ended—after it had become dry and brittle. The very long, tough fibers are shown in a cross section, while some (background) were stripped out of the stem and examined by themselves with polarized light. Milkweed fibers were used by native peoples to make twine and rope as well as fabric.

Sample

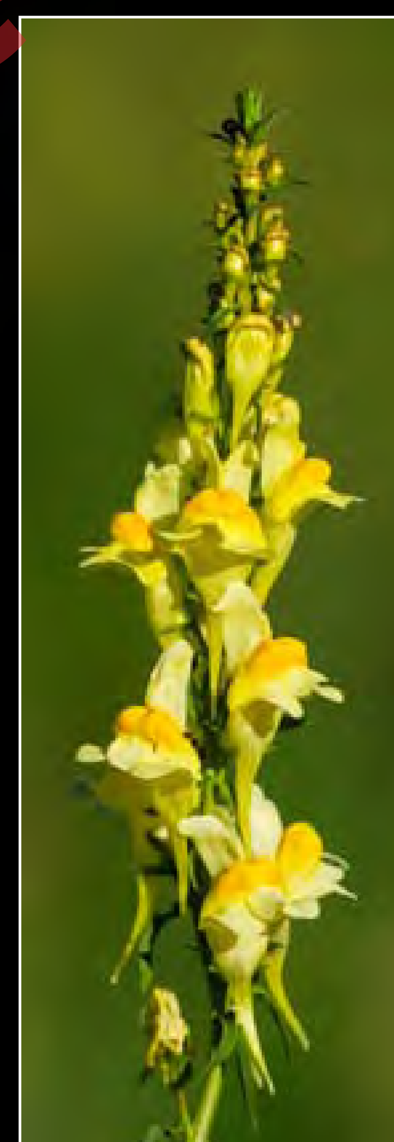


Bedstraw (*Galium*) — Bedstraw or madder family

Bedstraw has a knack of grabbing onto your clothing as you make your way through it. This is due to numerous short, curved hairs that occur on stems, leaves, and fruits. Parts of two such hairs are seen in this stem cross section. Producing lots of seeds and also spreading by clinging to unwary animals, including humans, explains why this plant is often weedy. The common name "bedstraw" refers to the fact that it was once used to fill mattresses. The hairs and clinging nature of dried stems and leaves helps keep it from compacting.

Mullein (*Verbascum thapsus*) — Figwort family

Mullein is an introduced and somtimes invasive species in North America. It is very soft to the touch, with a thick, felty layer of large, branched hairs on the leaves and stems.

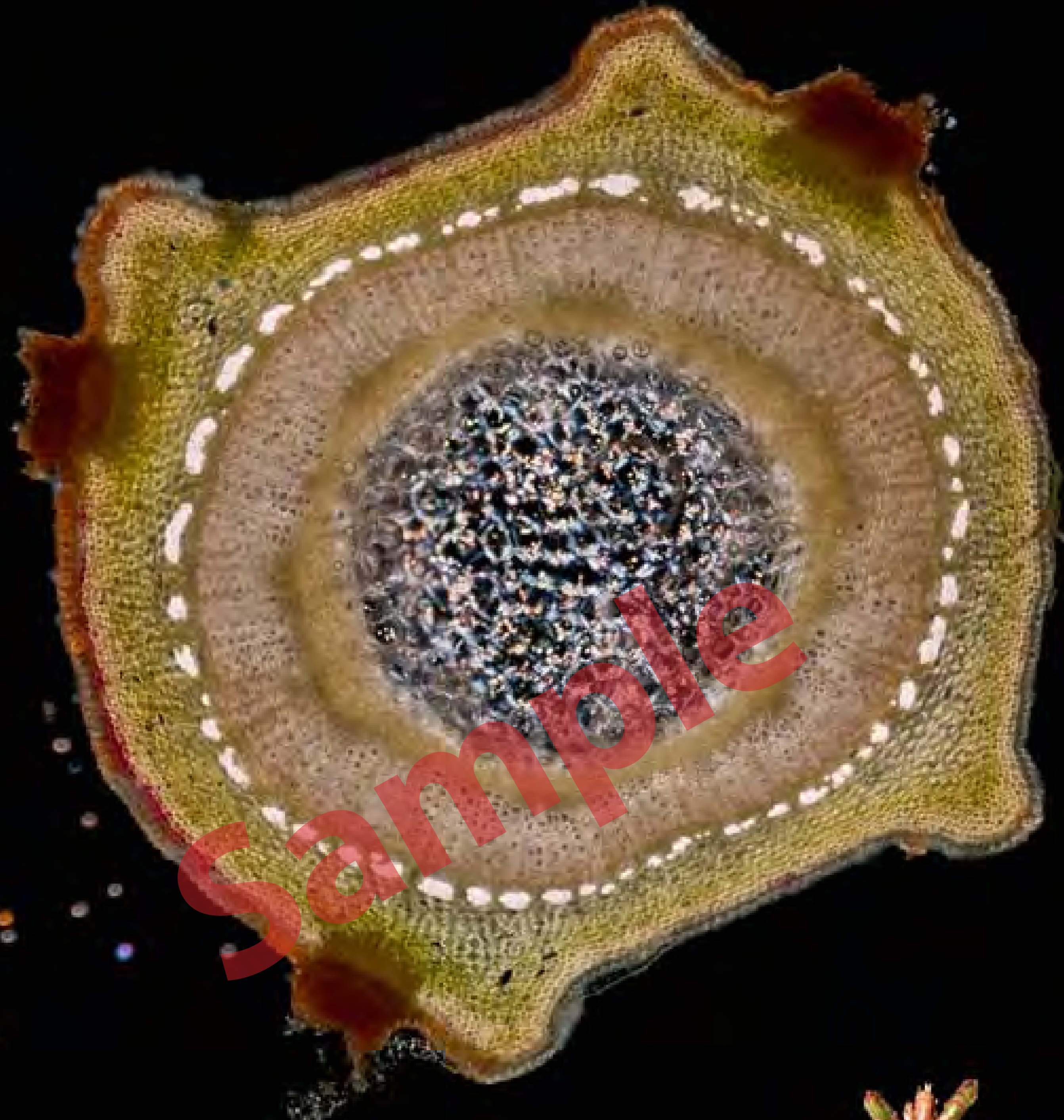


Butter and eggs (*Linaria vulgaris*) — Snapdragon family

This snapdragon family plant, also known as toadflax, is a common weed and has flowers with colors reflecting its common name. The stem has a continuous ring of photosynthetic tissue in the cortex.

Blue vervain (*Verbena hastata*) — Vervain family

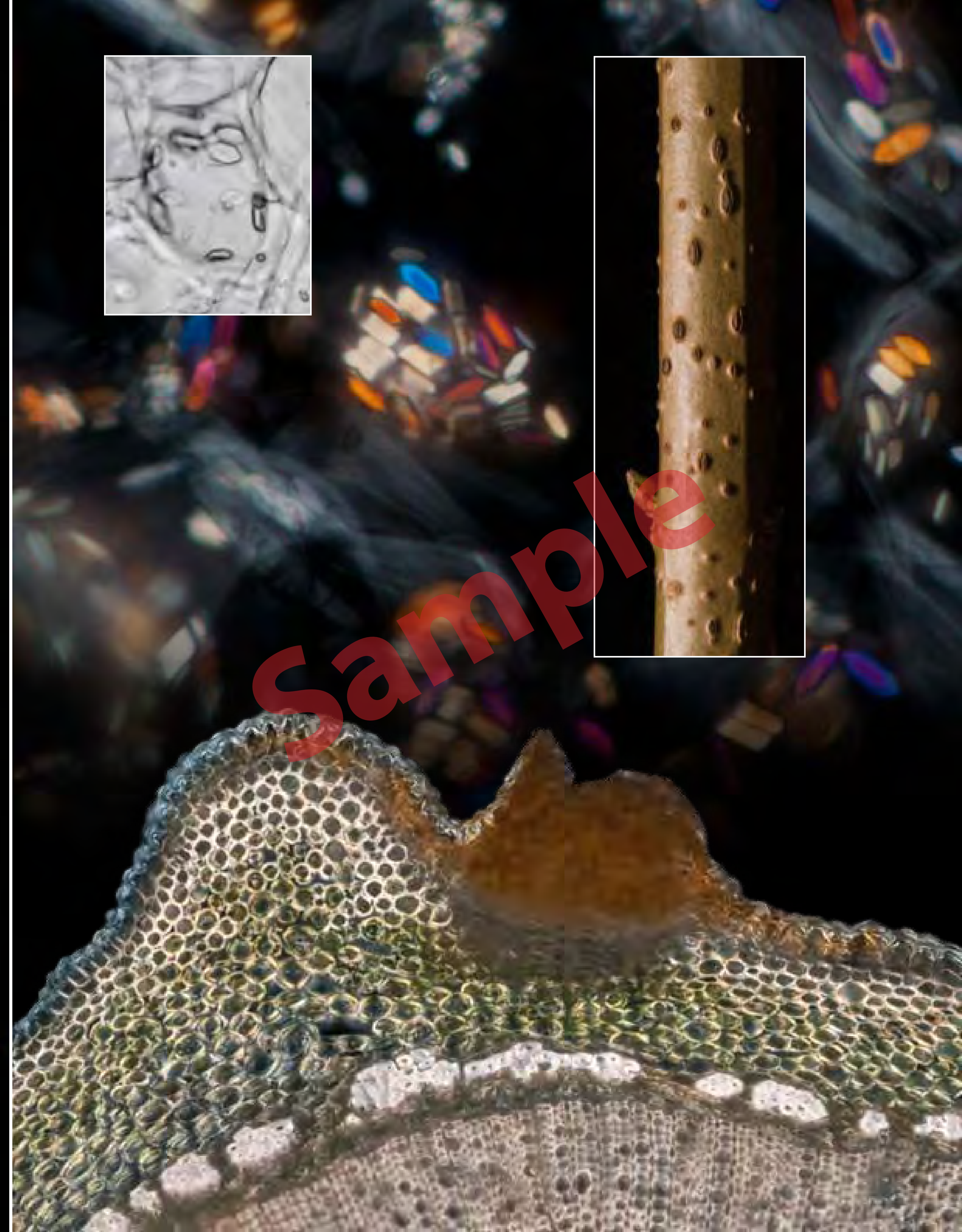
This hardy plant, though not a mint (see upcoming pages), has a square stem. It can form colonies of plants in part because of slowly growing underground rhizomes. This stem section comes from an upright, aboveground shoot.

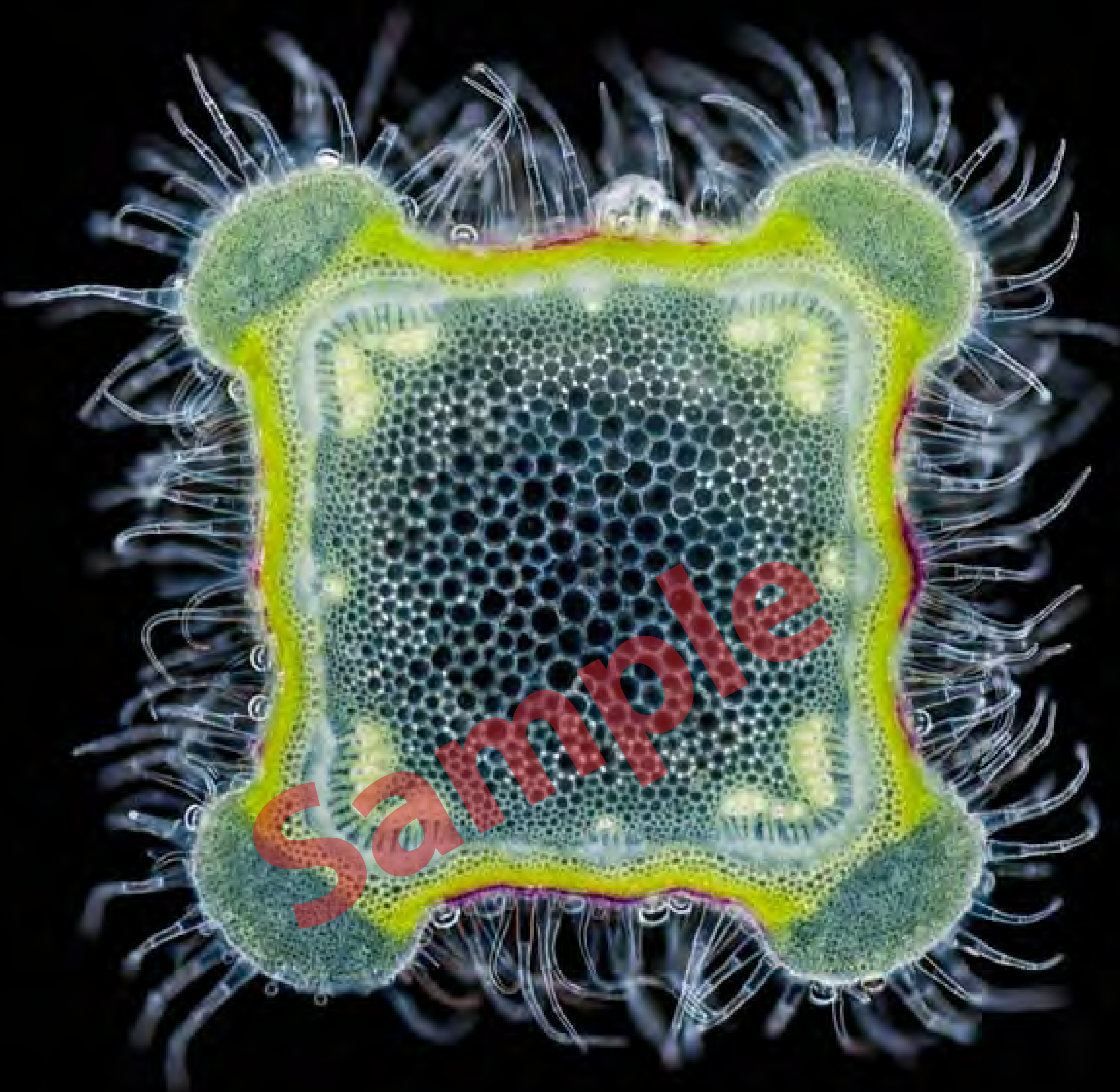


Forsythia (*Forsythia*) — Olive family

This page The familiar early-spring–blooming forsthia has stems that are dotted with lenticels. These structures represent places where the stem surface has erupted because of the proliferation of cork cells, a process that creates pathways for air to reach deeper stem tissues. The thin horizontal lines on birch trees are also lenticels. The stem has a ring of bright white fibers in the phloem and numerous crystals in the pith that are very colorful in polarized light.

Next page The crystals are shown close-up in the background image. One inset shows their not-so-colorful appearance under brightfield optics. Lenticels are shown on a stem surface and in a cross section.





Catnip (*Nepeta cataria*) — Mint family

This page Catnip is a typical mint in having a square stem. In this view with darkfield microscopy, the long multicellular hairs are striking. Closer to the epidermis, hemispherical glands can be seen that contain the fragrant mint oils. Ribs with supportive collenchyma cells form the four corners of the stem.

Next page Cross sections were made at different points along the stem (as well as the root) of a catnip plant. The stem remains square throughout, but the shape changes somewhat, the pith becomes hollow, and the stem gets a bit larger lower on the plant (where it is older). In the lowermost region of the stem, some wood (secondary xylem) is present, which provides rigidity. Notice that vascular tissue is found in the center of the root, as opposed to the stem, where the pith occupies the center. This reorganization occurs within the so-called transition region, which is located at ground level.

Catnip (*Nepeta cataria*)

This page A series of sections was made through a node of a catnip stem and photographed with a stereo (dissecting) microscope using darkfield illumination. Moving from bottom to top, the bases (petioles) of the leaves appear and the darker green vascular tissue (traces) can be seen moving into them. A bit higher up on the plant, the axillary buds appear. Notice that the pith is hollow in the internodes but there is tissue in the center of the stem at the node.

Next page Top: A similar node was sectioned but this time was photographed with polarized light optics. Bottom: A longitudinal section through a catnip node is shown (again with polarized light optics). Notice that there is green tissue in the pith region at the node (this section doesn't come from the exact center of the stem and is also quite thick and so it's not obvious that the center of the pith is hollow in the internodes above and below the node).

Motherwort (*Leonurus cardiaca*) — Mint family

This weedy member of the mint family has small fuzzy pink flowers that develop into bristly fruits, making it an unpleasant plant to encounter at that stage. The stem cross section is quite striking but still has the typical squarish shape that is common to mint family members.

This page Dotted horsemint (*Monarda punctata*) — Mint family

The typical square stem of mints is once again observed in this fragrant plant. As with catnip and other mints, short glandular hairs (seen in the top—brightfield—image) are present, which contain mint oils. The yellow flower petals are dotted (hence the name) and are accented by the pink leaf-like bracts.

Following pages More mints

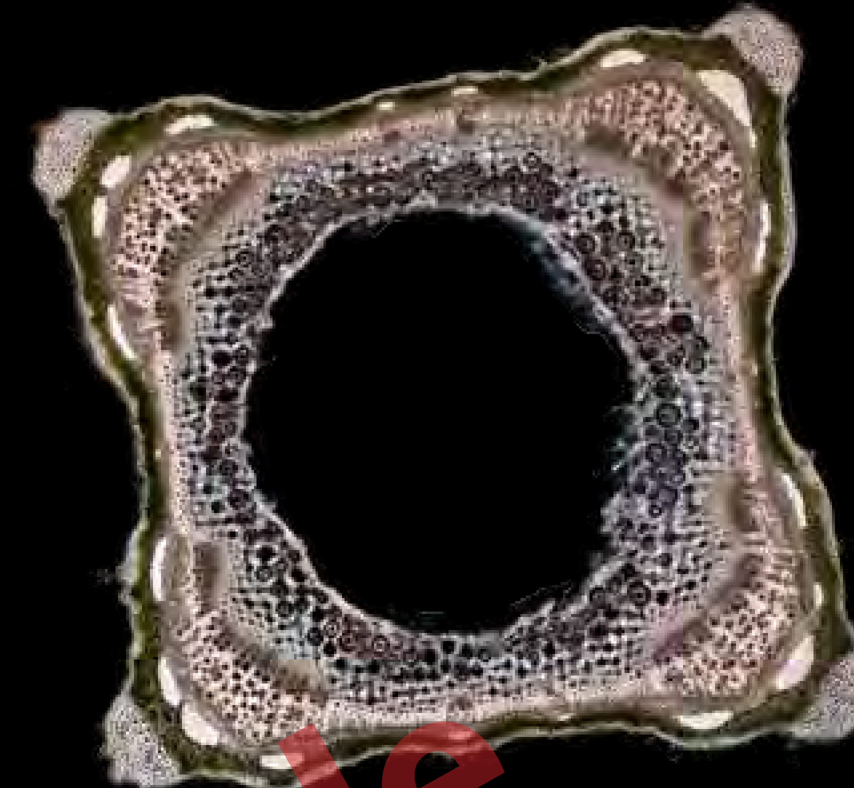
The square-stem theme is seen in a number of other mints.

Heal-all (*Prunella vulgaris*)

Beebalm or wild bergamot
(*Monarda fistulosa*)

Mountain mint
(*Pycnanthemum virginianum*)

Creeping Charlie
(*Glechoma hederacea*)

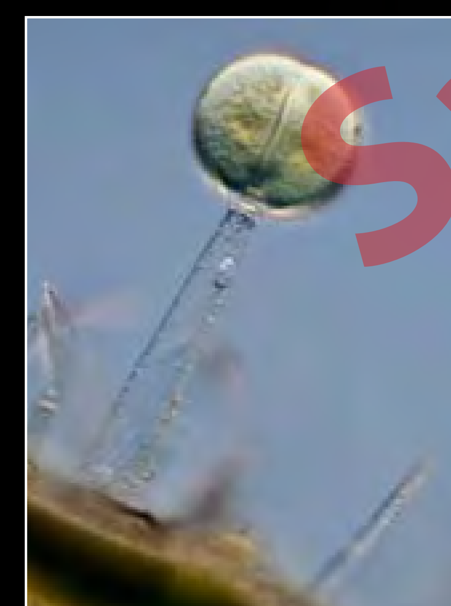


Water horehound (*Lycopus americanus*)

Basil (*Ocimum basilicum*)

Dodder (*Cuscuta*) — Morning glory family

Dodder is not a run-of-the-mill plant. For one thing, it lacks chlorophyll and cannot make its own food. Instead, it is parasitic on other plants, essentially behaving as the plant version of a vampire. Here, the string-like, orange-colored dodder stems are wrapped around a goldenrod plant. Specialized organs penetrate the host plant (the dark tissue—arrow—coming from the smaller, orange dodder stem in the cross section above) and make their way to its vascular system, where they siphon off food and water. It can produce large numbers of seeds and spread rapidly and is a pest of certain food crops, but is also helpful in attacking some other invasive plants. The bottom portion of a goldenrod leaf is attached to stem on the left in the cross section above.



Tomato (*Lycopersicon esculentum*) — Potato family

A good number of shorter glandular hairs (from which the familiar tomato odor originates) as well as longer hairs grace the tomato plant's stem.

Clammy groundcherry (*Physalis heterophylla*) — Potato family

This weedy plant has yellow flowers and fruits that resemble Chinese lanterns.

Bittersweet nightshade (*Solanum dulcamara*) — Potato family

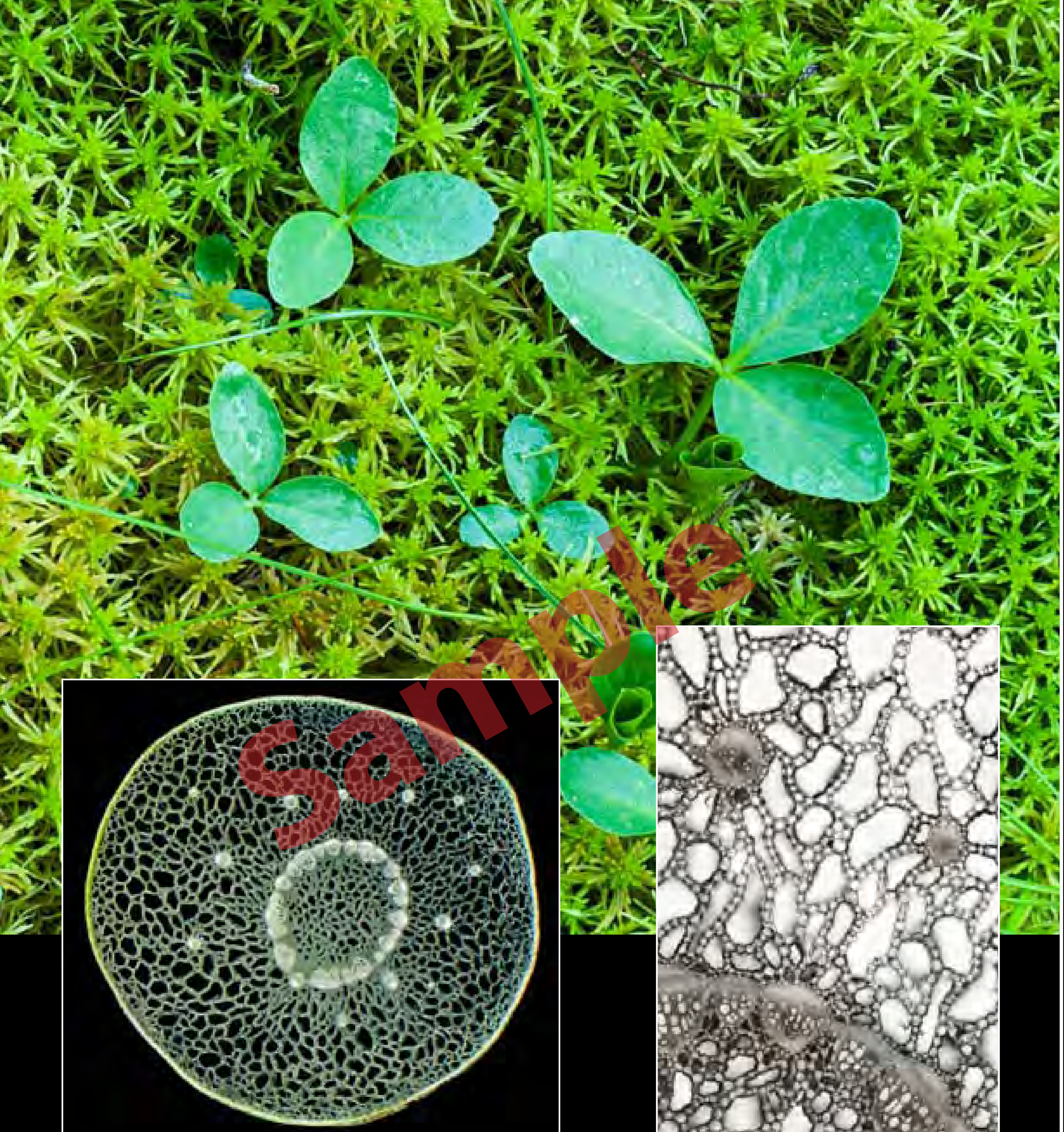
This common vine, related to potatoes and tomatoes, has colorful flowers as well as brightly colored fruits that change from green to orange to red. The stem has a layer of purple, water-soluble pigment in a layer of cells just beneath the eipdermis.

Winterberry (*Ilex verticillata*) — Holly family

This is a widespread shrub or small tree having bright red berries in late summer, fall, and into the winter (hence the common name). Though some holly family plants are evergreen, winterberry is deciduous. It prefers moist habitats.

Great blue lobelia (*Lobelia siphilitica*) — Lobelia family

This blue-flowered lobelia, which is typically found in moist to wet areas, has ribbed stems.



Bogbean (*Menyanthes trifoliata*) — Bogbean family

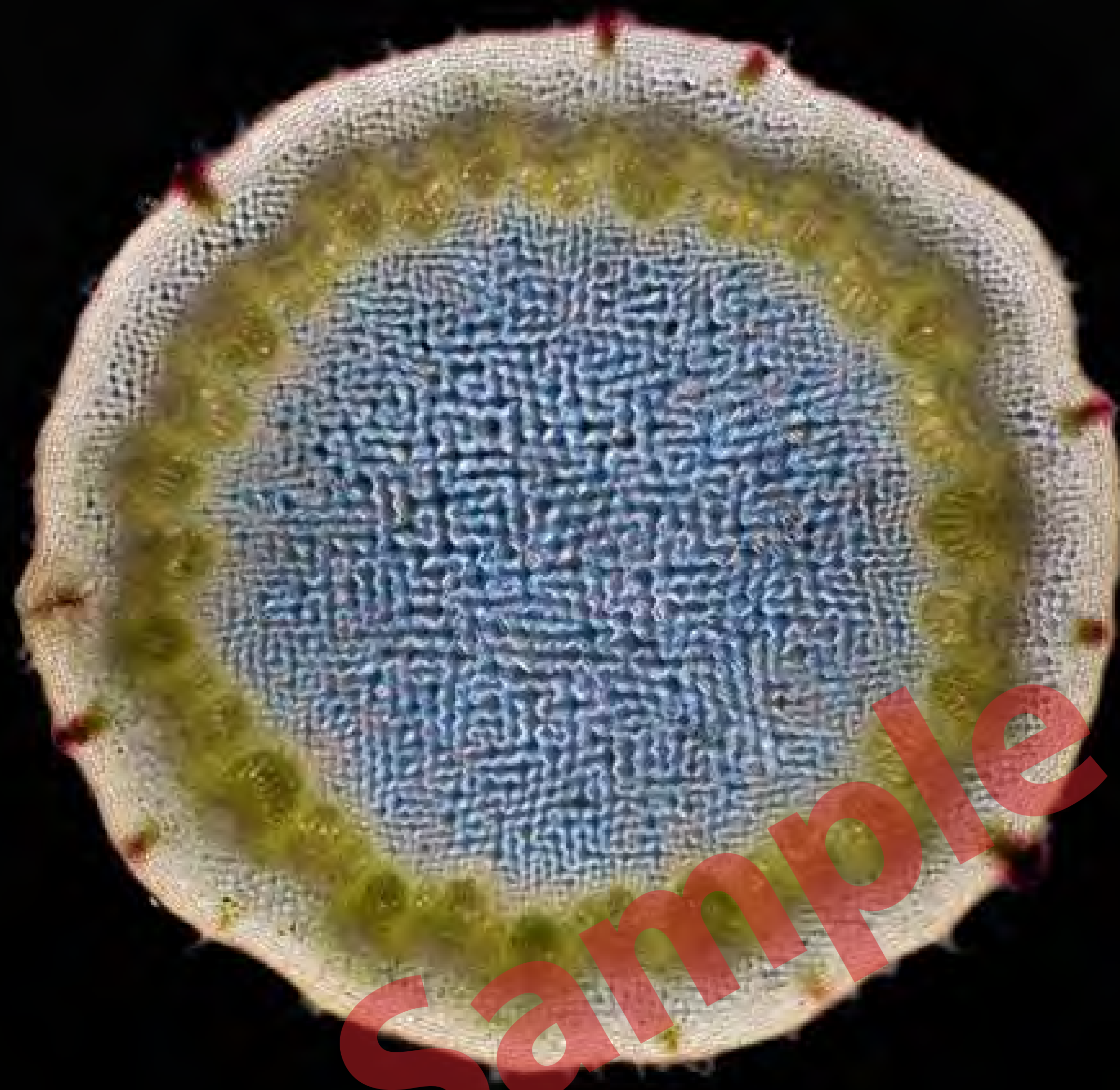
Although not closely related to legumes, leaves of this bog plant have three leaflets (hence the species name) and resemble those of bean plants. It is seen here growing among peat moss (*Sphagnum*). As with other plants that like to get their feet wet, there is a great deal of air space within the stem.

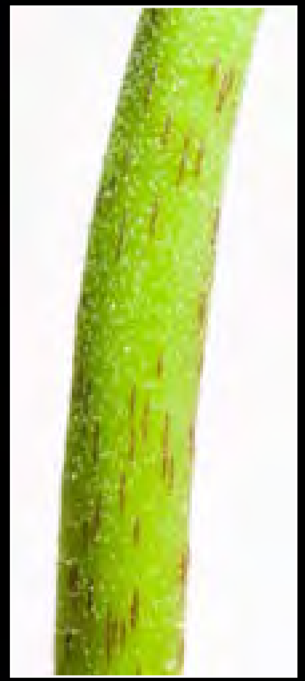
Chicory (*Cichorium intybus*) — Sunflower family

This common plant with attractive, usually blue, flower heads is often invasive in North America. Chickory is cultivated for its leaves and roots, the roots most often being used as a coffee substitute or additive.

Blazing star (*Liatris*) — Sunflower family

This attractive plant, typically found in prairies, is somewhat unusual in that the flowers at the top of the plant bloom first. Unlike sunflower heads, for example, which have small, tubular "disk flowers" in the center and petal-like "ray flowers" on the periphery, blazing star only has disk flowers.





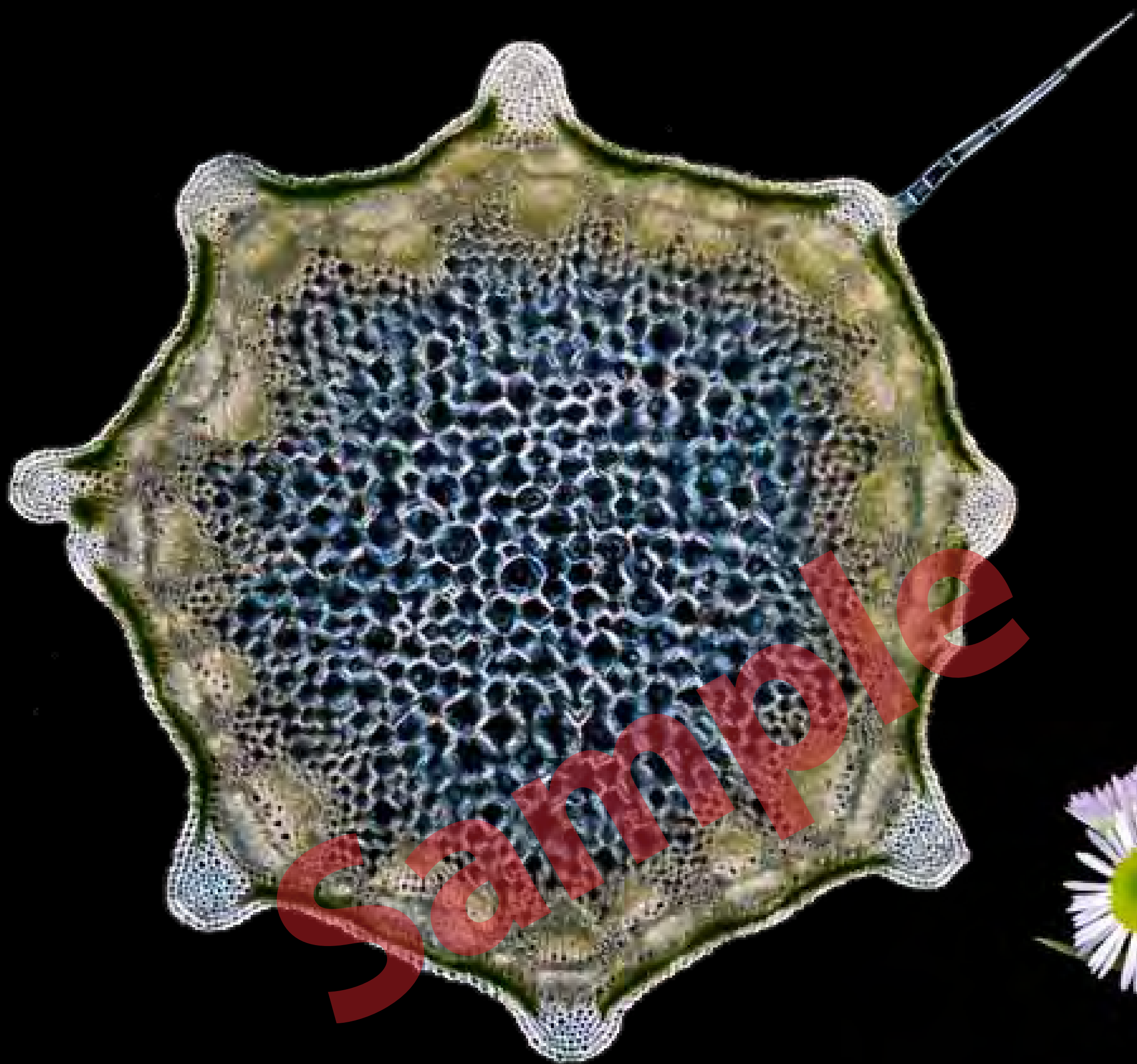
Joe-pye weed (*Eupatorium* [*Eutrochium*] *maculatum*) — Sunflower family

Joe-pye weed is a common plant in a variety of habitats including prairies, woodlands, and sedge meadows. Reddish streaks on the stem surface are also evident in cross sections, with the pigment extending fairly far into the cortex.

Boneset (*Eupatorium perfoliatum*) — Sunflower family

This plant occupies a wide variety of habitats, though mostly preferring low, moist spots, and has stems with an impressive wooly coat of multicellular hairs.

Sample



Fleabane (*Erigeron*) — Sunflower family

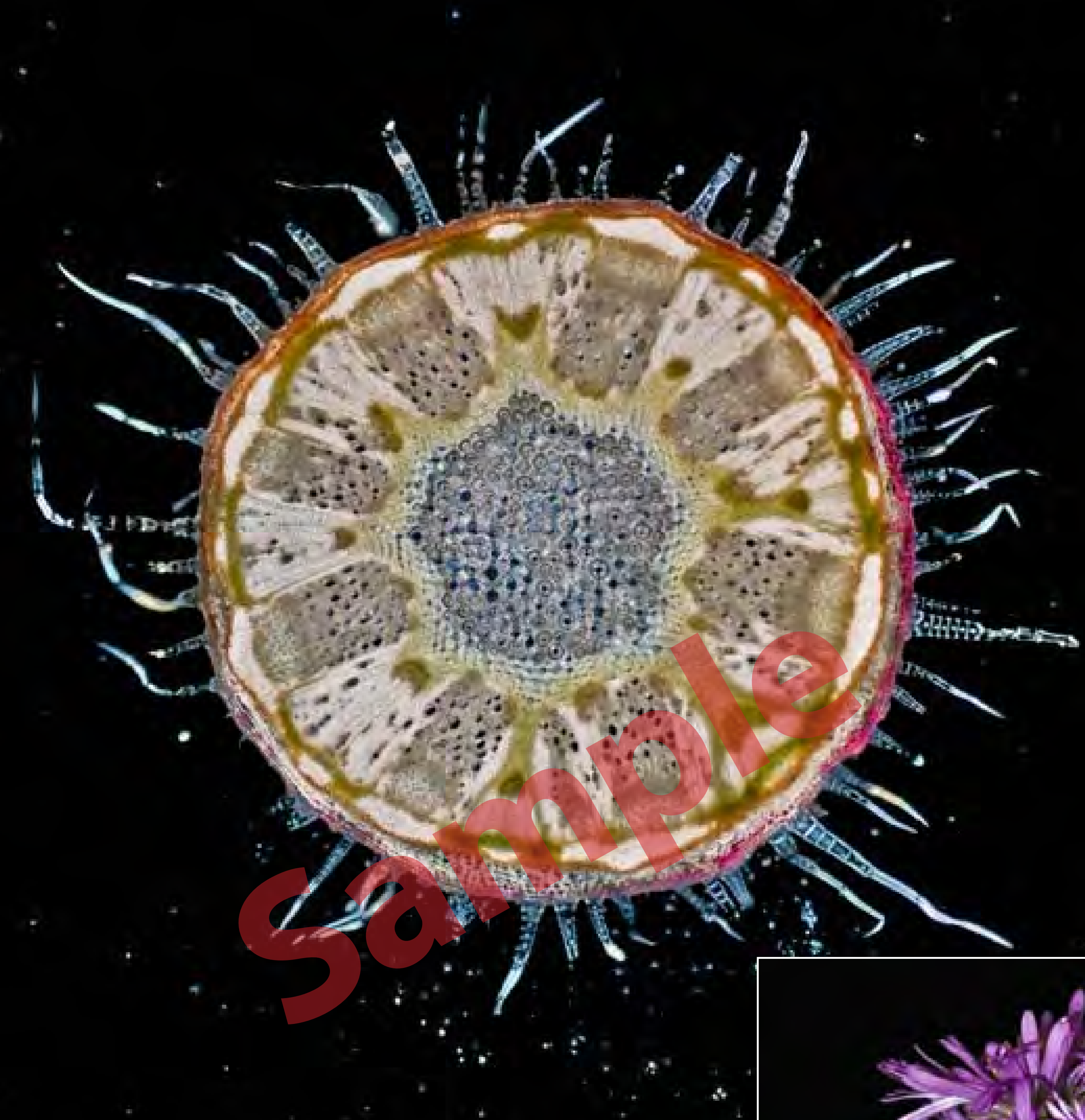
Fleabanes (there are very many speces) have small, daisy-like flower heads. The specimen shown here has relatively sparse multicellular stem hairs.

Spotted knapweed (*Centaurea biebersteinii*)
Sunflower family

This pink-flowered relative of the blue cornflower is a terribly invasive plant in North America that has colonized a vehicle track through a field in the photo above. The stem cross section was photographed with darkfield optics.

Black-eyed Susan (*Rudbeckia hirta*)
Sunflower family

Stems of the familiar black-eyed Susan have lots of hairs with red-pigmented bases.



Aster (*Symphyotrichum*) — Sunflower (or aster) family

This aster plant (there are very many species) has an impressive stem with numerous hairs, as well as purple pigments that complement the showy purple flower heads. The sunflower family is also known as the aster family and the name "Asteraceae" is the most commonly used scientific name for this important group of plants.

Tall swamp marigold (*Bidens coronatus*) — Sunflower family

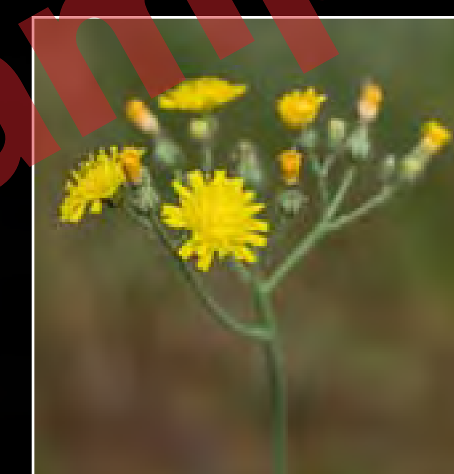
A wetland plant that can be found in large numbers, this *Bidens* species has stems with an elaborately patterened pith, most of which is occupied by air bubbles in this cross section.

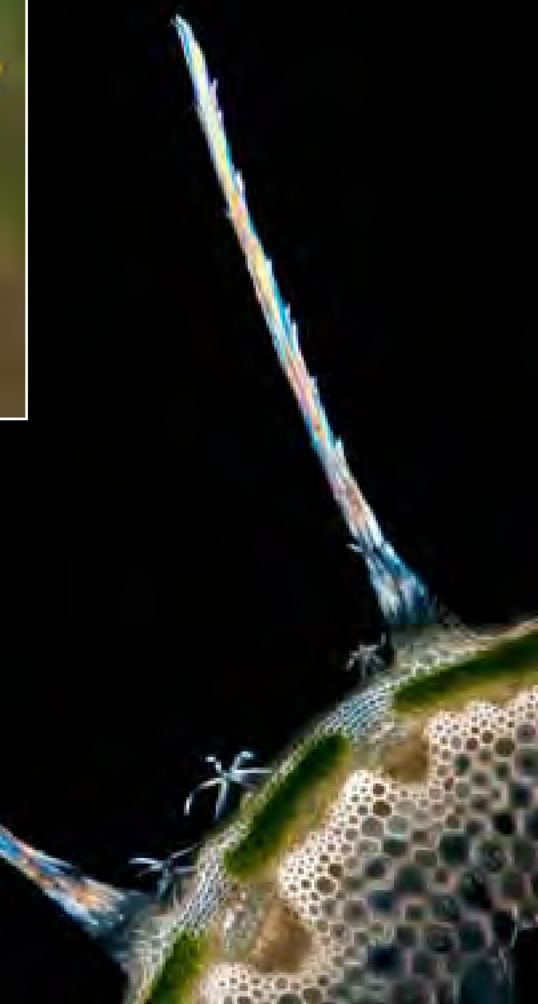
Prairie dock (*Silphium terebinthinaceum*) — Sunflower family

This prairie plant has broad, sandpapery leaves and is often joined in the prairie by other members of the genus *Silphium*, including rosinweed, cup plant, and compass plant.

Burdock (*Arctium*) — Sunflower family

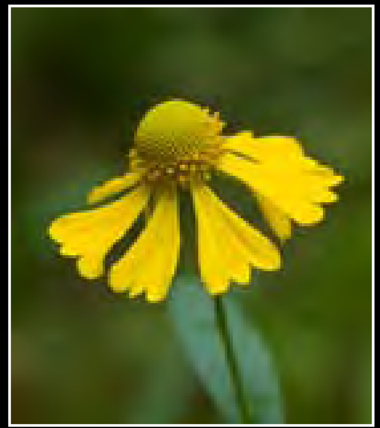
This often weedy plant common to disturbed areas is all too familiar to anybody or their pet encountering it when it is mature. The entire flower head breaks off and grabs onto nearly any clothing or fur. It has a flamboyant stem cross section to match the impressively large leaves.





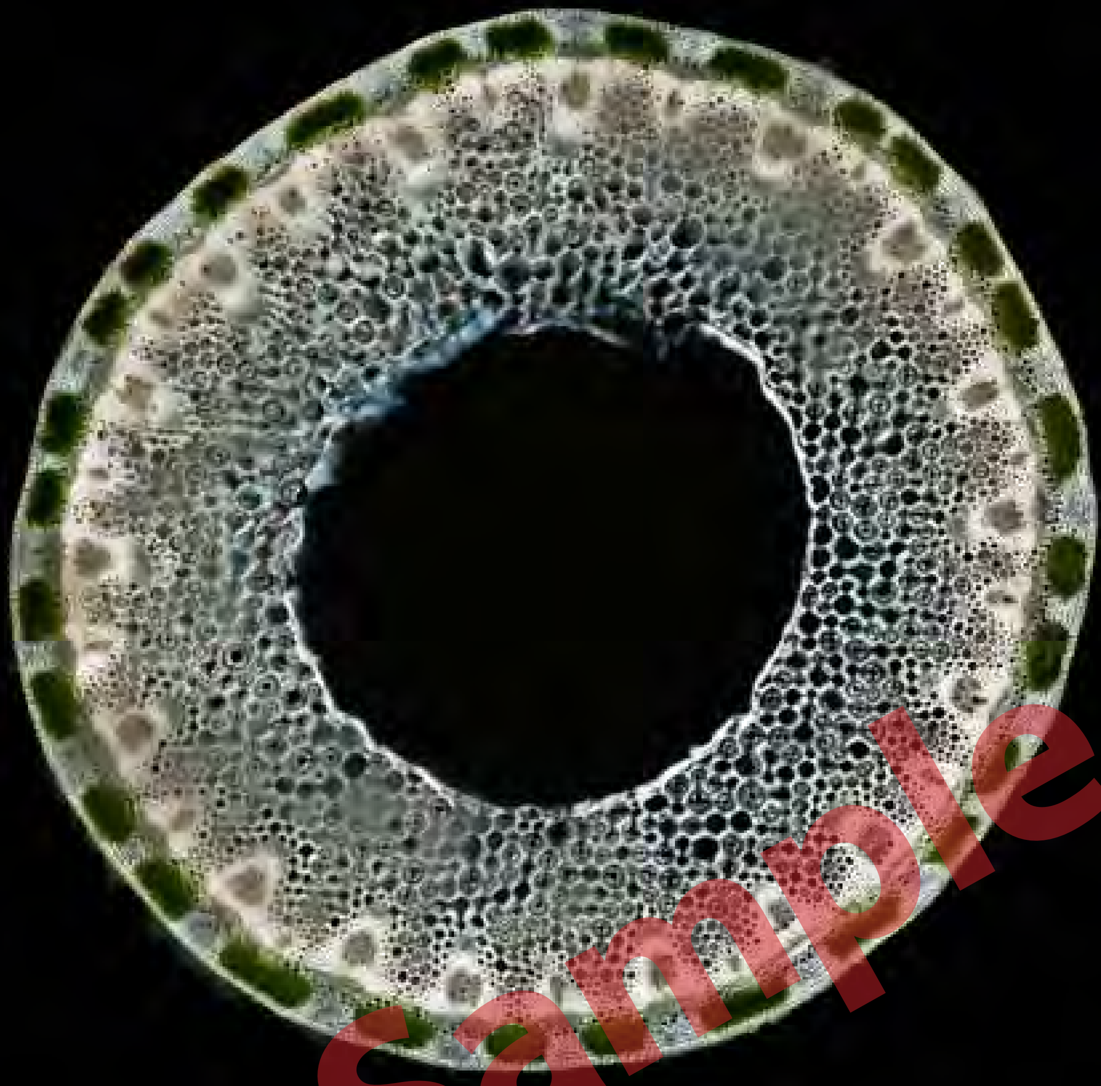
Hawkweed (*Hieracium*) — Sunflower family

Some hawkweed species have very long hairs on both stems and leaves. With the microscope, several types of smaller hairs also become visible, some of which have glands at their tips.



Sneezeweed (*Helenium autumnale*)
Sunflower family

Looking as if they could fly when seen in cross section, sneezeweed stems are unusual in that the leaf blades are fused for a considerable distance along the stem and it is the fused leaves that look like wings in the micrograph above.



Goatsbeard (*Tragopogon dubius*) — Sunflower family

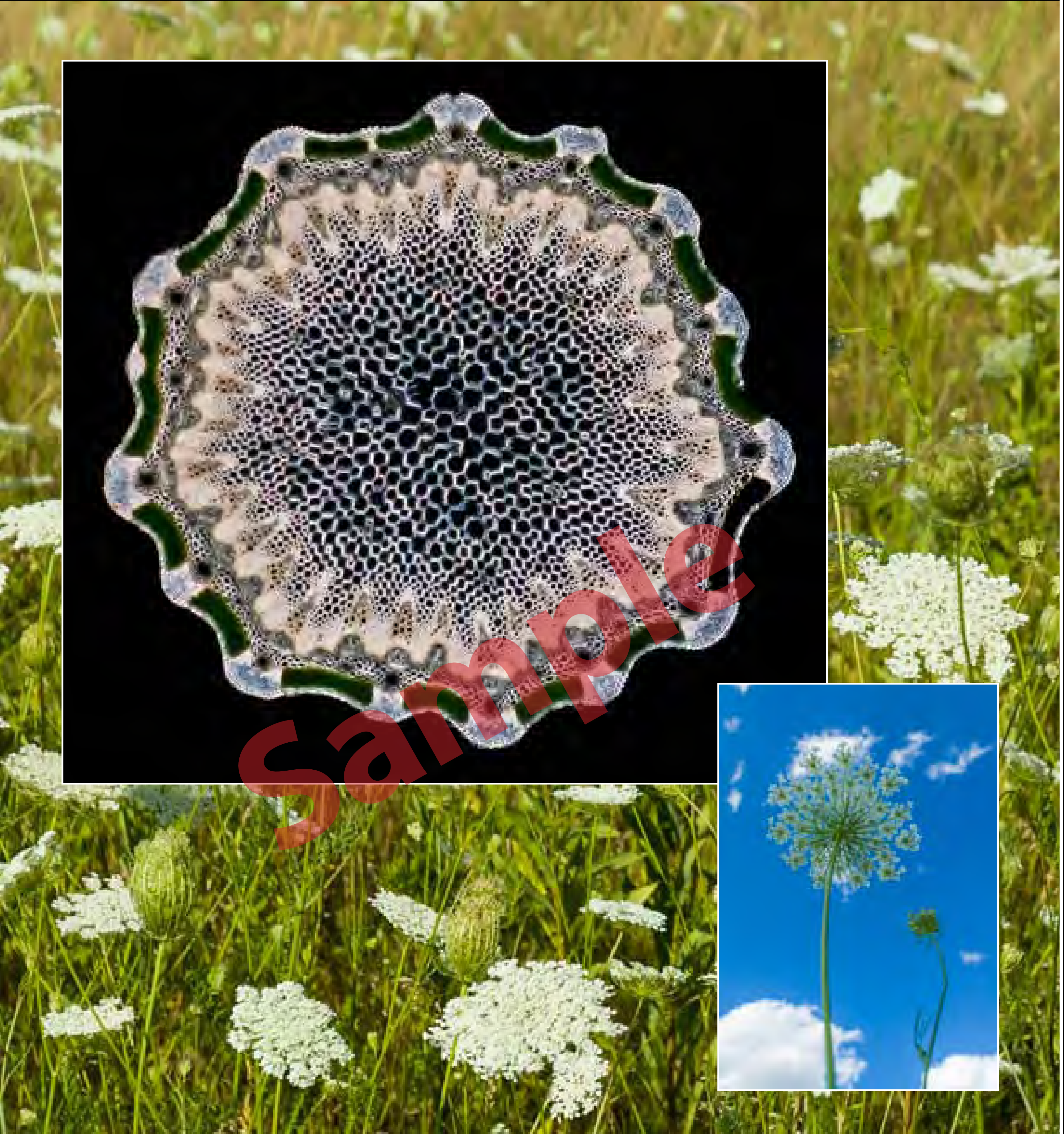
This common and often invasive plant is familiar for its seed heads, which resemble but are much larger than those of dandelions. The green photosynthetic stem tissue is obvious on the surface of the stem as dark green stripes.

Wild parsnip (*Pastinaca sativa*) — Carrot family

The wild parsnip is the same plant as the one cultivated as a root vegetable and can be quite invasive. When handling the foliage, care must be taken to avoid getting the toxic sap on one's skin. A chemical is present that can cause a bad rash when exposed to sunlight.

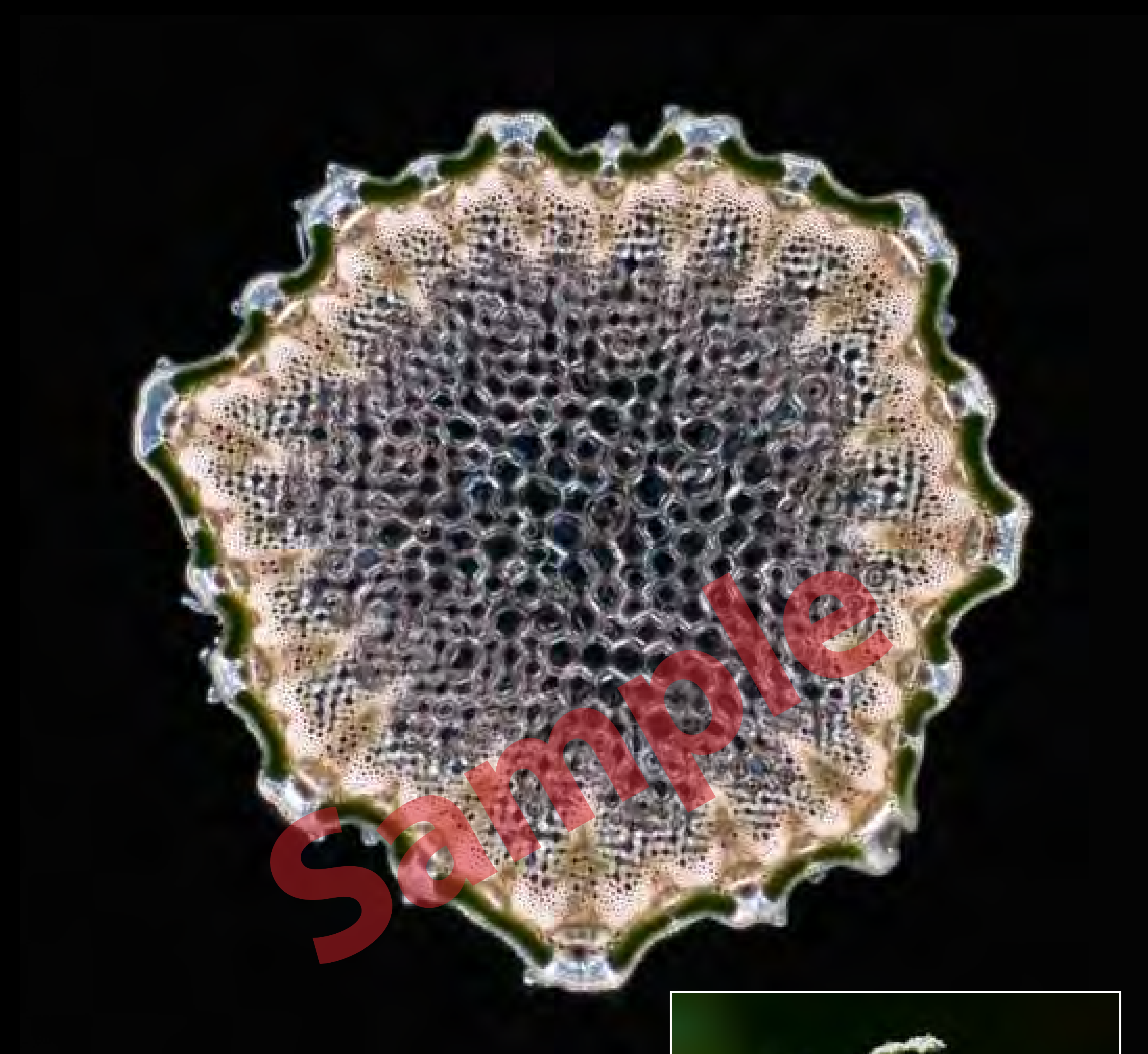
Great angelica (*Angelica atropurpurea*) — Carrot family

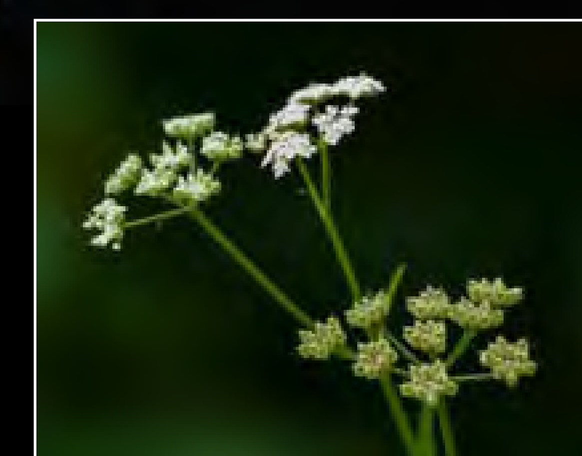
This often very large carrot-family plant has characteristic purple stems, which can be seen in both images here. Large bundles of collenchyma cells lie in the stem cortex. They are quite similar in appearance to those found in celery stalks (celery is also member of the carrot family).



Queen Anne's lace (*Daucus carota*) — Carrot family

Queen Anne's Lace, or wild carrot, is a familiar member of weedy roadside plant communities. Its stem has a large pith, very regular ribs, and underlying discrete blocks of green photosynthetic tissue.





Erect (Japanese) hedge parsley (*Torilis japonica*) — Carrot family

This weedy relative of Queen Anne's Lace has a similarly impressive ribbed stem when viewed in cross section.

Elderberry (*Sambucus canadensis*) — Honeysuckle family

Elderberry stems are often used in the botany classroom to illustrate lenticels. This darkfield image of a stem cross section includes one lenticel. The external macroscopic view shows the epidermis tearing apart as the stem increases in diameter and cork tissues expand from a lenticel.

Tartarian honeysuckle (*Lonicera tatarica*) Honeysuckle family

An invasive species in North America, Tartarian honeysuckle nevertheless has attractive flowers and a rather impressive stem cross section with short hairs.

Techniques

Preparation of stem material. Most of the microscopic images shown in this book are of fresh stem material that was freehand sectioned using very sharp, PTFE (Teflon®)-coated, single-edge razor blades. Most stems sectioned were 2–3 mm (~1/8 inch) in diameter and were mounted in water on standard glass microscope slides with coverslips, sometimes with a tiny amount of dishwashing detergent, which can help reduce the number of air bubbles—an issue with particularly hydrophobic specimens. Thinner sections reveal more of the fine detail but lose some of the color information compared to thicker ones (Figure 21). Some images were taken of specimens on commercially available prepared slides. Such material is typically "fixed" (preserved chemically), embedded in some sort of matrix (e.g., paraffin wax or plastic resin), and sectioned using a microtome—a device that can cut very thin sections of consistent thickness. Various stains are used to enhance contrast and differentiate the cells and tissues in such preparations.

Microscopy. The majority of stem sections were photographed using compound photomicroscopes with an attached camera. Most images were captured digitally, though a few were shot on film and scanned. A halogen lamp was used as the light source for most of the images, though a strobe was used in some cases. A few of the larger specimens were photographed with a camera mounted on a stereo dissecting microscope, which operates at lower magnifications.

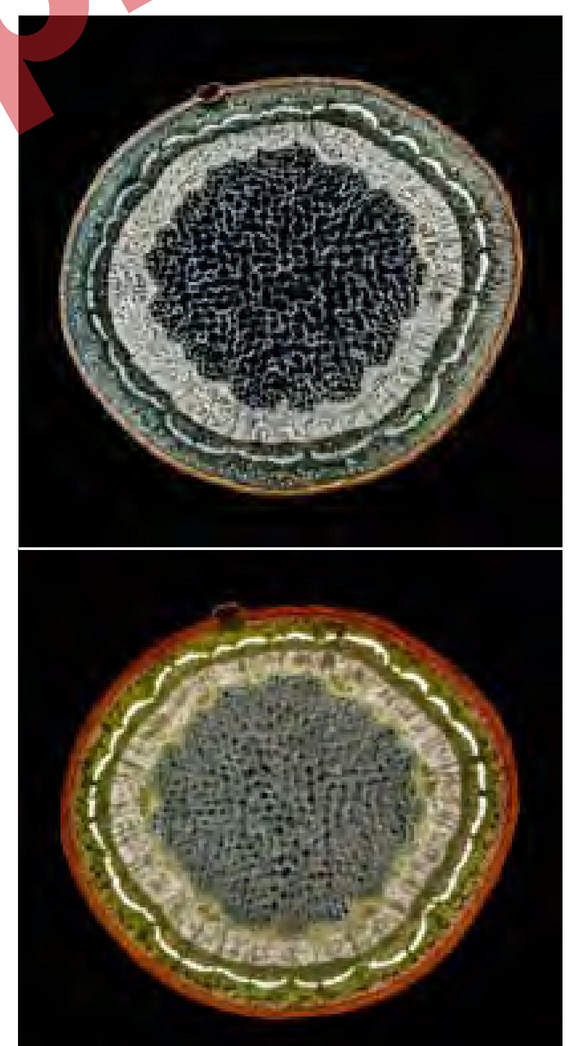
Several different optical techniques were used (Figure 22): brightfield, darkfield, polarized light, epifluorescence, and differential interference contrast (DIC). A brief description of each follows:

Brightfield optics—the type most commonly encountered in the classroom—produce an image with natural colors against a bright background (hence the name). It is the simplest of the techniques used here. Light passes directly through the specimen and is imaged with the objective lens and eyepieces. Contrast is controlled by a diaphragm (or a series of differently sized holes on simpler instruments) beneath the specimen stage of the microscope.

Darkfield optics yield a bright subject against a dark background and is particularly compelling with certain specimens. Rather than light passing straight through a specimen as with a brightfield setup, illuminating light instead travels through a ring-shaped opening at the edge of the optics and strikes the specimen from an extreme angle (so much so that the light misses the objective lens of the microscope such that only black is seen through the eyepieces). If a specimen is hit by the light, however, some can bounce off it and into the objective lens and be imaged.

Polarized light optics employ two filters much like polarized sunglasses to highlight materials in specimens that are crystalline in nature. The first filter lies beneath the specimen and "polarizes" the light, such that only light waves that are aligned in one direction pass through and strike the specimen. The second filter typically lies at 90° to the first ("crossed polarizers") and if no specimen were present, there would be a nearly black field. When crystalline structures in a specimen are struck by the polarized light, they interact with it and rotate some of the light waves, such that they are allowed to pass through the second filter. The majority of stem cross sections in this book were photographed using this technique. Plant stems contain lots of crystalline materials, especially in their cell walls. Polarized light optics sometimes produces striking colors that, while not seen with brightfield or darkfield optics, nevertheless reflect some underlying features of the specimen. Like darkfield microscopy, a dark background is produced.

Figure 21 Thinner (top) and thicker (bottom) sections of the same sugar maple (*Acer saccharum*) stem



Epifluorescence optics involve the illumination of the specimen from above (that is, the light doesn't actually pass through the specimen but instead reflects off it). Because of a series of filters and mirrors, the illuminating light passes through the objective lens, strikes the specimen, and bounces back through that same lens and is imaged. Light of a particular color (wavelength) hits the specimen and can excite electrons in certain molecules, which then emit light of a different color (with a longer wavelength) that has less energy. Here, only "autofluorescence" is shown, which means that naturally occuring chemicals/structures in the specimen absorb and then re-emit (fluoresce) light. In most scientific studies employing epifluorescence microscopy, fluorescent dyes are attached to molecules ("probes") that recognize and attach to other molecules in the specimen that are of interest to the researcher, allowing for their location to be determined within cells.

DIC optics were used in a few instances to examine some of the finer details of stems, particularly the hairs. A 3D-like appearance results that can be aesthetically pleasing. It is a more complicated technique, descriptions of which (along with discussions of the other optical approaches) can be found on a variety of websites (e.g., Nikon's excellent "MicroscopyU") or in textbooks or technical publications.

Image processing. Digital images were typically shot in RAW format and all images were processed in Adobe Lightroom and/or Photoshop. One of the challenges of macrophotography as well as photography through the microscope (photomicrography) is the inherent shallow depth of field. That is to say, not very much of a tiny subject will actually be in focus. With the advent of digital image processing, a number of software applications have become available that allow for "focus stacking," which basically means that a series of images are taken—each at a slightly different plane of focus—that are then stacked together by the software such that only the crisp, in-focus areas of each image are kept, while the out-of-focus areas are discarded. The result is a composite image that can have a considerably greater depth of field. This technique was used for the majority of stem photomicrographs shown in this book, since the handmade sections often did not lie completely flat or weren't of uniform thickness.

In some cases, portions of larger stem sections were photographed and the resulting images were then stitched together to create a photomontage with the aid of panorama-building software. In a handful of instances, both focus stacking and stitching were employed for the same specimen.

Images that accompany the stem sections were taken with a variety of cameras and lenses. Most close-ups were shot with macro lenses.

Figure 22 Top to bottom: brightfield, darkfield, polarized light, and autofluorescence images of a whisk fern (Psilotum complanatum) section