Warm & Comfortable within Hollow Stems, Leaf-mines and Galls: Little known habitats for Entomologists & Botanists to explore

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There is increasing botanical interest in the endomicrometeorology of plants, mostly of flowers (Kevan 1970, 1975, 1989, 2019a, 2019b, 2020; van der Kooi et al. 2019). The phenomenon of elevated temperatures within plant structures has implications for the effects of climatic warming (Kevan 2019b; Kevan et al. 2020). Of late, our attention at the University of Guelph has turned to hollow stems and fruits and the conditions that exist within those structures (Kevan 2019a, b; Kevan et al. 2020). Curiosity has led us to think about those places as arthropod habitats.

Preliminary surveys in Canada (ON, MB, central AB, BC and western QC), the UK in Scotland and England, and Far Eastern Russia indicate that probably over 50% of the herbaceous flora (excluding grasses (Poacaea)) produces hollow stems. There seem to be no reviews of the phylogenetic distribution of hollowness of stems, nor of any biogeographical, ecological or evolutionary overviews, but our surveys may allow some generalizations and explanatory hypotheses to be made. Sun and Frelich (2011) correlated various aspects of growth and maturation of 25 species with morphological characteristics, including stem hollowness, in a grassland in New England. The four solid stemmed plants in their study grew slowly and bloomed late. Of the 21 hollow stemmed species, 15 were noted to grow fast and bloom early (nine species) or late (six species) but five species grew slowly and bloomed late, and only one species was a slow grower and bloomed early.

It is known that many herbaceous plants grow quickly in temperate regions, lofting their reproductive structures (inflorescences and fruits) above much of the surrounding vegetation so becoming exposed to pollination and seed dispersal by wind or animals. At the same time, hollowness contributes to strength and flexibility while minimizing the amount of structural materiel (Niklas 1992; Niklas and Spatz 2012). A hitherto apparently unrecognized benefit to plant growth may be the microgreenhouse heating effect of translucent hollow stems. The model for that effect is given by Kevan et al. (2018). Examples of the extent of internal heating are presented in Kevan et al. (2018) and Kevan (2019a) which documents temperature excesses of several degrees C above the surrounding ambient air.

C. Coates

OMEGA datalogger with thermocouples inserted into hollow dandelion, *Taraxacum officinale* stems. The temperature inside the stems is 21.1 °C and the ambient air temperature at a similar height is 19.8 °C.

E.A. Tikhmenev

Kevan makes a spot check of temperatures within dandelion (*Taraxacum officinale* L. (Asteraceae) stems in Magadan region, Far Eastern Russia, Blue leads from thermocouples, one inserted into the lumen of the stem and the other in the adjacent air.

C. Coates

Radiation shield measuring ambient temperature next to hollow stemmed. Sow thistle (*Sonchus*) and Pumpkin (*Cucurbita pepo*) peduncles with thermocouples inserted.

With such ameliorated temperature regimes within hollow stems, insects and other arthropods would find the protected environment beneficial (except under extreme conditions). However, we have found no review on this subject even though some examples are well known.

For this essay, we have focused on insects that inhabit hollow stems of herbaceous plants rather than including all "stem borers", i.e., any insect larva, or arthropod, that bores into plant stems. Various Coleoptera and Lepidoptera have larvae that are well known to bore into stems, but the literature does not allow easy assessment of whether the stems of the host plant are naturally hollow or become hollowed out by the borers' feeding. Many of the points we make in this essay could apply to stem borers in general. For example, Meier (1995) in a pioneering study, measured the temperatures within stems and inflorescences of two High Arctic species, *P. lanata* Willd. ex Cham. and Schltdl. and *P. hirsuta* L. (Orobanchacea) with respect to the heat available to herbivorous larvae of *Olethreutes inquietana* (Walker) (Lepidoptera: Tortricidae) and *Gonarcticus arcticus* (Becker) (Diptera: Scathophagidae) living within the stems. She found temperatures excesses of several degrees C, and by removing the pubescence on *P. hirsuta* found that the temperature excesses were reduced and of shorter duration. There are a number of insects that inhabit hollow stems or culms of herbaceous plants, especially of grasses (Poacaea), but little seems known about the importance of the physical environment within the stems on the bionomics of the insects.

The most notorious of hollow-stem inhabiting insects is the wheat stem sawfly (*Cephus cinctus* Norton (Hymenoptera: Cephidae) (Beres et al. 2005), a persistent pest of cereal grains grown in the prairie provinces. It is native to North America and lives in grasses, mostly the wheatgrasses (*Agropyron spp.* (Poacaea)) and some other annual grasses. Associated with it are a few parasitoids, especially Hymenoptera: Braconidae (*Bracon cephi* (Gahan) and *B. lissogaster* Muesebeck) which can exert control over the sawfly populations.

R.K.D. Peterson

J.P.Michaud

Above: Young wheat stem sawfly larva (credit: R.K.D. Peterson, Montana State University, *from* Integrated Pest Management of Wheat Stem Sawfly in North Dakota, leaflet E1479, by J. Knodel, T. Shanower, and P. Beauzay, available from https://www.ag.ndsu.edu/publications/crops/integrated-pest-management-of-wheat-stem-sawfly-in-north-dakota/e1479.pdf.
Right: Larva of wheat stem sawfly within wheat stem. Photo from https://entomology.k-state.edu/extension/insect-information/crop-pests/wheat/wheat-stem-sawfly.html credit J.P. Michaud, *Wheat Stem Sawfly,* Kansas State University, April 2013.

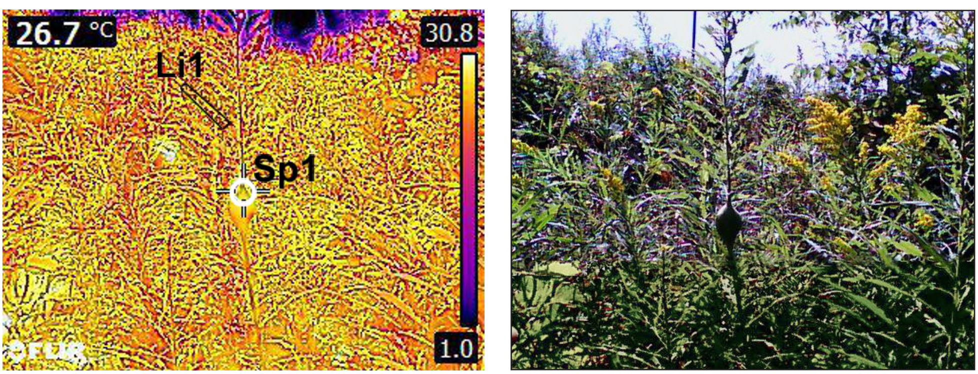
Lesser known pests are the grass stem flies. The wheat stem maggot, *Meromyza americana* Fitch (Diptera: Chloropidae) feeds in the stems of wheat and rye, sometimes doing much damage. The larva of *Chlorops graminea* Coquillett (Diptera: Chloropidae) lives in cigar-shaped galls on grass stems. Members of the genus *Oscinis* (Diptera: Chloropidae or Oscinidae) live almost invariably as larvae by boring into the stems of living plants, especially grasses (Poaceae). One species lives within the pods of the northern catalpa (*Catalpa speciosa* (Warder) Warder ex Engelm. (Bignoniaceae)). The famous European "frit fly" *Oscinella frit* (Linnaeus) (Diptera: Chloropidae) causes great damage to grain crops, especially in northern Europe. All those chloropids also feed as larvae within the stems of wild (native and introduced) grasses. Similar in habits is *Atherigona reversura* Villeneuve (Diptera: Muscidae), the bermudagrass stem maggot, named for its host preference for bermudagrass (*Cynodon dactylon* (L.) Pers. and stargrass (*C. nlemfuensis* Vanderyst) (Poacaea) (Grzywacz et al. 2013).

What of the temperature regimes in grass culms (stems)? Temperatures within the translucent culms of gigantic oats (*Avena sativa* L. (Poacaea)) growing in Magadan, Russia have been recorded at over 4 °C warmer in sunshine than the surrounding air (Kevan et al. 2019). We know of no other intra-culm temperature measurements in grasses but internodal hollowness is characteristic for many species. We suggest that a fuller understanding of the endomicrometeorology of the culms of economically important grasses may shed light on understanding their growth, health and maturation as well as of the stem-inhabiting pests.

Some cultivars of *Cannabis sativa* L. (Cannabaceae) have hollow stems. Our brief observations on the edge of a hemp production field in Ontario noted 3.5 °C temperature excess within the stems in sunshine at an air temperature of 27 °C. The Eurasian hemp borer (*Grapholita delineana* (Walker) Lepidoptera: Tortricidae, Olethreutinae) lives in the hollow stems. It has become established in North America and is of concern for pharmaceutical and fibre hemp production (Cranshaw 2018). The European corn borer (*Ostrinia nubialis* Hübner (Lepidoptera: Crambidae) has similar habits on cannabis. The mechanical properties of hemp plants have been reviewed for hemp processing (Khan et al. 2009), but information on how internal atmospheric and temperature conditions in the stems relate to the physical properties is not available.

Translucent structures also result from the leaf mining activities of various Diptera, especially Agromyzidae, a wide array of moths (Lepidoptera), some sawflies (Hymenoptera; Symphyta), and a few beetles (Coleoptera). They eat the green tissues of the leaf but leave the semi-transparent cuticles intact. Few studies have been made on the physical environment within mines, but it can be assumed that the humidity within is high and temperatures are elevated when insolated to the extent that lethally high temperatures may eventuate, even if buffered by evapotranspiration (Pincebourde and Casas 2006, 2019).

Galls can also be hollow structures on plants. They may be induced by many kinds of organisms from viruses to insects. The life histories of gall inducers and their associated pathogens, parasites, parasitoids and inquilines are notoriously complex. Few studies have been made on the physical conditions within hollow galls, even those with obviously translucent walls, as the well-known oak-apple (Connald 1908). One of the best studied galls is the goldenrod ball gall induced by the fly, *Eurosta solidaginis* Fitch (Diptera: Tephritidae). It occurs conspicuously on the stems of various species of goldenrod, *Solidago* spp. (Asteracea). Layne (1991) notes that the galls, which are thick-walled and probably not translucent, in sunshine can attain temperatures up to 5 °C above ambient air temperatures and do buffer the conditions within in hot summer and cold winter conditions. The pistachio horn gall is induced by aphids, *Baizongia pistaciae* L. (Hemiptera: Pemphigidae) on pistachio (*Pistacia* spp. (Anacardiacea)). The galls are large and inhabited by large numbers of aphids. Martinez (2009) records that the galls buffer the inhabitants from extremely high ambient temperatures and insolational heating.



C. Coates C. Coates

Golden rod (*Solidago candensis)* gall pictured left in infrared using a FLIR camera, and corresponding normal colour image on right. Yellow is represents the warmest colours in the FLIR image, showing that the gall is warmer than the surrounding plant tissues. The average temperature in Spot 1 (Sp1) on the surface of the gall is 26.7 °C. The average leaf temperature from Line 1 (Li1) is 24.5 °C.

Rumex species in Belgrade, Serbia with hollow stem displayed.

Our initial studies suggest that hollowness in the stems of herbaceaous plants is insufficiently documented as a plant characteristic, its phylogenetic and ecological significance in botany remains unexplored, and its potential importance as arthropodan habitat generally unrecognized. The implications with respect to the bionomics of both plants and arthropods as effected climate change may shed light on the changing biota of Canada and the world (Kevan 2019b; Kevan et al. 2020).

We are assembling a catalogue of herbaceous plants with and without hollow stems and invite colleagues to send us their observations by plant species, location, habitat, and a description of the "hollowness" (smoothly and clearly hollow through to pithy, spongey and solid, translucence). We would gratefully receive records of insects and other arthropods that inhabit hollow stems to add to our data base. As our surveys expand, we will be establishing an on-line, open-access data base to which those interested can contribute.

To join in, please contact Charlotte at coatesc@uoguelph.ca.

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