Thinking Outside the Box:

Temperature dynamics in a tree cavity, wooden box, and Langstroth hives with or without insulation

by Robin W. Radcliffe and Thomas D. Seeley

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When Lorenzo L. Langstroth designed his movable-frame hive in the 1850s, it seems clear that he paid little attention to the insulation value and the thermal mass of the walls, floors, and lids of his hives. These days, a Langstroth hive has changed very little as it still consists of a stack of rather thin-walled wooden boxes that sits on a wooden bottom board and is covered with a wooden lid. This means that managed colonies usually occupy homes that are poorly insulated and have a low thermal mass. (NOTE: "Poorly insulated" means the home has little resistance to heat loss; "low thermal mass" means the home has little heat storage capacity. Both properties slow the rate at which heat enters and leaves a home [Hampton 2010].)

This is unfortunate. We all know that the *insulation* of a building is valuable for stabilizing its interior temperature, whatever the season. Probably we all know, too, that the *thermal mass* of a building also helps stabilize the temperature inside it. So, both the insulation level and the thermal mass of a hive influence how much thermal protection a hive provides to the colony living inside it. This level of thermal protection, in turn, affects how much energy the colony must expend to maintain a proper temperature in its brood nest in summer and in its broodless cluster in winter.

To understand how the challenge of temperature control differs between colonies in tree cavities and colonies in beekeepers' hives, we compared the thermal protection provided by a tree cavity to that provided by a Langstroth hive. We presumed that the thick walls, floor, and ceiling of a tree cavity provide a colony with better thermal protection than a Langstroth hive. But we did not know whether the difference in thermal protection between these two sorts of homes is small, medium, or large.

So, we began our investigation by measuring the temperature variations in two empty cavities *that were identical in size and shape, but were different in structure.* One cavity was inside a large tree, and the other was inside a wooden box made of lumber like that used for Langstroth hives. We then extended our investigation to a comparison of the temperature fluctuations inside Langstroth hives (occupied by colonies) that were, or were not, well insulated.

We performed these studies to address two questions. First, how much better is a colony's living space buffered against external temperature fluctuations when its home is a tree cavity instead of a wooden box? Second, how much smaller are the temperature fluctuations inside a Langstroth hive (outside the winter cluster) when the hive is insulated with a thick, wool blanket than when it is not insulated in this way?

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Fig. 1 *Robin Radcliffe cuts out the tree cavity, using a gutter adze, as Tom Seeley looks on. This cavity mimics the size and shape of a natural nest cavity. At top of page, Tom uses a chainsaw on the same cavity.*

Study 1: Empty tree cavity vs. empty wooden box

<u>Methods</u>

We built two experimental nest cavities (Figure 1). One was in a live tree and the other was in a wooden box. The two cavities were matched in size and shape, and in entrance

Photographs by Robin W. Radcliffe

Fig. 2 *Views of the cavities inside the maple tree and the wooden box. One sees the temperature sensor in each cavity, positioned 25 inches (64 cm) above the floor.*

size, shape, and height. Both had the size and shape of a natural nest cavity, and both had an entrance opening like that of a natural nest cavity (as described in Seeley and Morse, 1976). So, both cavities had a height of 34 inches (86 cm), a square horizontal cross section of 9.5 x 9.5 inches (24 x 24 cm), and a volume of 1.8 cubic feet (0.05 cubic m). This volume is similar to that of a deep, 10-frame Langstroth hive with 1.5 cubic feet (0.04 cubic m). Both cavities had just one, circular entrance opening that was matched in size (2 inches [5 cm] in diameter), height above the cavity floor (7 inches [18 cm]), height above ground (40 inches [1 m]), and direction (south).

Our study site was on the edge of the Shindagin Hollow State Forest near the hamlet of Brooktondale, in New York State (latitude 42.33595°, longitude 76.32741°). The tree cavity was made by cutting an opening — using a chainsaw, adze, and chisel — in the side of a live sugar maple tree (*Acer saccharum*) whose diameter at breast height (DBH), 4.5 feet (1.4 m) off the ground, measured 36 inches (90 cm). A rectangular 34-inch-tall by 9.5-inch-wide by 15.5-inch-deep (86 x 24 x 39 cm) cavity was created in the south side of the tree. The opening was then fitted snugly with a 6-inch-thick slab of sugar maple wood, leaving a 9.5-inch-deep (24 cm) space behind it.

The thicknesses of the four walls that enclose the tree cavity are 13 inches (33 cm) on both sides, 20 inches (51 cm) on the back, and 6 inches (15 cm) on the front. Given that the R-value of hardwood lumber is about 0.7/inch (1.8/cm), we estimate that the average R-value of this cavity's walls is about 9.1. The wooden box is made of white pine (*Pinus strobus*) boards that were 0.75 inch (1.9 cm) thick, the same thickness as the lumber used for manufacturing most Langstroth hives. The R-value of a pine board is about 1.4/inch (3.6/cm), so the R value of this wooden box's walls (and those of a Langstroth hive) is about 1.0. This box was mounted on a platform on the south side of the study tree, and just 7 feet (2.1 m) from it. Therefore, the tree cavity and the wooden box were matched in elevation and exposure to wind and sun.

To obtain continuous recordings of the air temperatures inside both cavities, and of the air temperatures outside them, we installed three temperature sensors (HOBOnet Temperature/Relative Humidity Sensor Model RXW-THC-900; Onset Computer Corp., Bourne, MA). We put one sensor inside each cavity at 25 inches (64 cm) from the cavity floor, and an "ambient" one outside the cavities (Figure 2). The ambient sensor was placed in an adjacent tree inside a weather guard to shield it from direct sunlight. The three sensors were linked

Photographs by Robin W. Radcliffe

Fig. 3 *The completed tree and wooden-box cavities without insulation (left; winter 2019-2020) and with insulation (right; winter 2020-2021). Wires for temperature sensors lead into each entrance.*

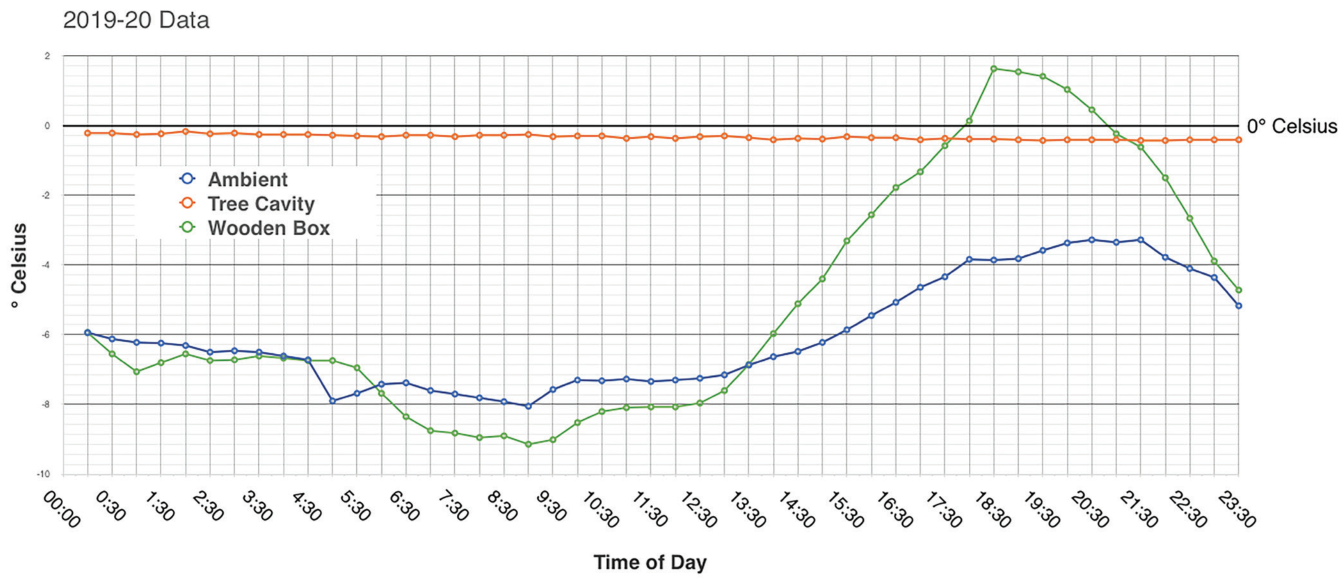

Fig. 4 *A 24-h (midnight to midnight) recording made on 28 February 2020*

to a wireless network using a Wi-Fi Remote Monitoring Station (RX3000, Onset Corp.). Each sensor was powered by batteries charged by a solar panel integral to the HOBOnet sensor. The sensors' outputs were recorded automatically every 30 minutes. We continued the temperature recordings across two winter-spring seasons in 2019-2020 and 2020-2021; data used for analysis started on 1 January 2020 and ended on 3 May 2021.

The wooden box was not insulated in the winter of 2019-2020, but in the winter of 2020-2021 it was covered with a wool hive blanket (Beehive Cozy Cover; BackYardHive, Eldorado Springs, CO) so we could study the effects of hive insulation. The insulation value of the four layers of wool in this hive blanket is R-30.

Results

Trial 1: Tree cavity vs. wooden box **without** insulation.

The pattern of ambient temperatures shown in Figure 4 is typical for a winter day in the northeast U.S. It was cloudy and cool (ca. 18°F [-8°C]) in the morning and sunny and warmer (ca. 25°F [-4°C]) in the afternoon. This recording also shows the temperature buffering of the tree cavity and the solar heating of the wooden box. The temperature in the tree cavity (ca. 32°F [0°C]) barely changed over the 24-hour period, but the temperature inside the box varied greatly. Its temperature tracked the changes in the ambient temperature, except in the afternoon, when sunshine warmed the box to nearly 36°F (2°C).

Trial 2: Tree cavity vs. wooden box **with** insulation

Now the wooden box was wrapped in a wool hive blanket. Comparing the records for the wooden box in Figures 4 and 5, we see that the blanket reduced the box's temperature fluctuations, but did not provide thermal protection as strong as the maple tree's trunk. The blanket improved the insulation of the wooden box, but it did little to augment the box's thermal mass.

Study 2: Occupied Langstroth hives with or without insulation

Methods

We compared the temperatures inside two Langstroth hives that were occupied by honey bee colonies of equal size. One hive was insulated with a wool blanket (Beehive Cozy

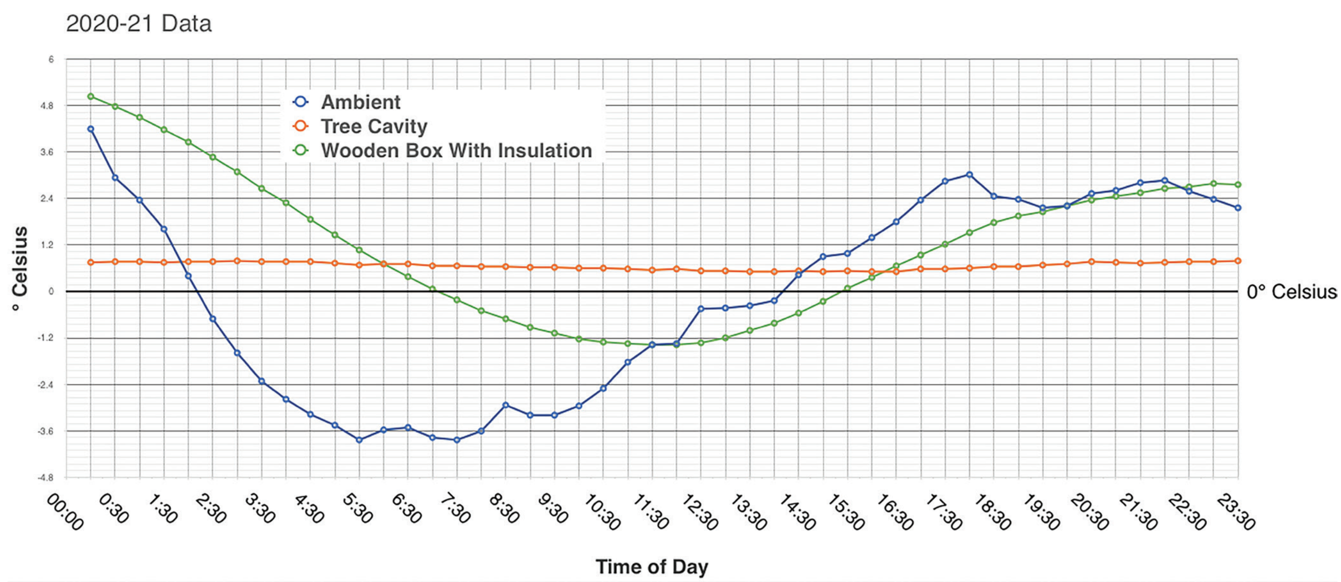

Fig. 5 *A 24-h recording made on 28 February 2021*

Cover) and the other hive was left bare (Figure 6). Neither hive had a top entrance, so neither colony experienced significant heat loss by convection/airflow from its hive. It is known that when honey bees get to choose their nest sites, they prefer tree cavities with the opening at the bottom (Seeley and Morse, 1978). It is known, too, that if a beekeeper provides a top entrance, then this increases greatly the rate of heat loss from a colony's hive, especially on cold days (Mitchell 2017).

The two hives sat 6 feet apart in an apiary that was 1600 feet (488 m) from the site of Study 1. The site for Study 2 had the same, treeless southern exposure as the site for Study 1. The colonies that occupied the two Langstroth hives were matched in size (assessed by inspecting the bees on each frame in both hives). Each colony was strong in late autumn; its population filled a hive that consisted of a deep 10-frame hive body above a medium 10-frame hive body (Figure 6). We installed one temperature sensor inside each hive in a standard location: between the outer wall of the upper hive body and the outermost frame, and 3 inches (7.6 cm) below the top of this frame. We chose this location for the sensors so they would be outside the winter cluster, hence would register only the hive's internal temperature. The sensors were linked to the Onset wireless network with temperature data recorded automatically every 30 minutes.

Results

Figure 7 shows three key results: (1) The temperatures inside the occupied hives (insulated and non-insulated) were elevated relative to the temperatures inside their comparable empty cavities (tree cavity and wooden box); (2) the occupied hive protected by the wool blanket showed temperature stability close to that observed in the tree cavity and; (3) the occupied hive *without* the wool blanket experienced temperature fluctuations nearly as wide as in the (empty) wooden box, including a temperature rise to well above ambient. This temperature rise was produced by passive solar warming in the afternoon (see weather inset in box to right of graph).

What Did We Learn?

Study 1: Tree cavity vs. wooden box

This study showed us that there is a vast difference in temperature stability between two empty nest cavities that are identical except that one is in a live tree trunk and the other is in a wooden box. In Figure 4, we see that the temperature variation in the former was minimal (it was rock steady at 31°F [-0.5°C]) and that in the latter it was highly variable (it ranged from 16°F [-9°C] to 36°F [+2°C]). This finding is not surprising, given the marked differences between these two cavities with respect to insulation and thermal mass. But the starkness of the difference reported here does raise questions about the suitability of the homes we give our colonies when we house them in standard, Langstroth hives. Does a colony have better health and survival if it lives in a massive, well-insulated tree cavity than if it lives in a lightly-built, poorly-insulated Langstroth hive? Also, do the nest-site scouts of swarms prefer a thick-walled nest cavity to one that is thin-walled, all else (cavity size, entrance size, etc.) being equal? These are important questions for future studies.

Study 1 also showed us that by simply providing better insulation, we can make a beehive more like a tree cavity, hence more like a natural home of honey bees. When the wooden box was insulated with an R-30 hive blanket, its interior temperature changed more slowly and less widely than when it was without a hive blanket. The temperature recordings for the insulated hive were not, however, as stable as those for the tree cavity. This is because the wool blanket did not provide much thermal mass. Engineers have long known that the best designs for humans' homes utilize both insulation and thermal mass to improve energy efficiency and comfort (Hampton 2010). However, to understand fully the buffering capacity of a live tree, we must go beyond thinking about buildings, and examine what determines the thermal mass of a tree cavity.

Ecologists who have studied tree cavities in northern hardwood forests have found that their temperatures are, as expected, greatly buffered by the thermal mass of their walls (Coder 2010; Coombs et al. 2010). Specifically, the air inside a tree cavity is warmer at night and cooler during the day than the air outside. Furthermore, the air temperature inside an empty tree cavity has more "inertia": It warms up and cools down more slowly than the outside air. But what exactly gives the walls of a tree cavity so much thermal mass? Two things: their thickness, and their water content.

Thickness: Coombs and colleagues (2010) found that tree DBH (diameter at breast height) is the most significant factor affecting cavity temperature. Thick-walled cavities in larger trees warm up slower during the day, and cool down slower during the night than thin-walled cavities in smaller trees.

Water Content: Coombs and colleagues (2010) also found that tree decay is an important factor affecting cavity temperature, with cavities in live trees warming up and cooling

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Fig. 6 *Setup for measuring temperatures inside occupied Langstroth hives, one without insulation and one protected with a wool hive blanket (Beehive Cozy Cover) that covered the upper, deep hive body. Both hives had a south-facing exposure, an entrance reducer, and a moisture box filled with wood shavings above the upper box (to control condensation). The colonies went into winter with similar bee populations, as estimated by counting the number of full frames of bees.*

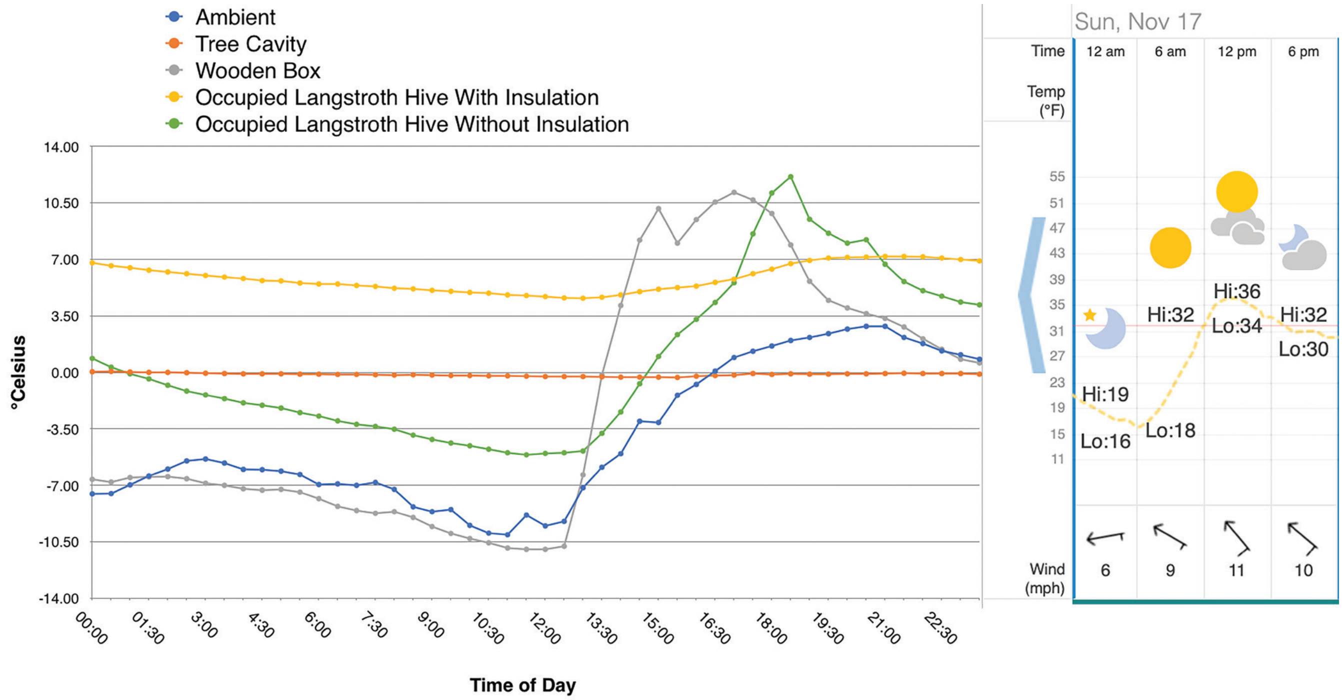

Fig. 7 *Comparisons of temperatures inside a pair of occupied Langstroth hives over a 24-hour period on 17 November 2019. One hive (yellow line) was protected with a wool hive blanket (Beehive Cozy Cover) and the other hive (green line) was not.*

down more slowly than those in dead trees. This is because live wood holds more water than dead wood. Water has a high specific heat capacity, meaning that it absorbs a lot of heat before it gets hot. Most wild colonies occupy cavities in live trees (Seeley and Morse 1976; Radcliffe and Seeley 2018), so most wild colonies experience the moderating effects on nest temperature of being surrounded by heavy, water-laden wood.

Study 2: Occupied Langstroth hive with or without insulation

This study shows us the beneficial effects of providing an R-30 hive blanket around a Langstroth hive. As expected, the temperatures in the air outside the winter cluster were higher and more stable in the hive that was protected by the blanket relative to the hive that was not protected. Figure 7 shows that in the hive *with* the blanket, the temperature outside the cluster was stable; it varied between 39°F (4.0°C) and 45°F (7.0°C). We see, too, that in the hive *without* the blanket, the temperature outside the cluster was below 32°F (0°C) all morning, but in the afternoon, when strong sunlight shone on the hive's bare walls, the temperature inside the hive rose to over 50°F (10°C). This temperature is high enough for a colony to loosen its winter cluster and perhaps shift its position to be closer to combs filled with honey.

What do these findings tell us? Mainly, they show that inside the well-insulated hive, but not inside the poorly-insulated hive, the temperature of the air near the cluster stayed near the temperature at which workers can leave their tight cluster ca. 50°F (10°C), even when ambient temperature was 14°F (-10°C). (For fuller discussions of the effects of hive insulation on how low the ambient temperature can go before a colony needs to form a tight cluster to stay warm, see Mitchell 2016 and Seeley 2019, pp. 227-229.) This means that a colony that is living in a well-insulated Langstroth hive is better able to stay in contact with its honey stores, and so survive winter, relative to a colony that is living in a poorly-insulated Langstroth hive.

More specifically, this means that colonies living in poorly-insulated hives, like the one in this study that did not have the Cozy Cover, rely on sunny days to experience times when the air temperature inside their hives rises enough for workers to leave the winter cluster. Figure 7 shows how this can happen, for it did happen in our poorly-insulated hive late in the afternoon of 17 November 2019. On this day, the temperature in this hive rose to above 50°F (10°C). Evidently, colonies living in cold climates in conventional Langstroth hives depend on having periods of strong sunshine to get refueled, if the winter cluster is not in direct contact with honey-filled cells. This raises the question of how many days of very cold and cloudy weather a colony in an uninsulated Langstroth hive can stay alive if it loses contact with cells containing honey.

If we investigate further the effects of providing additional hive insulation, we will compare the amounts of honey consumed by colonies that go into winter matched in size and condition but are living in well-insulated vs. poorly-insulated hives. It would be good, too, to study the effects of hive insulation on the timing and level of winter brood rearing. Clearly, there is much to learn about the effects of hive insulation and thermal mass on the biology of overwintering colonies.

Conclusions

Our study has two take-home messages. The first is that a basic Langstroth hive (i.e., a wooden box) is a poor substitute for the natural, tree-cavity home of a honey bee colony. This kind of hive is deficient with respect to both insulation and thermal mass. The second message is that a basic Langstroth hive can be made much closer to a natural home for a honey bee colony if its walls are built with, or wrapped in, good insulation. These findings are not startling, but we hope that by sharing them we will encourage the practice of using hives that have thick and well-insulated walls and ceilings.

We encourage beekeepers to use hives for which the insulation values of the walls and ceilings are *at least* R-10 and R-30, respectively (like in a tree). Also, we raise the possibility that providing even higher levels of hive insulation and, when possible, using hives with high thermal mass, will be even better for the health and survival of our bees.

Relevant Literature

Coombs AB, Bowman J and CJ Garroway. 2010. Thermal properties of tree cavities during winter in a northern hardwood forest. *Journal of Wildlife Management* 74(8): 1875-1881.

Hampton A. 2010. Thermal mass and insulation for temperate climates. Environmental Design Guide. EDG 65 AH: 1-11.

Coder KD. 2021. Trees & cold temperatures. University of Georgia, *Warnell School of Forestry & Natural Resources Outreach Publication* WSFNR21-08C. Pp.11.

Mitchell D. 2016. Ratios of colony mass to thermal conductance of tree and man-made nest enclosures of *Apis mellifera*: Implications for survival, clustering, humidity regulation, and *Varroa destructor*. *International Journal of Biometeorology* 60: 629-638.

Mitchell D. 2017. Honey bee engineering: Top ventilation and top entrances. *American Bee Journal* 157: 887-889.

Radcliffe RW and TD Seeley. 2018. Deep forest bee hunting: a novel method for finding wild colonies of honey bees in old-growth forests. *American Bee Journal.* 158(8): 871-877.

Seeley TD. 2019. The Lives of Bees. *Princeton University Press*, Princeton, NJ.

Seeley TD and RA Morse. 1976. The nest of the honey bee (*Apis mellifera L.*). Insectes Sociaux 23: 495-512.

Seeley TD and RA Morse. 1978. Nest site selection by the honey bee. *Insectes Sociaux* 25: 323-337.

Dr. Robin Radcliffe is a wildlife veterinarian at the Cornell University College of Veterinary Medicine. He directs a unique research and training program that connects health and conservation of endangered species with experiential training opportunities for students together with Jane Goodall. In addition to a scientist, Robin is an accomplished children's book author and illustrator, bringing to press a book on Rhinoceroses together with Jane and another featuring lessons from a lifetime of canoe building in his debut children's book biography, *Canoeman Joe*. Robin's fascination with honey bees began when his grandfather built him a beebox and together they followed wild bees across rolling Wisconsin meadows to his first bee tree. Robin and Tom recently teamed-up to follow wild honey bees into deep old growth forests as a prelude to the current study—see the August 2018 issue of the American Bee Journal! Robin lives on an 1890 homestead in Brooktondale, New York.

Dr. Tom Seeley has been watching and keeping honey bees since he was 10 years old, so for more than 50 years. He is now an Emeritus Professor of Neurobiology and Behavior at Cornell University, where he continues his research on the behavior, social life, and ecology of honey bees. At present, his home base is Ithaca, New York, but he aims to move soon to the small town of Pembroke in Downeast Maine.