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SMOOTH-BARK TREES AND BARK TEMPERATURES: GETTING OUR NATURAL HISTORY STORIES CORRECT

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ABSTRACT

A common belief of many hikers and naturalists is that smooth-barked species like *Arbutus menziesii* Pursh (Pacific Madrone, Ericaceae) have bark that is colder than the air temperature. Beliefs like this draw upon specific experiences people have after comparing different species. Natural history has a 'history' of stories like this that sometimes can misinform. The incorrect myths are not usually problematic, but there are instances of natural history myths that can influence policy decisions. The philosophy of science is to test theories and their assumptions; this study tests the pervasive 'fact' that species with especially smooth bark, specifically *Arbutus menziesii* and *Arctostaphylos* Adans. (Ericaceae) species in California, have substantially cooler bark than other species or the air temperature. When tested, however, results showed bark temperature did not differ from air temperatures among species on shaded stems, while on sunny stems temperatures differentially increased based on the relative color of the stem. Two experiments were conducted to test the human perception that smooth bark is cooler than other stems: (1) a test of the hypothesis that bark temperature is caused by xylem water cooling the stem, and (2) a surface-area experiment to test whether the perception is due to thermal conductance from hands to stem. Xylem-water cooling received no support, but surface-contact thermal conductance did. Perceptions of cold bark in smooth-barked species have persisted because only plant processes were considered, rather than the simple physics involved.

Key Words: Bark temperature, bark thickness, natural history myths, Pacific Madrone, plant functional traits, refrigerator tree.

Testing assumptions critical to scientific models is fundamental to science. Scientists often are taught that developing theory and applying it to natural systems usually involves accumulating data and formally inferring theory based on valid assumptions (Hempel 1966). However, models of how natural systems operate frequently are derived without formal development initially from ideas and observations based on experience. Such interpretations have been termed 'notions' (Pickett et al. 2007) and are considered pre-theoretic. When these notions seem obvious and supported by logic or experience, they may not be formally developed and tested for validity. Environmental management actions often are based initially on models that result from such observations and intuitive judgements. When these models are relatively accurate then management impacts on our ecosystems do not substantially shift the sustainability of the system; when untested models have unintended impacts, they can degrade the ecosystem in which they are being applied. The evolution of pre-theoretic observations into hypotheses or theories is a common development in ecology and testing often lags policy implementation. Assumptions provide the logical structure for models, and they represent the explicit presumptions about the nature of the system of interest, they justify the structure and content of the model (Lewis 1986; Lloyd 1987; Pickett et al. 2007). Testing the assumptions is the first and crucial step in developing credibility for such models (Hempel 1966; Lewis 1986; Lloyd 1987). The objective of this paper is to illustrate how a natural history narrative featuring counterintuitive data and reliance on experience and intuition can be misleading without formalizing and testing the assumptions of models.

Madrone trees (*Arbutus menziesii* Pursh, Ericaceae) are remarkable in Pacific coast mixed evergreen forests because of their orange-red bark in a community of otherwise gray tree trunks. The bark is also quite smooth in contrast to other neighboring species. A natural history story has evolved around Madrones that their bark is much cooler than other species (The New York Botanic Garden 2014; Martin 2022; The Pine Ridge Association 2022). If you place your hand flat onto the smooth Madrone bark after similarly touching the bark of other species, you will agree that the Madrone bark does feel colder. That becomes an experiential data point, and as a singularly unusual event, will be remembered and spread to others.

Although the cold bark of *Arbutus* seems a minor story, it is the same process of developing assumptions and policy without testing that occurs when science and other fields overlap. One example has been the persistent view that woody plants degrade grasslands. In California, one destructive example was that isolated Blue Oaks (*Quercus douglasii* Hook. & Arn.) inhibit grassland production and need to be cut down or killed to improve cattle pasture (Johnson et al. 1959; Murphy and Crampton 1964; Kay and Leonard 1980). This was based on the belief that shade and competition for nutrients reduce grassland

FIG. 1. Freshly peeling bark of *Arbutus menziesii* (left) and *Arctostaphylos insularis* Greene ex Parry (right) showing the green, chlorophyll rich new bark beneath. Photos by V. T. Parker.

productivity. But it turns out isolated savanna trees increase soil minerals and soil moisture in California (Parker and Muller 1982; Parker and Billow 1987; Callaway and Nadkarni 1991), and grass productivity is either greater beneath (Holland 1973, 1980; Bartolome et al. 1994) or is more dependent on particular site conditions (Kay 1987; Callaway et al. 1991; Connor and Willoughby 1997).

The bias against woody plants in grasslands used for pasture occurs in other countries as well. In Australia the invaders were woody shrubs, and like the Blue Oak story, subsequent research indicated that shrub invasion of grasslands did not degrade those ecosystems as thought but often enhanced mineral cycling or other soil conditions (Eldridge and Soliveres 2014; Ding and Eldridge 2023).

Other California examples include forest models for fire management being inappropriately applied to chaparral ecosystems. Consequently, fire managers and the media frequently describe chaparral as overgrown or uncontrolled due to fire suppression and requiring 'fuel' management to prevent unnaturally severe fires. As applied to biodiverse chaparral ecosystems, these assumptions are inaccurate, and this type of management of chaparral generally degrades the vegetation and ironically increases the chances of ignition due to annual grass invasion (e.g., Keeley et al. 1999, 2004; Moritz et al. 2004; Keeley and Syphard 2019). In chaparral systems the focus really needs to be on human structures (Cohen and Saveland 1997; Cohen 2000; Syphard et al. 2021). In these above examples, research results are often in conflict with public perceptions and policy. Acceptable management resolutions often take considerable time due to different approaches or counterintuitive data.

The perception of Madrone bark being cold to the touch is not likely to encourage some inappropriate management policy, but it provides a 'model' of how poor policies can be generated. Exploring why bark is perceived as cooler arises within the context of a growing interest with understanding the ecological functions associated with various bark traits (e.g., Niklas 1999; Pausas 2015; Rosell 2016). One recent argument, for example, is that bark is a fire adaptation. In fire-prone habitats either thick bark is selected to withstand heat, or thin-barked species like *A. menziesii* would sprout post-fire (Beadle 1940; Pausas 2015). Alternatively, others have argued that thick bark can be selected to protect trees from insect attacks, such as by beetles (Boland and Woodward 2021; Takei et al. 2021), whereas thin, frequently peeling bark is a method to rid plants of parasites and epiphytes (Nicolai 1986; Wyse and Burns 2011; Ferrenberg and Mitton 2014).

The evolution of bark traits, of course, can be driven by multiple adaptive alternatives, and species have a considerable and frequently complex history. Species with thin bark often have inner bark that carries out photosynthesis (Pfanz 2008; Wittmann and Pfanz 2007). That appears to be the case for *Arbutus menziesii* and for *Arctostaphylos* Adans. (Ericaceae) species (Fig. 1). In California, the thin bark peels off from the late growing season in early summer to early fall in both genera revealing new bark that is green with chlorophyll; eventually the orangish-reddish color returns. The seasonal timing is opportune for California plants because some research indicates that bark photosynthesis can not only contribute to stem growth but can also increase drought tolerance (Cernusak and Hutley 2011; Cernusak and Cheesman 2015).

In this context, correctly interpreting the significance and basis of bark conditions is important. When I touch the bark of *Arbutus menziesii*, I do perceive it as colder than bark of other trees. Madrone has been referred to as the "refrigerator tree" because of that perception (e.g., Martin 2022). But this contrasts with results of studies of other tree species, including smooth, thin-barked species like *Populus tremuloides* Michx. (Salicaceae), whose bark in shaded conditions comes into equilibrium with air temperatures (Harvey 1923; Derby and Gates 1966; Nicolai 1986; Sheppard et al. 2016). *Arbutus menziesii* actually would be quite unusual if the bark is colder that the air temperature.

Two processes have been proposed to explain the perceived coolness of *Arbutus* bark. One proposed mechanism for the apparent bark temperature disparity of *Arbutus* versus other trees suggests the bark is thin enough that you can feel cold water pulled from deep within the soil flowing through the xylem, the vascular tissue of the tree beneath the bark (Martin 2022). Water pulled from the soil should be colder than above-ground temperatures due to the insulating capability and the lag time of heat flow in soil, especially in closed-canopy forests with little solar radiation reaching the soil surface (Gates 1980; Campbell and Norman 1998). Because the bark is particularly smooth, an alternative hypothesis is simply that our hands contact the surface of *Arbutus* to a greater extent than bark of other species, resulting in a more rapid heat exchange and thus the perception of the bark feeling colder. This hypothesis results from the law of heat conduction, Fourier's law, that describes heat flow between two bodies as resulting from thermal conductivity, the total surface area in contact, and the temperature gradient (Hahn and Özişik 2012). Simply, Fourier's law states that the rate of heat transfer is proportional to the area through which the heat flows at right angles to a temperature gradient. Consequently, the smoother the bark, the greater the surface area in contact between a warm hand and the cooler bark, and the temperature gradient would be the body temperature versus the bark temperature. Here I test these two hypotheses.

METHODS

Field Site

The area around the east peak of Mt. Tamalpais, Marin County, CA, USA, was used for the field study portion (centered on 37.927307, −122.580053). Downslope on the south-facing side occurs a chaparral dominated by shrubs such as *Arctostaphylos canescens* Eastw. (Ericaceae), *A. glandulosa* Eastw. (Ericaceae), *Quercus wislizeni* A.DC. (Fagaceae), and *Adenostoma fasciculatum* Hook. & Arn. (Rosaceae), with a few other taxa. The north-facing side is a mixed evergreen forest dominated by *Umbellularia californica* (Hook. & Arn.) Nutt. (Lauraceae), *Pseudotsuga menziesii* (Mirb.) Franco (Pinaceae), *Quercus chrysolepis* Liebm. (Fagaceae), *Quercus wislizeni, Torreya californica* Torr. (Taxaceae), and *Arbutus menziesii*. The shrubs all have thin bark and stem diameters varied from 5–12 cm on stems used for temperature measurements. The two *Arctostaphylos* species have remarkably smooth, orange-red bark, while *Q. wislizeni* has relatively smooth gray bark, and *A. fasciculatum* has thin, gray, shreddy bark. The forest species were all mature and stem diameters were 15–25 cm for *T. californica*, 15–30 cm for *U. californica, Q. chrysolepis, A. menziesii*, and 25–50 cm for *P. menziesii* on individuals used for temperature measurements. Moderately thin, grayish bark was found on *U. californica* and *Quercus* species (0.3–4 cm); *A. menziesii* expressed both extremely smooth, thin, orange-reddish bark along with areas of rougher, thicker gray bark (∼1–2 cm) generally at the base; *T. californica* had thin, shreddy, gray bark (<0.5 cm); while *P. menziesii* had quite thick grayish-brown, deeply fissured bark in the larger individuals (∼3–5 cm on high parts).

Bark Temperatures

If *Arbutus* bark is cooler than other species, it should be measurable in the field. The field site was visited three times, 25 April 2022, 14 June 2022, and 14 October 2022; measurements were taken between 10 a.m. to 2 p.m. on each date. Air temperatures in the shade were measured with a digital thermometer (Habor model CP022A, Habor Precision Inc., Taichung, Taiwan), while bark temperatures were measured with an infrared thermometer (Etekcity 800 Lasergrip, Vesync Co., Ltd., Shenzhen, China). Bark temperatures were measured on shrubs between 1.0–1.5 m height, while temperatures were measured on trees between 1.0–2.0 m. Measurements were replicated 15–25 times. Air temperatures were taken at the same time paired with each bark measurement. For both *Arctostaphylos* and *Arbutus*, the bark is smooth in places and rough in other places and both were measured; in *Arctostaphylos* the rough areas are sites of bark dieback (bark striping), and in *Arbutus* they are sites of rough, gray bark forming.

Xylem Experiment

If xylem is cooling the bark, bark temperatures should be cooler than the air on a warm day, and cooler than similarly colored pieces of wood in the same conditions. As in the experiment above, air temperatures were taken with a digital thermometer and surface temperatures with an infrared thermometer. On a cloudless day, 11 May 2023, with air temperatures between 20–25°C, temperatures were taken of *Arbutus* bark on stems 18–20 cm in diameter, in both the shade and sun, as well as on wood patches painted different colors. A 1 × 12 × 120 cm piece of clear oak without blemishes was sanded smooth and on which 10 × 12 cm patches of different colors were painted. Craft Smart® Acrylic Paints (Michael's Stores Procurement Company, Irving, TX) were used to create the following color patches: white (white); gray (8:1, gray to white); red (7:1:1 bright red to orange to white); orange (6:1 orange to white), and light orange (3:1 orange to white). The wood was placed at 1.5 m elevation either facing the

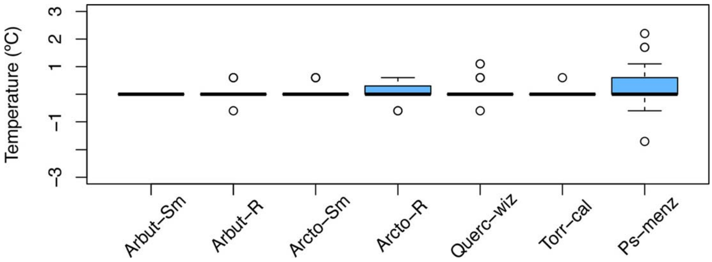

FIG. 2. Bark temperatures on the shaded side of stems from 0.5–1.5 m above the surface on 25 April 2022. Temperatures are represented as bark temperature minus air temperature. Arbut-Sm = *Arbutus menziesii* smooth bark; Arbut-R = *Arbutus menziesii* rough bark; Arcto-Sm = *Arctostaphylos* smooth bark; Arcto-R = *Arctostaphylos* rough bark; Querc-wiz = *Quercus wislizeni*; Torr-cal = *Torreya californica*; Ps-menz = *Pseudotsuga menziesii*. No species or bark type is statistically different from any other.

sun or in the shade of the *Arbutus*. Temperature measurements of *Arbutus* bark were followed by measurements of each colored patch taken sequentially over a roughly 20 min period (n = 12), first set in the shade, and then a set in the sun. Air temperatures in the shade were taken between each measurement.

Heat Transfer Experiment

The perception of cooler stems may be due to greater surface contact by a human hand. This was demonstrated by assessing heat transfer from a warm object to a cooler object. A 1 × 12 × 90 cm piece of clear oak was sanded smooth. Four 10 × 12 cm patches were marked and spaced 10–12 cm apart, then randomly assigned a treatment. Each patch was divided into 12 one-cm wide strips. Within each strip, 0, 20, 40, and 60 percent of the surface wood was removed lengthwise using wood carving tools (Augsun US, San Diego, CA) creating 2–3 mm deep grooves. A 1 liter Qinline PEVA bag (polyethylene-vinyl acetate) (Q-inline Co USA, Houston, TX) was filled with 250 ml of water. A large container of water was heated to 80–90°C and held at that temperature. The water bag was immersed for 10–15 sec until it was heated to ∼60°C, then dried and permitted to cool to 50°C using an infrared thermometer to measure temperature. The heated bag was then placed to cover one of the wood patches for 30 sec, removed, and the upper wood surface temperature immediately recorded. This process was repeated (n = 10) for each of the treatment surface patches. Temperatures were measured using an infrared thermometer.

Statistical Analyses

Multiple sample types for temperature were analyzed using ANOVA, and the Tukey Test was used to determine which pairs of samples were statistically different for the field temperature and xylem temperature transfer. The surface temperature transfer experiment used linear analyses to assess the relationship between percent surface area and temperature transfer. All statistical analyses were conducted in R (R Core Team, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Bark Temperatures

Bark temperatures on the shaded side of both shrub and tree trunks were statistically the same as air temperature (Fig. 2) (April: $F_{6,133} = 1.058$, $P > 0.391$). The data in Figure 2 are presented as the difference of bark temperature from the paired air temperature ($T_{bark} - T_{air}$); (positive values mean the bark was warmer than air, negative values mean the bark was cooler when measured). While seasonally the air temperatures became warmer, statistically results were the same in June and October (Parker, unpublished data). Stems in the sun varied considerably in temperature but were warmer than shaded stems and positively correlated with how dark the color of the stem was, and the size and duration of sun flecks (data not shown).

Xylem Experiment

In the sun (Fig. 3A), there were significant differences between all the treatments and the air, as well as among treatments (ANOVA, $F_{6,\,65} = 170.1$, $P < 0.0001$). By a Tukey test, among paired treatments, the only ones not significantly different were *Arbutus* bark versus the wood painted either light orange ($P = 0.987$) or white ($P = 0.657$), orange versus gray ($P = 0.99$), and light orange versus white ($P = 0.335$). Thus, in the sun, *Arbutus* bark was statistically the same as wood painted a light color, specifically light orange (like the bark) and white. All other pairs were different at least at $P = 0.0006$ or better. In the shade (Fig. 3B), there were no significant statistical differences in temperatures for *Arbutus* bark versus the shade air temperature, nor those of any color painted on the piece of wood (ANOVA, $F_{6,93} = 0.561$, $P = 0.76$). There were no differences between any paired treatments by a Tukey test.

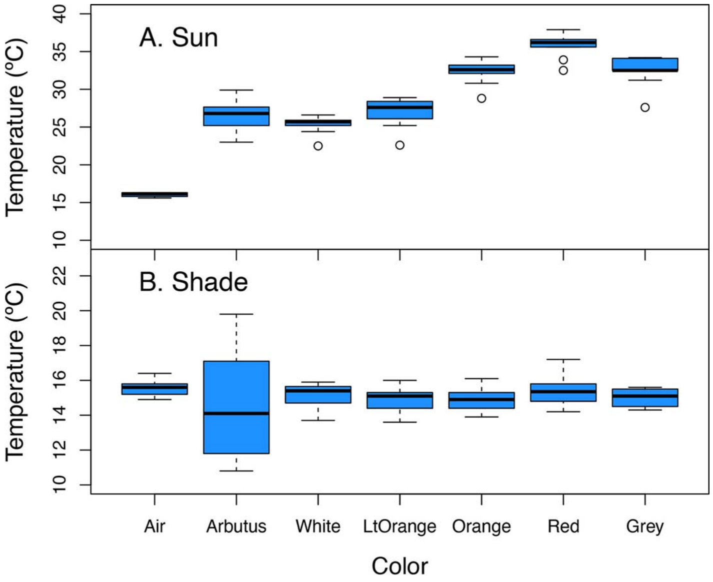

FIG. 3. Comparing surface temperatures of *Arbutus* bark and color-painted areas on wood in both sun and shade. A. Temperatures taken in the sun or sunny places of the bark of *Arbutus* and color-painted patches of wood, air temperatures from shade; B. Temperatures taken in the shade of *Arbutus* bark and color-patches of wood.

Surface Heat Transfer Experiment

In this experiment, the greater the contact area, the greater the heat conductance to the wood surface (Fig. 4) ($F_{1,46} = 139.5$, $P < 0.0001$, adj $R^2 = 0.75$). In this circumstance, temperature increased by conduction 0.105°C linearly for every percent of increased surface area, or 2.095°C for each 20 percent increment under the experimental conditions.

DISCUSSION

The concept that *Arbutus menziesii* has colder bark than other coexisting tree species is not supported by the data. Thin-barked species like *Arbutus menziesii* and *Arctostaphylos* species do not have bark temperatures different from other trees or the air; all the shaded surfaces are in equilibrium with the air temperature like other tree species (Harvey 1923; Derby and Gates 1966; Sakai 1966; Nicolai 1986; Sheppard et al. 2016). If the colder bark was due to underlying cold xylem water transport, bark surface temperatures should have been cooler than warmer air temperatures and remain that way throughout the day. In fact, the bark equilibrates with air temperature in shade, and painted patches on wood the same color as *Arbutus* can match temperatures of *Arbutus* bark in both sun and shade conditions, indicating no cooling of *Arbutus* bark by xylem water. Instead, the smoothness of the bark simply permits more rapid heat transfer from warm hands to cooler stems, an example of Fourier's law of thermal conductivity by surface area contact. This was supported by the experiment varying surface area and determining rates of heat transfer, which occurred proportionately to surface area as would be expected when other factors were kept constant. Rougher bark is not a good surface to rapidly absorb body heat.

The case of Madrone bark illustrates that our perceptions can lead us to be confident we can interpret accurately, only to realize after testing that our interpretation is mistaken. These results indicate that the natural history stories associated with *Arbutus menziesii* bark, as well as with other very smooth-barked plants like *Arctostaphylos* species, are misinformed. This does not change the fact that when we touch the bark of madrone it really does feel cooler to us. It is just as significant, perhaps even more so, to have people touch the bark, marvel at the coolness, and then tell them that it is the same temperature as the Douglas-Fir (*Pseudotsuga menziesii*) or Tanbark Oak (*Notholithocarpus densiflorus*) next to it. That counterintuitive story is even more powerful. Natural history myths are significant parts of human history and in many cases are representative of historic events, modified through time to change dramatic geological, meteorological, or biological occurrences to something else both memorable and part of the human worldview at the time. This study's intention is not to remove creative interpretations of nature, as that often stimulates interest in natural history. Instead, this study's intention is to reawaken the critical side of our curiosity and as scientists to challenge perceptions and assumptions.

We expect these perceptions of nature to be accurate after we are trained as scientists or are experienced naturalists, and we strive to find accurate bases for these perceptions. Sometimes we encounter

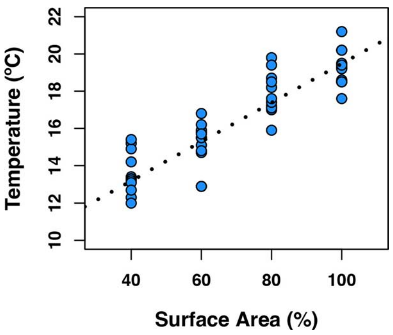

FIG. 4. Temperature of different sections of a smooth piece of wood following heat transferred from heated water bag. The data represent heat transferred to sections of 100, 80, 60, and 40 percent surface contact area. This is a simple and crude demonstration of thermal contact conductance.

situations we are confident we can interpret correctly, but wrongly do so. In this case, we tend to interpret the perception of cool bark based on our botanical knowledge, when it turns out that our knowledge of physics would have been more relevant. These types of stories ultimately may become natural history myths. But a more proper term is misinformation, and misinformation can lead to failed hypotheses or theories, inaccurate models of how natural systems work, and ultimately poor actions and policies. The case of the "refrigerator tree" is merely a relatively harmless, but instructive, example. Scientists are successful in the long run only if they constantly question their models and the assumptions supporting those models. As noted almost a century ago, "Misinformation is even worse than ignorance." (Shinn 1925).

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