Evaluation of an Easy-to-Install, Low-Cost Dendrometer Band for Citizen-Science Tree Research

Michael G. Just and Steven D. Frank

Michael G. Just (mjust@ncsu.edu) and Steven D. Frank (sdfrank@ncsu.edu), Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, NC 27695.

Abstract
Tree-stem growth is an important metric for evaluating many ecological and silvicultural research questions. However, answering these questions may require monitoring growth on many individual trees that span changing environments and geographies, which can incur significant costs. Recently, citizen science has been successfully employed as a cost-effective approach to collect data for large-scale projects that also increases scientific awareness. Still, citizen-science-led tree-growth monitoring requires the use of tools that are affordable, understandable, and accurate. Here, we compare an inexpensive, easy-to-install dendrometer band to two other bands that are more expensive with more complex installations. We installed a series of three dendrometers on 31 red maples (Acer rubrum) in two urban areas in the eastern United States. We found that the stem-growth measurements reported by these dendrometers were highly correlated and, thus, validate the utility of the inexpensive band.

Keywords: Acer rubrum, Public Participation in Scientific Research, forest measurement, monitoring

Radial stem growth is a common response variable in forestry and ecological tree research, as it is related to tree health, yield, and ecosystem functioning (Way and Oren 2010, Yoon et al. 2013, Chojnacky et al. 2014). Consequently, the method used to monitor stem growth is important, and there are myriad tools and methods to do so (e.g., contact and optical dendrometers, LIDAR). Some of the most common hand tools to measure stem growth are contact dendrometers, including diameter tapes, calipers, and dendrometer bands, each with its own advantages and disadvantages related to precision (Drew and Downes 2009), accuracy (Keeland and Sharitz 1993, Moran and Williams 2002), expense (labor and materials) (Carvalho and Felfili 2011), and user expertise (Anemaet and Middleton 2013). For example, a dendrometer band typically consists of a metal strap that is affixed around a tree stem using a spring fastener. The spring-fastened design allows the dendrometer band to expand or contract with the tree while maintaining its position on the stem relative to the ground. For repeated, long-term monitoring on the same tree, dendrometer bands may provide advantages over diameter tapes and calipers, since they continuously measure the same location on the stem, avoiding measurement errors that may occur when periodic measurements are made at mislocated stem positions (Cattelino et al. 1986).

Monitoring changes in stem diameter on many individual trees is often the preferred approach to reach robust conclusions about tree-growth questions. Considerable expenses may accrue when many contact dendrometers are required. In addition to the expense of the dendrometer itself, there are expenses related to installation and monitoring, and travel for studies.
covering large geographic areas. Fortunately, for some projects, these costs can be reduced through citizen-science data collection or monitoring. Citizen science enlists volunteers to contribute to scientific studies, including data collection, and has made some studies logistically and economically possible by reducing costs (Roman et al. 2017, Ryan et al. 2018). It has also proven to be a successful way to develop a large-scale ecological monitoring network (Taylor et al. 2014, Kullenberg and Kasperowski 2016, Ballard et al. 2017). Moreover, citizen science provides an opportunity to engage community members in the scientific process.

We recently developed and launched a citizen-science research project, A Tree’s Life (http://ecoipm.org/a-trees-life/), which aims to obtain a better understanding of how climate and urbanization affect tree growth and health, and, thus, ecosystem services, including carbon sequestration. Despite the many important roles that trees occupy in our ecosystems, information on the effects of warming and urbanization on adult tree growth is lacking; these measurements are necessary to assess the effects of global change on trees and tree-provided services. To this end, A Tree’s Life enables citizen scientists to monitor the annual radial stem growth of a red maple (Acer rubrum L.)—one of the most common street trees in the eastern United States (Raupp et al. 2006)—in their yards over the course of several years. To date, we have enrolled citizen scientists from 33 states and three Canadian provinces with the majority of the participants in the southeastern United States. However, given the unknown and potentially wide range of participant expertise and the great number of trees to monitor, the project needed to balance the accuracy of stem growth monitoring with deployment costs and ease of volunteer participation. Accordingly, our objective was to evaluate the performance of a commercial, yet inexpensive and easy-to-install dendrometer band and compare it to two other more expensive dendrometer bands with more complex installations.

### Materials and Methods

We monitored stem growth for a 15-month period (October 2017 to January 2018) on 31 red maple, a common eastern United States tree in both planted and natural settings (Abrams 1998, Nowak and Greenfield 2018). We selected study individuals from two locations, Raleigh, NC (n = 17) and the Newark, DE–Philadelphia, PA urban corridor (n = 14). We selected red maple individuals from 18 urban forest fragments (Raleigh, n = 8; Newark–Philadelphia, n = 10) within the Forest Fragments in Managed Ecosystems (FRAME) research network (Dunn et al. 2016). The initial mean diameter at breast height (dbh) of the study trees was 8.57 in. ±0.37 (21.76 cm ± 0.93; SEM), with a range of 5.51–13.07 in. (14.00–33.2 cm). Trees selected for this study were generally free of externally visible defects or injuries.

To monitor stem growth, we installed three dendrometer bands (Figure 1) on each tree: (1) a commercial precision dendrometer band (Series 5 Manual Band Dendrometer, Agricultural Electronics Corp., Tucson, AZ), (2) a self-fabricated (DIY) dendrometer band, and
(3) a commercial plastic dendrometer band (Tree Band, CJT & Assoc., Mount Enterprise, TX). The precision dendrometer band had a 0.13-in.-wide (0.32-cm-wide) stainless-steel strap that attached to a brass housing consisting of a hinge, spring, and Vernier scale. The brass housing was attached to the tree with two stainless-steel bolts anchored 1.2 in. (3.0 cm) into the tree stem. With the Vernier scale, the precision dendrometer band reported stem-diameter growth to the nearest 0.004 in. (0.01 cm). The precision dendrometer band recorded up to ~1.2 in. (3.0 cm) of stem-diameter growth before needing to be reset. The DIY dendrometer band was constructed from 0.5-in.-wide (1.27-cm-wide) stainless-steel embossing tape and a stainless-steel spring following the designs of Keeland and Young (2015). The DIY dendrometer band was marked with an awl after installation to indicate tree starting diameter, and growth was recorded with a digital caliper. The plastic dendrometer band consisted of a plastic strap and a metal spring, and the strap was printed with a scale that reported the diameter of the stem in inches.

For each study red maple, the first dendrometer band was installed at breast height (bh; 4.5 ft [1.37 m] above the ground). The second dendrometer band was installed above the first, and the third, below. Dendrometer bands were installed as closely together as possible, and dendrometer band order was random. We installed the dendrometer bands on the study trees without surface preparation, that is, we did not smooth the outer bark or otherwise alter the circumference of the tree. We chose this installation method, as it did not require specialized tools (e.g., bark scraper) or other expertise (e.g., bark smoothness estimations). Thus, it reduced possible barriers to participation for citizen scientists with varying degrees of forestry acumen. After installation, we allowed the dendrometer bands to settle for one month before recording our initial measurements. Fifteen months after installation, we visited each tree and recorded stem growth as reported by each of the dendrometer bands.

All statistical analyses were performed in R 3.5.1 (R Core Team 2018). We used a correlation analysis to compare the association of recorded growth between pairings of each of the dendrometer bands. The red maple stem growth data did not meet the assumptions of normality (R package stats, function shapiro.test), thus, we used Spearman’s ρ rank correlation statistic. We also compared the correlations between Raleigh and Newark–Philadelphia for differences using the Fisher “r-to-z” transformation (Fisher 1921). We used linear regression to test for an effect of initial dbh on the correlations between dendrometer band pairings but did not find dbh to be a significant covariate (P > .05). Additionally, we tested for an effect of band position (i.e., top, middle, bottom) but did not find band position to have a significant effect on the association of recorded growth.

**Results and Discussion**

We examined the utility of a low-cost, easy-to-install plastic dendrometer band as compared to two other
bands that were more expensive and complicated to install. We found stem-diameter growth to be highly correlated between each dendrometer band pairing ($\rho \geq 0.914$; Table 1, Figure 2). We also found that the associations did not differ between any of the pairings between cities (Table 1). The mean, 15-month radial stem growth for our study trees was 0.118 ± 0.02 in. (0.299 ± 0.05 cm), 0.121 ± 0.02 in. (0.307 ± 0.06 cm), and 0.091 ± 0.02 in. (0.230 ± 0.05 cm), as recorded by the precision, DIY, and plastic dendrometer bands, respectively. Averaging across dendrometer bands, Raleigh mean stem diameter growth was 0.137 ± 0.02 in. (0.349 ± 0.04 cm) and for Newark–Philadelphia 0.076 ± 0.02 in. (0.194 ± 0.05 cm).

Understanding or identifying the environmental factors that affect tree growth is a goal of many ecological or forestry research questions. Acquiring sufficient data to resolve these questions comes down to balancing the costs of data acquisition and data accuracy (Clark et al. 2000). For some tree-growth studies, especially those encompassing large geographies, citizen-science projects may provide an opportunity to collect sufficient data with a limited budget while balancing accuracy and cost (Clark et al. 2000).

### Table 1. Spearman’s rank correlation statistic ($\rho$) values for each dendrometer pairing (Plastic = commercial plastic, Precision = commercial precision, DIY = self-fabricated) with adjusted 95 percent CI for $\rho$.

<table>
<thead>
<tr>
<th>Dendrometer pair</th>
<th>Spearman’s $\rho$</th>
<th>Adjusted 95 percent CI</th>
<th>Raleigh versus Newark/Philadelphia (z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic–Precision</td>
<td>0.945*</td>
<td>0.87, 0.98</td>
<td>0.18 ns</td>
</tr>
<tr>
<td>Plastic–DIY</td>
<td>0.934*</td>
<td>0.85, 0.97</td>
<td>–1.67 ns</td>
</tr>
<tr>
<td>Precision–DIY</td>
<td>0.914*</td>
<td>0.83, 0.96</td>
<td>–0.26 ns</td>
</tr>
</tbody>
</table>

Note: Raleigh versus Newark reports the z-values based on Fisher’s $\rho$-to-z transformation to compare $\rho$ for each dendrometer pairing between study locations.

* $P < .001$, ns = not significant ($P \geq .05$).

### Figure 2. Scatterplots and Spearman's rank correlation statistic ($\rho$) values for each contact dendrometer band pairing by city (Newark/Philadelphia = green, Raleigh = purple, overall correlation = black). Density plots (on the diagonal) are also presented for each dendrometer band by city.

Conclusions

Dendrometer bands provide accurate measurements of tree stem growth at yearly intervals (Carvalho and Felfili 2011), so choosing the least expensive band that accurately captures yearly growth is the likely objective when selecting a band. In our study, we found that each of these bands reported stem growth that was highly correlated. Thus, of the bands we studied, we contend that the plastic...
band was the best for citizen science or other large-scale projects that measure growth on annual or longer basis. For example, the plastic band was less expensive (~US$2) than the DIY (~US$3, not including labor) or precision bands (~US$45). Moreover, the plastic band was the easiest to install, requiring no tools. The DIY band, constructed from stainless steel embossing tape, required metal-specific tools (e.g., shears, metal-punch), and care (metal strap edges can be sharp), and the precision band required tools to install bolts into the tree stem, which may also damage the tree (Carvalho and Felfili 2011). Finally, the plastic band included a preprinted ruler that allowed for participants to easily monitor and, thus, report the growth of their tree, whereas the DIY band required calipers, and the precision band required the ability to read a Vernier scale. However, as is, the plastic dendrometer band will only work on trees between 6.0 and 12.0 in. (15.2 and 30.5 cm) in diameter. For example, this constraint affected <10 percent of potential volunteers interested in the A Tree’s Life project. Our results demonstrate that this low-cost dendrometer band is an appropriate and competitive choice for projects that include many trees and installers, such as citizen-science monitoring projects.

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Literature Cited


