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REVIEW

Review of rope-based access methods for the forest canopy: safe and unsafe practices in published information sources and a summary of current methods

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Summary

1. The availability of reliable information on tree climbing methods is critical for the development of canopy science and for the safety of workers accessing the forest canopy.

2. To assess the breadth and quality of information contained in published climbing information, we performed searches in Web of Science and Google Scholar and evaluated 54 published sources on 10 predetermined criteria related to safety.

3. We found a high incidence of unsafe recommendations that, if followed, could result in serious injury or death. Common errors included recommendations for equipment not suitable for tree climbing, advocating methods suitable for rock climbing but that can result in falls and trauma in tree climbing, and outdated information that no longer reflects best practices.

4. We conclude by providing safety recommendations and a short review of tree climbing methods. This article thus serves as a guide for finding and interpreting best sources of methods for canopy access.

Key-words: ANSI Z133.1, best practices, forest canopy access, safety, tree climbing

Introduction

The canopy is an essential component in the functioning of forest ecosystems and a major source of biodiversity, yet has remained understudied due to the difficulty of access or observation into upper reaches of the forest (Lowman & Rinker 2004). Rope-based methods provide unbiased and replicated sampling of canopy organisms including epiphytes (Nadkarni 1981; Sillett 1995), birds (Anderson 2009), reptiles (Dial & Roughgarden 1995), rodents (Swingle & Forsman 2009) and tree growth and structure (Sillett & Van Pelt 2007), but climbing and working at height are inherently dangerous, and accidents can result in serious injury or death (Centers for Disease Control & Prevention 2014).

The published literature is an important source of information on climbing methods for canopy ecologists. Since Perry (1978) first published on methods of access into forest canopies, the very science of canopy ecology has evolved at a dramatic pace, and published sources of information on canopy access have grown from one to dozens. Over this same time period, canopy access methods have continued to progress with advances in technology and the development of new climbing equipment. Further, as climbing equipment and methods continue to change, so do best practices for climbing safety. Partly for these reasons, published sources vary widely in the breadth of climbing methods described and in their adherence to best safety practices. This variability in breadth of content and adherence to modern safety practices creates a dual challenge for would-be climbers and canopy scientists: how to identify sources of information and equipment that best suit their needs, and distinguishing safe from unsafe methods that are often contradictory from one source to another.

The purpose of this study was to meet that challenge. It is written to help climbers find published sources with content most suitable to their needs, and to clearly distinguish safe from unsafe practices. This review and commentary are based on >80 years of combined climbing experience in the arboriculture industry as professional arborists and tree climbing trainers (BF, JL, SRA, WK), and 15 years as a biologist working in forest canopies (DLA). We focus on canopy access methods that are rope-based, because rope-based methods are relatively inexpensive and widely available, portable, and therefore provide frequent and easily replicated access to sites in the forest canopy. Thus, the topics of canopy cranes (Walther 2003), canopy walkways (Lowman & Bouricius 1995) and hot air balloons (Lowman, Moffett & Rinker 1993) are not discussed herein although all have been used to access forest canopies. Finally, we follow guidelines written by the American National Standards Institute (ANSI 2012) as our benchmark for best practices and current safety standards in tree climbing.

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Before proceeding, one basic tenet of climbing must be clarified that is central to safety and underlies much of the current review: tree climbing and rock climbing (or, more broadly, mountaineering) are related but not equivalent disciplines and differ in fundamental ways. Rock climbing technique typically consists of a 2-person system in which a climber's motion derives from scrambling across a substrate, installing anchor points in succession through which the climbing rope passes and then climbing above the anchors until new ones are installed. Movements are not dependent on the rope; instead, the non-tensioned rope passes through the anchor points, and the trailing end is held by the second person who belays the rope to the climber. The entire system is designed to arrest the fall of a person climbing above the last anchor point (Eng 2010). In contrast, tree climbing is a 1-person system in which an anchor is first installed above the climber, and the climber then hangs from a tensioned rope that passes through the anchor, depending on the rope for movement into and positioning within the tree. Contact with the substrate is not required, no belay is used, and the system is not designed to protect the climber from a dynamic fall (Jepson 2000; Coffey & Andersen 2012). Hence, the two systems can be described as a dynamic or fall arrest system (mountaineering) and a work-positioning system or tensioned system (tree climbing). This is not a minor philosophical point based on aesthetics or personal preference. Inherent differences in the climbing systems create different physical forces on ropes, substrates and climbers and dictate the use of different types of equipment. Ultimately, the improper use of mountaineering equipment and methods for tree climbing can result in serious injury or death (Smith & Padgett 1996; Kane 2011; ANSI 2012; Coffey & Andersen 2012).

Methods

SOURCES OF INFORMATION

We performed searches in Web of Science and Google Scholar using the search string 'canopy access' (downloaded 2 January 2014). After performing all searches, we conducted a careful revision of the reference sections of each source to obtain additional publications. Finally, we conducted a forward search in Web of Science from all references. We limited our searches *a priori* to peer-reviewed journals and published books, and we therefore exclude from this review popular articles in trade journals and industry magazines.

We next obtained a citation history of all sources from Google Scholar inasmuch as this serves as an index of a source's visibility to climbers (i.e. a climber is more likely to encounter a source that is cited more often). We then evaluated breadth of content by noting whether each source presented information on five primary climbing methods or topics: safety, climbing spurs, single rope technique (SRT), doubled rope technique (DdRT) and aerial traverse.

To evaluate content quality and to rank sources by adherence to modern safety standards, we established 10 review criteria (Table 1) and evaluated all sources based on these criteria. Criteria were further grouped into two categories based on their deviation from best practices: minor safety deviations (references that could expose a climber to unnecessary risks; $n = 5$) and major safety deviations (recommendations that, if followed, could result in serious injury or death; $n = 5$). To evaluate sources, two of us (BF and WK) independently read every

Table 1. Ten criteria used to evaluate safety standards in published sources on canopy access methods. Number of occurrences that each criterion was observed in all sources and number of sources that fulfilled a given criterion are given

Evaluation criteria	Level of safety deviation*	Criterion number	Total occurrences	No. of sources
Proposes equipment options that are inappropriate for tree climbing	Minor	1	27	11
Outdated information or methods no longer reflects best practices	Minor	2	37	16
Mentions a need for instruction, but does not specify experienced tree climbers	Minor	3	10	7
Blurs the distinction between fall arrest systems and work-positioning systems appropriate for trees	Minor	4	12	7
Vague and unclear writing (i.e. even an experienced climber cannot interpret, or methods named but not described)	Minor	5	6	6
Proposes methods that could lead to a dynamic fall in the canopy	Major	6	8	6
Proposes free climbing or disconnecting from tree and ropes	Major	7	10	6
Advocates use of hand ascender as a fully loaded anchor point for life support or belay	Major	8	3	2
Contains photos or illustrations that show major safety deviations (e.g. PPE lacking, improper equipment or methods)	Major	9	39	15
Contains passages that could reasonably be interpreted as advocating unsafe practices	Major	10	7	5

*Minor safety deviations, references that could expose a climber to unnecessary risks; major safety deviations, recommendations that could result in serious injury or death.

Table 2. Published sources revealed during our search that mentioned methods for canopy access, but which were excluded from discussion because of limited utility in imparting knowledge on methods of canopy access

Reason for exclusion	No. excluded	References
Source written without primary intent of instruction on climbing methods	**20**	
Review papers on the status of canopy science; methods named but not described	8	Lowman & Moffett (1993), Moffett & Lowman (1995), Munn & Loiselle (1995), Lowman & Wittman (1996), Barker & Sutton (1997), Sutton (2001), Lowman (2009), Lowman, Schowalter & Franklin (2012)
Ecological article, climbing technique mentioned but not described in Methods section	8	Nadkarni (1981), Dial & Roughgarden (1995), Sillett & Van Pelt (2000), Ellyson & Sillett (2003), Dial *et al.* (2004a), Williams & Sillett (2007), Anderson (2009), Dial, Nadkarni & Jewell (2011)
Meeting abstract	1	Oates (1994)
Knot compatibility	1	Kane (2012)
Survey of canopy biologists	1	Barker & Pinard (2001)
Popular book	1	Moffett (1993)
Sources intended to impart knowledge on canopy access, but methods unsuitable for various reasons	**9**	
Experimental or unproven method	1	Donahue & Wood (1995)
Insufficient height (i.e. below canopy height)	1	McCarthy (1988)
Cost prohibitive, not portable, not replicable (hot air balloons, canopy walkways, construction scaffolds, cranes)	4	Lowman, Moffett & Rinker (1993), Lowman & Bouricius (1995), Jackson (1996), Walther (2003)
Peripheral relationship to canopy access (e.g. platforms, swings, slingshots)	3	Nadkarni (1988), Munn (1991), Peña-Foxon & Díaz (2012)
Total number of excluded sources	**29**	

source and recorded each occurrence that a particular criterion was mentioned in the text. For the purposes of the evaluation, we defined an occurrence as a section or subheading in books, a paragraph in peer-reviewed papers, or individual photographs in either. We treated all criteria independently, such that no occurrence could be counted more than once. We recorded detailed notes in a source-by-criteria matrix, listing the page number and content for each occurrence observed, and after completing the evaluations, we tallied all occurrences of the criteria for all sources. We then reviewed the results for discrepancies in which one reviewer reported an occurrence that the other did not. Finally, all authors met as a committee to resolve discrepancies and to reach final agreement on all results.

Results

Our searches produced a total of 54 published sources, including 40 peer-reviewed articles, seven books, five book sections and two government documents. We excluded 29 sources from further consideration because they were not written with the primary intent of instructing on climbing safety or methods (Table 2). The remaining 25 sources (Table 3) are herein reviewed on their usefulness to modern climbers based on their breadth of content and adherence to modern safety standards.

Sources differed widely in their citation frequency (Table 3), with a single source (Perry 1978) receiving 218 more citations than the second most cited source (Perry & Williams 1981) and 261 more citations than the median number of citations (12). Sources were published over a span of 41 years, from 1972 to 2013. We used linear regression to examine the relationship between source age and frequency of safety deviations and found no relationship ($P = 0{\cdot}34$, $r^2 = 0{\cdot}05$), suggesting that older and newer sources were equally likely to contain minor and major safety deviations.

Sources differed in terms of the breadth of climbing-related topics discussed, with two being the median number of topics covered (Table 3). Fifteen sources (58%) addressed two or fewer climbing topics, and only six sources (25%) discussed as many as four topics. Five sources made no or negligible mention of safety (Table 3), including the most highly cited source (Perry 1978).

Recommendations for unsafe climbing practices occurred often in the published literature (Table 1). The minor safety deviations that we found most often were outdated information that no longer reflects best practices (criterion #2, 37 occurrences in 16 sources) and references to equipment options that are inappropriate for tree climbing (criterion #1, 27 occurrences in 11 sources). Seven sources blurred the distinction between fall arrest and work-positioning systems (criterion #4), whereas only six sources made this important distinction. Ambiguity in writing was also a recurring issue with important safety implications. Seven passages in five sources could be reasonably interpreted as advocating unsafe practices (criterion #10). Another six passages in six sources were too vague to be interpreted by experienced climbers and could result in misuse of equipment or methods (criterion #5). We found nine sources that mentioned a need for instruction, but failed to distinguish between rock climbing instructors and tree climbers with specific knowledge and skills required for training others in climbing trees.

We observed 67 occurrences of major safety deviations in 18 sources (72%). The most common was the depiction in photographs or illustrations of serious safety deviations (39 photos in 15 sources; criterion #9 in Table 1). The authors of six sources advocated methods that could lead to climbers falling from trees (10 occurrences, criterion #7). Another six sources

Table 3. Published sources discussed in this review that describe methods for canopy access. Provided are the number of times each source was cited in Google Scholar, the respective coverage of five primary climbing topics and number of minor and major safety deviations

Source	No. times cited*	Primary climbing topic					Total topics	Minor deviations	Major deviations
		Safety	Spurs	Single rope technique	Doubled rope technique	Aerial traverse			
ANSI (2012)	n/a	✓					1	3	
Beranek (1996)	1	✓	✓	✓	✓		4	13	11
Blair (1999)	14	✓	✓	✓			3	3	
Castilho *et al.* (2006)	3		✓				1	1	
Coffey & Andersen (2012)	0	✓		✓			2		
Davis (2005)	5	✓	✓	✓	✓		4	4	4
Denison *et al.* (1972)	32			✓			1	4	4
Dial & Tobin (1994)	39	✓		✓	✓	✓	4	2	
Dial *et al.* (2004b)	4	✓				✓	2		1
Dial, Sillett & Spickler (2004c)	n/a					✓	1		1
Haefke *et al.* (2013)	1	✓			✓		2		2
Houle, Chapman & Vickery (2004)	13	✓	✓	✓			3	14	10
Jepson (2000)	33	✓	✓	✓	✓		4	2	
Kane (2011)	0	✓		✓			2		
Kilgore *et al.* (2008)	6	✓			✓		2	1	3
Laman (1995)	37	✓		✓			2	2	2
Mitchell (1982)	21	✓	✓	✓		✓	4	11	7
Mori (1984)	19		✓				1	2	3
Pagel & Thorstrom (2007)	n/a	✓	✓	✓			3	7	6
Perry (1978)	273			✓			1	3	4
Perry & Williams (1981)	55	✓		✓		✓	3	1	1
Risley (1984)	2	✓		✓			2	4	1
Smith & Padgett (1996)	11	✓	✓	✓	✓		4	6	1
Tucker & Powell (1991)	7	✓		✓			2	4	4
Whitacre (1981)	35	✓		✓			2	5	2

*Citation record not provided by Google Scholar.

advocated methods that could lead to a dynamic fall (eight occurrences, criterion #6), in which improper use of rope and harness configurations prevent the climber from falling to the ground but which can lead to serious impact and trauma occurring in the tree. We provide a complete listing of all minor and major safety deviations by source in the Supporting Information to help climbers identify and avoid them.

Discussion

Safe climbing demands an awareness of the distinction between rock and tree climbing principles, but this distinction was blurred in many of the sources we reviewed. This error is important from the standpoint of advocating unsafe practices and also underscores a larger issue in the tree climbing literature, namely a widespread and ongoing misunderstanding of basic tree climbing principles and safety standards. Several observations serve to reinforce this observation. Pagel & Thorstrom (2007) described methods suitable for climbing cliffs to access raptor nests, but then transferred the same methods to tree climbing with recommendations that were inappropriate for use in trees. We frequently found photos of unsafe practices, some potentially life-threatening, executed by authors in sources that otherwise advocated suitable tree climbing methods. How unsafe practices continue to surface in publications is important to consider. Intuitively, it seems reasonable that the publication of unsafe practices simply relates to a source's age: older sources are more likely to be outdated, and new sources are more likely to include information that is safe. We found no relationship between source age and the frequency of minor and major safety deviations. In other words, even new publications often contain bad information. We speculate on two potential reasons for this. First, there is an overreliance on citing early publications without careful consideration of the content, and some common errors carry over from one publication to the next. More seriously, the continued prevalence of unsafe recommendations in modern sources reflects a basic lack of knowledge on proper methods for tree climbing.

SOURCE AGE AND RELIABILITY

Technology changes rapidly in many disciplines, and tree climbing is no exception. During the past 15 years, there has been a virtual explosion in tree climbing technology, with new equipment and methods being developed every year. These developments have improved climber safety and climber efficiency (i.e. requiring less effort and time to ascend trees). Therefore, best standards for tree climbing change often, and it is important for climbers to remain abreast of current standards. For example, we found recommendations in our benchmark for safety, ANSI (2012), that were already outdated due to changes in technology. We urge would-be climbers to seek the most recent information and training from experts in modern practices.

CLIMBING METHODS

Canopy access methods can be divided roughly into two planes of movement: vertical movement up into or down out of trees, and horizontal movement within tree crowns or between trees. Specific methods used to move either vertically or horizontally include climbing with spurs, SRT, DdRT and aerial traverse. Because the amount of information available to new climbers can be overwhelming and varies greatly in quality, we review published sources on canopy access methods. Although some authors have attempted to provide general guidelines that prescribe when one method is preferred over another (Dial & Tobin 1994; Houle, Chapman & Vickery 2004), there are no hard and fast rules, and choice of method will depend on the unique circumstances of every individual climb as well as on the climber's knowledge and experience.

CLIMBING SPURS

Tree climbing spurs are metal gaffs that attach to a climber's legs by use of metal or fibreglass stirrups and leather or nylon straps and are used to ascend the trunks of trees (Davis 2005). The gaffs point downward and puncture the surface of the tree trunk, providing traction as the climber steps up the trunk. Spurs damage the tree, leaving open wounds that may ooze sap, attract insect pests and allow pathogens into the tree (Beranek 1996; Jepson 2000; Castilho *et al.* 2006). We urge against using spurs because the repeated climbing of individual trees can alter the ecology of a tree by reducing its vigour or killing it (Castilho *et al.* 2006). More importantly to the climber, in most instances the use of SRT and DdRT provides canopy access that is both safer and more efficient in terms of energy and time expended (Blair 1999; Coffey & Andersen 2012).

SINGLE ROPE TECHNIQUE

Single rope technique is a fixed rope system in which the rope is either cinched off around a limb in the tree or placed over a branch and tied off to a solid object near the ground (Coffey & Andersen 2012). The climber then ascends the free end of the rope with mechanical ascenders or friction hitches, mechanical devices or knots that grip the rope and slide upward but not downward (Coffey & Andersen 2012; other citations in Table 3). SRT is the most energy efficient means of ascending ropes (Coffey & Andersen 2012) and as such is the most common method of access into tall trees (Dial & Tobin 1994; Coffey & Andersen 2012).

The first step in SRT typically involves placing the climbing rope over a branch strong enough to support the climber and high enough to reach the desired position in the tree (Dial & Tobin 1994; Jepson 2000). This step is made easier by first placing small diameter fishing line or a light cord over the desired branch, then using this line to pull the climbing line into place. This initial line can be installed by (i) throwing a cord (called a throwline) with a weighted bag on one end (Dial & Tobin 1994; Jepson 2000), (ii) shooting a weighted line with a hand-held slingshot (Tucker & Powell 1991), (iii) shooting lines with a crossbow or compound bow fitted with a fishing reel (Perry 1978; Dial & Tobin 1994; Dial *et al.* 2004b) or (iv) shooting a weighted line with a large slingshot made from an 2·4-m extendable fibreglass pole and designed specifically for use in tree climbing (brand name 'Bigshot'®; Jepson 2000). Choosing a method is largely a matter of personal preference and experience, although some guidelines are helpful to new climbers. First, we can rank methods by the height each can achieve, from lowest to highest: hand-held throwline, hand-held slingshot, Bigshot, compound bow and crossbow. For heights >30 m, the crossbow is generally the most accurate in shooting a line through small spaces in branches and foliage and over the desired branch. Regardless, setting a line takes time and there is no substitute for practice. Time spent using the separate methods for rope placement will only make this step in canopy access faster and easier.

Due to the sheer variety of mechanical ascenders and related pieces of equipment, there is a nearly infinite number of ways to configure SRT climbing systems. To test and compare multiple SRT systems, we refer climbers to Smith & Padgett (1996), Coffey & Andersen (2012) and general guidelines outlined in Jepson (2000).

An important safety consideration in SRT is the use of multiple points of attachment between climber and rope to prevent accidental detachment from the rope, which can occur through human error or should one point of attachment fail (Whitacre 1981; Laman 1995; Smith & Padgett 1996; Jepson 2000; Coffey & Andersen 2012). Multiple sources (Perry 1978; Mitchell 1982; Risley 1984; Dial & Tobin 1994) omit this important guideline.

DOUBLED ROPE TECHNIQUE

Doubled rope technique differs from SRT in the relative position of the anchor point in relation to the climber. In DdRT, one end of a rope is tied to the climbing harness, the rope passes over a branch, and the opposite end of the rope is attached to the harness by means of a friction hitch (a knot or mechanical device that grabs the rope when weighted and releases when pulled downward). As the climber pulls rope through the friction hitch, the length of rope above the climber is shortened and the climber advances up the tree (Jepson 2000).

Doubled rope technique allows controlled movements up and down ropes, which a climber can use to walk out onto branches by easily controlling the amount of tension or slack in the rope (Jepson 2000). DdRT therefore is useful for total canopy access needed for some replicated sampling in ecology (Dial & Roughgarden 1995; Sillett & Van Pelt 2007; Williams & Sillett 2007). Until recently, the sole use for SRT was to climb ropes upward into trees. However, new equipment and methods for SRT now allow total canopy access with this method as well (Coffey & Andersen 2012).

AERIAL TRAVERSE

Aerial traverse is a technique whereby climbers move horizontally between trees. The advantage is that it that provides access to places in the forest canopy such as delicate branch tips, dead tree crowns, epiphytes and open space that often cannot be accessed by spur climbing, SRT or DdRT. The disadvantage is that aerial traverse is more technical and potentially more dangerous than other methods and requires advanced skills and training from tree climbers with proper experience. The principle of aerial traverse is to suspend the climber between two trees using one or two ropes that support the climber's weight and provide movement in the horizontal plane (Perry & Williams 1981; Dial & Tobin 1994; Dial *et al.* 2004b). We refer readers interested in aerial traverse to excellent descriptions in Dial & Tobin (1994), Smith & Padgett (1996) and Dial *et al.* (2004b). Here, we briefly summarize critical points on safety. A major difference between SRT, DdRT and aerial traverse is in the climber's ability to test an anchor point before hanging on it. In SRT and DdRT, a climber can hang and bounce on a rope at ground level and thereby assess the strength of an anchor point before climbing on it. In aerial traverse, a climber is already at height in one tree when she or he installs a rope in a second tree. Working at height, the climber has to gradually transition from supporting their total weight on the first rope that has been climbed and tested, to supporting their weight on the second rope and anchor point that have not been tested. Caution at this stage can prevent a catastrophic fall should the second anchor fail. Less obvious but even more important are the nonlinear accelerating forces placed on both trees and ropes when a rope that is supporting a climber's weight is tensioned to horizontal (Dial *et al.* 2004b). As a rope is tensioned from slack to horizontal, the physical forces exerted can exceed the strength of the rope and can cause it or the anchor point to break (Harris 2010). Also important to consider is that branches are typically stronger when pulled downwards than when pulled to the side. Therefore, it is absolutely critical to leave a slight amount of slack in any rope that supports a climber during aerial traverse (Perry & Williams 1981; Mitchell 1982; Dial *et al.* 2004b) and to cautiously test the new anchor before depending on it. Finally, climbers attempting aerial traverse must consider the difficulty of aerial rescue or self-rescue should an emergency occur.

SAFETY CONSIDERATIONS

Despite the inherent risks involved in climbing trees, safety receives infrequent attention in climbing sources. Although individual climbers may differ in their personal opinions of what practices are safe or unsafe, The American National Standard for Arboricultural Operations Safety Requirements, ANSI Z133.1, provides accepted safety guidelines for professional tree climbing (i.e. arboriculture) in the United States. Similar standards exist outside the United States, and we recommend that climbers in other countries obtain the applicable standards. Below we highlight ANSI standards that were frequently overlooked in the sources we reviewed.

Helmets for tree climbing must be capable of sustaining impacts from both above and the side and must have a chinstrap (ANSI 2012). Arborist helmets are constructed to meet this standard, but not all industrial or rock climbing helmets are. Helmets that comply with this standard are stamped on the inside ANSI Z89.1 to alert the user.

Carabiners used for life support in tree climbing must be self-closing and self double-locking, that is have a gate-locking mechanism that requires at least two deliberate, consecutive actions to unlock. They must be capable of withstanding a 22-kN (5000 pounds) load along the major axis (ANSI 2012). The minimum rated strength in kN is stamped on carabiners and other climbing hardware for easy identification. Single-locking carabiners in which the gate opens and closes by unscrewing are not acceptable for life support in tree climbing systems. ANSI standards for carabiners in tree climbing are required because the dynamic motions of ropes during tree climbing can unscrew and open single-locking carabiners.

Ropes and cords used for life support in tree climbing must have a minimum tensile strength of 24 kN (5400 lbs) when new (ANSI 2012). The properties of ropes for tree climbing have developed rapidly in recent years with the introduction of a variety of new materials and types of construction. We advise climbers that DdRT, SRT and rock climbing methods require ropes with different properties and that ropes constructed and sold for rock climbing do not necessarily meet the properties required for tree climbing. Inappropriate rope choice can lead to serious injury and death. Specifications for tree climbing ropes are provided in catalogues for tree climbing gear, but the onus is on the climber to carefully research the available options to ensure that a rope meets current ANSI specifications and is suitable for the intended use.

ANSI regulations state that arborists will wear eye protection capable of sustaining shock. Eye protection that meets this standard is stamped Z87.1 for easy identification. Although we can understand that there are situations in which a climber may need to remove eye protection while climbing (e.g. profuse sweating in a tropical environment), the general rule should be to follow ANSI regulations and wear eye protection.

Conclusions

Rope-based access methods are the key to unlocking canopy science, and we offer recommendations for improving climber safety over the foreseeable future. First, we recognize that valuable information on climbing exists outside the scientific literature, and we provide lists of national and on-line climbing affiliations, companies that specialize in tree climber training and sources of tree climbing equipment in Appendix S1. Secondly, we recommend that novice climbers obtain proper training from experienced tree climbers who follow ANSI standards for equipment choices and best practices. Thirdly, training and regular practice in aerial rescue methods are essential for safe climbing. Fourthly, independent audits of existing canopy research programmes could help improve safety standards and prevent climbing accidents. Finally, careful review of new manuscripts can improve the published standards available to future climbers.

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Data accessibility

Data for this article consist of a list of safety deviations and positive recommendations culled from 25 published sources on climbing methods and are contained in Table S1.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Table S1. Complete list of safety deviations and positive recommendations occurring in 25 published sources on climbing methods.

Appendix S1. Additional sources of information useful to tree climbers.