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ORIGINAL ARTICLE

Advances in increment coring system for large tropical trees with high wood densities

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ABSTRACT

Incremental coring of trees is the key method used in non-destructive dendrochronological sampling. Despite the advances in developing such methods, the sampling of large, high-density trees still poses a challenge in remote tropical forests. Manually operated incremental drills, while easy to transport across difficult terrain, limit sample size and can often get damaged in the sampling process, especially when trees have wood densities above 0.8 g/cm^3. Here, we discuss the existing available alternatives and present an up-to-date incremental coring system composed of a borer coupled to a hand-held drilling machine and a support attached to the tree which can collect incremental cores of 1.5 mm in diameter and over 1.0 m in length. The support ensures stability for the drill throughout the sampling process. This system is relatively lightweight and portable, offering field flexibility and suitability for sampling in remote locations. It provides a core sample of an appropriate diameter and amount for carrying out ring-width measurements, stable isotope and radiocarbon analyses on some of the large, older trees which are now being found in the tropics. We expect that this methodology will broaden the possibilities in the now-blossoming sub-field of tropical dendrochronology.

1. Introduction

Retrospective analyses of preserved growth rings of living trees provide information on tree ages and growth rates over the course of their life span. These analyses can be applied across the large multi-disciplinary and interdisciplinary field of ecology, geosciences, archaeology and forest sciences, addressing ecologically guided logging systems (Schöngart, 2008; Andrade et al., 2019), dynamics of tropical forests (Baker et al., 2005; Vlam et al., 2017), relationships between tree growth and climatic variations at different scales (Brienen et al., 2010; Schöngart et al., 2004), tree response to anthropogenic disturbance in pre-colonial and contemporary times (Caetano-Andrade et al., 2019; Resende et al., 2020) and detailed, annual reconstruction of climatic parameters for pre-instrumental periods (Granato-Souza et al., 2019). While once thought impossible in the tropics, a growing literature of tropical dendrochronology is demonstrating the wide variation in ages and diametric growth patterns between individual trees, species, ecosystems and biomes (Brienen et al., 2016; Schöngart et al., 2017). There is, however, an urgent need to extend this information to cover more tropical species, environments, and regions of the world, if better understandings of tree ecosystem functions, growth responses to past and present human activities and climate trends (Caetano-Andrade et al., 2020), as well as sustainable forest management policies, are to be obtained.

To do this, it is essential that a reliable method of increment coring is developed that can reach the different corners of the tropics and deal with the increasingly large and old trees now known to grow there (Lindenmayer and Laurance, 2017). Recently performed studies based on tree-ring analyses in the Neotropics report tree ages of over 400 years for *Bertholletia excelsa*, *Cariniana micrantha*, *Caryocar villosum*, *Dipteryx micrantha*, *Manilkara huberi* from non-flooded Amazonian *terra firme* forests (Brienen and Zuidema, 2006; Jenkins, 2009; Schöngart et al., 2015; Andrade et al., 2019; Worbes and Schöngart, 2019) and for *Hymenolobium mesoamericanum* in Costa Rica (Fichtler et al., 2003). However, sampled maximum diameter of these tree species by non-destructive methods rarely gets over 1.5 m, mainly due to technical

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and logistical restrictions. Information on the maximum age of tropical trees is still controversially discussed among scientists (Chambers et al., 1998; Worbes and Junk, 1999; Vieira et al., 2005; Brienen et al., 2016; Schöngart et al., 2017). Sampling cores from giant tropical trees such as *Bertholletia excelsa*, *Ceiba pentandra*, *Dinizia excelsa* and *Hymenolobium* spp. from the Amazon, which can achieve diameters of more than 3 m have rarely been sampled (e.g., Camargo et al., 1994) and can provide reliable age estimates attending this pending question. For dendrochronologists non-destructive sampling of old trees is crucial to extend tree-ring chronologies to better understand the natural variability of past climate conditions. Providing information on the age of giant tropical trees is particularly important for ecosystem maintenance and conservation. This is because large, old trees play critical ecological roles within their tropical forest environments, providing nest and sheltering cavities for a variety of vertebrate species, storing large quantities of carbon, creating distinct microenvironments with high levels of soil nutrients, and providing food for local fauna (Lindenmayer et al., 2012). Furthermore, they have enormous cultural and symbolic importance for human societies and conservation policies (Blicharska and Mikusiński, 2014).

Increment coring of trees is a pivotal non-destructive method used to obtain growth history information present in wood. It is often the preferred sampling method for many scientists because, although the method is invasive, it can collect samples of wood without killing the living tree, although further studies in more diverse environments and species are needed to assess this generalization (Wunder et al., 2013). Manual increment borers are the most commonly used tool to obtain core samples, particularly in difficult-to-reach areas tropics, being easily portable and able to collect large numbers of samples up to 12 mm in diameter (Grissino-Mayer, 2003). However, when it comes to large tropical trees with high wood densities (>0.8 g/cm^3), this tool presents some disadvantages as it was originally designed for softwoods of the Northern Hemisphere or low-density hardwoods. Trees from the tropics can reach density values up to 1.35 g/cm^3 in Central America and 1.21 g/cm^3 in tropical South America, compared to 0.84 g/cm^3 in Europe (Chave et al., 2009), which often results in damage to manual increment borers when used in tropical forests.

Dendrochronological laboratories around the world have been, sparingly over the last few decades, attempting to make the sampling process more comfortable, easier, and faster, by developing several types of drilling systems and borers (Bowers, 1960; Johansen, 1987; Steenkamp et al., 1999; Speer, 2010; Krottenthaler et al., 2015; Kagawa and Fujiwara, 2018). Advances in the mechanization process of drilling include innovations such as a drill attached to a chainsaw device (Hall and Bloomberg, 1984), whose power is converted into rotation by a drilling accessory, an electric drilling machine coupled to a gearbox, powered by a generator (Steenkamp et al., 1999), an electric drilling system powered by batteries (Kagawa and Fujiwara, 2018) in addition to other gasoline engine systems (Speer, 2010; Krottenthaler et al., 2015). There are also some specialized companies that manufacture these tools, for example the gas-powered CSIRO Trecor system, which was designed mainly for the coring of small diameter *Eucalyptus* spp., and the variety of drills offered by Pressler © GmbH (Germany; http://www.pressler.com.de). However, there is a lack of a stable and light drill and support system adequate for transporting in the field and sampling large diameter tropical trees.

Here, we present a new, portable gasoline sampling system for tackling large diameter tropical hardwoods in remote areas that makes a series of key advances on existing approaches. By clearly describing the parameters, composition, and use of our system we hope to encourage the widespread use and reproducibility of our methodology in a variety of different tropical regions over the world. We have repeatedly tested this equipment in the tropical forests of the Amazon Basin in Brazil over the past three years, sampling large, dense *Bertholletia excelsa* (Lecythidaceae) trees, with diameter at breast height (DBH) up to three meters. It has also proven to be easily transportable in even the most difficult of working conditions. While, as with all existing systems, some considerations and limitations have been identified, particularly under humid fieldwork conditions, we believe that this represents an important new option for researchers seeking to sample the increasingly large trees now being documented in different parts of the tropics, in order to dendrochronologically reconstruct past human activities, climate changes, and forest dynamics.

2. Description

2.1. Drilling machine

The hand-held drilling machine we use in our system is the commercially available Stihl® BT45 (power output 0,8 kW). It has a two-speed gearbox, 910 and 2710 revolutions per minute (rpm), and a reverse gear (810 rpm) for releasing the drill in case it is jammed. In the drilling process, the first gear is more suitable for having more torque force. It weighs about 4.8 kg and has capacity for 0.25 L of fuel (gasoline mixed with two stroke enging oil with a mixing ratio of 50:1), which permits the sampling of up to 2 cores over 1 m in length before refueling. The volume is roughly 0,35 m^3 - or 35 L -, suitable for being carried in a backpack with reinforced lining. The chuck for coupling the drill to the drilling machine has 13 mm width, and the machine has an anti-vibration system to absorb vibration from the engine and rotating cutting tool and keep the handles vibration-free for more accurate use.

2.2. Drill

Most of the specifications described here for the manufacture of the drill were proposed by Krottenthaler et al. (2015), which consists of a stainless-steel tube, an adapter to connect to the drilling machine and a cutting tip to drill the tree (Fig. 1). The stainless-steel tube has a bayonet-type recess on one side to fit the adapter that is connected to the drill (Fig. 1(a)). This bayonet-type accessory was used due to the ease of uncoupling the machine from the tube, in addition to allowing the use of the reverse gear. The tube is connected to the drilling machine by an adapter (Fig. 1 (a)), also made of stainless steel. The diameter of the adapter in the part that connects to the tube is slightly smaller than the inner diameter of the tube (18.8 mm). The side inserted in the drilling machine's socket is hexagonally milled to prevent slippage during rotation and smaller than the socket opening (12 mm).

The cutter tip (Fig. 1 (c)) is an adaptation of a commercially available cutter commonly used in carpentry, which is called Tenon Plug Cutter (Fig. 1 (c)). There are many options available for this type of cutter on the market that vary in diameter, type of alloy and number of cutting teeth. We opted for the model already tested in the field (Krottenthaler et al., 2015) manufactured by FAMAG®, (Remscheid, Germany; http://www.famag.com), with an internal diameter of 15 mm, external diameter of 26 mm, and cutting edges made of Widia©, a very hard and

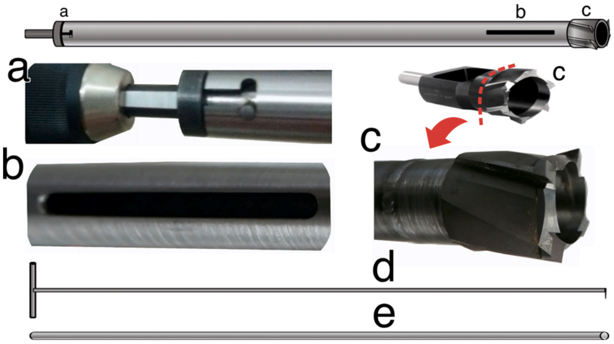

Fig. 1. Drill to collect increment cores from high density, large trees. (a) Bayonet type entrance and adapter to connect the drill to the drilling machine, (b) side opening of the tube, (c) cutter tip, (d) extractor, (e) rebar.

resistant metal alloy. The connection between the parts is made by removing the cutting tip from the original piece and welding it to the stainless-steel tube (Fig. 1 (c)). We used silver welding due to its increased durability and resistance.

The forged tube has an internal diameter of 19 mm and a wall thickness of 1.5 mm, meaning that the internal diameter is slightly larger than the sample diameter to prevent it from becoming stuck inside during the operation. Further, the outside diameter of the tube (22 mm) is 2 mm smaller in relation to the diameter of the hole in the tree, thus reducing abrasion and preventing overheating. We have, however, made one important modification to Krottenhaler et al.'s system by adding two diametrically opposed openings in the tube (Fig. 1 (b)). These are important for facilitating the release of wood chips during the drilling process, preventing the core from becoming trapped inside it. As these openings are inserted in the tube, this does not compromise the welding of the cutting tip. It also allows the operator to see the material during the pushing and pulling movement of the drill, enabling them to recognize when the core breaks, if there are liquid leaks, or whether any abnormalities during the drilling process occur.

To extract the core from inside the tube, we use a rebar to push out the sample (Fig. 1 (e)), which has a diameter slightly smaller than the diameter of the cutter (13 mm) and a length at least 20 cm longer than that of the drill. To extract the wood core from inside the tree, we use a 3 mm diameter extractor (Fig. 1(d)), folded at 90° at one end, with a 5 mm long section with a 'sickle' shape that is sharpened to cut the remaining sample still connected the tree at the bottom of the hole. To collect the core, the extractor must be inserted into the free space around the core, and cut through circular movements until the core becomes loose (Krottenthaler et al., 2015). We recommend that the extractor be made of a single piece, and of a resistant metal alloy, as it is subject to high torsional forces.

2.3. Support

We have designed a novel support set-up to ensure stability against vibration and torque force. It consists of a base made of light aluminum alloy, a channel to guide the drill, four screws to adjust the drill input line on the tree, and a ratchet strap to fasten the support to the tree (Fig. 2). The piece was produced at the Reinhard Dobrindt Workshop (https://www.einschiessen.com), Hamburg, Germany and weighs a total of 7.2 kg (plus 2.5 kg from the ratchet strap). The base is 30 cm high by 40 cm wide, suitable for fitting in trees of 1–4 m DBH, however, this size can be readjusted if there are no large trees in the sampling area, resulting in a smaller and lighter support. All parts are connected with screws, allowing them to be replaced if necessary.

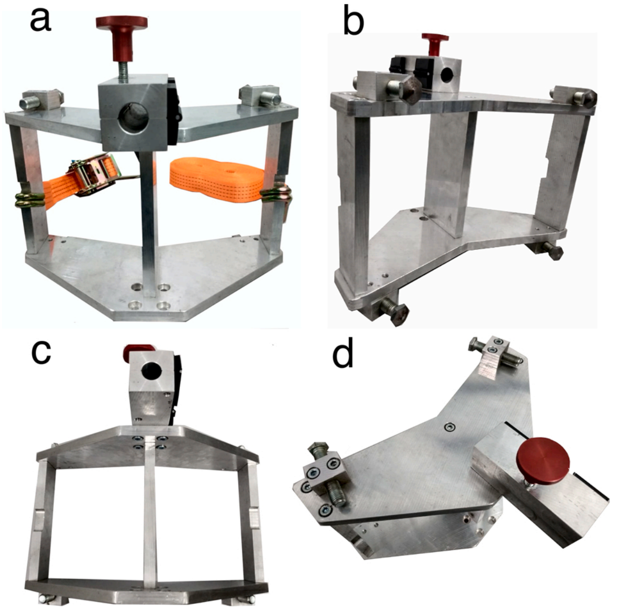

Fig. 2. Support developed to ensure drill stability during the sampling process.

The channel is a light aluminum alloy structure connected to the support by 4 screws (Fig. 2 (c)). It is 5 cm high, 5 cm wide, and 15 cm long. The hole diameter is 1 mm larger than the outside diameter of the tube (19.1 mm). It is divided in half and connected by hinges on one side and by a screw on the other. To adjust the input shaft, ensuring that the drill reaches the center of the tree, four screws are located in the four corners of the support (Fig. 2 (b)). The support is fixed to the tree using a ratchet strap (Fig. 2 (a)) which is fixed by hooks in the lateral recesses of the support and, once fixed, it guarantees 100 % stability until it is decoupled from the tree.

3. Operating instructions and system testing

The system was tested in five areas of the Brazilian Amazon between October 2018 and October 2019. Although it is capable of drilling trees with higher densities, such as *Hymenaea stigonocarpa* (0.9 g/cm^3), *Lithraea brasiliensis* (0,98 g/cm^3), and *Parapiptadenia rigida* (1.2 g/cm^3), as it uses the same cutting tip and engine tested by Krottenthaler et al. (2015), our system was used exclusively to collect Brazil nut trees (*Bertholletia excelsa*), which have a wood density between 0.59 and 0.63 g/cm^3, during these fieldwork periods (density values extracted from Lorenzi, 1998; Martins, 1944; and Fearnside, 1997). Some of the individuals we sampled measured up to three meters in DBH, which tested the efficacy of the system regarding its ability to efficiently collect samples from large trees. In some of the regions where the tests took place, the maximum daily displacement by foot was four kilometers into the forest, with the equipment divided into two backpacks with reinforced linings. We store the drills in Polyvinyl chloride (PVC) tubes for transport in the field, wrapping the cutting edges with foam to prevent wear. In addition to the drilling system, we carried tools such as screwdrivers, pliers, extra spark plugs for the engine, lubricating oil, gasoline, and personal protective equipment. This equipment is essential in order to make repairs in the field, especially if issues occur in remote regions and weight no more than five kilos, depending on the amount of gasoline, which varies according to the number of trees to be sampled. After having carried out field incursions with teams of two, three, and four people, we recommend a team of at least two people in the field to load and operate the system for effective use (example of the full process of sampling in Video.1).

After selecting the tree to be sampled, it is important to observe the surrounding terrain in order to choose the side that the support will be installed on, the ideal is that it be a flat place without obstacles, so that the work for the drill operator is made easier. The installation of the support is of paramount importance for the sampling as, once installed, the support will guarantee a stable input shaft for the drill until it is uncoupled. First, it is necessary to locate the side of the tree where the support will remain stable (i.e. without irregularities in the trunk), and adjust the four screws to regulate the entry angle pointed by the channel. It is also recommendable to clean the bark surface to remove moss, earth and any dirt before cutting, the whole process of installing the support can take from 5 to 15 min, but the time spent in this part of the operation is essential. After installing the support, the drill is inserted into the channel (Fig. 3 (b)). We put a small amount of mineral lubricating oil in the channel before closing, to ensure that the tube slides easily and does not overheat. We note, however, that for high temperature applications, vegetable oil (e.g. coconut oil) may also be used for optimal stability (Woma et al., 2019). Compared to mineral oils, vegetable oils in general possess high flash point, high viscosity index, high lubricity, low evaporative loss, are renewable, and are environmentally friendly (Woma et al., 2019). It is important, however, that the operator prevents the contact of the open part of the tube (Fig. 1 (b)) with the channel during the pulling and pushing movement of the drill, stopping the movement

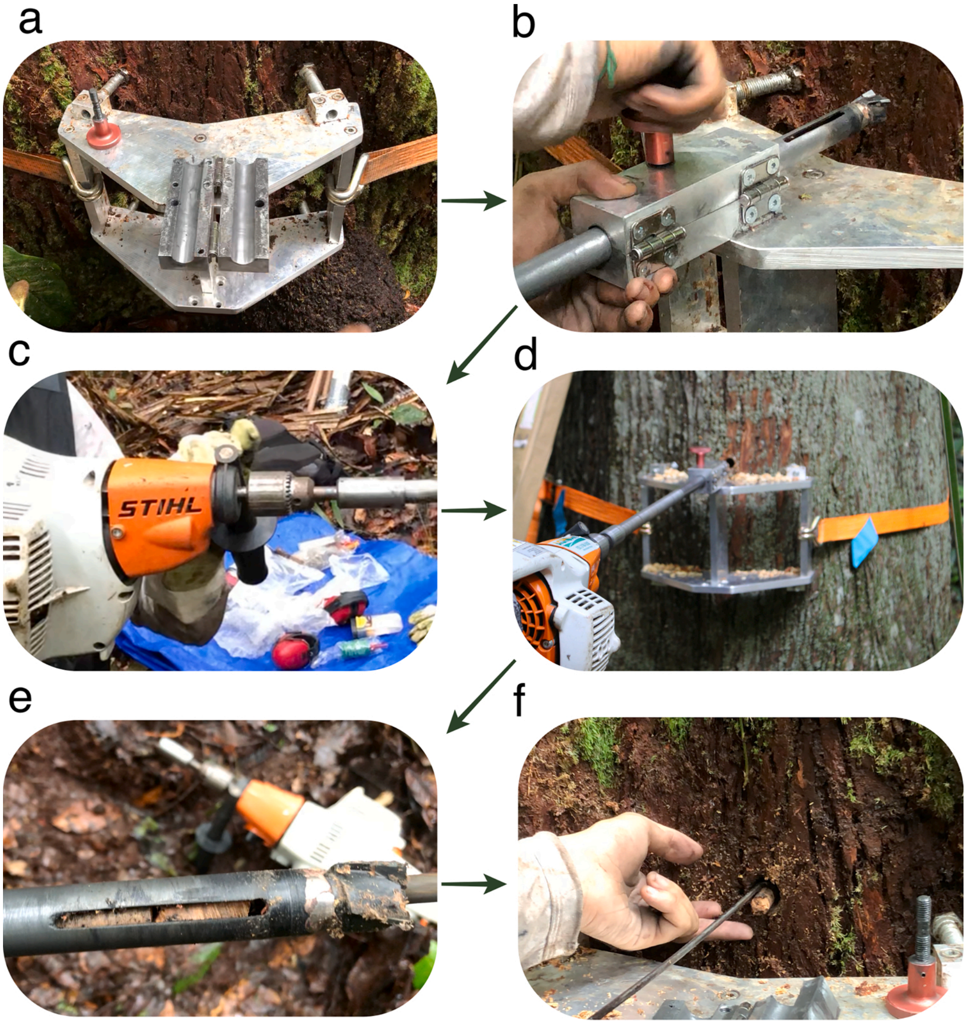

Fig. 3. Workflow for the sampling process.

before the drill opening contacts the channel and preventing oil from entering the tube. This is essential so as to avoid contamination if stable carbon isotope analysis or radiocarbon dating is intended.

With the tube fixed in the channel, the engine is started and coupled to the other end (Fig. 3 (c)). From there, the operator begins the repetitive pulling and pushing movement. At each movement the drill enters about 0,5 cm and expels sawdust when the drill leaves the tree. The total time spent to collect a sample of one meter in length, including the assembly of the support varies from 20 to 30 min. During the whole sampling it is important to observe whether the sample has broken inside the drill, if there has been any leakage of liquid from the tree, and any other eventualities. If something like this occurs, the operation must be stopped and actions taken accordingly. If the sample is released from the tree into the tube, we recommend that the drill is taken out of the channel and the sample is collected using the rebar (Fig. 1 (e)). The rebar is carefully inserted at the end of the cutter so that it does not damage the cutting edge, and the sample is pushed and collected at the other end. The sample can be stored in a tube with a diameter slightly bigger than the sample for storage and further processing. After taking the sample out, the drill can be re-attached to the channel and re-connected to the drilling machine so that work can continue. At the end of the sampling, the extractor must be used to remove the rest of the sample from inside the tree. After the sample is taken, it is important to reduce the risk that the tree will be attacked by phytopathogens. To seal the hole made by the drill, we use bee wax, which is a malleable material when heated and easy to carry, although alternative methods, such using a cork, can also be used (Krottenthaler et al., 2015).

4. Discussion

Drilling systems have been proposed and improved over the last few decades, while the frontiers of dendrochronological studies have been expanding, especially in the case of tropical forests. Drilling systems are fundamental alternatives to destructive sampling approaches that seek to obtain a complete disk of wood. Although the sampling of cores always results in wounded bark, cambium, and wood, potentially leading to a cambial necroses and the entrance of micro-organisms, trees mostly heal themselves rapidly (Eckstein and Dujesiefken, 1999). Trees are capable of actively compartmentalizing the wounded region, separating it from the healthy wood (Blanchette and Biggs, 2013). The effectiveness of healing depends on a variety of factors, such as the season of wounding in the case of observations on non-tropical trees (Eckstein and Dujesiefken, 1999), but mostly on the tree species being sampled. Individuals from the Norway spruce (*Picea abies*), for example, presented no signs of disease five decades after they were sampled (Wunder et al., 2013). Tropical forests, however, currently largely lack such extensive long-term studies. A study with 11 tropical tree species from Singapore showed that the best predictor of borehole closure after 12 months of sampling was also the species (Neo et al., 2017). Importantly, the results of this study nonetheless indicated that increment coring does not negatively impact the health and growth of the evaluated species (Eckstein and Dujesiefken, 1999; Wunder et al., 2013; Neo et al., 2017).

In our case, we observed that the majority of Bertholletia excelsa produced exudate in abundance in the first days after sampling, often expelling the beeswax that we put in to delay the entry of phytopathogens. This indicates the resilience of the species, already observed in its resistance to fire (Scoles and Gribel, 2011). Furthermore, over the last years, many tropical tree species have been drilled by different techniques in several tropical environments and future studies should be able to evaluate the impacts of coring on georeferenced trees.

The application of non-destructive methods to collect samples from large tropical trees carries the potential to further extend dendrochronological data, both by cross-dating measured ring-widths and by extending isotopic records. The joint application of radiocarbon dating with dendrochronology has helped to develop robust time series of growth patterns of particular species, with applications such as testing the annuity of ring formation and the factors that influence the growth rhythm of trees across tropical South America (Baker et al., 2017), as well as improving growth-oriented logging cycles in sustainable management forest areas of the Amazon Basin (de Miranda et al., 2018). Precisely dated tree rings also have the potential to extend radiocarbon calibration curves back into past, which is especially important for the Southern Hemisphere across tropical regions (Santos et al., 2020). Stable oxygen (δ18O) and carbon (δ13C) isotopic analyses have been used to provide information on changes in water sources (Ladvocat Cintra et al., 2019) and to indicate changes in light availability that are likely linked to alterations in the canopy structure, respectively (van der Sleen et al., 2014). These isotopes have also been used together to provide information on changes in complex climate systems in the tropics (such as the El Niño-South Oscillation and Asian Monsoon System) (Grießinger et al., 2011; Brienen et al., 2012), as well as their potential impacts on human societies (Buckley, 2010; Caetano-Andrade et al., 2020). In the face of the current rapid disappearance of tropical forest environments, the popularization of these sampling methods is essential to promote research and guarantee the conservation of tropical forests and their oldest trees which have, in turn. been shown to be of significant importance to ecosystem function (Lindenmayer and Laurance, 2017).

The drilling system described is capable of sampling trees with high wood density and diameters up to 3 m in remote regions, and the 15 mm diameter samples consist of enough wood so that anatomical, densitometric, isotopic, and ring count analyses can be performed on the same core which can be radially split into two halves by sophisticated cutting devices under laboratory conditions. We produced two drills with lengths of 100 cm and 180 cm, respectively, and the innovative design of the support proved to be capable of ensuring the stability of the input shaft for even extremely large drills. Other systems presented so far have not reported this type of device attached to the tree. In addition, our system is easy to assemble / disassemble, and the samples collected were of high quality, remained very solid, and could be successfully collected without carbonization (Fig. 4 (a,b)). Nevertheless, exceptions occurred in cases where the tree presented rotting wood, had been consumed by termites in the interior, or when the drill was worn out after long periods of use, leading to low quality samples (Fig. 4 (c)). In Fig. 5 we present 27 cores of Bertholletia excelsa that were collected at Tapirapé Aquiri National Forest (Pará, Brazil), in October 2018. The samples were processed by repeatedly sanding (grit up to 600) so as to evidence the anatomical features of the wood. The cores ranged from approx. 50–95 cm in length, presented overall long segments (> 30 cm), with no signs of carbonization, and with enough surface for anatomical observation (15 mm width), with some exceptions due to the abovementioned reasons. In these cases, the segments needed to be removed sequentially and carefully stored for further processing. This can pose a problem with regards to anatomical dendrochronological dating (Williams et al., 2015), but is unavoidable regardless of the system used to drill large trees.

In terms of reliability and resilience, the silver welding we use in our system has never come off, ensuring a long life for the drill. The Tenon Plug Cutter's Widia © blade remained sharp at all times, making it possible to carry out about 50 samplings before it needed to be replaced. A future improvement could be a tip which is not welded, but screwed on the stainless-steel tube. This would allow to use the tube for longer times. Despite that, we did notice that the performance of the drill dropped over time due to small teeth that formed at the cutting edges. This was also noted by Krottenthaler et al. (2015), who recommend good maintenance and cleaning practices for this portion of the system. We note, however, that the high relative humidity of the rainforest and the constant use of the equipment may be responsible for accelerating the process of deterioration of the cutting tip. Performance may have

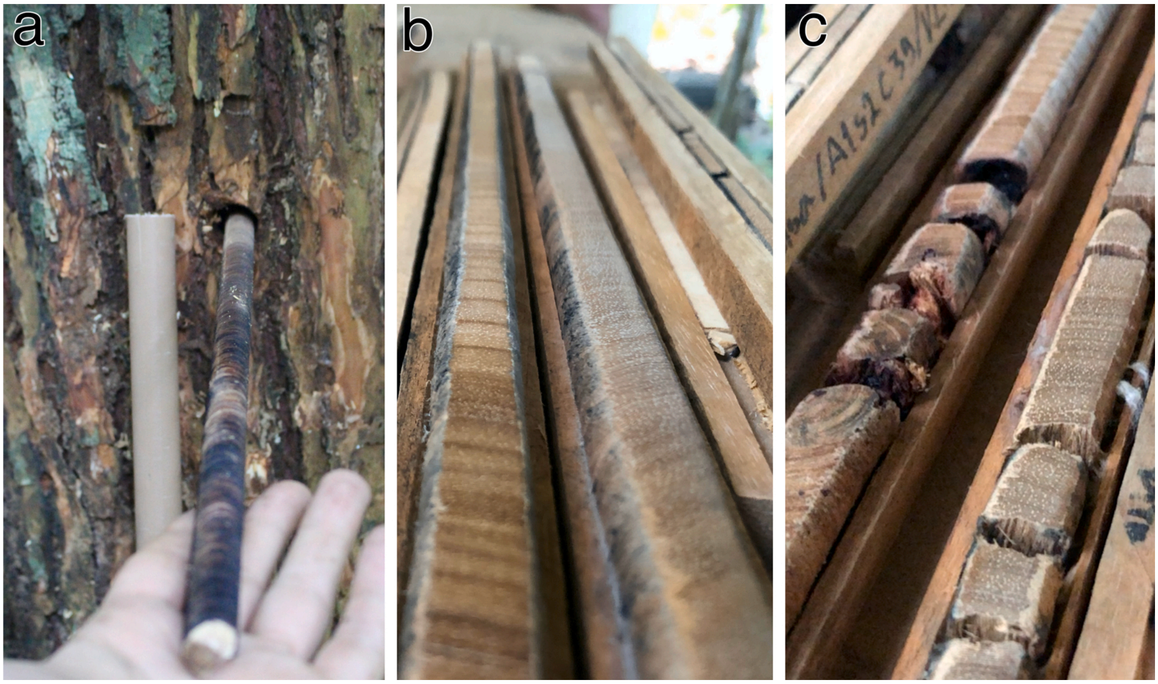

Fig. 4. Cores of Bertholletia excelsa exemplifying the sample quality.

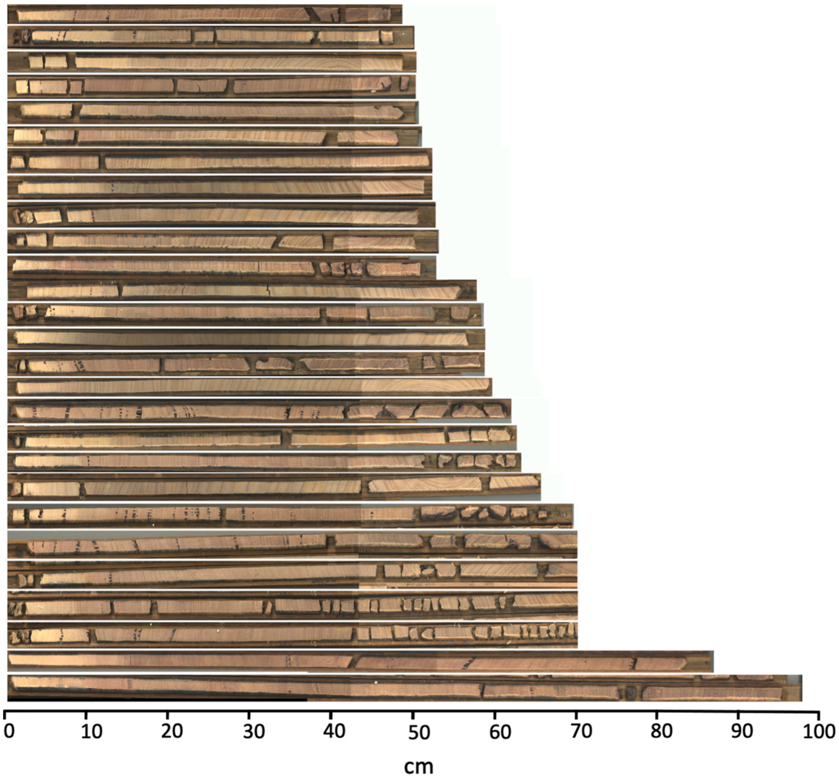

Fig. 5. Cores of Bertholletia excelsa after processing with repeated sanding.

been lower in our tests due to the fact that they were done exclusively in very humid environments, in contrast to tests done across diverse areas, such as the Atlantic Rainforest (Mata Atlântica), woody savannah (Cerrado) and wetlands (Pantanal) in Brazil, which yielded around 100 samples before requiring replacement of the cutting tip (Krottenthaler et al., 2015).

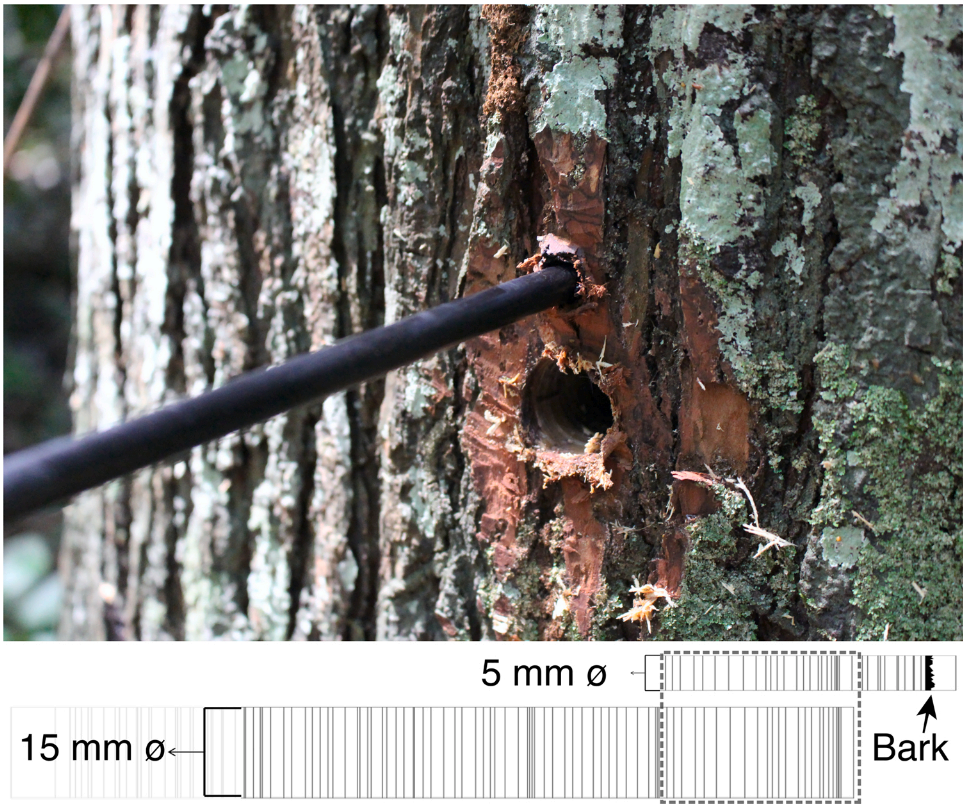

Fig. 6. Scheme of sampling and crossdating the outermost part that might be damaged during the drilling.

There are lighter drilling systems available, which provide the operator with comfort during use by absorbing reaction forces and, at the same time, guaranteeing high-torque drilling (Kagawa and Fujiwara, 2018). However, systems that are powered by batteries are incompatible with the reality of field work in remote regions, where sometimes there is no electricity easily available for recharging. In addition, the aforementioned system adapts commercially available manual borers to an energy powered engine, limiting the sample size to the size of the borer. There are manual increment borers up to a meter in length, like those produced by Haglöf® (https://haglofsweden.com), but this nonetheless represents a disadvantage since it is not possible to manufacture custom-made drills for larger trees. As a result, it is important to know the circumstances of the field and the tree sizes targeted in order to choose the system that best suits the research needs.

A disadvantage of our presented system is, first, the weight (16,5 kg in total), which requires that it be divided between at least two people to carry it comfortably in the field. In addition, we noted that the outermost part of the sample may be damaged due to repeated removal and insertion of the drill during sampling. To avoid loss of information from the outermost rings, we used a manual increment borer to collect a short sample immediately above the collected core, to then crossdate the two segments (Fig. 6). This results in more damage to the tree and more time spent sampling, but on the other hand, it enhances the quality and precision of the sampling, fitting the collector choose what best serves at the time of collection.

Another limitation is that the system requires even, stable ground for the operator to work and a regular surface on the trunk to install the support. This makes it near to impossible to collect trees on very irregular terrain (i.e. hillsides) and with very irregular trunks. With the wear and formation of small teeth close to the Widia© blades, it is still possible to continue sampling but, eventually, the cutting tip must be replaced. This requires that the drill to be taken to a professional turner to weld a new tip, which represents a limitation since this process cannot be done in the field. Therefore, it is recommended that field work for remote regions be planned in order to avoid these problems, by taking extra drills to the field or including moving to locations where repairs can be done accordingly.

5. Conclusions

This system represents an advance on systems previously presented to the dendrochronological community for non-destructive sampling of trees. The most notable advance presented here is the portability and high stability provided by the support which allows efficient collection of samples from extremely large trees, something which has always been a great challenge to be collected in remote tropical regions. The widespread popularization and application of methods for collecting large tropical trees will bring important insights into the mechanisms that influence tree growth and forest dynamics in tropical forests in different regions around the world. This carries a great potential for future analyzes concerning the extension and compilation of dendroclimatological data, human influence on forest dynamics, maximum ages and further ecological studies of elderly tropical trees.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.dendro.2021.125860.

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