Journal of Tropical Forest Science 29(4): 519–529 (2017)
https://doi.org/10.26525/jtfs2017.29.4.519529

SHORT-TERM EXTERNAL EFFECTS OF INCREMENT CORING ON SOME TROPICAL TREES

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Submitted December 2016; accepted May 2017

The invasive technique of increment coring may be unavoidable in forest ecology research requiring data on wood traits. Despite this, no study has examined the effects of increment coring on tropical forest trees. We cored 35 trees of 11 species from nine families, with wood densities ranging from 0.30 to 0.69 g cm^{-3}, at two sites in Singapore. Tree survival, borehole closure and external signs of damage resulting directly from the coring were monitored for 1 year. Tree radial growth was estimated from changes in diameter at breast height. Of the cored trees, only one died after 1 year. Twenty-five out of the 35 trees had at least one closed borehole, and the median time to closure was 10 months. The species of tree cored was the only significant predictor of borehole closure. We observed three main categories of external damage: discoloured bark, surface wounds and the presence of fungal fruiting bodies or insects within the boreholes. Changes in the trunk diameter were not significantly different between cored and uncored trees. Our results suggest that increment coring in the tropics does not negatively impact the survival and growth of some species of tropical forest trees within the first year after coring.

Keywords: Plant disease risk, wounding, trunk wound response, tree radial growth

INTRODUCTION

Increment coring is an invasive process which involves the use of an increment borer to extract cylindrical wood samples from living trees, inevitably causing some injury to the trees. It has conventionally been practised in forestry for decay detection to examine tree growth (Meyer & Hayward 1936), wood density and anatomy (Lawton 1984, Francis 1994), as well as for dendrochronology (Eckstein & Dujesiefken 1999). Outside of these traditional areas of study, tree coring has in recent years become necessary also in theoretical and applied environmental research areas that are rapidly growing in popularity such as the estimation of wood density or wood specific gravity for the study of tree functional traits (e.g. Chave et al. 2009, Schüller et al. 2013), the assessment of forest carbon stock (e.g. Martin & Thomas 2011), and the approximation of sapwood area (e.g. Parolin et al. 2008, Pfautsch et al. 2012) in the study of plant water use (e.g. Smith & Allen 1996) or forest ecohydrology (e.g. Asbjornsen et al. 2011). Extracting a tree core can often be a more feasible alternative to obtaining a trunk section or felling the whole tree, especially when the tree is valuable for other reasons. A considerable body of literature has been developed on the effects of increment coring on the health and mortality of temperate coniferous and deciduous tree species. In general, the wound left behind by an increment borer has been found to be susceptible to fungal infection, cankers, splitting of the bark around it, and poor healing (Lorenz 1944, Clark 1966). Reactions to wounding have been found to be dependent upon many factors, including the species of the tree (Hepting et al. 1949, Laflamme 1979, Dujesiefken et al. 1999), tree vigour (Lorenz 1944), whether the tree is fast or slow growing (Neely 1988), and whether the tree has resin or latex (Meyer & Hayward 1936, Grissino-Mayer 2003). As with other kinds of tree wounds, damage caused by increment coring on tree trunks can usually be compartmentalised, and the wound closed within 2 to 3 years (Shigo & Shortle 1983; Norton 1998). Most studies did not find conclusive evidence for increased mortality or negative effects on health over time in cored trees in comparison with uncored trees (Norton 1998, van Mantgem & Stephenson 2004, Harris et al. 2009, Wunder et al. 2011). Only a handful of studies have reported poor healing of the boreholes even after many years (Hepting et al. 1949, Clark 1966).

The current emphasis in the literature on increment coring studies situated in managed forests and temperate latitudes was highlighted in a recent review by Tsen et al. (2016). The authors outlined the gaps in tree coring research and the need for studies outside of these systems and on a wider diversity of species. Dendrochronological studies in the tropics have been limited, owing to a lack of consensus about whether growth rings can be determined from tropical wood samples (Worbes 2002). The relevance of increment coring in the tropics has only recently increased because of other forest ecology applications. To our knowledge, there is no study that has looked at the effects of increment borer coring specifically on the survival, health and growth of tropical tree species. There is thus a need to address this information gap and to boost the documentation in this area of research.

The risk of fatal trunk damage and colonisation by fungi is higher for trees growing in warmer and wetter climates (Grissino-Mayer 2003, van Mantgem & Stephenson 2004). Although this has not been directly demonstrated, Tsen et al. (2016) showed in a meta-analysis that wounding at lower latitudes did not necessarily result in more adverse effects in the tree. Wounds inflicted at lower latitudes were found to close significantly faster than those at higher latitudes—however, the studies examined by Tsen et al. (2016) were restricted to latitudes of 33° and above only. A handful of studies have investigated the effects of other types of tree wounding in Neotropical species, but not increment coring. For example, Guariguata and Gilbert (1996) examined the rates and mechanisms of drill-wound closure in seven tree species in Panama, and found that wound closure mechanisms differ by species. Another study by Romero and Bolker (2008) looked at the damage caused by the removal of sections of the stem of seven species in the Bolivian Amazon, and found that xylem and phloem traits are related to wound closure rates. Other studies have investigated the use of tree climbing spikes in the Amazon and found no difference in survival between trees that were wounded by climbing and those that were not wounded (Phillips et al. 1998, de Castilho et al. 2006).

Given the immense diversity of tree species in the tropics, there is a need to test if what has been observed in Neotropical species is generalisable to other tropical regions. Moreover, given that a high proportion of tropical tree species are rare or threatened, insights on the impacts of wounding or increment coring on tree health and mortality will be invaluable when decisions must be made about conducting studies that necessitate such invasive data collection. Documenting and understanding the effects of coring and how they progress through time is necessary for the effective management of the cored trees.

We conducted increment coring on some secondary forest trees in Singapore. The responses of the trees to wounding were monitored for 1 year after coring. We looked at natural borehole closure and how some of the characteristics of the cored trees might be linked to the rates of closure. Some studies have found that tree size can determine the rate of borehole closure. Larger trees were found to close their wounds earlier, but smaller trees tended not to heal as well, with some even developing large wounds at the site of coring (Lorenz 1944, Clark 1966). Contrary to this, Guariguata and Gilbert (1996) did not find that initial tree size significantly affected wound closure within the first 3 months after wounding. Wound closure rates have also been shown to vary by species, which might be explained by interspecific variations in wood traits (Neely 1988, Guariguata & Gilbert 1996). Wood density is closely related to the growth strategies of trees—fast-growing, light-demanding species generally have low wood densities, and slow-growing, less light-demanding species have higher wood densities (Lawton 1984, Poorter et al. 2010). It can thus be inferred that species with higher wood densities may take longer to complete borehole closure. We also examined the cored trees for signs of coring-related external damage. This included discolouration of the bark, changes in the extent of wounds in the bark or cambium layers, and the presence of fungal fruiting bodies or insects within the boreholes. We investigated how these effects might be related to the rates of borehole closure. Finally, by matching each cored tree to an uncored individual of the same species and similar trunk diameter at breast height (DBH), we compared if wounding affected changes in DBH over the year. From our findings, we draw some conclusions about the immediate and short-term effects of increment coring on the survival, health and growth of tropical tree species.

MATERIALS AND METHODS

Increment coring and monitoring of cored trees

Singapore is a city state in South-East Asia, located just north of the equator (1° 22' N, 103° 48' E) at the southern tip of Peninsular Malaysia. The climate is equatorial and is characterised by a narrow diurnal temperature range (23–31 °C on average), high humidity, and annual rainfall of more than 2000 mm that is rather uniform throughout the year (National Environment Agency (Singapore) 2016). The growing season for plants is thus year-long. We carried out increment coring on 35 trees on Singapore Island from July–August 2013. The trees were from 11 species and nine families. Twenty-five of the cored trees were of species which were non-native but common in local regenerating vegetation (Neo et al. 2013a, b). These comprised a mixture of street trees and dryland secondary forest trees found on the Kent Ridge Campus of the National University of Singapore (1° 17' N, 103° 46' E). The remaining 10 trees were native species from Springleaf Forest (1° 23' N, 103° 48' E), a small patch of secondary forest in the centre of Singapore Island that comprises a mixture of dryland secondary forest and degraded freshwater swamp forest. We selected species common in the respective habitats. The list of species under study, their native or non-native status in Singapore (Chong et al. 2009), and the number of trees cored per species, are presented in Table 1. Trees were selected following visual inspection to ensure that they were healthy, well-growing and non-suppressed individuals without disease. Prior to coring, we measured the DBH of each tree at 1.3 m above the ground, and the position at which DBH was measured was marked out along the trunk for future re-measurements at the same spot. We photographed the tree crown and trunk to document the health of each tree. We selected trees that were at least 5 cm in DBH and ensured that there was a representative range

Table 1 Details of the 35 trees cored in this study

Species	Family	No. of trees cored	Native status/site	Initial DBH range (cm)	Average wood density (g cm^{-3})
Acacia auriculiformis	Fabaceae	5	Non-native/Kent Ridge	10.3–83.0	0.680
Adenanthera pavonina	Fabaceae	5	Non-native/Kent Ridge	7.9–87.5	0.687
Falcataria moluccana	Fabaceae	5	Non-native/Kent Ridge	11.7–98.5	0.310
Hevea brasiliensis	Euphorbiaceae	5	Non-native/Kent Ridge	8.8–34.4	0.467
Muntingia calabura	Malvaceae	1	Non-native/Kent Ridge	9.0	0.300
Spathodea campanulata	Bignoniaceae	4	Non-native/Kent Ridge	14.3–50.0	0.351
Campnosperma auriculatum	Anacardiaceae	1	Native, common/ Springleaf Forest	47.5	0.327
Knema malayana	Myristicaceae	2	Native, endangered/ Springleaf Forest	9.6–11.4	0.630
Macaranga gigantea	Euphorbiaceae	2	Native, common/ Springleaf Forest	12.0–19.9	0.295
Pellacalyx axillaris	Rhizophoraceae	3	Native, endangered/ Springleaf Forest	26.1–55.3	0.380
Xanthophyllum flavescens	Polygalaceae	2	Native, endangered/ Springleaf Forest	14.5–20.9	0.642

of sizes for most species. The ranges of initial trunk DBH of the cored trees are given in Table 1. At each site, each cored tree was paired with an uncored tree of the same species and similar DBH (the experimental control). Two cores were taken per tree, one at 5 cm above the point of measurement of DBH and one at 5 cm below. We used a 20.32 cm (8 inch) long increment borer that was 5.15 mm in outer diameter, and each core was taken perpendicular to the longitudinal axis of the trunk to a depth either equivalent to the radius of the tree or 20.32 cm, whichever was shorter. The increment borer was disinfected with 70% ethanol between trees to prevent the spread of pathogens from tree to tree. None of the boreholes were artificially plugged or filled up, as the disadvantages of plugging on tree recovery have been known to outweigh the benefits (e.g. Hepting et al. 1949, Eckstein & Dujesiefken 1999, Grissino-Mayer 2003).

Monitoring was conducted bi-monthly to assess the health of both cored and uncored trees, and to determine if there was natural borehole closure. Healing is defined as a process by which damaged cells are replaced in the same spatial position (Shigo 1984). Hence, we defined natural borehole closure as the unassisted filling up of boreholes with wood, and we visually deemed boreholes as closed when the surface opening was completely sealed off. Visual observations were made of tree survival and external abnormalities of the trunk, especially in the area immediately around the boreholes. We looked for staining of outer bark, splitting, swelling or decay of the bark, dieback in the bark or cambium layers, and colonisation of the boreholes by fungi or insects. These effects were photographed. At each 2-month interval, we remeasured the DBH of each tree.

Data analyses

We conducted Kaplan–Meier survival analysis on time to borehole closure (an 'event') in all cored trees. We used the 'survival' and 'KMsurv' packages in the statistical programming environment R, version 3.1.1 (2014). An event was considered to have occurred in an individual tree if at least one of the two boreholes had closed. Borehole closure was assumed to be independent among trees and constant over the monitoring period. Observations were right-censored if the monitoring period ended before borehole closure. A log-rank test was used to compare the differences in time to borehole closure in the two study sites. This test is sensitive to late differences in survival (boreholes remaining open), under the assumption of proportional hazards.

Initial trunk DBH and species were fitted as predictors to logistic regression models of borehole closure. Backward dropping of the predictors was performed, followed by a chi-squared test between pairs of models at each step. To test if wood density had an effect on borehole closure rates, a Spearman's correlation test was conducted between wood density and the number of trees of each wood density value with at least one closed borehole at the end of the monitoring period. We calculated the average wood density of each species (in Table 1) from wood density values obtained from the Global Wood Density Database available online (Chave et al. 2009, Zanne et al. 2009). We also tested for differences in closure between boreholes which had discoloured bark and/or surface wounds and those which did not. Pseudo-replication can cause the interpretation of results to be problematic, in tree-coring studies which have treated individual wounds as individual units of experimentation even if there were multiple wounds per tree (Tsen et al. 2016). We therefore used mixed-effects logistic regression models with each tree as random effect to account for the fact that boreholes were nested within trees (there were two non-independent boreholes per tree). Survival analysis was also conducted on the probability of occurrence of surface wounds around the boreholes (an event), followed by a log-rank test to compare between the two study sites.

RESULTS AND DISCUSSION

Mortality

At the end of the 1-year monitoring period, two of the 70 trees had died. Both trees were of the native species, *Macaranga gigantea*, and one was cored while the other was not cored. The cored tree was completely defoliated at 10 months after coring, and we confirmed it to be dead at 12 months after coring. The uncored tree was found uprooted at 12 months after coring. No abnormalities of the trunk, around the borehole or otherwise, were observed in the two trees. Given that *M. gigantea* is a relatively short-lived, fast-growing pioneer species (Davies 2001), and that both individuals were large-sized for this species (of 10–20 cm in DBH), the cause of death could have been weakening of tree structure or declining health at old age. Our overall findings nevertheless concurred with other studies that found no significant differences in mortality rates of wounded trees compared with unwounded trees, whether in the short (Phillips et al. 1998, de Castilho et al. 2006) or long term (van Mantgem & Stephenson 2004, Wunder et al. 2011).

Borehole closure

One year after coring was conducted, 25 of the 35 trees had at least one closed borehole (Figure 1). Since tree responses to wounding can be influenced by species-specific and site-specific characteristics, we compared borehole closure between the two study sites. At Kent Ridge, where only non-native species were cored, 3 out of 50 (6%) of the boreholes were closed at 2 months after coring, and 34 out of 50 (68%) were closed at 1 year after coring. In comparison, at Springleaf Forest, where only native species were cored, all boreholes remained open at 2 months after coring, with 2 out of 20 (10%) closed at 4 months after coring, and 10 out of 20 (50%) closed at 1 year after coring. Median time to closure overall, i.e. the number of months taken for at least one borehole to close in half of the trees, was 10 months (Figure 2). Median time taken was 6 months at Kent Ridge and 12 months at Springleaf Forest. However, this difference was not statistically significant (log-rank test p = 0.166).

Time taken for wound-healing varies widely in published studies. In a study of wounded temperate deciduous and coniferous species, 24% trees did not have complete closure at 10 years after coring (Tsen et al. 2016). Also in temperate deciduous tree species, wounds smaller than 12 mm in width were closed within 1 year (Neely 1988), and wounds of 10 mm in width were closed within 10–20 weeks (Martin & Sydnor 1987). In seven Neotropical tree species, 7 mm-

Figure 1 Examples of borehole closure in (a) *Adenanthera pavonina*, (b) *Falcataria moluccana*, (c) *Campnosperma auriculatum* and (d) *Xanthophyllum flavescens*; bright red markings indicate the position on the trunk where DBH was measured

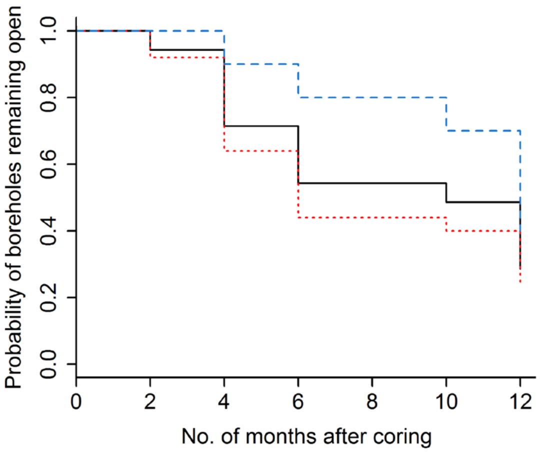

Figure 2 Kaplan-Meier curve of borehole closure in all trees (solid line), native trees at Springleaf Forest (dashed line) and non-native trees at Kent Ridge (dotted line)

wide drill wounds were found to take between 3 to 22 months to completely close (Guariguata & Gilbert 1996). On the other hand, none of the 5 mm-wide boreholes in 20 trees of a temperate deciduous species were found to have healed after 3 years (Laflamme 1979). Our results showed an average to above-average rate of borehole closure and provided some support for the observation of Tsen et al. (2016) that wounds made at lower latitudes may close significantly earlier because of the more favourable growing conditions of warmer and wetter climates. Although the complete closure of a wound does not necessarily preclude internal decay, it is likely that wounds which close earlier have lower exposure time to pathogens from the environment (Tsen et al. 2016).

In testing the effects of initial trunk DBH and species on the probability of borehole closure at 1 year after coring, the interaction term was not significant ($X^2 = 2.80$, p = 0.947). Subsequently, species was found to have significant effect when dropped from the statistical model ($X^2 = 22.7$, p = 0.0117), but not initial DBH ($X^2 = 3.45$, p = 0.0634). These results suggested that species of the tree had strong influence on the rate of borehole closure, but initial trunk DBH did not. The ability of a tree to properly compartmentalise an injury is genetically-controlled (Shigo 1984). Differences in wood structural traits may also explain why borehole closure rates vary by species (Neely 1988, Guariguata & Gilbert 1996, Dujesiefken et al. 1999). In temperate regions, broad-leaved species show higher rates of borehole closure within a shorter time than coniferous species, which have longer trajectories of borehole closure (Tsen et al. 2016). When we looked at borehole closure by individual species, we found that at 1 year after coring, all boreholes were left open in two species (*Muntingia calabura* and *Knema malayana*), while four species had complete closure of all boreholes (*Hevea brasiliensis*, *Spathodea campanulata*, *Campnosperma auriculatum* and *M. gigantea*) (Figure 3). The *H. brasiliensis* trees were either remnant or escapee trees from past cultivation for commercial rubber tapping in the area. *Spathodea campanulata* is a pioneer and often invasive species of many tropical secondary forests (Lugo & Helmer 2004). *Campnosperma auriculatum* and *M. gigantea* are fast-growing, disturbance-adapted, secondary forest species (Shono et al. 2006). All four species for which all boreholes had closed had low or medium wood density values, which seemed to suggest a relationship between wood density and wound closure. However, the correlation between wood density and the number of trees of each species with at least one closed borehole was weak and non-significant (Spearman's $\rho = 0.205$, p = 0.882). This might be accounted for by the fact that other species with low or medium wood density values showed less than 100% closure (*Falcataria moluccana* and *M. calabura* showed 70 and 0% borehole closure respectively). Although lower wood density is associated with more rapid growth, a competing argument suggests that a trade-off between investing in growth instead of damage protection in fast-growing species should conversely result in slower borehole closure than slower-growing species (Guariguata & Gilbert 1996, Tsen et al. 2016). It may be necessary to test the relationship between wood density and wound closure on a larger sample and wider range of tropical species of different wood densities to investigate these conflicting hypotheses.

Discoloured bark around boreholes

Discoloured bark (darker in colour than the surrounding) around the boreholes was the most prevalent effect of wounding that we observed in our study (Figure 4). Discoloured bark is a common sign of injury and can suggest either incipient decay or a phenomenon known as 'wetwood' (Shigo & Hillis 1973, Shaw et al.

(a)

(b)

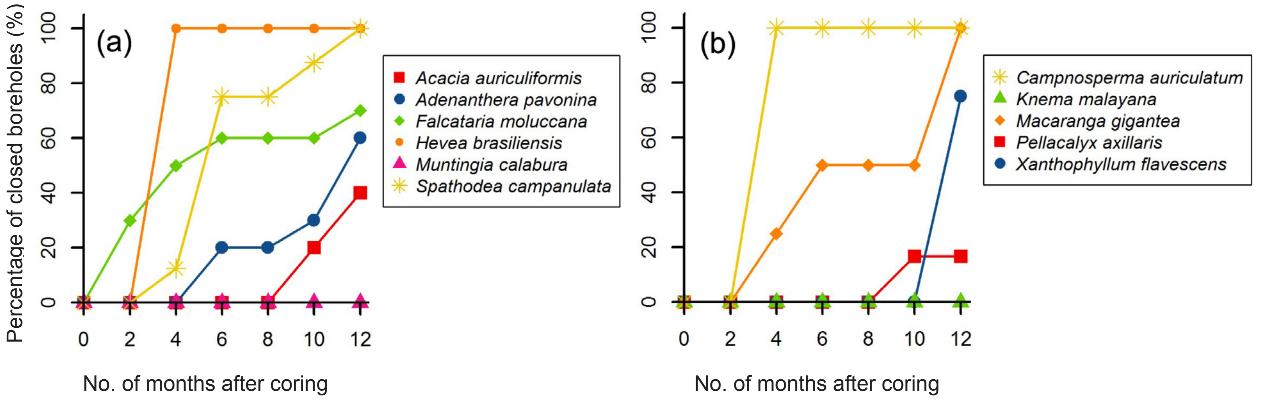

Figure 3 Borehole closure over 1 year; percentage of closed boreholes of the total number of boreholes cored per species at (a) Kent Ridge and (b) Springleaf Forest

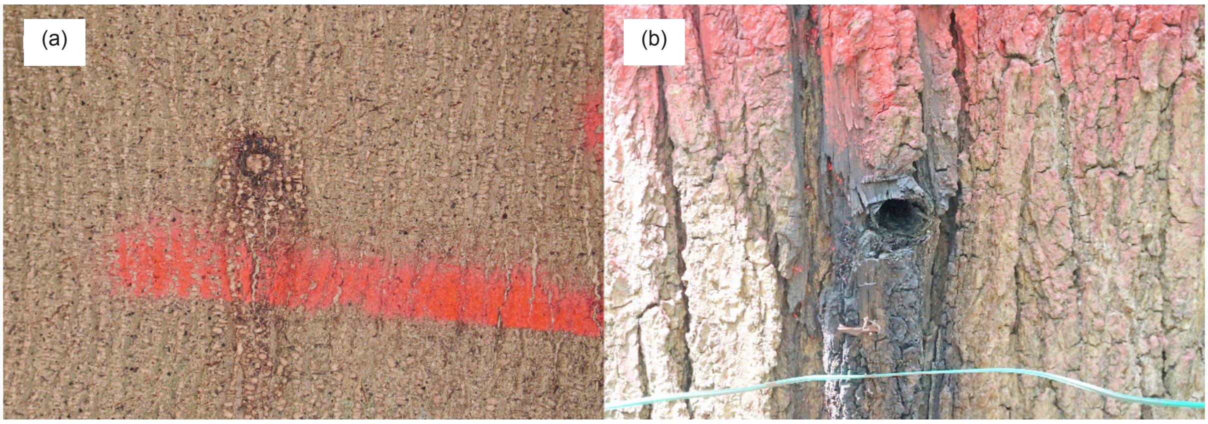

Figure 4 Examples of discoloured bark (dark colour) around the opening of boreholes in (a) *Falcataria moluccana* and (b) *Acacia auriculiformis*; bright red markings indicate the position on the trunk where DBH was measured

1995). Wetwood is recognised as a water-soaked appearance in wood and may be caused by bacterial or mould infection, or it may be a general physiological response to mechanical wounding (Ward & Pong 1980, Shaw et al. 1995). Wetwood is known to be associated with a distinctive odour (Ward & Pong 1980, Worrall & Parmeter 1982), but this was not observed in our study trees. Unfortunately, because it was not within the scope of our study to examine the extent of internal decay in each tree, or perform cultural isolation of microorganisms, we could not confirm if the discoloured bark we observed was truly indicative of incipient internal decay. We also could not confirm if the discoloured bark indicated wood discolouration. The response of a tree to a wound has been understood to follow a model of compartmentalisation of decay (Shigo 1984), which leads eventually to the formation of an internal barrier zone that isolates the impacted wood from the rest of the trunk. Following the creation of a wound in a tree, wood within the region of injury will often become discoloured as a result of electrophysiological and chemical processes in the living cells (Shigo & Hillis 1973, Shigo 1984). Wood discolouration around the site of extraction is generally accepted as a component of the first stage of a natural responses of the tree to wounding and is one of the most commonly observed effects of tree coring (Hepting et al. 1949, Shigo & Hillis 1973, Dujesiefken et al. 1999). Wood discolouration does not necessarily imply decay or negative consequences for tree health (Lorenz 1944, Shigo 1984), although the amount of discolouration is known to be greatest in species with weak compartmentalisation (Eckstein & Dujesiefken 1999). At the end of our study, 32 out of 70 boreholes (46%) had discoloured bark around them. However, there was no significant difference in the proportion of boreholes closed between those with discoloured bark and those without ($X^2 = 3.24$, $p = 0.0717$). The proportion of trees per species which had discoloured bark around at least one borehole is shown in Table 2.

Surface wounds around boreholes

We use the term 'surface wounds' here to refer to anything ranging from vertical cracks or splits in the outer bark above and below the borehole (Figures 5a and b), to large areas of outer bark to cambial dieback (Figures 5c and d). Despite the lack of significant differences in borehole closure by initial trunk DBH, we observed surface wounds more often in trees with smaller initial DBH than in the larger trees. This is in accordance with what has been reported in other studies (Lorenz 1944, Clark 1966). However, while splits in the bark near the site of coring are thought to retard borehole healing (Laflamme 1979), we did not find significant differences in the proportion of boreholes closed among those with surface wounds and those without ($X^2 = 2.35$, $p = 0.1255$). Although the probability of surface wounds being observed in the native trees at Springleaf Forest was higher compared with non-native trees at Kent Ridge, this was not significantly different (Figure 6, log-rank test $p = 0.289$). The proportion of trees per species which had surface wounds around at least one borehole is shown in Table 2.

Presence of fungal fruiting bodies and arthropod fauna inside boreholes

The wound orifice created by an increment borer is a site for opportunistic infection by fungal spores or for colonisation by insects. The presence of fungal fruiting bodies (Figure 5c) or insects was noted in about one-third (35.7%) of the boreholes. An overview of these occurrences by tree species cored is presented in Table 2. Fungal fruiting bodies were visually observed in six boreholes. Infection of large surface wounds by fungi may exacerbate the impact of the wound itself (Hepting et al. 1949). Colonisation of the boreholes by arthropods may also have unknown effects on borehole closure. Opportunistic utilisation of the boreholes by insects was observed in 22 instances. The diversity of insects colonising the boreholes appeared to differ by tree species and by site of coring. At Kent Ridge, ants and termites were the only group of insect colonisers, while at Springleaf Forest, fly larvae and beetles were also observed. The difference in the incidence of fungal fruiting bodies and insect colonisation among tree species or sites suggests that certain tree species may be more susceptible than others to the invasion of their wounds. However, with our small sample sizes per tree species, we could only make qualitative observations regarding this.

Table 2 Summary of the external effects of wounding by tree species cored

Species	% with discoloured bark	% with surface wounds	Presence of fungal fruiting bodies	Type of insect colonisation
Acacia auriculiformis	80	80	No	Ant/termite trails
Adenanthera pavonina	40	100	No	Ant/termite trails
Falcataria moluccana	100	40	1 tree	Ant/termite trails
Hevea brasiliensis	40	20	No	Ant/termite trails
Muntingia calabura	100	100	1 tree	None
Spathodea campanulata	0	25	No	None
Campnosperma auriculatum	33.3	0	No	Fly larvae
Knema malayana	50	100	1 tree	Beetles
Macaranga gigantea	100	0	No	Ant/termite trails
Pellacalyx axillaris	50	0	No	Insect larvae; ant/termite trails
Xanthophyllum flavescens	100	50	No	Beetles

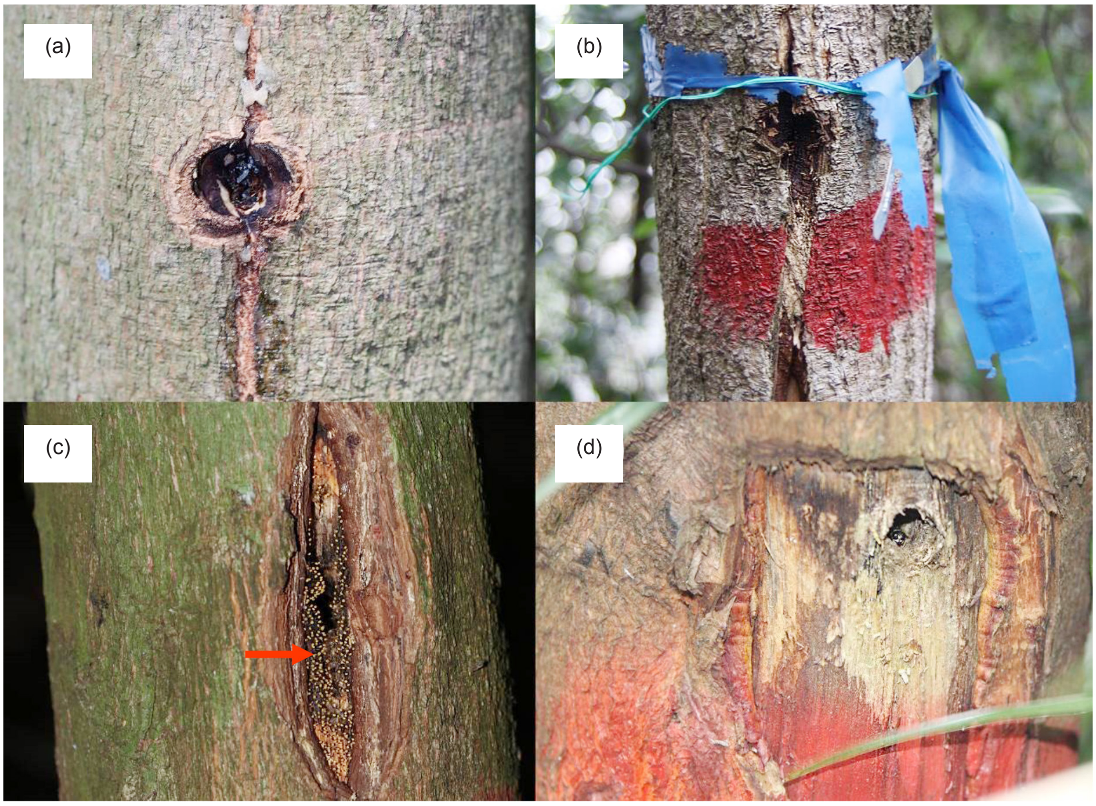

Figure 5 Examples of surface wounds in cored trees: (a and b) vertical cracking or splitting of the bark above and below the borehole, (c and d) large areas of outer bark to cambial dieback around the borehole; yellow dots (arrowed) are fungal fruiting bodies, bright red markings indicate the position on the trunk where DBH was measured

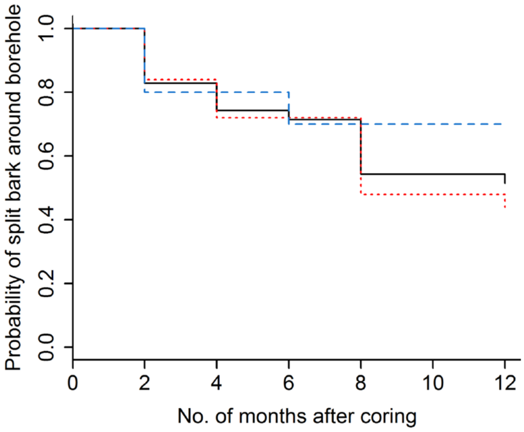

Figure 6 Kaplan-Meier curve of surface wounds around individual boreholes of all trees (solid line), native trees at Springleaf Forest (dashed line) and non-native trees at Kent Ridge (dotted line)

Changes in DBH

Previous studies have indicated that wounded trees did not have slower growth rates compared with unwounded trees (Neely 1988, de Castilho et al. 2006). We measured tree radial growth in terms of changes in DBH. DBH increase was greater in uncored trees compared with cored trees at 2 months after coring (Figure 7).This suggested that there was an initial redirection of resources from growth to coping with wounding in the cored trees. However, following this immediate response, DBH changes were not significantly different between the cored and uncored trees from the fourth month after coring onwards. There was an overall increase in DBH throughout our monitoring period in the cored and uncored trees alike.

CONCLUSIONS

Increment coring was found not to have any significant negative impacts on the survival and growth of 11 species of tropical forest trees within the first year following coring. Borehole closure also seemed to proceed quite rapidly in the tropics, at least for nine of the 11 species that we studied. The species of each tree was the only significant determining factor for the rate

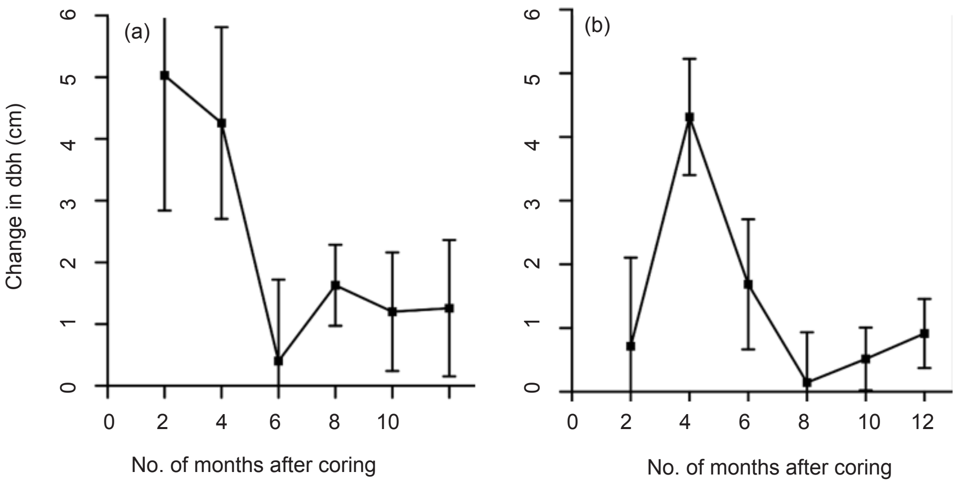

Figure 7 Changes in DBH over 1 year in (a) uncored and (b) cored trees

of closure. Small wounds such as those caused by increment coring may weaken a tree, but our study suggests that they may not contribute significantly and immediately to tree death. The next step for tree coring research in the tropics would be to examine how the main types of external damage arising from increment coring may relate to or predict internal damage in the trunk, if any.

ACKNOWLEDGEMENTS

We thank ATK Yee for advice on improving the manuscript, and LX Soong, MS Ahmad Muqit, JP Wong and FWZ Chong for their help in monitoring the health and mortality of the trees. We were supported by the National Parks Board, Singapore research permit no. NPRP13-009-2c and grant no. R-347-000-198-490.

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