NEW APPROACHES TO THE ARCHAEOLOGICAL INVESTIGATION OF CULTURALLY MODIFIED TREES: A CASE STUDY FROM WESTERN CAPE YORK PENINSULA

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Abstract

There is a wealth of ethno-ecological knowledge and ethnographic material on the use and creation of tree products in contemporary and classical Aboriginal societies, including western Cape York Peninsula. However, culturally modified trees (CMTs) associated with the collection of tree products in the past have been subject to relatively little research in Australia despite being often highly valued by Aboriginal communities. In western Cape York Peninsula, CMTs are a very common element of the archaeological record and are routinely identified in cultural heritage management work undertaken ahead of extensive strip mining operations occurring in the region. This paper reviews the methods and results of work harnessing both well-established and emerging technologies relevant to the archaeological investigation of culturally modified trees, including statistical analysis, spatial analysis, dendrochronology and dendroecology. We argue that techniques such as these can provide valuable insights into Aboriginal lifeways in the pre- and post-contact eras and generate results that are of value to community groups concerned about the ongoing destruction or removal of these features, as well as other parties involved in heritage assessments and management of CMTs in the region.

Introduction

Aboriginal Culturally Modified Trees (CMTs) are commonly encountered during archaeological surveys in Australia, are highly valued by Aboriginal community members and are often a prominent part of heritage interpretive strategies. However, despite this, archaeologists have tended to neglect
CMTs as the subject of serious research. They are routinely noted in regional studies and cultural heritage management work (David 1996; Godwin et al. 1999; Pardoe 2003; Rowland et al. 1994; Shiner and Morrison 2009) and a considerable proportion of research on CMTs has concentrated on those with symbolic engravings or carvings (Carver 2001; Grimwade et al. 1995; Lees 2010) or those scarred through the removal of bark or wood for canoes or other smaller items of material culture (Czerwinski 2002; Edwards 1972). Most published studies have tended to focus on methodological issues, particularly diagnostic criteria and recording techniques (Grimwade et al. 1995; Irish 2004; Lees 2010; Long 2005) though there has been notable work on using CMTs to examine patterns in past land use and resource collection (Rhoads 1992; Webber and Burns 2004). Here we argue that CMTs should be the focus of considerably more research than has previously been the case and outline examples of how such work can make novel contributions to our understanding of past Aboriginal lifeways while also informing management strategies in contexts where CMTs are threatened.

International examples highlight the range of insights that analytically focussed investigations of CMTs can bear, particularly in North America and Scandinavia where they have been used to explore important aspects of past Aboriginal lifeways inaccessible via other archaeological sources. For example, dendrochronological analysis of CMTs gives access to fine-grained temporal data concerning land use and demography, particularly for the recent past (Martorano 1981; Mobley and Lewis 2009; Pegg 2000; Prince 2001). Analysis of CMT distribution patterns have facilitated examination of regional subsistence and resource management practices (Marshall 2002; Östlund et al. 2002; Wilke 1988; Stryd and Eldridge 1993), while historical documents, ethnographies and oral histories have been productively used alongside CMT data to demonstrate the important and often under-appreciated role of tree products in Indigenous societies (Gottesfeld 1992; Swetnam 1984; White 1954).
The reasons for the limited extent of analytical work on CMTs in Australia are likely diverse, however we suggest two key factors. First, CMTs typically represent a single event at a specific moment in time and thus provide only a very narrow insight on past Aboriginal lifeways. Second, it is difficult to easily assess the age of CMTs and despite some success in commercial contexts (Long et al. 2005), to date no Australian study has published age determinations on CMTs. These factors constrain the ability of archaeologists to incorporate CMTs into regional or local syntheses or to generate new information that can be incorporated into community interpretation strategies.

Here we propose that there are compelling reasons for archaeologists to see CMTs as the subject of serious research. These unique sites provide a valuable yet neglected source of information about the lifeways of Aboriginal people in the past; in particular, their presumably young ages and the frequency with which they occur in some regions affords a unique opportunity to explore specific questions about continuity and change in Aboriginal economies and patterns of landscape use through the colonial period and into the 20th century.

We illustrate the potential of CMT research through a case study from Weipa, on Cape York Peninsula (north east Australia) where we are undertaking research on a growing database of CMTs that have primarily been recorded during cultural heritage management work associated with mine clearance. We explore the insights generated by both new and conventional methods such as statistical analysis, spatial analysis and dendrochronology and argue that such techniques provide important insights when CMTs are analysed collectively, via a regional approach, rather than as isolated, individual sites. In short, we call for more sophisticated research on CMTs to address substantive questions about pre- and post-contact Aboriginal lifeways and to support Aboriginal peoples’ aspirations for improved management of these features.
The Study Area
Western Cape York Peninsula is located well within the north Australian tropics, with an annual rainfall of over 1600 mm annually, the bulk of which occurs during the summer months (December to February). Extensive, open sclerophyll woodlands are a dominant feature of contemporary landscapes in the region and of particular note is a vegetation community known locally as messmate or ‘timber country’ by local Aboriginal people (Figure 2) and as *Eucalyptus tetradonta* woodlands according to Queensland Herbarium...
classifications (Anon. 2005). These woodlands are extensive across western Cape York Peninsula and are supported by a unique geology that is relatively homogenous over a very large area, consisting of shallow (<50cm) soils overlying bauxite gravels that are typically three to five metres in depth (Godwin 1985; Taylor and Eggleton 2004). This landform, known as the Weipa Bauxite Plateau, is relatively flat and lacks any notable hills and rises only gradually as one moves eastward from the coast and towards the more geologically diverse Iron Range approximately 100km to the east near central Cape York Peninsula. The region is relatively well watered and shallow seasonal and permanent watercourses along with numerous small springs incise the bauxite plateaus. The plateau is abutted in coastal areas by younger, Quaternary sediments in the form of Pleistocene and Holocene dune systems, seasonal wetlands and rich forests and swamps, although there is considerable regional variation in the structure and extent of these more recent coastal systems.

Figure 2 An example of messmate or *Eucalyptus tetradonta* woodland near Weipa.
Ethnographic accounts indicate that pre-contact population densities in western Cape York Peninsula were among the highest in Australia (Chase and Sutton 1981; Sutton 1994). Although initial contacts between Europeans and Aboriginal people in western Cape York occurred during the 1600s (Sutton 2008; Wharton 2005), Aboriginal groups appear to have had only irregular and brief encounters with Europeans until more sustained invader/settler incursions into northern central Cape York Peninsula during the late 1800s.

Several small cattle stations were established in far northern Cape York in the 1860s, however it was not until the 1880s that several were established in the vicinity of Albatross Bay (Wharton 2005). The Native Mounted Police – a unit of the Queensland Police force made up mostly of Aboriginal men – were used to help maintain and expand pastoral activities by forcibly removing or ‘dispersing’ local Aboriginal groups through violence (Richards 2008) and some local massacres are noted in oral histories and fragmentary historical records (McNaughton 2006).

Invader-settler incursions were not restricted to land-based expansion for they also came by sea and from the 1880s Torres Strait-based pearl shelling and bêche-de-mer fishing boats sought Aboriginal people from the northern coastlines of Cape York as labourers (Kidd 1997:39; Loos 1982; Saville-Kent 1890). Reports of illegal recruiting, kidnapping and general mistreatment of Aboriginal labourers are documented in northern Cape York as early as 1884 and increasing after the late 1880s (Harrison 1974:37).

The violence and mistreatment associated with invader-settler expansion provided the justification for establishing Aboriginal reserves and missions on the northwest coast of Cape York Peninsula (Anderson 1988; Harrison 1974; Kidd 1997; Loos 1982; Wharton 2000, 2005). In 1892 the Presbyterian Church of Queensland took the advice of the Queensland Government and established a mission at Port Musgrave – later renamed Mapoon (Kidd 1997:39; Wharton 2000) (Figure 1). In 1898 a second mission was established on the upper reaches of the Embley River at a location known to contemporary Anhatangaith Traditional Owners as Waypanden and referred to as ‘Weipa’.
by missionaries while a third settlement was established at Aurukun to the south in 1904 (Wharton 2005). Today the region has four primary population centres at Aurukun, Weipa, Napranum and Mapoon (Figure 1).

**CMTs on Western Cape York Peninsula**

Since 2000 the scope and extent of archaeological and cultural heritage research in western Cape York Peninsula has expanded considerably from the previous focus on coastal shell midden sites. This work is being undertaken in two very different contexts. First, systematic cultural heritage management activities driven by local bauxite mine expansion commenced in 2003 and the focus on bauxite plateaus and messmate woodlands has resulted in the identification of thousands of CMTs with more than 1400 reported in one study alone (Shiner and Morrison 2009). Nowhere else in Australia have such large numbers of CMTs been reported and at a local level at least this prompted initial research to understand the cultural significance of these sites, in part to address management concerns associated with mine expansion (Morrison and McNaughton 2005).

A second key development in recent years has been an increase of research into topics or issues that have been identified by Aboriginal people and where community members drive the research process. Such work has a long tradition in western Cape York Peninsula (e.g., Cribb et al. 1988) and one clear theme that has emerged since 2000 is the need for greater research into post-contact Aboriginal histories. Missions are a major focus of community memory in Cape York Peninsula and associated places are often of high cultural significance and thus a key priority for senior Aboriginal people. The contemporary Aboriginal communities of Aurukun, Napranum and Mapoon trace their origins to the formation of mission settlements and for many older community members, a large portion of their childhood or early adult lives were spent under the authority of mission superintendents. At Napranum, conversations about priorities for historical and archaeological work almost always centre on mission histories. As a result, there has been an increasing amount of research investigating
intercultural engagements, economic change and contemporary cultural heritage values in these contexts (Barkley et al. 2008; McNaughton 2006; Morrison et al. 2010; Morrison and Shepard in press).

Community interest in post-contact histories and heritage values and the relatively newly emerged but extensive body of CMT data derived from cultural heritage management work have intersected to form an important and challenging area of research – namely exploring the cultural significance of CMTs. The large numbers of CMTs raise important management issues because the messmate woodlands in which they are found are the sole focus of extensive bauxite strip-mining activities with tens of thousands of hectares of woodland earmarked for mining over the coming decades. A range of CMT types have been documented within these woodlands, however, only some of these are amenable to archaeological analysis. Here we are primarily concerned with CMTs associated with the pre-1970 period, rather than those resulting from the more contemporary use of tree products.

**CMT Types**

There are four types of CMT in the region that are suited to archaeological investigation. All of these occur on Cooktown ironwood (*Erythrophleum chlorostachys*), a hardwood species common in savannah woodlands across northern Australia and well-known for its resistance to termite attack, fire and natural decay (Taylor 2002).

Scars associated with the collection of sugarbag or the wax and honey of Australian native stingless bees have been recorded in their thousands and are the most frequently occurring CMT type in the region (Shiner and Morrison 2009). Australian native bees are typically elusive and many species make their hives deep inside natural cavities within trees. In order to collect sugarbag it is necessary to cut open an aperture through which honey and wax can be removed. This aperture and the associated intense scarring are the key diagnostic feature for sugarbag CMTs (Figure 3). Toe-holds created to climb up to nests located higher in some trees are also recorded, while some have other kinds of axe marks, such as examples of unfinished apertures.
The second most commonly occurring CMT type are woomera scars. These very distinct CMTs are associated with the removal of uniquely shaped strips of wood from ironwood trees that were used in the manufacture of spear throwers or woomera. In many cases, several ‘woomera blanks’ were removed resulting in a series of adjoining scars extending around the bole of the tree (Figure 4). Again, the unique shape, intense axe scarring and large scar areas make these kinds of CMTs easily distinguishable.
There are a number of other kinds of CMT that are found in very small numbers. Occasional scars associated with making resin bats have been recorded and these are characterised by the removal of a 30-50cm long sheet of outer sapwood immediately beneath the cambium (Figure 5). This paddle-like tool was flat, elongated and examples from the Queensland Museum indicate they had an animal tooth or stone flake hafted on the handle. Oral and ethnographic accounts suggest these were used for smoothing the resin on spears after it was applied (Morrison and McNaughton 2005; Sutton 1994:48) and the scars have a distinctive symmetrical shape often with visible axe marks around the margin of the scar. Various types of ‘marker tree’ have also been recorded.

Figure 4 Example of a woomera or spear thrower CMT near Weipa.
in the region. In a number of cases, Traditional Owners have identified trees with symmetrical circular or ovate scars and also with often heavily weathered tool marks. Another unusual example of CMTs are those where large stones have been placed in the forks of numerous trees at specific sites. These are unlikely to be recent because in all cases, the tree has grown around the stone effectively fixing it in place. Senior Traditional Owners suggest such CMTs are markers that are associated with social conflict or competitive events.

![Figure 5 Example of a resin bat scar near Weipa.](image)

**The Archaeology of Wild Honey Collection**

Sugarbag scars have received the most attention from archaeologists in part due to their frequency both on the Weipa Peninsula and more broadly across the region. While other CMTs do require research in the future, here we outline the results of recent and ongoing work on sugarbag scars to address a range of questions about changes in Aboriginal economies and societies through the 19\textsuperscript{th} and 20\textsuperscript{th} centuries. Sugarbag CMTs have previously been used to explore the economic, social and cultural significance of Aboriginal labour and bush food production over the past century or more (Morrison et al. 2010). Ongoing work is investigating
sugar bag CMTs in order to better understand Aboriginal patterns of landscape use not represented in other archaeological datasets as well as on how sugarbag collection patterns changed through time.

Sugarbag CMTS have not been reported elsewhere in northern Australia although anecdotal accounts from consultant archaeologists in the Northern Territory and northern Queensland suggest they are found in other locations. This is not unsurprising, given that the wax and honey from various species of Australian native stingless bees (including *Austroplebeia* spp. and *Trigona* spp.) are of economic, social and symbolic value to many Aboriginal communities across northern Australia (e.g., Akerman 1979). Sugarbag scars have very distinct features and elsewhere it has been proposed that the shape and form of these features varied depending on the cultural and economic contexts in which sugarbag was being procured (Morrison *et al.* 2010; Morrison and Shepard in press). This work has proposed three key modes of sugarbag collection:

1. **Classical collection.** This method was proposed to have been used in ‘classical’ (Keen 2004) or pre-contact Aboriginal societies and involved the use of edge ground stone axes to create small apertures on trees to insert thin fibrous branches pounded to form sponge-like tips. These expedient tools were used to soak up and remove honey before cavities were sealed with grass or earth. Small aperture sizes and aperture sealing were practices used to encourage hive health. Oral histories indicated that trees were marked to denote ownership and that individuals returned to trees for subsequent re-use. This method was principally employed before and probably shortly after colonisation and saw the formation of small, inconspicuous scars with poorly defined axe marks.
2. **Classical methods with new technologies.** This method comprised much the same strategy as classical collection, but with the addition of both new technology in the form of steel axes, and increasingly residential foraging strategies as Aboriginal people moved into mission settlements. Scars associated with this strategy were argued to be similar in morphology but with more defined axe marks due to the use of sharper (steel) axes or hatchets.

3. **Intensive methods.** This method represented a significant shift in sugarbag collection. New types of scars appear with the use of larger steel axes mounted on long-handles, enabling large apertures to be created where increased quantities of honey and wax could be more easily extracted. These methods are thought to be linked with the emergence of land use strategies associated with the involvement of Aboriginal men in the cattle industry (after 1930) and the early mine exploration industry (after 1950).

Here we review results of archaeological research investigating whether these models are applicable and can be supported archaeologically, and thus whether there is tangible evidence of sugarbag collection strategies changing through the post-contact period.

**Statistical Analysis**

Well-designed statistical methods provide an important means of identifying trends and patterns within large datasets, for comparing variables and for interpreting the statistical significance of results. Rhoads (1992) demonstrated the utility of statistical approaches when applied to CMTs in western Victoria, arguing that the analysis of archaeological materials resulting from low-intensity activities can yield important insight into regional patterns. Recent work on sugarbag CMTs near Weipa has used a range of statistical methods to address several specific aims (Morrison and Shepard in press). First, what relationships exist between the size of sugarbag apertures – as a proxy measure of extraction intensity (i.e., the amount of sugarbag...
being collected) and other CMT attributes such as whether the tree had been felled or the number of scars per tree? Second, do samples of CMT data from different study areas indicate similar or different patterns in regards to scar frequency, collection method or morphology? In 2011, a database was compiled of all sugarbag CMTs on the Weipa Peninsula resulting in a total of 1502 sugarbag scars located on 982 individual CMTs. These records were used because they had largely been recorded by several of the authors (MM, ES) after 2004 and had consistent attribute data and images. Much larger datasets are available, however, these were beyond the scope of our trial.

Relationships between CMT attributes were investigated by performing several statistical tests. The Spearman’s Rank Order correlation was used to examine the relationship between height above ground and aperture size. This method provides a non-parametric measure of whether there is a correlation between both of these variables; for example, does aperture size increase with height above ground? While two sets of variables can be visually compared using a scatter graph, the use of Spearman’s Rank allows for statistical significance (p <0.05) to be measured.

A Mann-Whitney U test was used to explore differences in aperture size between felled and non-felled CMTs. Rather than explicitly exploring correlations between these variables, this test was used to assess whether aperture size was larger or smaller on felled and non-felled CMTs. As with Spearman’s Rank Order, this test arrives at measures of statistical significance: that is, what is the probability that these size differences are the result of chance (p <0.05)?

Finally, a Chi Square or goodness of fit test was used to explore the relationship between felling condition and the number of sugarbag scars found on each CMT. This tests the degree to which the observed number of scars per felled tree fits with what we would hypothesise might occur if these values were due entirely to chance. The test was used to compare the distributions of both felled and non-felled trees and number of scars on each CMT in the two study areas.
Although these are relatively simple statistical tests, the results point to some important patterns that require further investigation. The Spearman’s Rank tests indicated a statistically significant relationship whereby aperture size decreases with increased height above ground (p <0.05). This suggests that hive height above ground had implications for the way in which apertures were created and that targeting high hives may be associated with less-intensive or more classically oriented production activities. Other tests further support this view.

The Mann-Whitney U test indicated a statistically significant relationship (p <0.05) between aperture areas on felled trees and on non-felled trees with apertures on felled trees being larger in area and thus associated with more intensive extraction techniques. Finally, the Chi square test suggested that the proportion of CMTs with two or more scars is higher on felled trees than non-felled trees.

Overall, these results provide useful insight on whether collection practices documented through ethnographic and oral history work can be identified archaeologically. In particular, it illustrates that while no single variable on CMTs is a clear indicator of extraction intensity, the relationships between a range of variables can be used to illustrate that particular CMTs are more likely to be associated with more or less intensive production strategies.

**Spatial analysis**

Geographical Information System (GIS) based spatial analysis is a key area where technological approaches can yield important insights on historical patterns of sugarbag collection and patterns of landscape use more broadly. These methods have not been widely adopted in Australian archaeology, however, these tools can assist with interpreting the mass of CMT ‘point data’ that are emerging for western Cape York Peninsula and have distinct applications in other similar contexts. As with the conventional statistical methods, spatial analysis tools are best applied in relation to a specific and well-considered question in order to generate results that are meaningful and relevant in relation to broader research agendas. In this case,
spatial analysis aimed to identify relationships and correlations in scar frequency, distribution of felled and non-felled trees, aperture area and scar area. ESRI ArcGIS 10 was used to undertake these analyses.

One of the more attractive elements of GIS-based analysis is their capacity to allow for the analysis of relationships between archaeological datasets and other kinds of variables, such as environmental or cultural features. However, the spatial resolution of these datasets has a considerable bearing on the accuracy of these analyses. For this reason, it is important to draw on datasets of the highest possible resolution to avoid misleading or erroneous results. Here, all GIS datasets used were at 1:50,000 scale and at present these represent the highest accuracy spatial data available in the study area. Coordinate data for CMTs were collected with handheld consumer GPS devices and with variable accuracy between ±10 to ±30m.

**Spatial Extraction and Proximity Analysis**

The first round of analysis undertaken aimed to use GIS tools to generate new data about the environmental and historical contexts in which CMTs were found. These tools effectively add new data to each CMT record in the database based on their relationships to other variables represented within GIS datasets. They are particularly helpful because with relatively little effort new data can be generated about the relationships between each CMT, their immediate environmental context and spatial relationships to predefined areas of interest.

A spatial extraction query was used to add to information about the ecosystem and landzone for each CMT based on their spatial relationship to state-wide landzone and ecosystem datasets created by the Queensland Herbarium (Anon. 2005). The resulting data provide a useful overview of CMTs in the region: 95% of sites occur on bauxite plateau landzones and >91% occur within messmate woodland (Morrison and Shepard in press). This reflects two underlying factors. First, Cooktown ironwood – the primary species on which evidence of cultural modification survives – generally occurs in messmate woodlands and is less common in other ecosystems. Second, bauxite plateau landzones have
been the primary focus of the majority of cultural heritage surveys in the region as a result of mining-related development interests in these areas.

Non-bounded proximity analysis was used to calculate distance between CMT locations and the nearest freshwater watercourse. This tool effectively searches to find the nearest adjacent watercourse to each CMT and then adds the resulting distance measurement to the CMT database. Statistical methods were then used to explore relationships with other CMT variables. The Spearman’s Rank Order correlation was used to explore the relationship between the CMT variables aperture and scar area in relation to CMT distance to watercourse. The rank-order correlation between distance to nearest water source and both aperture size and scar area was found to be not statistically significant. The Mann-Whitney test was used to investigate differences in distance to nearest watercourse for both felled and non-felled CMTs and similarly, this test also indicated that there is no significant difference between distance to water for felled (median = 459m) and non-felled (median = 494m) CMTs. Overall, these results suggest that distance to water had no clear bearing on the size of scars or apertures and that other factors more likely influence scar morphology.

Previous research has suggested that the economic and cultural contexts in which sugarbag collection took place are a key factor influencing sugarbag collection practices (Morrison et al. 2010). The Weipa Peninsula study area has had a range of distinct historical phases, each associated with specific nodes of historical activity and proximity analysis was also used to investigate whether aperture area, scar area or felling status had any obvious relationships when compared to distances between CMTs and these historical settlements (see Figure 6). To do this, distance to the nearest historical settlement was calculated for each CMT and then the Spearman’s Rank Order correlation was calculated for both aperture and scar area to both distance to nearest historic place. The Mann-Whitney test was used to investigate relationships between distance to nearest historic place for felled and non-felled CMTs.
A rank-order correlation test on the resulting data suggested that distance to nearest historic site and either aperture size or scar size were not significant. Therefore, the present data do not point to any strong correlations between aperture or scar metrics and distance to nearest historical site. However, a Mann-Whitney test indicated that there is a significant difference between distance to historic place between felled (median = 3399m) and non-felled (median = 3899m) CMTs trees. This result strongly suggests that on the whole, felled CMTs are located closer to historical sites than non-felled CMTs pointing to a relationship between more intensive collection practices and proximity to historical settlements (Morrison and Shepard in press).

**Frequency and Cluster Analysis**

The second phase of the spatial analysis was to explore the dataset for patterns in spatial frequency and clustering. Spatial frequency tests provide an excellent means of visually identifying patterns in the frequency with which particular variables occur within a dataset and could be applied to variables such as the frequency of particular artefact types, raw material types or, as is the case here, the frequency of individual sugarbag scars. Frequency data were collated by aggregating the number of individual scars at each point a CMT was recorded into a new table. These aggregated point data were converted to a raster dataset where each 50m cell was allocated a mean scar frequency value, based on a circular neighbourhood of 500m diameter from each CMT location. The resulting frequency data are highlighted in Figure 6 and indicate that for most areas subject to sampling, the mean scar frequency per 500m sample cell is less than 40 scars. However, several distinct peaks occur, most notably at those areas most closely related to post-1930s historical activity areas where 40-60 and 60-100 scars per 500m cell occur. This indicated that there were spatial patterns worth exploring further.
Figure 6 Sugarbag scar frequency data for the Weipa Peninsula.
Clustering analysis is an important initial step in spatial analysis of archaeological data and is used to test whether the sample population is distributed randomly or occurs within clusters (Hodder and Orton 1976; Wheatley and Gillings 2002). Here, two local spatial statistical tests were used to test for spatial clustering in values of scar frequency, aperture area and scar area. First, Anselin’s local Moran statistic was used to test variation in the means of variables between points based on relationships with adjacent neighbours (Mitchell 2005:2:165; Schwarz and Mount 2006:173). The local Moran statistic tests the null hypothesis that spatial patterning within these variables is random and categorises statistically significant clusters or outliers by attributing Z-scores to each feature (Mitchell 2005:167).

Statistically significant high positive Z-scores (p <0.05) indicate clustering of high or low values, which are allocated a Cluster/Outlier Type (COT): HH or LL for clusters of high or low values respectively (e.g., high scar frequency or large aperture/scar area). Statistically significant low positive Z-scores indicate outliers, or features that are either high values surrounded by low values (HL) or low values surrounded by high values (LH). Hence, COT categorisations identify spatial clusters or outliers within the data that meet statistical significance criteria.

Secondly, hot spot analysis was used to identify clusters of high or low values based on their relationships with neighbouring values using the Getis-Ord Gi* statistic. Spatial clustering of high values is indicated by statistically significant (p <0.05) high Z-scores, while clustering of low values is indicated by statistically significant low Z-scores. Hence, clusters of high and low values can be identified in relation to those features where clustering is not statistically significant. In order for a point to be a statistically significant hot spot, a feature will have a high (or low) value and be surrounded by other features with contrasting high (or low) values as well.

The key difference between both techniques is that Anselin’s local Moran statistic identifies clusters based on the variation of individual points from a locally derived mean, whereas Gi* is a measure of the extent to which features in a
neighbourhood are surrounded by similarly high or low values. Importantly, all cluster analyses were run only on sub-sets of points with valid data; so, for example, CMTs lacking aperture data were not included in analyses focusing on aperture areas.

These cluster analysis techniques were used to explore spatial patterns in scar frequency and aperture area and only results pointing to clusters of higher frequency scarring or large aperture and size areas are included here. In interpreting cluster results, most weight is given to concentrations of three or more cluster points, which provide stronger evidence for clustering around a particular location than, for example, a single cluster point. Figures 7 and 8 show the results of both cluster analysis tests on scar frequency for the Weipa Peninsula dataset.

These results broadly correlate with scar frequency data though notably, there are areas that clearly lack any clusters of high scar values despite the seemingly larger number of scars on simple frequency tests (Figure 7). Distinct clusters of high scar frequency occur at Mbinning, Kwanter and Myka Creek and these represent the closest sample to the second Weipa Mission and suggests some degree of higher-intensity scarring with proximity to the post-1932 settlement. The Myka Creek clusters occur approximately 3km from the Dinningwulung Cattle Yards, however, they do not represent the nearest adjacent CMTs to this location. A total of 450 scars occur within a 3km radius of this historic site and all high frequency clusters occur at the margin of this zone in the east. This result suggests that the cattle yards do not represent a location of high frequency scarring compared to other locations, but that nearby Myka Creek does.

Using cluster analysis to identify locations of statistically significant clusters of large aperture area values also proved insightful and these results are outlined in Figure 8. Again, clusters or large apertures are not entirely consistent with scar frequency data and help to identify more subtle patterns in the data.
Figure 7 Clusters of high scar frequency, Weipa Peninsula (p < 0.05).
Figure 8 Clusters of large aperture areas, Weipa Peninsula (p <0.05).
Clustering of high aperture areas occurs at Wandrupayne which is a large permanent water body near the centre of the Weipa Peninsula where simple frequency tests indicated no visually obvious patterns. This indicates the potential value of clustering analysis to test for spatial patterning in regards to specific variables and research questions, and in relation to CMTs, highlights patterns that are worthy of further investigation.

**Dating CMT Scarring Events**

The above examples illustrate that statistical and spatial techniques can add a great deal to the interpretation of CMT data and are providing considerable insights on the question of whether there is evidence for spatial and temporal change in the intensity of sugarbag collection (Morrison et al. 2010; Morrison and Shepard in press).

Previous research has made inferences about historical changes in collection intensity by exploring spatial relationships between variables associated with increased collection intensity – including scar morphology, frequency and felling practices – and proximity to historical settlements. While these inferences are worthy of further exploration and testing via larger datasets, a key issue hampering this work is the lack of firm estimates on CMT age ranges and so resolving this issue is a key focus of ongoing work in the region.

Only one unpublished study has attempted to date scar ages on CMTs in Australia (Long et al. 2002) and the topic has seemingly attracted little attention within the Australian archaeological community. One likely reason for this is the perception that obtaining absolute determinations on scar ages is of little research significance, because it is assumed that in most cases CMTs represent recent and isolated events. However, there are genuine obstacles associated with applying existing techniques such as AMS radiocarbon dating to CMTs, not least of which is the fact that in order to obtain appropriate samples, tree felling is often required.

There are very good reasons for attempting to develop suitable techniques for dating CMTs, both in western Cape York Peninsula and in Australia more broadly. At Weipa,
determining ages on CMTs complements and supports the aspirations of local Aboriginal people in terms of community education and heritage management. Previous anthropological and historical investigations (Morrison and McNaughton 2005; Morrison et al. 2010) highlight the high cultural significance of CMTs to community members who value them because they provide a tangible connection with past generations of Old People (known relatives and ancestors). CMTs are also of value for educational or interpretive strategies: numerous monuments containing CMTs have been created in recent years as a direct outcome of mine-related clearance work (see Barkley et al. 2008) and many CMTs occur within areas of high public visitation where detailed interpretation incorporating age determinations would be of value. Furthermore, in recent years the region has undergone a considerable industrial and urban expansion and this places CMTs under significant pressure as a result of land clearing. Traditional Owners are routinely required to make decisions about whether particular CMTs (including living trees) should be preserved or removed. Development of a low impact technique to assess CMT age would be of high value to community members involved in assessing their cultural heritage significance. This may be of particular importance in situations where CMTs are to be destroyed or where living trees with evidence of scarring are to be felled and relocated so as to allow mining to take place.

**Determining Scar Ages on CMTs**

As noted, the vast majority of CMTs in western Cape York Peninsula are on Cooktown ironwood. While oral histories clearly indicate that sugarbag was also collected from other trees, these trees do not appear to survive long enough to be identified during archaeological surveys. Conversely, Cooktown ironwood is extremely resilient to fire, termite attack or natural decay. This is in part due to its density as well as chemical compounds within the wood itself (Taylor 2005). Previous studies have suggested quite slow growth rates on Cooktown ironwood, particularly when it occurs in natural, undisturbed savannah woodland (Cook et al. 2005:823; Taylor and Eggleton 2004:127). Trees with a Diameter at Breast Height (DBH − 1.3m) of ~350mm have
been estimated to be ~180 to 300 years old based on conventional radiocarbon dating and growth rate observations (Cook et al. 2005). As such, at a general level the species has potential to provide evidence of cultural scarring over the past century or more.

Counting annual growth rings on CMTs is an obvious means of obtaining relative age estimates and previous work at Horsham, Victoria (Long et al. 2002) illustrated the potential of the technique for dating CMTs in conjunction with radiocarbon dating. However, directly counting rings is notoriously difficult on Cooktown ironwood. In one study counting was used to assess the age of a tree and although neither the methods nor results were published in detail, ring counts were said to be “an unreliable method of estimating the age and growth of this species” (Cook et al. 2005:823). The key reason for this is that unlike many faster growing species, Cooktown ironwood often lacks distinct inter-annual banding and may in fact evidence intra-annular bands. The second key limitation with dating CMTs at Weipa is the difficulty of directly dating scarring events with a technique such as AMS radiocarbon dating: obtaining small dateable samples from the dry face of a scar is simple enough, however, there are distinct limitations associated with accurately dating recent samples such as CMTs which are likely to be less than 150 years of age. In summary then, conventional techniques require some refinement in order to be applied to anthropogenic scarring on Cooktown ironwood.

The method we are currently testing in the region involves the use of more sophisticated analytical tools for ring counting and the development of a robust dendrochronology to support estimating the age of individual trees. This chronology will be built up by obtaining two 2cm core samples from a range of healthy, living Cooktown ironwood trees in the region – both with and without anthropogenic scarring – that are located in natural stands of woodland. Following preparation, growth rings on each core will be counted, visually cross-dated and measured with the aid of a binocular microscope and using a Velmex measuring stage attached to a linear encoder (resolution 0.001mm) and computer. An ITRAX core scanner at the Australian Institute of Nuclear Science and Energy (AINSE) will be used to obtain
information on wood density patterns, which helps to support the classical ring counting at a very high resolution. COFECHA, a quality control tool (Holmes 1994) will then be used to check for missing/false rings and check cross-dating. If the cross-dating is successful, a local chronology for the study area will then be developed using other specialised computer software.

This local dendrochronology will be tied into calendar years through the use of bomb radiocarbon recorded in Cooktown ironwood tree rings. It will act as an independent check on tree ring counts and dendrochronology and allow us to test whether these growth rings are annual as well as validate the tree-ring ages. Hua and Barbetti (2004) have shown that the bomb pulse caused by atmospheric nuclear detonations in the late 1950s and early 1960s can be used to date recent organic materials with a variable resolution of one to a few years. The tree-ring age analysis is carried out in two steps. First, the accuracy of ring-count ages for the last 50 years will be checked by bomb radiocarbon. As bomb $^{14}C$ delivers two possible windows of calendar ages for each sample $^{14}C$ value, two individual rings of each tree core have to be sampled for $^{14}C$ analysis. Second, the results of the first step are used to extrapolate back in time to estimate the scar ages of the study trees. For example, if ring-count ages for the last 50 years agree well with those based on bomb $^{14}C$ we can be confident in the use of ring counts to determine scar ages. If there is a difference between ring-count ages for the last 50 years and those from bomb $^{14}C$, we assume that the same difference can be applied for every 50 years when ring counts are used to estimate the scar ages.

Hence, through this method it will be feasible to develop a high-resolution dendrochronology for the region and also to obtain age estimates for scarring events for sampled trees. If the technique is workable, core samples taken from near scarring events on new CMTs within the local study area can be further cross-matched against the master chronology and then allocated dates without the need for intensive AMS dating. This master record can be expanded as new samples from surrounding regions are incorporated, thus providing a potentially valuable tool for research and management in the region.
Dendroecology Applications
The use of the AINSE ITRAX core scanner has additional benefits. Not only can this tool be used to quantify variations in wood density as a supplement to classical ring counting approaches, but it can also be used to identify seasonal variations in a range of trace elements and to establish elemental profiles. Of specific interest are inter-annual variations in calcium, lead, phosphorous and sulphur from wood in order to understand the dynamics of local climatic systems over the life of the tree. This will provide data that will serve as a proxy measure of past rainfall variations through time (Poussart et al. 2006) and potentially, to trace historical changes in firing regimes which may have implications for contemporary land management practices.

No previous palaeoenvironmental studies have been undertaken in the Weipa region. Dendroecological approaches have been successfully applied to palaeoenvironmental questions elsewhere in Australia and beyond. For example, δ^{13}C and δ^{18}C isotope chronologies obtained from tree cores have been successfully used to reconstruct recent climate histories (Cullen and Grierson 2007; Cullen et al. 2008). Poussart et al. (2006) report on the success of trace element analyses on whole wood samples to reconstruct tree growth history and highlight the value of this technique for palaeoenvironmental modelling, particularly for tropical species with poorly defined growth rings. This is an important tool because high-resolution palaeoenvironmental models are typically beyond the reach of archaeological investigations of the past several centuries despite the potentially valuable data such models bring to such investigations. High-resolution rainfall records would be valuable to archaeological and historical studies exploring cultural and environmental change in this period as well as quantifying changes in fire regimes.
Discussion and Conclusions

There is no replacement for rigorous field data carefully collected via conventional approaches. However, the analytical techniques summarised here provide new insights on an otherwise homogenous mass of CMT point data that are relevant to assessing the cultural significance of CMTs and investigating questions about Aboriginal economic practices and landscape use over the past century or more.

A key issue for management of CMTs in western Cape York Peninsula is the expanding impacts of mine related development which will destroy tens of thousands of hectares of largely undisturbed messmate woodland over the coming decades. Currently, decisions about management in these contexts are typically made in isolation, and in consultation between Senior Aboriginal Representatives and mine staff, without any attempt to relate data from a specific locale or study area to the broader regional picture. We suggest that undertaking research to draw greater meaning from CMT data can help to inform management strategies adopted at a regional level. For example, we have demonstrated here that the results of statistical analyses can help to understand whether newly recorded trees are similar to others known at a regional level or in relation to particular study areas. Similarly, spatial analysis may help to understand the extent to which particular groups or clusters of CMTs are representative of regional patterns or if they indicate practices unique to specific locales.

CMTs also provide a concrete record of Aboriginal peoples’ use of woodland environments over the past century or more. One of the unique characteristics of these woodlands is that beyond CMTs, there are often few other types of archaeological sites, at best consisting of small, highly dispersed and infrequently occurring stone artefact scatters around watercourses, or midden sites in close proximity to coastal areas (Shiner and Morrison 2009). Applying these types of techniques to CMTs allows for the development of more sophisticated models of Aboriginal peoples’ use of these landscapes which can potentially broaden our understandings of Aboriginal lifeways over the past century or more. At this point, there is good evidence
that patterns in sugarbag collection changed through time towards more intensive modes of extraction and this is supported by evidence for increased felling in close proximity to historical activity areas and larger apertures on felled trees (Morrison et al. 2010; Morrison and Shepard in press). There are also specific locales where higher intensity sugarbag collection has taken place both in terms of high scar frequency and large aperture areas, revealing patterns in the data that are not accessible via other means. While results of work to obtain determinations for CMT scarring events are not yet available, there are good reasons to attempt to obtain absolute dates for scar formation both on western Cape York Peninsula and in Australia more generally. Dating allows Aboriginal people and others to place CMTs within a more specific historical and cultural context, thus contributing potentially useful information into locally based processes of significance assessment, management planning and interpretation. From a research perspective, dating also will allow for existing models for historical changes in sugarbag collection practices to be considerably refined and improved.

In conclusion, we suggest that there is a need for an increased emphasis on archaeological research on CMTs that extends beyond previous approaches focussing solely on methodological issues or basic documentation. Our research, as well as work by others (Rhoads 1992; Webber and Burns 2004), points to the research potential of these unique but diminishing representations of Aboriginal peoples’ engagements with landscapes over the past several hundred years. We have demonstrated here that the insights generated through work on CMTs is enhanced when analysed collectively, across particular study areas, rather than as isolated examples of past economic practices; indeed, after almost four decades of heritage management work in some states, it is likely that many heritage databases around Australia already have considerable potential for such research to be undertaken without the need for any new data collection at all.
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