Is Australian Flora Unsuitable for the Bow-and-Arrow?

Nicholas George[1]

[1] School of Molecular and Life Sciences, Curtin University, Kent St., Bentley, Perth, WA 6102, Australia

*Corresponding author; e-mail: nicholas.george@curtin.edu.au

Abstract: The bow-and-arrow was not manufactured or widely used by Indigenous Peoples within the Australian continent, and the suitability of woody Australian plant species for constructing bows is poorly understood. The mechanical and physical properties of 326 plant species, including species highly suitable for self-bows and 106 native Australian species, were analyzed and compared using principal component analysis. Additionally, qualitative information regarding the use of Australian woods for bows was obtained from bow-making internet forums. The results suggest that Australian woods have combinations of properties that make them sub-optimal for bows compared to common woods from other parts of the world. The findings may explain the historical absence of bow-and-arrow technology on the Australian continent. Future work is needed to collect data from a broader range of woody Australian species, along with empirical research to assess the suitability of Australian woods for bow-making. The work also demonstrates, for the first time, that principal component analysis is a useful technique for exploring the suitability of woods for self-bows and should be investigated further for this purpose.

Keywords: Bowyer, Bow-making, Australia native plants, Principal component analysis

Introduction

The bow-and-arrow has been used for millennia as a projectile technology for hunting, warfare, and recreation across diverse cultures and environments (Heath 1971; Lombard and Phillipson 2010). A *bow* is a length of wood or other material that is bent and held in tension by a string; when the string is drawn, the bow stores potential energy, and when the string is released, the energy is used to launch a projectile (Bergman 1993; Carignani 2016). Various materials and construction methods can be used to make bows, but those manufactured from a single piece of wood without adding other materials are termed *self-bows.* Self-bows are the simplest bow to make, particularly without metal tools, and are likely to be the original and oldest type of bow design (Baker 1994; Bergman 1993).

Locally made bow-and-arrow technology is not known to have been used by Indigenous Peoples within the Australian continent at the time of European colonization, nor is there evidence for its use in the past (Flood 1999; Hambly 1936; McCarthy 1953; Mulvaney and Kamminga 1999). The author only knows one account suggesting Indigenous Australians traditionally made bow-and-arrow-like objects (Russell 1888). These were reported to be made from "myall" (probably *Acacia pendula* A.Cunn. ex G.Don) and were described as "children's toys," "miniature," and "harmless." Instead, the spear and spear-thrower were the main projectile hunting tools and weapons used throughout the continent (Flood 1999; Hambly 1936; McCarthy 1953; Mulvaney and Kamminga 1999). In this context, a *spear-thrower* is a tool used to project a spear where lever action increases the

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velocity and distance the spear can travel. It is unclear why the bow-and-arrow was not used in Australia when it was commonly used in other parts of the world. Bow-makers, or *bowyers*, build functional self-bows from Australian plant species, but reports regarding this appear mostly in internet forums (OzBow 2022; Paleo-Planet 2022; Primitive Archer 2022; TradGang 2022). Without a history of bow-making and little scholarly literature addressing the topic, the suitability of Australian woods for bows is poorly understood.

Wood, meaning any lignified plant material (Schweingruber and Büntgen 2013), requires particular mechanical and physical properties to be suitable for a self-bow (Baker 1992, 2008a). The mechanical properties of wood, which are measures of its behavior when subjected to applied forces or loads, are of particular importance. In simple terms, the required mechanical properties for self-bows include sufficient tensile strength to bend without breaking but high enough compressive strength and resistance to bending to store energy that can be usefully transferred to the arrow on the release of the string (Baker 1992; Bergman 1993; Kooi 1991a, b; Kooi and Bergman 1997).

The mechanical and physical properties of wood are measured routinely because they are relevant to the use of wood in various engineering applications (Kretschmann 2010). The most commonly measured variables are modulus of elasticity (MOE), modulus of rupture (MOR), and density. Modulus of rupture, or flexural strength, is the maximum load experienced at failure and is related to tensile strength; larger values indicate a higher tensile strength (Kretschmann 2010; Shmulsky and Jones 2011). Modulus of elasticity is the situation of a material resisting being stretched with a tensile force; a larger value indicates a "stiffer" material (Kretschmann 2010; Shmulsky and Jones 2011). Density is mass per unit volume (Kretschmann 2010). The values of these properties often show low relative variation among different samples of the same species but can display greater relative variation between different species (Green and Kretschmann 1991).

The physics of ancient and modern bows have been studied and applied to understanding the mechanics and optimal design of bows (Hickman et al. 1947; Klopsteg 1943; Kooi 1991a, b; Kooi and Sparenberg 1980; Kooi 1981; Kooi and Bergman 1997; Marlow 1981; Meyer 2015). However, the use of mechanical and physical properties for identifying woods suitable for self-bows has not been as widely explored in formal research literature. Moliński et al. (2016) is one of the few examples where it is done explicitly.

In non-peer-reviewed literature (Baker 1992, 2008a, 2008b; Meier 2021), and internet forums, people have used single mechanical or physical variables to rank the suitability of wood for bows and to identify plant species that may be suitable for bows but which do not have a well-documented history for this. Baker (2008a), for example, used density, given its ease of measurement and positive correlation with values like modulus of rupture and elasticity. Density is commonly used as an index of mechanical wood properties for this reason (Kretschmann 2010). However, it has been found that no single mechanical property correlates perfectly with the known suitability of species for bows. Instead, differences in absolute and relative values of variables appear to interact significantly (Baker 1992, 2008a; Meier 2021; Moliński et al. 2016). Given this, some individuals have attempted to develop single metrics based on combinations of multiple values. For example, the relationship between the modulus of rupture and modulus of elasticity is considered a strong predictor of a wood's suitability for bow-making (Baker 1992; Meier 2021). Due to its simplicity, the ratio is commonly used to rank bow woods in online communities and published sources (Meier 2021). Kooi (1991c), as another example, proposed using the modulus of rupture, modulus of elasticity, and density to calculate a single "strain per unit mass" measure.

Can these various metrics reliably rank the suitability of woods for self-bows? Some plant species are demonstrably more suitable for self-bows than others and have a long history of use for this purpose. *Maclura pomifera* (Raf.) Schneid., *Taxus brevifolia* Nutt., and *Taxus baccata* L. are considered among the best species in the world for self-bows and other traditional bow designs (Hardcastle 1992; Strunk 1992), and are rated highly by the metrics. This suggests the metrics have merit for meaningfully ranking and identifying woody species for bow-making.

There are, however, two potential problems with objectively assessing the reliability of mechanical and physical properties for evaluating wood for bows. Firstly, the suitability of wood for bows cannot be easily quantified and instead relies on the subjective experience of the archer, so there is no quantitative response variable against which to test the metrics. Secondly, wood properties vary due to genetics, growing environment, and genotype-by-environment interactions (Antony et al. 2011; Bradbury et al. 2011; Marini et al. 2021; Shmulsky and Jones 2011; Wodzicki 2001; Zhang et al. 2011). Individual wood properties can display average within-species coefficients of variation of approximately 20% (Kretschmann 2010), which will cause concomitant variation in suitability for self-bows (Baker 1992). Intra-specific variation in wood properties, therefore, makes placing a species as a whole in a simple ranking scheme less meaningful, and generalizations about the suitability of a species for bows will be misleading, especially when based on data from a limited range of samples.

A further problem with ranking schemes is that the suitability of wood for self-bows requires compromises in mechanical and physical properties. For example, lower-density wood is weaker and more prone to breaking and other forms of damage, but denser wood is more challenging to work and reduces arrow speed due to increased bow mass (Baker 1992; Shmulsky and Jones 2011). An "optimal" wood density for a bow will necessarily be a moderate value. This phenomenon, the need to consider multiple mechanical and physical variables simultaneously, and the importance of significant interactions between mechanical and physical variables, create a multivariate optimization problem when assessing woods for bow-making.

Table 1. The number of wood samples in the final dataset and the continent to which the species are native

Region of origin	Samples
Africa	25
Asia	27
Australia	127
Europe	7
North America	183
South America	62

Principal component analysis (PCA) with biplots is a widely used data analysis and visualization technique. It increases the interpretability of multivariate data sets while minimizing information loss and preserving variance, and it does not require a numerical response variable (Jolliffe and Cadima 2016; le Roux and Gardner 2005). The technique is used to analyze wood properties (Marini et al. 2021; You et al. 2021) but has not previously been used to explore mechanical and physical wood properties in the context of the known suitability of plant species for self-bows.

This study explored the suitability of woody Australian plant species for self-bows. The first objective was to test the applicability of principal component analysis for exploring the suitability of woods for manufacturing self-bows based on mechanical and physical properties. The second objective was to apply the method to understand the suitability of woody Australian plant species for self-bows and what designs are most appropriate. The statistical approach was to place Australian species, whose suitability for self-bows is largely unknown, into an analysis alongside world species whose suitability for self-bows is known. To complement the quantitative analysis, qualitative information regarding the experience of Australian bowyers with native species was sourced from internet-based discussion forums. The implications of the research findings for the lack of bow-and-arrow technology in Australia are discussed.

Methods

Dataset

Mechanical and physical wood property data were obtained from publicly available sources (Bootle 2010; CSDUH 2021; FPC 2020; Kretschmann 2010; Meier 2021). The dataset is available in the supplemental material. The most common properties reported in the sources were modulus of rupture, modulus of elasticity, and density. Only values for dry (12% moisture) wood were used. The final data set comprised 431 samples, representing 326 individual species from Africa, Asia, Australia, Europe, and North and South America (Table 1). Approximately 25% of all the samples were replicates of the same species, and over 90% were two replicates of a species. The dataset had a range of mean, minimum, and maximum values for the mechanical and physical properties: MOR, modulus of rupture = 106 (22 to 213) MPa, MOE, modulus of elasticity = 13,300 (3,400 to 28,000) MPa, MOR/MOE × 100 = 0.8 (0.53 to 1.36), and density = 0.7 (0.24 to 1.4) g cm^{-3}. Data was available for 127 samples of 106 Australian species from 32 genera native to ecosystems throughout the continent (AVH 2023). The proportion of replicated samples was similar for the Australian species as for the data set overall. The level of correlation between wood properties and the magnitude of variation between samples of the same species were comparable to those reported in other studies, suggesting the final dataset captures the variation that would be expected in a diverse collection of wood samples (Green and Kretschmann 1991; Marini et al. 2021; You et al. 2021; Zhu et al. 2015).

Wood Suitability for Self-bows

The suitability of a plant species for bows is subjective, variable, and continuous, so it is impossible to dichotomously classify any one species as suitable or unsuitable. However, for the PCA, the species in the data set were categorized based on their known suitability for self-bows (Table 2 and ESM1). *Maclura pomifera*, *Taxus baccata,* and *Taxus brevifolia* are accepted as highly suitable for self-bows and were classified as *high-quality* species. Other species are commonly used to make functional self-bows. This list is not exhaustive, but the category includes maple (*Acer nigrum* F.Michx. and *Acer saccharum* Marshall, but possibly other *Acer* species); many if not all species of hickory (*Carya* spp.); many ash species (with the most commonly reported being *Fraxinus americana* L. and *Fraxinus excelsior* L.); most Oak (*Quercus* spp.); most Elm (*Ulmus* spp.); Mulberry (*Morus* spp.); and Locust (*Robinia pseudoacacia* L.*)* (Comstock 1992). Palmwood from the genus *Borassus* in tropical Asia was also commonly used for bow-making (Baker 1994; Green 2010). The species in this category are categorized as *secondary* species. The remaining non-Australia species were classified as *other*. The suitability of species in the *other* category for making self-bows is not well documented, so it will likely include suitable and unsuitable species. Finally, native Australian species are distinguished from all others. Australian species reportedly used for self-bows are distinguished within this category.

Table 2. The number of wood samples in each category in the final dataset

Category	Samples
High quality	9
Secondary	44
Other	251
Australian	127

Analytical Methods

Data management and manipulation were performed using the R software (R Core Team 2020). Preliminary data exploration was conducted using the *PerformanceAnalytics* package (Peterson and Carl 2014). The PCA was performed and visualized with the *factoextra* and *ggplot2* packages (Kassambara and Mundt 2020; Wickham 2009), using centered and scaled data for MOR, MOE, the MOR/MOE × 100 ratio, and density. Principal component analyses with a small number of variables like this are statistically valid, provided a relatively large number of samples are included in the dataset (Björklund 2019). Principal component analysis preserves relationships between variables, so the analytical output was the same when only two of the three mechanical variables — MOR, MOE or MOR/MOE × 100 — were included. All were included to visualize the relationship between each in the biplot.

The correlation between duplicates of individual species for the mechanical properties and the loadings of the PCA was assessed by randomly separating the duplicates into two samples and then evaluating the linear correlation between the duplicates. This was repeated twenty times, and the mean value for the linear fit statistics was calculated.

Qualitative Information from Online Sources

OzBow (https://ozbow.net/) is a public internet forum dedicated to traditional bowhunting in Australia and includes multiple sub-forums, including ones related to bow-making. At the time of writing, it was the online community with the largest number of users where the suitability of Australian plant species for bow-making was regularly discussed. Following the suggested methods of Giles (2017) and Smith et al. (2017), relevant posts were reviewed for qualitative information regarding the species used, the bow designs, and people's subjective experiences sourcing, making, and using self-bows from the species. The forum was initially searched for terms such as "self-bow," "Australian wood," "native species," and "wood supplies" to find posts and responses related to self-bows made from Australian plant species. When specific species were noted, the forum was searched by common and species names for further mentions of the species. Individuals usually referred only to common names, so the taxonomic identity of the species had to be inferred. If the common name could refer to multiple species, attempts were made to identify the species based on factors like geographic location referred to in the post. However, it was occasionally unclear which species had been used, and these references had to be excluded from the analyses. There was no way to determine whether the individual making the posts identified the species correctly.

Results

Preliminary Data Exploration

Preliminary analyses found significant positive correlations among the mechanical and physical properties (Fig. 1). However, these correlations were imperfect, implying that individual species show relative variation in absolute mechanical properties and their suitability as bow woods may then vary due to significant interactions between properties. There was a lack of correlation between the individual measured variables and the MOR/MOE ratio; variation in the ratio among species is, therefore, independent of variation in the absolute value of either. The duplicate samples showed a highly significant correlation for all the mechanical variables. However, some variation was present (Table 3). Species, therefore, display intra-specific variation in wood properties of up to 30%, which is expected (Kretschmann 2010).

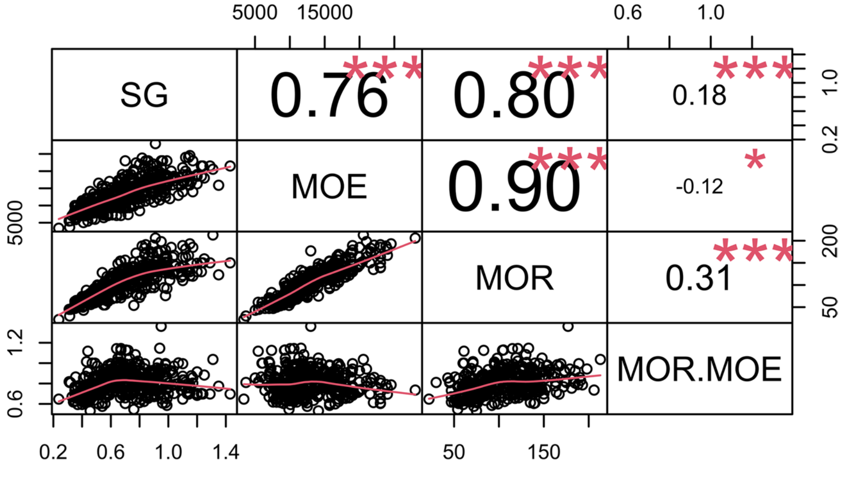

Fig. 1. Correlation among mechanical wood properties in the dataset. Numerical values show the test for the association between paired samples using the moment correlation coefficient. The software scales the font size relative to the strength of the correlation. ***= highly significant to *= weakly significant. MOE, modulus of elasticity; MOR, modulus of rupture; MOR.MOE, the ratio between modulus of elasticity and modulus of rupture multiplied by 100; SG, specific gravity

Table 3. Mean values for the correlation between replicate values of the mechanical properties and the loadings of the principal components

	Adjusted R2	RMSE	Pearson correlation
MOE	0.72	2122	0.85
MOR	0.74	17	0.86
MOR/MOE × 100	0.72	0.07	0.85
SG	0.79	0.1	0.89
PC1	0.81	0.45	0.90
PC2	0.71	0.32	0.85

MOE modulus of elasticity, *MOR* modulus of rupture, *MOR.MOE* the ratio between modulus of elasticity and modulus of rupture multiplied by 100, *SG* specific gravity

Principal Components Analysis

The PCA found that the first two components (PC1 and PC2) explained most of the variation in the data set (> 90%) (Fig. 2). The plot is therefore a good representation of variation in the mechanical and physical properties of the samples. Variations in MOR and density were associated and negatively correlated with the first principal component (PC1). Variation in MOE was also negatively correlated with the first principal components axis, but less strongly. The MOR/MOE ratio was correlated with the second principal component (PC2) and was mostly orthogonal to the other variables, indicating little or no correlation, in agreement with the results in the correlation analysis (Fig. 1). The duplicate samples showed a strong positive correlation for PC1 and PC2 loadings (Fig. 1), implying replicates of the same species can be expected to cluster in a similar region of the biplot but can still vary in principal component loadings by up to 15%.

When categorized by suitability for self-bows, species consider suitable clustered in the same region of the biplot. These species had larger loadings for the second principal component, indicating a tendency for a larger MOR/MOE ratio, or higher tensile strength relative to stiffness (Fig. 2). Although the categories overlap, this relationship was stronger for *high-quality* than *secondary* species. The absolute mechanical values varied among the samples and individual species. *High-quality* and *secondary* species clustered closer to the origin of the first principal component than woods overall, indicating a tendency for moderate absolute values of individual wood properties.

The species in the *other* category showed a range of mechanical and physical properties. Some clustered with *high-quality* and *secondary* species. Inspection of the results (Fig. 2 and ESM1) found that these species usually belonged to genera with species known to be suitable for self-bows, such as *Fraxinus* (points 137, 140, and 141). In other cases, online discussions suggest some species in the *other* category that cluster with *high-quality* or *secondary* species are suitable for self-bows, such as *Carpinus caroliniana* Walter (point 94). Species in the *other* category that clustered in the lower right of the biplot have low density, are very weak in tension, or have little resistance to bending (low stiffness). These properties would not make these species suitable for self-bows. Inspection of the results found these species include those well known to be unsuitable for self-bows, such as species in the genera *Populus* (points 234 and 235) and *Tilia* (points 293 and 294).

Although there were exceptions, Australian species tended to be negatively correlated with both principal component axes, indicating that most are relatively strong and dense but have relatively high stiffness, and low tensile strength relative to stiffness. Some Australian species overlap with the region of the biplot where woods have properties that make them putatively suitable for self-bows. These include species that cluster with *high-quality* woods, like *Allocasuarina fraseriana* (Miq.). L.A.S.Johnson (point 322) and *Intsia bijuga* (Colebr.) Kuntze (point 405), and species that cluster with *secondary woods* like *Eucalyptus andrewsii* Maiden (point 346) and *Eucalyptus camaldulensis* Dehnh. (point 352), *Eucalyptus laevopinea* R.T.Baker (point 372), *Eucalyptus marginata* Donn ex Sm. (points 376 and 377), *Acacia mangium* Willd. (point 310), *Acacia penninervis* DC (point 317), and *Argyrodendron peralatum* (F.M.Bailey) Edlin ex J.H.Boas (point 327). The Australian species reported in online communities as suitable for making self-bows (Table 4) do not cluster with species considered suitable for bow-making and instead overlap with other Australian

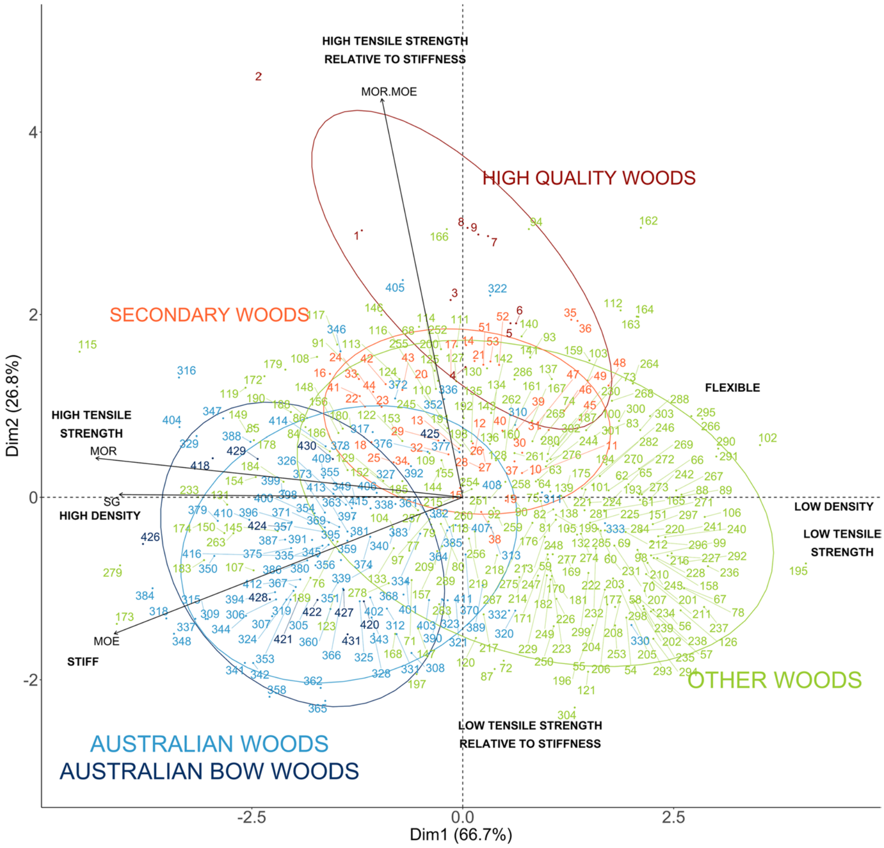

Fig. 2. Principal components biplot of mechanical wood properties, with species categorized by suitability for self-bows (or origin of Australian native species). The ellipses show the 90% multivariate t-distribution. The identity of the individual samples, indicated by the number, is provided in the supplemental material. MOE, modulus of elasticity; MOR, modulus of rupture; MOR.MOE, the ratio between modulus of elasticity and rupture multiplied by 100; SG, specific gravity or density. *Maclura pomifera*, *Taxus baccata*, and *Taxus brevifolia* were classified as high-quality species. Other species commonly used to make functional self-bows include maple (*Acer* spp.); hickory (*Carya* spp.); ash species (with the most commonly reported being *Fraxinus americana* and *Fraxinus excelsior*); Oak (*Quercus* spp.); Elm (*Ulmus* spp.); Mulberry (*Morus* spp.); Locust (*Robinia pseudoacacia*), palmwood from the genus *Borassus* are categorized as secondary species. The remaining non-Australia species were classified as other. The suitability of species in the other category for making self-bows is poorly documented. Native Australian species are distinguished from all others, and Australian species reportedly used for self-bows are distinguished within this category

species. The only exception is *Eucalyptus macrorhyncha* F.Muell. ex Benth. (point 425) that clusters with the *secondary* species.

Qualitative Information from the OzBow Internet Forum

At the time of writing, the bow-making sub-forums of OzBow (https://ozbow.net/) had approximately 19,000 individual posts (which include individual posts and responses to the post). Between 2005 and 2023, approximately 7000 individual posts were found discussing using Australian plant species for bows. Species referred to positively at least once are presented in Table 4. The PCA included those species with mechanical and physical data available. Some species did not have published data available and could not be included.

TABLE 4. NATIVE AUSTRALIAN SPECIES REPORTED BY USERS OF THE OZBOW INTERNET FORUM TO BE SUITABLE FOR MAKING SELF-BOWS

Species	Common name
*Acacia aneura** F.Muell. ex Benth	Mulga
Acacia cambagei R.T.Baker	Gidgee
*Acacia falciformis** DC. *or Acacia implexa** Benth	Hickory wattle
*Acacia harpophylla** F.Muell. ex Benth	Brigalow
Acacia shirleyi Maiden *or Acacia doratoxylon* A.Cunn	Lance wood
Alphitonia excelsa (Fenzl) Benth	Red Ash or Soap tree
*Chionanthus ramiflora** Roxb	Northern Olive
Corymbia maculata (Hook.) K.D. Hill & L.A.S.Johnson	Spotted gum
*Corymbia tessellaris** (F.Muell.)K.D.Hill & L.A.S.Johnson	Moreton Bay ash
Eucalyptus camaldulensis Dehnh	River gum
Eucalyptus flocktoniae Maiden	Merrit
Eucalyptus grandis W.Hill	Southern blue gum
Eucalyptus laevopinea R.T.Baker	Silvertop Stringybark
Eucalyptus macrorhyncha F.Muell. ex Benth	Red Stringybark
Eucalyptus paniculate Sm	Grey Ironbark
Eucalyptus saligna Sm	Sydney blue gum
Eucalyptus salubris F.Muell	Fluted gimlet
Eucalyptus sideroxylon A.Cunn. ex Woolls *or*	Red Ironbark
Eucalyptus sieberi L.A.S.Johnson	Red Ironbark
*Eucalyptus tricarpa** (L.A.S.Johnson) L.A.S.Johnson & K.D.Hill	Silvertop Ash
Eucalyptus tereticornis Sm	Forrest red gum
*Eucryphia lucida** (Labill.) Baill	Leatherwood
Flindersia australis R.Br	Crow's ash
*Gossia bidwillii (syn Austromyrtus bidwillii)** (Benth.) N.Snow & Guymer	Python Tree

The asterisk (*) indicates that mechanical wood data regarding the species was not available for use in the principal component analysis

Some people expressed the opinion that Australia has many woody plant species suitable for self-bows. Individuals use terminology such as "highly suitable [for bows]," "great success [with native species]," "a great many of the Eucalypt and Wattles are excellent [for bows]," and "there are plenty of Aussie woods out there that will make good bows." However, other posts were more negative; the general impression is that people often find it challenging to make functional bows from Australian wood. Individuals report that Australian species suitable for self-bows are hard to find or do not commonly grow to the size and quality needed for bows or that a species can be suitable for self-bows when found growing in one region but not in others. Some said they needed to "back" Australian species to make functional bows (which is explained in the Discussion). Posts stated that most species were challenging to work with hand tools due to "high density" or "interlocking wood grain," and one individual explicitly said they had attempted to make functional self-bows with stone tools and found it very challenging.

Acknowledging the low tensile strength of common Australian woods, individuals state the need to make bows long and wide to minimize tensile forces. A schematic diagram of the self-bow design reported as most suitable for Australian species, with approximate dimensions, is presented in Fig. 3. The schematic was developed from images and written descriptions provided by users of the OzBow forum. Some individuals explicitly use the

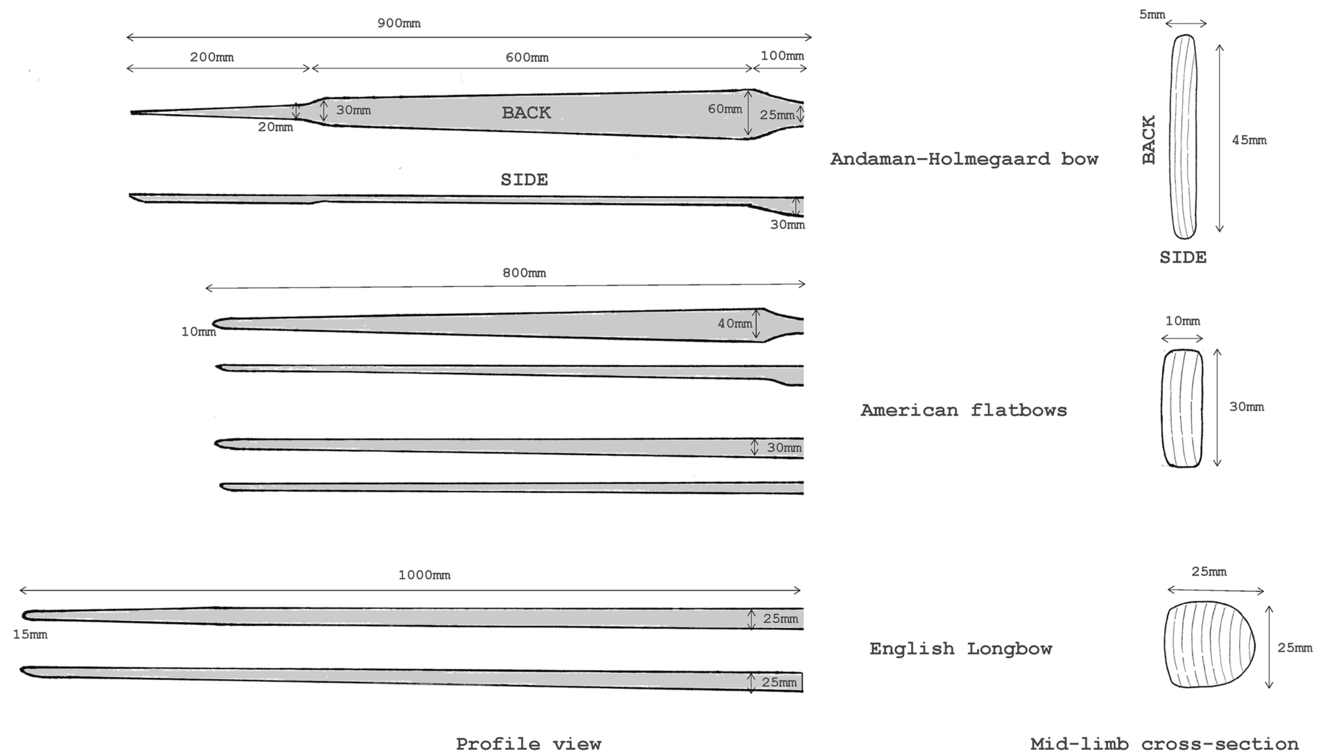

Fig. 3. A schematic representation showing the back (facing away from the archer) and side views of the Andaman — Holmegaard, American flatbow, and English longbow style self-bows adapted from Allely et al. (1992), Asbell et al. (1993), Baker et al. (1994), and Allely et al. (2008). The American flatbow and English longbow are presented for comparison purposes to illustrate the general shape of these bow styles. A cross-section showing the approximate mid-limb dimensions is also presented to illustrate the differences between the bow styles. The internal lines indicate wood growth ring orientation. Individual bows will vary in length, width, and thickness, so the dimensions should be considered approximate

term "Andaman–Holmegaard" to describe this bow style. Individuals state that all native Australian species they had tried were unsuitable for "English longbow" and narrower "flatbow" style bows, also depicted in Fig. 3. Please note that "English" and "American" denote commonly used names for the bow style and that bows of a similar style were made in many regions worldwide. An English-style longbow will be relatively narrow and tend towards being circular in cross-section, while flatbows will be wider than thick, as shown in the figure. The bows may or may not have handle sections.

Discussion

This study aimed to explore the suitability of woody Australian plant species for self-bows using principal component analysis of mechanical and physical wood data, complemented with qualitative information from internet forums. The discussion briefly addresses principal component analyses and then focuses on the suitability of woody Australian plant species for self-bows.

The Applicability of Principal Component Analysis for Identifying Bow Woods

Woods clustering in the upper middle region of the biplot have a high modulus of rupture to elasticity ratio, which is recognized as an indicator of suitability for self-bows (Baker 1992; Meier 2021). These species have sufficient tensile strength to bend without breaking but high enough compressive strength and resistance to bending to store energy that can be usefully transferred to a projectile. The tendency of these species to also have moderate absolute values for mechanical properties likely reflects the need for compromises in these properties in functional self-bows (Baker 1992; Shmulsky and Jones 2011). In terms of absolute and relative mechanical properties, the clustering of species in the biplot agrees with the quantitative and qualitative understanding of how wood properties impact the bow performance (Baker 1992, 2008a; Bjurhager et al. 2013; Meier 2021; Moliński et al. 2016). The method must be tested further, but the results suggest principal component analysis with biplots can be used to analyze and visually explore the suitability of woods for self-bows. The method avoids issues with ranking systems based on single mechanical and physical values and accommodates intra-specific variation due to genetic and environmental factors.

The Suitability of Woody Australian Plant Species for Self-bows

Most woody Australian plant species considered in the analysis have mechanical properties that make them sub-optimal for self-bows. Being relatively strong, Australian woods can be made into self-bows and other traditional bow designs. Still, the tendency for low tensile strength relative to stiffness makes the wood prone to breaking under tension, and high density makes the wood challenging to work and negatively impacts bow performance (Baker 1992; Shmulsky and Jones 2011). The findings agree with the published (Baker 2008a) and anecdotal experience of bowyers experimenting with Australian species. The consistency in the clustering of the Australian species is surprising given that many are only distantly related, native to different parts of the Australian continent, and presumably grown under differing conditions. Woods that are relatively weak in tension require *backing* to make functional bows, where material, usually consisting of tension-strong wood or other material such as sinew, rawhide, silk, or plant fiber, is applied to the back of a bow to prevent tension breaks (Baker et al. 1994). Australian bowyers report this is required for many Australian species.

The analysis identified some Australian species as suitable for self-bows, but only one of these, *Eucalyptus camaldulensis*, is mentioned as suitable for bows by individuals in internet forums, and even then, little information is provided. Empirical research is required to explore if these species are, in fact, suitable for self-bows in agreement with the analysis.

Bow design, such as limb length and width, impacts performance and must be tailored to the properties of a particular wood (Kooi 1991a, b; Kooi and Bergman 1997). Self-bows made from tension-weak woods must be relatively long and have broad limbs with a rectangular cross-section to distribute and minimize tensile forces. High-density woods require limbs to either be short or outer limbs to be as thin and narrow as possible to reduce near-tip mass that will otherwise reduce arrow speed. The Andaman–Holmegaard bow style is characterized by these features (Baker 1994, 2008b), and is described by sources such as Baker (1994) and Baker (2008b) as suitable for dense and tension-weak woods. Via sources like Baker (1994) and Baker (2008b), Australian bowyers are aware of this design and appear to have consciously chosen it. The Andaman-Holmegaard style is regarded to be among the most challenging self-bow designs to build, particularly with simple tools (Baker 1994, 2008b).

The statistical analysis and anecdotal reports suggest that Australian flora is not well-suited to making self-bows, but some individuals in online communities contradict this. What is the reason for the disagreement? It may be because the analytical approach does not accurately represent the suitability of woods for bows, failure to include some highly suitable Australian woods in the analysis, or species identification in online sources being incorrect. Further work is needed to address these issues. Another possible explanation is that some Australian bowyers only consider local species "highly suitable" for self-bows due to limited experience with species from other regions. Australian species can be made into functional bows, so Australian bowyers perceive them as "suitable" bow woods. In contrast, North American bowyers, who can more easily compare Australian and North American species because *Eucalyptus* and *Acacia* species grow in places such as California, regard the Australian species as sub-optimal (Baker 2008a). This aligns with the experience of the current author, who has found it relatively straightforward to make functional bows from species of *Carya*, *Fraxinus*, *Quercus*, and *Ulmus*. All genera that are common and widespread in the Northern Hemisphere. Their mechanical and physical traits make it comparatively easy to create functional bows, and they can be relatively "forgiving" in terms of the design used. In contrast, the author has found producing functional bows from common Australian species much more challenging. It demands the meticulous selection of the piece of wood and careful design considerations.

Implications for the Historical Absence of Bow-and-Arrow Technology in Australia

The oldest evidence for the use of bow-and-arrow technology has been found in southern Africa and is dated to between 60,000 and 70,000 years old, although it may be as much as 80,000 years old (Backwell et al. 2018; Lombard and Phillipson 2010; Lombard and Shea 2021), and there is evidence of bow-and-arrow use along the human dispersal route between Africa and Australia that is approximately 50,000 years old (Laffont et al. 2007; Langley et al. 2020; Metz et al. 2023; Oppenheimer 2009). This could suggest that humans possessed bow-and-arrow technology when they originally expanded out of Africa (Oppenheimer 2012; Shea and Sisk 2010), and the bow-and-arrow may pre-date the arrival of people in Australia (Clarkson et al. 2017; Langley et al. 2020; Oppenheimer 2009).

Regardless of whether the founding human population of Australia had the bow-and-arrow, the technology could have dispersed into the continent at later dates or been developed independently. The bow-and-arrow was used by people on the islands to the north of Australia and had been present in the region for at least several thousand years (Perston et al. 2021). There was contact and trade between Indigenous Australian Peoples and people that made and used the bow-and-arrow in the Indonesian archipelago and Torres Strait (Mulvaney and Kamminga 1999). Bows and arrows made by people in the Torres Strait were traded to and used by people in the Cape York region of far-northern Australia (Hambly 1936; McCarthy 1953; Mulvaney and Kamminga 1999). Russell's (1888) report is also possible evidence that "simple" bows were being made in Australia before European contact, but the technology had not developed further into more powerful weapons and hunting tools.

It has been suggested that the absence of the bow-and-arrow in Australia relates to the technology being sub-optimal for hunting Australian fauna in Australian ecosystems (Flood 1999). However, even self-bows constructed from less-than-ideal woods shoot faster than spear-throwers (Bergman et al. 1988), and experiments suggest the bow-and-arrow is superior to spear-throwers under some circumstances, such as for hunting small- to medium-sized (< 200 kg) and more agile animal species (Tomka 2013). The bow-and-arrow is also easier to learn than a spear-thrower, and more projectiles can be carried at any one time and shot from more concealed positions (Angelbeck and Cameron 2014; Whittaker 2013). The bow-and-arrow was and is used in Papua New Guinea to hunt a variety of fauna, including tree and ground-dwelling marsupials, similar to those found in Australia (Bulmer and Menzies 1972; Pangau-Adam et al. 2012; Roscoe 1990). The bow-and-arrow was used effectively in a diversity of global ecosystems and is also effective for hunting exotic fauna in Australian ecosystems. Hunting native wildlife using the bow-and-arrow is illegal in Australia, yet some individuals still do so with apparent success. The bow-and-arrow should, therefore, have been suitable for hunting Australian fauna in prehistory. The widespread use of spear-throwers in Australia should also not have excluded the bow-and-arrow because both technologies were used simultaneously on other continents (Whittaker 2013). Therefore, the historical absence of locally made bow-and-arrows is surprising, and has perplexed cultural historians (Flood 1999) and individuals in online communities alike.

This study suggests the absence of bow-and-arrow technology in Australia may be related to the mechanical and physical wood properties of native flora. It is proposed that manufacturing self-bows from common Australian woods, while not impossible, is inherently more challenging than from common woods in other regions. If this is correct, it was less likely that bow-and-arrow technology suitable for hunting and warfare would persist in (or develop independently in) Australia. Spears and spear-throwers are easier to make and maintain than the bow-and-arrow (Bergman 1993; Whittaker 2013) and, therefore, became the main projectile technology used on the continent.

Conclusions

The key conclusion of this work is that common Australian plant species may be sub-optimal for self-bows due to their mechanical properties. The findings could explain the lack of bow-and-arrow technology among Indigenous Peoples in Australia. More work is required to explore this subject further.

This study relied on publicly available data sources, only a single sample represented most species, and there was no way to control data quality. Furthermore, there was a lack of data for some Australian species that bowyers report to have used successfully, and only 127 samples from 106 Australian species were included overall, in contrast to the diversity of woody plant species on the continent (Chapman 2009; Orchard 1999). There is also uncertainty regarding species identification by Australian bowyers. Properly assessing the potential of Australian flora for self-bows will require mechanical and physical data from more species (both Australian and global), along with replicate samples to capture variation due to genotype, environment, and genotype-by-environment effects. Steps must also be taken to reliably identify species. Further understanding the potential of Australian woods for self-bows will also require empirical experimentation to compare mechanical and physical wood properties with suitability for bows.

This work only used three commonly measured wood properties, which may not be optimal for representing the suitability of wood for self-bows. Other wood properties are measured and could be investigated, such as crushing strength, surface hardness, work to maximum load, and compression and shear parallel and perpendicular to the grain (Kretschmann 2010). The work to maximum load, which measures the combined strength and toughness of wood under bending stresses, is closely correlated with the suitability of wood for self-bows (Alden 1995; Kretschmann 2010; Moliński et al. 2016). Whether these variables could complement or be superior to the values used in this study should be investigated. Furthermore, assessing the suitability of wood for self-bows using existing mechanical and physical variables may not be entirely appropriate. For example, the modulus of rupture represents the maximum load endured at failure, surpassing the maximum force usually endured by wood in a self-bow, and it also does not account for the effects of cyclic bending that a bow experiences. This suggests that future work may require identifying and collecting new or different mechanical variables.

The subject matter in this paper involves traditional plant use by Indigenous Australians. Any future research in this area should ideally involve Indigenous perspectives regarding the traditional use of native Australian woods for manufacturing bow-and-arrow technology and reasons for the historical absence of the technology in Australia.

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Data Availability The dataset used in this study is available in the supplemental material.

Declarations

Ethics Approval Not applicable.

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