A Quest for a Sustainable Alternative Wood Species to Produce World Class Clarinets

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Clarinets are made with a variety of materials, *e.g.*, plastic, graphite, porcelain, or even metal. However, the most commonly used material to make clarinets is wood. Today, African granadilla or African blackwood (*Dalbergia melanoxylon*) is the most popular and most widely used species by leading international companies in terms of clarinet production, because of its high density, color, fine texture, and exceptional durability. This species is also used to manufacture flutes, oboes, and bagpipes, making African blackwood one of the most valuable tree species in the world. However, the focus on the usage of a single species puts considerable pressure on a rare and endangered wood species. Therefore, this work aims to identify viable alternatives to African blackwood in terms of manufacturing clarinets as well as providing a similar combination of instrument characteristics that musicians and companies believe contribute to the value of the instrument, *e.g.*, acoustics, aesthetics, and price.

Keywords: Woodwind instruments; Music; Endangered species; Tropical wood; African blackwood

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INTRODUCTION

The clarinet is a member of the woodwind family and is one of the most popular musical instruments in the world. The earliest clarinet was created by Johann Christoph Denner during the 1700s in Germany. It was made entirely with wood, except for the metal keys (Hoeprich 2008).

Contemporary clarinets consist of five parts: the mouthpiece, barrel, left-hand section, right-hand section, and bell (as shown in Fig. 1). The most common key system found in clarinets today is the Boehm system clarinet, which was developed between 1839 and 1843 by Hyacinthe Klosé and Auguste Buffet. This key system is played by the majority of musicians in the world (Hoeprich 2008).

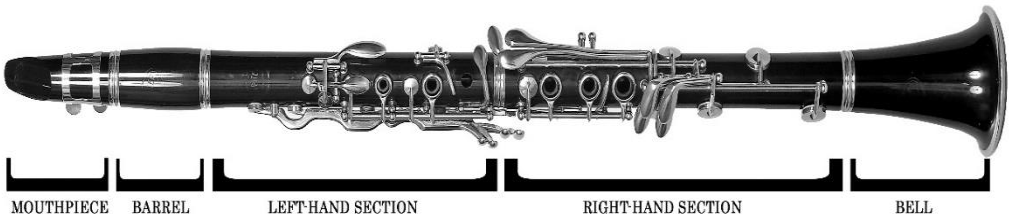

Fig. 1. Parts of the clarinet: the mouthpiece, barrel, left-hand section, right-hand section, and bell

While contemporary clarinets are also made with a variety of materials other than wood, *e.g.*, plastic (in various colors), graphite, porcelain, ebonite, hard rubber, or even metal, wood remains the most commonly used material, and African blackwood (*Dalbergia melanoxylon* Guill. and Perr. a species of the Fabaceae family), is the most popular wood species for clarinet-making. African blackwood started to dominate the clarinet market at the beginning of the 20th century when the commercial export of this species began from Mozambique and Tanzania (Jenkins *et al.* 2002). Other species are used, but on a much smaller scale.

Some characteristics that make African blackwood the favorite species for making clarinets is the black color of the heartwood, its wood density, its toughness, and the durability of the heartwood (Lincoln 1986). The heartwood of this species has high durability against both termite and fungal attacks (Nakai and Yoshimura 2020) and high durability in terms of dimensional stability, characteristic required for clarinets to resist to high level of moisture and, therefore, to keep the clarinet quality (Wegst 2006). According to Lincoln (1986), "its oiliness, resistance to climate change, and ability to take an exceptional finish makes it preferable to ebony for making high-quality clarinets."

African Blackwood, is also known as Grenadilla, Mpingo, Mozambique Ebony, and Pau Preto. According to Barstow (2020), this species is found in: Angola, Botswana, Burkina Faso, Cameroon, Central African Republic, Chad, The Democratic Republic of the Congo, Côte d'Ivoire, Eritrea, Eswatini, Ethiopia, Kenya, Malawi, Mali, Mauritania, Mozambique, Namibia (Caprivi Strip), Nigeria, Senegal, South Africa (Limpopo Province, Mpumalanga), South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe (as shown in Fig. 2). However, it is only possible to find enough trees of sufficiently harvestable size in East Africa (Ball 2004). Specifically, Mozambique and southern Tanzania are the two places where most African Blackwood comes from. Besides its economic value, this species has cultural importance in Tanzania because it is considered a national tree (Kenyon 2011).

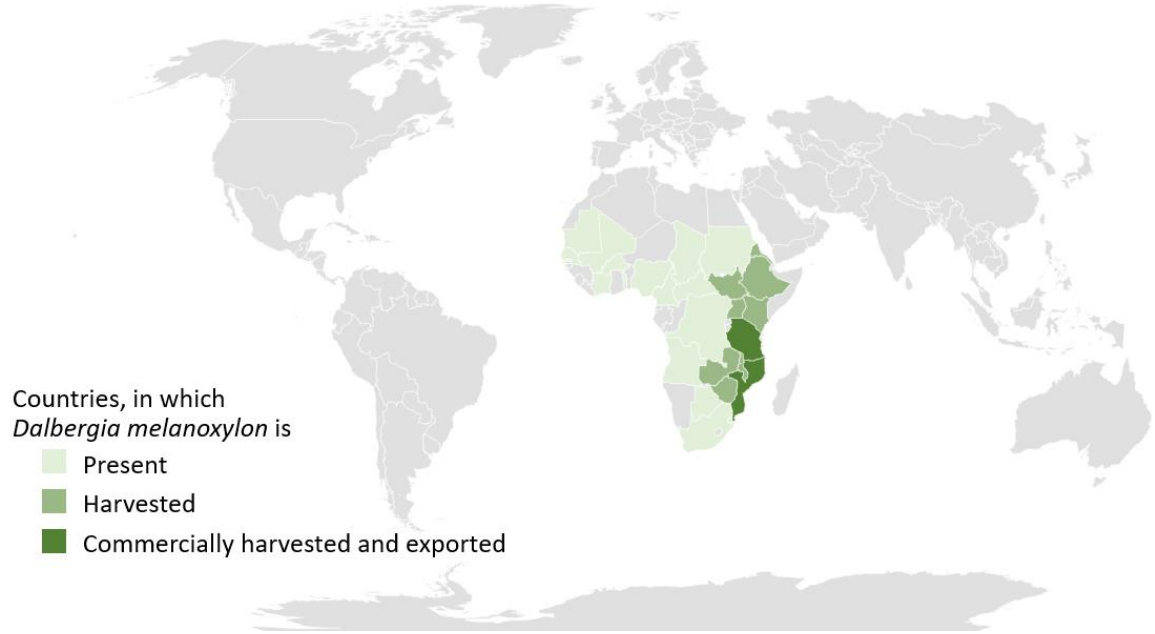

Fig. 2. Distribution of African Blackwood across the world (Barstow 2020; Ball 2004)

Apart from clarinets, African Blackwood is also used to make flutes, oboes, and bagpipes, making it one of the most prized trees in the world. This species can have an export value as high as US$ 18000 per cubic meter. However, the use of this particular species to make clarinets puts considerable pressure on a limited resource. According to Jenkins *et al.* (2002), every year approximately 7500 to 20000 African Blackwood trees are harvested to produce musical instruments. In 2004 and 2005, it is estimated that as much as 96% of the timber logged in Tanzania was illegally harvested (Harrison 2008). It is estimated that 20,000 to 25,000 clarinets are sold annually in the United Kingdom and that most of these are made from African Blackwood. Currently, global clarinet production is dominated by a small number of manufacturers that produce over 65,000 African Blackwood clarinets and oboes annually (Jenkins *et al*. 2002).

The manufacturing of clarinets demands high quality-part of wood without any defects or imperfections. These requirements make the production of clarinets extraordinarily wasteful because many trees are harvested to make only a few clarinets, making this an unsustainable process. Each clarinet requires billets totaling a volume of 0.0015 m^3. However, the waste from hidden defects can run as high as 25%, increasing the volume of billets used to manufacture each instrument to up to 0.0019 m^3. Therefore, the manufacturing of clarinets and oboes likely accounts for anywhere between 120 m^3 and 190 m^3 of exported billets annually (Jenkins *et al.* 2002). Instrument makers lose some of their perfect African Blackwood pieces during the machining process at the factory; it is estimated that up to 20% of their workpieces are lost (African Blackwood Conservation Project 2018).

Furthermore, African Blackwood plantations are not economically viable due to long rotation time (Gregory *et al.* 1999). A harvestable-sized tree has a minimum age of at least 80 years old, since this species grows very slowly (Jenkins *et al.* 2002) and a minimum diameter at breast height (DBH) over 24-cm, regulated in Tanzania (Nakai 2020). Regional experts do not believe current exploitation levels are sustainable, although this information needs to be verified (Ball 2004). This means that the raw timber materials for the most valued woodwind instruments comes from an unsustainable source. Therefore, it is necessary to preserve this tree and manage a sustainable harvest to keep African Blackwood as an option for commercial timber. Right now, African Blackwood is not threatened with biological extinction, but illegal harvesting, deforestation, and unsatisfactory fire management could make it commercially out of reach in the near future (Ball 2004). Consequently, African Blackwood has already disappeared from parts of its former range in Eastern Africa, and the rate of deforestation is increasing. Commercial stocks of African Blackwood have been exhausted in various parts of Tanzania (Jenkins *et al.* 2002). In addition, this species has already been recorded as rare in Mozambique through intensive exploitation. According to Scott Paul from Greenpeace, "If we lose some of these species, we are going to lose the sound" (Perry 2008).

Many organizations are working on the conservation of this species: Daraja Music Initiative, also known as "Clarinets for Conservation", African Blackwood Conservation Project, Mpingo Conservation & Development Initiative (MCDI), and Fauna & Flora International, as well as the Tanzanian government (Ball 2004; Palmer 2016; Nakai *et al*. 2019). Most of these organizations work to support rural communities to sustainably manage their forests by training communities to responsibly harvest timber and connect communities and buyers.

Therefore, it is necessary to identify viable alternatives to this rare and endangered wood species for the manufacturing of clarinets. In order to be successful, the search for

sustainable alternatives to African Blackwood to be used for manufacturing of clarinets must carefully consider the physical, mechanical, and aesthetic properties of the replacement, as well as the readiness of the music local community to accept it.

Research Aims

The aim of this article is to identify alternative wood species used to produce clarinets and to determine the instrument characteristics that musicians and companies believe contribute to their value, *e.g.*, quality sound, aesthetics, and price.

EXPERIMENTAL

Methods

The information presented in this study was collected from three types of sources: literature review, direct interviews with experts in the field, and online surveys distributed *via* email.

Literature review

In the first stage of the literature review, specialized journals and books focused on topics related to musical instruments were identified through a university library network (https://search.library.oregonstate.edu/). This review turned up more than 60 articles and 20 books about musical instruments in general and about clarinets specifically. The general topics reviewed included clarinet history, clarinet manufacturers, the variety and innovations about materials used to make clarinets, the physical and mechanical properties of the utilized wood species, and the physics of woodwind instruments.

Interviews

Interviews with 47 experts in the field were conducted *via* email (40), telephone (3), and personal contact (4).

The institutions contacted included clarinet manufacturers, musical instrument museums, and conservatories. Their locations are listed in Table 1. Manufacturers were contacted in order to identify the wood species and other materials used to make modern clarinets as well as the physical and mechanical properties of the wood species that companies believe are important for clarinet production. Museums were consulted in order to collect historical information about clarinets. Music schools and conservatories were contacted to gather general information about clarinets played by professional musicians and to connect with clarinetists, both professors and students, who were then targeted with surveys.

Online survey

Clarinet teachers, clarinet renovators, repair shop owners, clarinetists, and members of clarinet associations were contacted to answer an online survey sent *via* email. The list of invited individuals and institutions is presented in Table 2. The objective of this survey was to gather specific information about clarinets not otherwise found in the reviewed literature, *e.g.*, the opinions and knowledge of musicians, manufacturers, and repair shop owners on clarinets and the materials they are made of. In addition, repair shop owners were asked about the use of broken clarinet pieces.

The questionnaire was implemented by using a free version of an online survey

service (Survey Monkey), available at https://www.surveymonkey.com/s/FS9L7CD. The questions were related to durability, factors associated with clarinet quality and depreciation, as well as types of wear or damage that make clarinets permanently unusable. An additional point addressed was the importance of the brand, aesthetics, quality, tradition, and price in the choice of instrument, as well as brand preference. The list of questions is presented in Table 3.

Table 1. List of Institutions Contacted for Interviews and their Location

	Institutions Contacted	Location
Clarinet Manufacturers	Buffet Crampon	Paris, France
	Chadash Clarinet	New York, USA
	Devon & Burgani	Diadema, Brazil
	Hand Made Clarinets - L. Rossi	Santiago, Chile
	Hanson - England	Hanson Clarinet Company - West Yorkshire, England
	Henri Selmer Paris	Paris, France
	Jupiter	Mount Juliet, Tennessee, USA
	Leblanc	Wisconsin, USA
	Selmer	Elkhart, Indiana, USA
	Yamaha	Yamaha Corporation of America – California, USA
Musical Instruments Museums	European Traditional Instruments The Grassi Museum	Brussels - Belgium Leipzig, Germany
	Metropolitan Museum of Art	New York, New York
	Musical Instrument Museum	Phoenix, Arizona
	Musical Instruments Museum	Musical Instruments Museum
	The Orpheon Foundation - Museum of Historical Musical Instruments	Vienna, Austria
Conservatories	Conservatoire National Superieur de Musique et de Danse de Paris	Paris, France
	Conservatório Dramático e Musical Dr. Carlos de Campos de Tatuí	Tatuí, Brazil
	The Boston Conservatory, Minnesota State College – Southeast Technica	Minnesota, USA

Table 2. List of Institutions Contacted for the Online Survey and their Location

	Institutions Contacted	Location
Associations	Deutschen Klarinetten-Gesellschaft	www.deutsche-klarinetten-gesellschaft.de
	International Clarinet Association	http://clarinet.org/
	World Clarinet Alliance	http://www.wka-clarinet.org/
Repair Shops	American Music	Lynnwood, Washington
	Beacock Music	Vancouver, Washington
	Gracewinds	Corvallis, Oregon
	Guitar Center	Portland, Oregon
	Music & Arts	Redmond, Washington
	Portland Music Co. 'On Broadway'	Portland, Oregon
	Ted Brown Music	Washington

Table 3. Questionnaire

	Questions
1	What do you believe the typical service life of a clarinet to be? (years) What is the oldest clarinet that you ever played or found in your experience?
2	List the factors you believe to contribute to clarinet depreciation.
3	List the factors that will make a clarinet permanently unusable. Check all answers that apply. • When it falls and breaks. • When it dries out excessively. • Keys wear • Other (please specify)
4	Which is your favorite brand? • Buffet Crampon • Chadash Clarinet • Devon & Burgani • Hand made Clarinets - L. Rossi • Hanson - England • Henri Selmer Paris • Jupiter • Leblanc • Selmer • Yamaha
5	If you know which wood species are used to make the clarinet, list them here (Please write the scientific name)
6	How important do you believe the following motives to be for musicians selecting a Clarinet. Most important – 5 and less important - 0 • Brand • Esthetics • Quality (sound) • Tradition • Price • Others: Please specify
7	Describe characteristics that, in your opinion, contribute to the musical quality of a clarinet.
8	How familiar are you with clarinet manufacturing techniques? • Not familiar at all • Somewhat familiar (I know the principal steps of the manufacturing process) • Very familiar (I know specific tools and/or techniques) • I am an expert (e.g. I make or repair clarinets myself)
9	Are you familiar with the clarinet history? Its manufacturers and materials used in the past? • Not familiar at all • Somewhat familiar • Very familiar (I read books and/or articles about the topic) • I am an expert (e.g. academic, museum curator, or writer on this topic)
10	Do you know what happens with broken or abandoned clarinets?

The online surveys were sent to 200 people, including musicians, members of associations, music teachers, and repair shop owners. The response rate was calculated using the formula shown in Eq. 1,

$$\text{Response rate} = \frac{Responses\ received}{Surveys\ sent} \quad (1)$$

Information analysis

The information collected from the three different sources (literature review, interviews, and online surveys) was processed and combined to provide a list of sustainable alternative wood species to produce clarinets.

RESULTS AND DISCUSSION

The results include data about the characteristics of clarinets that musicians and manufacturers believe contribute to their value, such as sound quality, aesthetics, and price. These data also include information about alternative species used to make clarinets and how their key characteristics compare to African Blackwood.

The results from the three different sources (literature review, interviews, and online surveys) are presented separately.

Literature Review

Based on the literature review, some conclusions could be made about the variety and innovations of materials used to manufacture clarinets. Considering the variety of materials used to make clarinets, African Blackwood is the most used species for clarinet production, although other species are used on a smaller scale. According to Hoeprich (2008), "Occasionally ebony wood (*Diospyros melanoxylon*) is used, and in the past, cocus (*Byra ebenus*), boxwood (*Buxus sempervirens*) and various types of rosewood (*Dalbergia nigra*) have been popular […] Ebonite, developed to have a density similar to that granadilla [*Dalbergia melanoxylon*], is cheaper and unlikely to crack". According to Wegst (2008), besides African Blackwood (*Dalbergia melanoxylon)*, Brazilian rosewood (*Dalbergia nigra*) and Macassar ebony (*Diospyros celebica*) are also preferred for clarinet production. These woods are used because of their high density, fine grain, and good dimensional stability under the influence of moisture.

One clarinet manufacturer innovated its clarinet production process by starting a Green-Line project, the objective of which was to limit the use of African Blackwood in their clarinets and oboes. According to Hascoet (2020), this company developed a patented process for fabricating instruments with a wood plastic composite, in which wood powder from this species, generated as waste from production of solid wood instruments, is combined with carbon fiber (95% to 5% ratio, respectively). While this production method still uses African Blackwood to make the Green-Line clarinets, it results in less "waste" of overall wood material than the regular process.

There are many clarinet companies around the world, and some of them were contacted in this research. According to an online compilation, the 30 best-known companies are listed in Table 4 (Ranker 2018).

Table 4. List of Clarinet Companies

ID	Companies	ID	Companies	ID	Companies
1	Buffet Crampon	11	Devon & Burgani	21	Luis Rossi
2	Leitner and Kraus	12	Wolfgang Dietz	22	Amati-Denak
3	Yamaha Corporation	13	Schreiber	23	Leblanc
4	Morrie Backun	14	Jupiter	24	Palatino
5	Herbert Wurlitzer Clarinets	15	Stephen Fox	25	Peter Eaton
6	Hakam Din and Sons	16	Hammerschmidt	26	Mirage
7	F. Arthur Uebel	17	Gerold Klarinetten	27	Bay
8	Hanson Clarinet Company	18	E. K. Blessing	28	Selmer
9	Schwenk Und Seggelke	19	L. A. Ripamonti	29	Etude
10	Howarth of London	20	Chadash Clarinet	30	Patricola
Note: According to Ranker (2018)					

Interview

Interviews provided information about the history of clarinets and the materials used to make a clarinet. According to the interview with Palmer (2015), a museum educator at the MIM (Musical Instruments Museum), almost all clarinet makers used boxwood (*Buxus sempervirens*) in the past. However, during the late 1800s, clarinet makers started to use African Blackwood (*Dalbergia melanoxylon*), because its durability and tone quality were much better than boxwood. In addition, during this time, clarinet makers were adding additional keys and tone holes; consequently, they needed a stronger wood to support the new weight of the clarinet. Currently, other species are used to make clarinets, *e.g.*, Honduran rosewood (*Dalbergia stevensonii*). However, its density, one of the most important wood properties in terms of quality of the tone, is lower than that of African Blackwood (Rossi 2015).

Considering the physical and mechanical properties of a wood species that manufacturers believe are important for clarinet production, Jousserand (2015), a research engineer at the Buffet Group, states that the dimensional stability, especially in the tangential and radial direction, is one of the most important properties of clarinets. Additional important properties include impermeability to air and supporting the weight of the keywork. Since African Blackwood has all these characteristics, it remains the most widely used species to make the highest quality modern clarinets.

Online Survey

The online survey was sent to 200 individuals, of which 73 responses were received by November 08, 2015. Therefore, the response rate was calculated using Eq. 1, and found to be 36.5 %, which was considered satisfactory.

The first question involved the service life of a clarinet. The responses ranged widely: respondents believing that the service life of a clarinet is at least 3 years but can be as long as 200 years. The average of all responses was 100 years. Some responses were

more nuanced; one respondent replied "I have played on a 50 years old clarinet. Still worked, but not the greatest sound". It is reasonable to assume that these results depend on the usage, clarinet care, properties of the wood species, and manufacturing techniques.

The belief that clarinets can be played for as long as 200 years, as expressed by some respondents, is contradicted by Jenkins *et al.* (2002), who reported that professional quality clarinets may maintain their high performance for approximately six years. The reason for this is that the moist spray blown inside the instrument by the player causes the internal surface to become wet. Under normal circumstances, wetting would cause the wood to swell, but the internal surface of the clarinet is restricted, and the suppressed swelling generates stress that may lead to damage. With time, the repeated wetting of the internal surface of the instrument also deteriorates the quality of the wood, even if extremely careful cleaning and conservation procedures are applied. This is different from some stringed instruments, *e.g.*, violins, which, given the appropriate maintenance, could be played for hundreds of years without appreciable loss in quality. Even if the number of musicians remains the same, the relatively short life of the clarinet guarantees a steady demand for replacement instruments. Despite the relative short life, wood materials are still necessary for high quality clarinet manufacturing. Therefore, the alternative wood species with both high durability and sustainability is highly required in the future.

Table 5 shows the factors believed to contribute to clarinet depreciation. The principal factor is damage to the body of the clarinet. One factor that contributes to clarinet depreciation, according to the survey, is exposure to temperature extremes, *i.e.*, rain and dry weather, and human saliva, which will increase the amount of moisture present in the clarinet. Additional factors addressed were damage to the keys due intense usage, inadequate care and maintenance, wearing down of the tone holes, and not being played for a long period of time.

Table 5. Factors that Contribute to Clarinet Depreciation

Factors	Subtotals	Specific Factors	Specific Answers
Damaged bodies	53	Cracks or breaks in the wood	15
		Drying of the wood and change size in the body	13
		Human saliva and moisture	12
		Body broken	4
		Rot and depreciation of wood	4
		Bad manufacturing and design	3
		Material	2
Damaged keys owing to intense use	36	Loss of silver covering of the keys owing to intense use	16
		Shaky mechanics	10
		Deformation and broken keys	5
		Torn worn pads	5
Bad care and maintenance	29	Improper care	19
		Neglect cleaning	6
		Neglect oiling	4
Exposure to extreme weather	21	Temperature extremes	14
		Rain and extreme dry weather	7
Wearing down of the tone holes		8	
Not being played		4	

According to Jenkins *et al.* (2002), wood deformation or cracking, as well as keyhole breakage, is produced by stresses between the inside and the outside of the instrument. This stress is due to the fact that when blown into, the air inside the clarinet varies in humidity and temperature; for this reason, the material needs to constantly resist the stresses of playing. Clarinet maintenance is especially important to avoid cracks or breaks in the wood or the breakage of the keys. Factors that are believed to make a clarinet permanently unusable are presented in Table 6. The most popular responses are serious mechanical damage and excessive dryness.

Table 6. Factors That Will Make a Clarinet Permanently Unusable

Factors	Answers
When it falls and breaks – mechanical damage	41
When it dries out excessively.	29
Keys wear out, crooked or broken keys	21
Strong and large cracks in the wood	10
Changes in bore size (deformation)	9
Break of bore	1
Warping or rotting of the wood	1

Clarinets are permanently unusable if they fall and break, causing mechanical damage. In addition, if the wood becomes excessively dry, it could result in changes in bore size, which causes permanent deformation and crooked keys. The keys could wear out because of continuous usage. Large cracks in the wood cannot be repaired. In addition, warping or rotting of the wood can also make the clarinet unworkable. Favorite clarinet brands named by the survey respondents are listed in Table 7. Most respondents selected Buffet Crampon, a French company which has produced clarinets since 1825.

Table 7. Favorite Clarinet Brands of the Participants

Manufacturers	Answers
Buffet Crampon	33
Schwenk & Seggelke	7
Selmer	7
Yamaha	7
Henri Selmer Paris	4
Leitner & Kraus	4
Wurlitzer	4
Ridenour (Lyrique)	3
Backun	2
Buffet Green Line	2
F.A. Uebel – Superior	2
Fratelli Patricola	2
Hammerschmidt	2
Leblanc	2
Wolfgang Dietz	2
Chadash Clarinet	1
Hanson - England	1
Howarth - England	1
Hueying	1
Hufnagel (German System)	1
Karl Friedrich Todt	1
Schreiber	1

Considering the survey answers, the favorite clarinet manufacturing company was Buffet Crampon. A small number of large manufacturers monopolize the production of woodwind instruments, producing several thousand instruments annually. There are also a number of small-scale manufacturers that make a few hundred instruments annually. According to Jenkins *et al.* (2002), there are four global large manufacturers of clarinets and oboes, with the largest manufacturer producing just over 30000 wooden clarinets annually. On the basis of wood use, the second largest manufacturer probably produces approximately two thirds of this number of clarinets and oboes combined."

Responses concerned with the importance of brand name/reputation, aesthetics, musical quality (tone), tradition, and price for selecting a clarinet are presented in Table 8. For musicians, music quality and brand are very important, while price is named as "important", and tradition and aesthetics are "somewhat important."

Table 8. Reasons for Selecting a Clarinet in Order of Importance

Level of Importance	Musical Quality	Brand	Tradition	Aesthetics	Price
Very Important	70	25	11	10	9
Important	1	21	18	20	30
Somewhat Important	1	21	37	37	27
Not Important	1	6	7	6	7

Therefore, musical quality and brand are the most important aspects compared to aesthetics, tradition, and price, which are less important to musicians. For this reason, musicians tend to buy a musical instrument based on experience, *i.e.*, trying the instrument before buying, according to survey responses. Despite price and aesthetics be "somewhat important" for musicians, they are still a determining factor for selecting a clarinet. Aesthetics, more specifically, the body color and the keys material (nickel, silver or gold), are essential for the acceptance by musicians. It is known that black is the traditional color of wood preferred by musicians (Slooten and Souza 1993), and nickel keys is the material used in more affordable clarinets.

Table 9. Characteristics That Contribute to the Musical Quality of a Clarinet

Characteristics That Contribute to the Musical Quality of a Clarinet	Responses
Resonance intonation	18
Tone quality (timbre and sonority)	17
Resistance of keys and keyword design	16
Material	14
Good mouthpiece	11
Simple and accurate bore shape and size	10
Easy response flexibility in sound	6
Equality of sound in all registers and ability to seal completely	5
Good craftsmanship (manufacturing)	5
Reed	5
Wood density	4
Good pitch	3
Right balance of the harmonics	3
Tightness of pads (material also)	2

Survey responses concerned with the characteristics that contribute to the musical quality of a clarinet are presented in Table 9. The characteristics selected most often are resonance intonation, tone quality, the resistance of the keys and keyboard design, as well as the material used in the clarinet.

Responses about the level of familiarity with clarinet manufacturing techniques are presented in Table 10. Most respondents claimed to be somewhat familiar with the principal steps of the manufacturing process of clarinets. That should not be surprising since respondents targeted by the survey were musicians, clarinet teachers, clarinet repair professionals, and members of clarinet associations.

Table 10. Familiarity of Respondents with Clarinet Manufacturing Techniques

Answer Choices	Responses (%)
Somewhat familiar (I know the principal steps of the manufacturing process)	60.27
Very familiar (I know specific tools and/or techniques)	23.29
Not familiar at all	8.22
I am an expert, *i.e.*, I make or repair clarinets myself	6.85

The familiarity of the respondents with clarinet history, manufacturers, and materials used in the past are presented in Table 11. Most respondents claim that they are very familiar with clarinet history, clarinet companies, and the materials. They pointed to books and articles about these topics as the source of their information.

Table 11. Familiarity of Respondents with Clarinet History, Manufacturers, and Materials Used in the Past

Answer choices	Responses (%)
Very familiar (I read books and/or articles about the topic)	60.27
Somewhat familiar	26.03
I am an expert, *i.e.*, academic, museum curator, or writer on this topic	9.59
Not familiar at all	4.11

In conclusion, it was possible to categorize the respondents by their knowledge about wood species used to make the clarinet, manufacturing techniques, and clarinet history. These two questions are especially important because the confidence in the outcome of the survey is based on the fact that the targeted population was composed of professional musicians, clarinet teachers, clarinet association members, and repair professionals, most of whom declared their familiarity with clarinet manufacturing techniques, clarinet history, clarinet manufacturers, and materials used in clarinet production.

The last survey question was about the final disposition of broken or abandoned clarinets. The responses revealed a variety of ways broken clarinets are utilized. If the amount of damage is low, they can be sent to instrument donation centers or musical instrument museums. Permanently damaged clarinets can be sent to repair shops where they can be used for spare parts or used as decoration, *e.g.*, lamps or chandeliers, or even pulverized to a fine powder for use in repairs and other applications, *e.g.*, the green line of reconstituted wood-plastic clarinets produced by the Buffet Crampon group. Finally, some

broken clarinets are discarded and sent to a landfill, as confirmed by repair shop owners who reported that they sell broken clarinets to people who want to use them for decoration or other uses. One repair shop donated pieces of broken clarinets to researchers.

This information about the destinations of broken or abandoned clarinets will contribute to the development of the second part of this report, which is concerned with the measurement of the physical properties of the materials used for clarinet manufacturing (currently prepared for publication).

Information Analysis

The information collected from the three different sources (literature review, interviews, and online surveys) was processed and combined to provide a list of sustainable alternative wood species to produce clarinets (as listed in Table 12). These species were separated into three categories: (P) species used in the past before the arrival of tropical wood species in Europe; (C) species used currently by manufacturers; and (F) potential wood substitutes for use in the future, as garnered from respondents to this report.

Table 12. List of Species Used to Make Clarinets Found in Literature Reviews, Interviews, and Surveys

Scientific Name	Common Name	Categories	Origins	Source
Buxus sempervirens	European Boxwood	P	Southern Europe, Asia and North America	(Wegst 2006)
Prunus domestica	Plum	P	Europe to West Asia	(Wegst 2006)
Pyrus communis	Pear	P	Northeastern United States	(Wegst 2006)
Acer platanoides	Norway Maple	C	Northeastern Europe to Caucauses	(Wegst 2006)
Acer pseudoplatanus	Sycamore (Curly) Maple	C	Northwest to central Europe, Italy, Western Asia	(Wegst 2006)
Artocarpus lakoocha	Ma-Had	C	Southeast Asia	(Wegst 2006)
Byra ebenus	Cocus wood	C	Jamaica, Cuba	(Hoeprich 2008)
Calycophyllum multiflorum	Castella Boxwood, Castelo	C	South America	(Wegst 2006)
Casearia praecox	West Indian Boxwood, Zapatero	C	Central America to Northern S. America	(Wegst 2006)

Colophospermum mopani	Mopane, Mopani, Mupane, Musharu, Turpentine tree	C	Southern Africa	(Jousserand 2015)
Dalbergia cearenses	Brazilian Kingwood	C	Brazil	(Jousserand 2015)
Dalbergia decipularis	Bahia Rosewood	C	Brazil	(Wegst 2006)
Dalbergia latifolia	Indian Rosewood	C	India, Indonesia, Nepal	(Wegst 2006)
Dalbergia melanoxylon	African Blackwood, Granadilla, Mpingo, Pau-Preto, Mozambique Ebony	C	East Africa	(Hoeprich 2008)
Dalbergia nigra	Brazilian Rosewood	C	Brazil	(Hoeprich 2008)
Dalbergia oliveri	Ching-Chan	C	Myanmar; Thailand; Viet Nam	(Wegst 2006)
Dalbergia retusa	Cocobolo	C	Central America	(Hoeprich 2008)
Dalbergia Stevensonii	Honduras Rosewood	C	Belize	(Rossi 2015)
Dalbergia variabilis	Brazilian Tulipwood	C	South America	(Wegst 2006)
Diospyros celebica	Macassar Ebony	C	Indonesia	(Wegst 2008)
Diospyros crassiflora	Gaboon Ebony, African Ebony, Nigerian Ebony, Cameroon, Ebony	C	Central Africa	Survey
Diospyros melanoxylon	Coromandel, Ebony	C	India, Nepal, Pakistan	(Hoeprich 2008)
Guibourtia schliebenii	Red Chacate	C	Kenya, Mozambique, Tanzania	(Wegst 2006)
Guibourtia tessmannii	Bubinga	C	Equatorial Africa	(Wegst 2006)
Olea europea	Olive	C	Mediterranean	(Wegst 2006)

Stephegyne parviflora	Indian Kamba	C	India, Pakistan and Sri Lanka	(Wegst 2006)
Handroanthus impetiginosus	Purple Trumpet Tree, Purple Ipe, Purple Lapacho, Pau D'arco	F	Argentina, Brazil, Costa Rica, Mexico	(Jousserand 2015)
Handroanthus serratifolius	Yellow Trumpet Tree, Yellow Poui, Yellow Ipe	F	Central America to South America	(Jousserand 2015)
Note: P = Species used in the past; C = Species used currently; F = Possible Species for the future;				

According to the list of species used in clarinet production, which was created from various sources for this study, very few wood species are considered suitable for the manufacturing of woodwind instruments. Such species must have a flawless and even-grained wood and be capable of being worked to extremely fine tolerances (Jenkins *et al.* 2002). African Blackwood is the most used species for clarinet production because the characteristics of this species meets the all the criteria for clarinet manufacturing better than any known alternative species. These characteristics include high density, close-grained nature, natural oiliness, fine texture, high durability and black color. For this reason, clarinet manufacturers consider this species to be superior for clarinet production (Slooten and Souza 1993; Jenkins *et al.* 2002). The manufacturing of other instruments from African Blackwood is evidently on a much smaller scale. Other species used in clarinet production share some of these characteristics (most commonly high density and high durability) but fall short in other respects.

However, the intense exploitation of African Blackwood for musical instruments since 1970 increases the potential risk of extinction of this species (Jenkins *et al*. 2002). As such, African Blackwood has been considered an endangered species, categorized as "Near threatened (NT)" by the International Union for Conservation of Nature's Red List of Threatened Species, IUCN Red list, (Barstow 2020). This is an organization that classify species at high risk of global extinction. These categories are shown in Fig. 3.

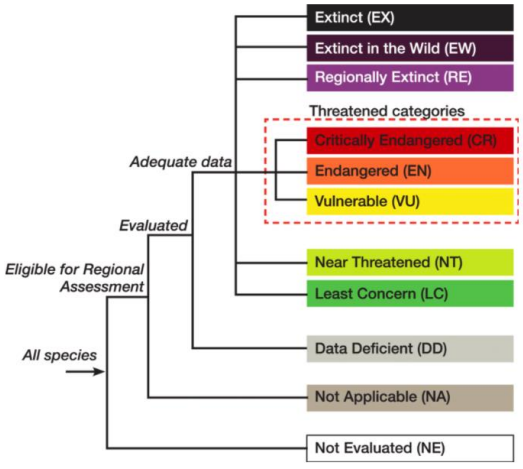

Fig. 3. Structure of the categories used at the regional level (IUCN 2012)

The levels of exploitation of African Blackwood are very high; for this reason, individual trees are becoming increasingly rare. This causes the concern of genetic erosion (lost genetic diversity) in several populations. According to Barstow (2020), African Blackwood is experiencing a population decline in many countries of Africa, due primarily to international demand to produce musical instruments, but also due to the production of traditional 'hongmu' furniture in China. In addition, other factors causing this population decline include habitat loss and degradation. As reported by Barstow (2020), "Over the last 150 years it is suspected that population decline is between 20% and 30%. (…) The [tree] population decline is ongoing and, moving into the future, decline is suspected to be equivalent (20% to 30% decline over the next one hundred years)". Apart from the existence of national legislation and forestry policy to reduce the over-exploitation of the species, it is also necessary to use alternative species to produce clarinets, and consequently, decrease the pressure on this limited resource.

Therefore, with the objective of finding viable alternative species for clarinet production, the key properties of African Blackwood were compared to other species (table 13). These properties are high density, exceptional durability, fine texture, straight grain, and the black color of the wood. These are important characteristics to determine the clarinet's acoustic, except color, which is a valued property only for aesthetic quality. The potential alternative species were classified into five classes, being A the best one and E the worst one, for clarinet manufacturing. Class A has all characteristics similar to African Blackwood, class B has 4 similar characteristics, class C, 3, class D, 2, and class E presents only 1 similar property. Visual color determination is a subjective and delicate enterprise. To evaluate color similarities, this property was divided in 2 classes: dark and light colors. The wood colors of species from table below fall in a relatively small range between light yellow and dark brown, with some species that are black, which is the preferred color for clarinet production. These species were also classified by IUCN Red List.

Table 13. Classification of Possible Alternative Species for Clarinet Production

Scientific Name	Heartwood Color	Grain	Texture	Density	Durability	Class	Red List
Dalbergia melanoxylon	**Black**[a]	**Straight**[a]	**Fine**[a]	**High**[a]	**High**[a]		NT
Diospyros melanoxylon	**Black**[e]	**Straight**[e]	**Fine**[e]	**High**[e]	**High**[e]	A	NE
Handroanthus serratifolius	**Dark brown**[f]	**Straight**[f]	**Fine**[f]	**High**[f]	**High**[f]	A	NE
Colophospermum mopane	**Dark reddish brown**[a]	Interlocked[a]	**Fine**[a]	**High**[a]	**High**[a]	B	LC
Dalbergia cearensis	**Dark purplish or reddish brown**[a]	Straight to interlocked[a]	**Fine**[a]	**High**[a]	**High**[a]	B	NE
Dalbergia nigra	**Darker chocolate brown to a lighter purplish or reddish brown**[a]	**Straight**[a]	Medium to coarse[a]	**High**[d]	**High**[a]	B	VU
Diospyros crassiflora	**Black**[a]	Straight to interlocked[a]	**Fine**[a]	**High**[a]	**High**[a]	B	VU

Handroanthus impetiginosus	**Brownish brown[d]**	**Straight[d]**	Fine to medium[d]	**High[d]**	**High[d]**	B	LC
Acer platanoides	**Darker reddish brown[a]**	**Straight[a]**	**Fine[a]**	Mediu m[b]	Low[a]	C	LC
Byra ebenus	Reddish brown[a]	Straight to wavy[a]	**Fine[a]**	**High[a]**	**High[a]**	C	NE
Casearia praecox	Light yellow[c]	**Straight[c]**	**Fine[c]**	**High[c]**	Low[c]	C	LC
Dalbergia decipularis	Yellow to red[a]	**Straight[a]**	**Fine[a]**	**High[a]**	Low[a]	C	LC
Dalbergia oliveri	**Medium orange to a darker reddish brown[a]**	Straight to interlocked[a]	Fine to medium[a]	**High[b]**	**High[a]**	C	EN
Dalbergia retusa	Ranging from yellow, orange, red, and shades of brown[a]	Straight to interlocked[a]	**Fine[a]**	**High[a]**	**High[a]**	C	CR
Dalbergia variabilis	Ranging from yellow, orange, red, and pink[a]	**Straight[a]**	**Fine[a]**	**High[a]**	Low[a]	C	NE
Diospyros celebica	Yellow to reddish brown[a]	Straight to interlocked[a]	**Fine[a]**	**High[a]**	**High[a]**	C	VU
Acer pseudoplatanus	**Darker reddish brown[a]**	Straight to wavy[a]	**Fine[a]**	Mediu m[b]	Low[a]	D	LC
Buxus sempervirens	Light cream to yellow[a]	**Straight[a]**	**Fine[a]**	Mediu m[b]	Medium[a]	D	LC
Dalbergia latifolia	Golden brown to purplish brown[a]	Interlocked [a]	Medium[a]	**High[a]**	**High[a]**	D	VU
Guibourtia tessmannii	**Pinkish red to a darker reddish brown[a]**	Straight to interlocked[a]	Fine to medium[a]	**High[a]**	Medium to High[a]	D	EN
Olea europaea	Cream or yellowish brown[a]	Straight to interlocked[a]	**Fine[a]**	**High[e]**	Low[a]	D	NE
Pyrus communis	Pink to light reddish brown[a]	**Straight[a]**	**Fine[a]**	Mediu m[b]	Low[a]	D	LC
Calycophyllum multiflorum	Light brown to pale yellowish[a]	Straight to interlocked[a]	**Fine[a]**	Mediu m[b]	Medium[a]	E	NE
Dalbergia stevensonii	Brownish-purple to a light-brown[a]	Straight to interlocked[a]	Fine to medium[a]	Mediu m[b]	**High[a]**	E	NE

Source: [a](Meier 2021), [b](Harja *et al.* 2021), [c](Record and George 1925), [d](Mainieri and Chimelo 1989), [e](Zadro 1975), [f](Teles and Souza 2005)

IUCN Red list categories: NE = Not evaluated; LC = Least Concern; NT = Lower Risk/near threatened; EN = Endangered; VU = Vulnerable; CR = Critically endangered;
Legend: Bold: Similar characteristics, Not bold: Different characteristics

Note: Classes represent the number of properties similar to African Blackwood: A = 5; B = 4; C = 3; D = 2, E = 1.
Some species from table 12 was not included in table 13 due to insufficiency of data, such as: *Artocarpus lakoocha, Prunus domestica, Guibourtia schliebenii, Stephegyne parviflora*

From the list of species presented above (Table 13), *Diospyros melanoxylon* and *Handroanthus serratifolius* are the most favorable for clarinet manufacturing, since they have the greatest number of similarities with African Blackwood: high density and durability, fine texture, straight grain, and dark colors. Therefore, these two species were classified in class A. From 23 species, only 5 species were categorized in class B as they match 4 characteristics and differ in only 1 characteristic from African Blackwood. *Dalbergia cearensis, Diospyros crassiflora, Colophospermum mopane* have high durability and density, fine texture and dark color but not a straight grain, differing in this aspect from African Blackwood. Although *Dalbergia nigra* and *Handroanthus impetiginosus* have high durability and density, dark color, and straight grain, they also differ from African Blackwood in the texture property. Most species from this list fall into class C, having 3 similar properties with African Blackwood. Another 6 species were classified into class D because they present 2 similar characteristics. Finally, Class E has only 2 species that have 1 similar and 4 different characteristics compared to African Blackwood.

Nevertheless, the acoustical quality of a species is not the only matter for the clarinet industry; the extinction threat due exploitation is also a concern. From the list of alternative species for clarinet manufacturing, 16 species were classified into different categories from the IUCN Red list, and 6 were not evaluated (NE). Even though class A and B have 7 species that have 4 or 5 characteristics similar to African Blackwood, only 3 were not evaluated - NE by IUCN Red List, implying that these species are not endangered and, therefore, can be considered potential alternative species to produce high quality clarinets. They are *Diospyros melanoxylon*, *Handroanthus serratifolius* and *Dalbergia cearensis*. Another 2 species were classified as "Least Concern (LC)", and other 2 species as "Vulnerable (VU)", consequently, they cannot be considered as potential alternative species to produce clarinets since they are being exploited for other uses.

Therefore, further studies are needed to test the physical properties of African Blackwood and use these properties as a key for testing and matching the potential alternatives. This data, rather than the opinions expressed by the community, may convince manufacturers to change. The empirical study is the topic of the second part of this research.

One problem faced in this research is that the information about alternative species was often in its common name or a group of species and not the scientific name of a specific species, making species identification by popular name difficult, but necessary, to create the list of alternative species for clarinet production.

CONCLUSIONS

1. Results suggest that the material used in clarinet production contributes to the musical quality of the instrument, so the physical properties of the wood species are crucially relevant to the quality of the instrument. Then, potential alternative wood species for clarinet production have the following characteristics: high density, fine texture, exceptional durability, black appearance of the wood, natural oiliness, dimensional stability, impermeability to air, strength sufficient for supporting the weight of the keywork, resistance to climate change, and the ability to achieve an exceptional finish quality.

2. Therefore, it is suggested that similarities in the key properties of density, durability, grain, texture, and color, can help in selecting the wood best suited for the manufacture of high-quality clarinets similar to the reference African Blackwood wood. Based on this study, *Diospyros melanoxylon*, *Handroanthus serratifolius*, and *Dalbergia cearensis* are potential alternative wood species for clarinet manufacturing, since these species have the greatest number of similarities and are not endangered.
3. Most of the respondents from the survey cited a species that was already known. This shows the traditional use of this species and possibly suggests some difficulty in introducing new species to the market with characteristics different from the traditionally used species.

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