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Alternative hardwood timbers for use in marine and fresh water construction

Project: SC070083/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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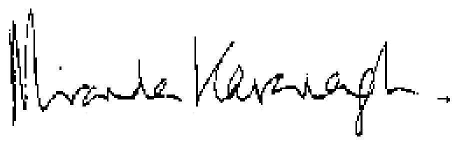


Miranda Kavanagh

Director of Evidence

Executive summary

The aim of this guide is to encourage the specification and use of lesser used species of hardwood timber in marine and freshwater construction applications, as alternatives to Greenheart and Ekki. The guide is based on a research project commissioned by the Environment Agency and will be of interest to anyone who uses timber in marine and freshwater applications, particularly structural and civil engineers, design consultants, building contractors and asset managers. It contains a step-by-step methodology to identify the most suitable timbers for use in different applications, together with a table containing technical data on the key properties (e.g. strength, marine borer and abrasion resistance) of five lesser used species which have been benchmarked against the performance of Greenheart and Ekki. The five species are Angelim Vermelho (*Dinizia excelsa* Ducke), Cupiuba (*Goupia glabra* Aubl), Eveuss (*Klainidoxa gabonensis*), Okan (*Cylicodiscus gabunensis* Harms) and Tali (*Erythrophleum micranthum*).

Contents

1 Introduction

The aim of this guide is to encourage the specification and use of lesser used species of hardwood timber in marine and freshwater construction applications, as alternatives to commonly used species such as Greenheart and Ekki. It focuses on the technical properties of selected lesser known hardwood species, established during the course of a collaborative research project, and compares their performance and material attributes to that of Greenheart and Ekki. Softwood timbers were not considered due to their inferior strength properties and lack of natural durability. The restrictions which apply to using wood preservatives to treat softwoods and concerns regarding their long term performance also discounted them from this research programme.

The guide is intended to complement rather than replace established design references, national or international standards and codes of practice. The guide also builds on the work of Crossman and Simm (2003) detailed in the *'Manual on the use of timber for coastal and fluvial engineering'.*

This guide will be relevant to anyone that specifies or uses timber in marine and freshwater applications, particularly structural and civil engineers, design consultants, building contractors, asset managers and procurement professionals.

A summary of the research project is provided in Section 1.1, but a detailed account of the scope of work undertaken, including research and testing methodologies, is contained within a published Report[1] which is freely available.

1.1 Project overview

The rationale for undertaking the research project is summarised below:

- The Environment Agency and much of the wider UK and European construction industry have historically favoured a narrow range of 'tried and tested' hardwood timbers for use in marine and freshwater applications. However, this over-reliance on a few species is not compatible within sustainable forest management in the longer term, as certain species are being over-exploited and this is likely to cause security of supply and inflationary price pressures in the future.

- There is a tendency to over-specify the technical properties of timber needed for a required end use, particularly if strength is critical. This means that timbers such as Greenheart and Ekki are often selected by default rather than on the basis of sound engineering judgement. The marine and freshwater construction industry is typically conservative and there is a general reluctance to specify timber species without a proven track record. This is understandable as often the material cost of timber in a construction scheme is dwarfed by the overall construction cost. However, it means that this impasse can only be overcome if reliable data on the performance of lesser used species of timber are obtained.

The research project was split into three stages:

[1] Williams *et al* (2010) available from: http://www.trada.co.uk/techinfo/research/

Stage 1	A desk based study to identify lesser used species of timber which may merit further investigation (known as the 'long list') based on a review of previous research, existing literature and database reference sources.
Stage 2	Fast-track novel laboratory screening trials to assess the potential marine borer resistance and abrasion resistance of the long list of timbers, together with a marine exposure trial. Marine borer resistance focussed on the crustacean *Limnoria* spp. (gribble) and the mollusc *Teredo* spp. (shipworm). Novel, fast track screening trials were chosen because guidelines in BS EN 275, which explains how species with the potential for use in marine construction can be evaluated, specifies a 5-year test period. This is too long a period for screening tests to be economically viable. Moreover, this standard does not provide a route by which abrasion resistance can be determined. Resistance to marine borers and abrasion was therefore established by using test methods developed by Borges *et al* (2003) Williams *et al* (2004B) and Sawyer and Williams (2005).
Stage 3	Testing to determine the strength properties of five timbers on the long list on the basis of the findings of Stage 2 and various other considerations (e.g. cost, availability within project timescales). The test material was selected from commercial stocks of timber and was visually strength graded to HS grade in accordance with BS 5756:2007. Strength properties were determined by the requirements of BS EN 384: 2004. The programme of tests determined the bending strength, stiffness, density and moisture content of graded timber. Testing was conducted in accordance with BS EN 408: 2003, and the timber species were allocated to their appropriate strength classes as detailed in BS EN 338: 2003.

The research has provided data to allow the five timbers tested at Stage 3 (Angelim Vermelho, Cupiuba, Eveuss, Okan and Tali) to be used with confidence in marine and freshwater construction applications. All reasonable testing of these timbers has now been undertaken and their key material attributes are known.

We now have reliable data on marine borer resistance and abrasion for the other thirteen timbers on the long list (see description of the stages above), and although their strength class has not been determined, they can still be used with confidence in applications where strength is not critical.

1.2 Timber sourcing issues

Illegal logging and unsustainable forest management are now recognised as a global problem. Forests are a precious natural resource, and their destruction has wide-ranging social, economic and environmental impacts.

In the construction industry there is demand for strong, durable, cost-effective and environmentally acceptable construction materials. Timber is a renewable resource and an environmentally acceptable choice of material if recycled or obtained from well-managed forests.

The Environment Agency has a strict timber purchasing policy which supports the UK Government's position on sourcing timber. From 1 April 2009, the UK Government's timber procurement policy requires central government departments, their executive agencies and non-departmental public bodies to procure timber and wood derived products originating from either independently verifiable legal and sustainable or

FLEGT (Forest Law Enforcement, Governance and Trade)-licensed or equivalent sources. As an alternative, contracting authorities can use recycled timber.

The policy requires evidence of chain of custody (movement of the timber through the supply chain from the forest source to the end product or user) and that the source of the timber is legally and sustainably managed or FLEGT-licensed. Evidence can come in three forms:

- **Category A** - independent certification of the timber and timber products under a forest certification scheme recognised by the UK Government.
- **Category B** - alternative documentary evidence that provides assurance that the source is legal and sustainable and chain of custody exists.
- **FLEGT-licensed, or equivalent**[2] – licence documentation which indicates that the timber has arrived in the UK from a country that has negotiated a bilateral Voluntary Partnership Agreement (VPA) with the European Community. From the point of import, additional Category A or B evidence is needed to demonstrate supply chain controls.

The Environment Agency has a stated preference for Category A evidence and as a result purchases certified timber in virtually all cases.

During Stage 1 of the research project, it was checked that all candidate timbers on the long list could be sourced with evidence of legality, sustainability and chain of custody (FSC certification in all cases).

Further information about the UK Government approach can be found at www.proforest.net/cpet. Information about the Environment Agency's policy can be found at www.environment-agency.gov.uk/aboutus/procurement

1.3 Timber properties

Timber has been used for marine and fresh water construction for centuries and this is a reflection of the properties that make it an attractive choice of construction material which include:

- high strength to weight ratio
- high density
- good workability
- good durability to attack by decay-causing fungi
- resistance to attack by marine borers
- high tolerance to short duration loads
- resistance to abrasion.

Timber has the ability to withstand dynamic loads such as those caused by wind, waves or vessels better than most other structural materials and the natural resilience of timber has considerable benefits in coastal and river situations where impact loads often produce the highest stresses. Traditionally the requirements for large section

[2] Currently, there is no FLEGT-licensed timber available in the market.

sizes, long lengths and good durability have meant that tropical hardwood species have been commonly used. The two best known are perhaps Greenheart or Ekki (which is why they were chosen as benchmark species), although a few other dense tropical hardwoods such as Yellow Balau, Opepe and Jarrah have also been used successfully. These have the advantage over softwood species of much higher resistance to physical abrasion and damage, and to biological degradation by marine borers.

Marketing lesser used species and encouraging the use of unfamiliar species has always tested the timber industry and this has been seen very clearly in the use of timber for marine construction. The two principal obstacles in using lesser used species are that either little is known about their resistance to marine borer attack, or there is limited confidence in the pedigree of the technical information of these species.

The key material attributes for hardwood timber for use in marine construction are resistance to attack by marine borers, abrasion resistance and strength (Williams et al 2004A). For freshwater applications, natural durability, abrasion resistance and strength are important.

The heartwood of all lesser used timbers detailed in this guide, unless indicated to the contrary, are classified as being naturally durable or better. In other words, they are resistant to attack by wood decaying and soft rot fungi. It should be borne in mind that high natural durability in terrestrial conditions does not necessarily guarantee robust marine performance.

Tables 1, 2 and 3 in Section 3 of this guide present technical data on these key material attributes for a range of lesser used species, together with comparative performance data for Greenheart and Ekki. Additional information is also provided in Annexes 3 and 4.

Marine borers

Timber that is exposed in the marine environment below the high tide mark is subject to attack by marine bacteria, fungi and wood boring animals. Of the three risks, marine boring animals are the most significant as they may cause severe damage to a timber structure over a comparatively short space of time. Although the distribution of marine borers varies around the UK coastline, in the absence of up-to-date survey information (post 1960s), users of this guide should assume that there is a risk of attack by marine borers unless local experience or data can demonstrate otherwise.

There are two main groups of marine borers in coastal waters around the UK: *Teredo* spp. (more commonly known as shipworm); and *Limnoria* spp. (more commonly known as gribble). Further information about these organisms is presented in Annex 1.

Abrasion resistance

In the coastal environment, timber is exposed to abrasion that may comprise simple rubbing of shingle over the surfaces and impact from stones thrown against the surfaces of the wood, in particular during storm conditions. Weakened wood, particularly if affected by marine borers, may then abrade more easily.

Most movement of sand and shingle and consecutive abrasion occurs in the zone where the waves are breaking and disturbing the shingle, which varies with the height of the tide.

1.4 Specifying and using timber

The design and specification process for timber-containing marine and freshwater structures should be informed by a review of the key material and performance requirements of these structures. In other words, design parameters should be determined on the basis of an assessment of the dominant risks that exist at a given location, for a given structure, e.g. risk of attack by marine borers, risk of abrasion, risk of attack by decay-causing fungi, requirement for strength etc, or any combination of these factors.

To help inform this process, the performance of similar structures nearby, operating under comparable conditions, should be considered, together with any monitoring records. If a risk-based approach is adopted, this will present opportunities to consider lesser used species of hardwood timber alongside traditional favourites such as Greenheart and Ekki.

The technical properties detailed in Tables 1, 2 and 3 (Section 3) of this guide provide the basis for the incremental development of confidence in specifying and using lesser used species of timber in the marine and freshwater construction industry, in the UK and elsewhere.

Where structural performance is critical, the five lesser used species identified in Tables 1 and 2 may be considered as alternatives to Greenheart and Ekki, provided their resistance to marine borer attack and abrasion, where relevant, and their strength properties meet project requirements. These timbers have been allocated to strength classes, as detailed in Table 1, on the basis of test results for bending strength, bending stiffness and density. The strength classes provide values that may be used in design for all the necessary mechanical properties. Table 2 contains the species-specific characteristic bending strength, bending stiffness and density values determined by testing these five timbers.

A description of the full design procedures is beyond the scope of this user guide so reference should be made to BS 5268 or EC5/EN338 for further information. The 'D' labels for strength classes are the same for the two standards, as can be seen in Table 8 of BS 5268 and, for EC5, the table in EN 338, but this is where the similarity ends. **The values in the two tables of these standards are clearly different, and one set of values should not be used with the design procedures of the other**. The BS 5268 values are permissible stresses that assume a member is under permanent load. The EC5/EN 338 strength class values, as detailed in Table 1, are characteristic material properties that are modified for duration of load and safety during the design procedure.

However, one step in the design procedure is addressed within this user guide. A modification is made within both design procedures to reduce the material properties when the members are exposed under Service Class 3 (SC3) conditions. The definition of SC3 is the same in both standards and is met when the average moisture content of the timber is greater than 20%. This is likely to be the case for most marine and fresh water structures. In BS 5268, values of the modification factor K_2 for SC3 are given in Table 16, while in EC5 values of k_{mod} (for SC3) are given in Table 3.1. In both cases the reduction in strength is about 20%.

Given that the characteristic strength values for the five lesser used species detailed in Tables 1 and 2 were derived from timber tested at a moisture content close to that likely to be found in service for SC3 (i.e. greater than 20%), and that no correction was made for this high moisture content during the test programme, structural engineers need not apply any of the strength reduction for SC3 in their designs when specifying Angelim Vermelho, Cupiuba, Eveuss, Okan and Tali. **However, this must not be**

taken as advice that the strength values may be increased if the expected Service Class is SC1 or SC2.

If structural performance is not critical, a longer list of thirteen lesser used timber species, as detailed in Table 3, can be considered.

Although it is recommended that the functional performance of a timber and its ability to withstand the most dominant site-specific hazards should drive the specification of timber species, it is recognised that other factors such as availability within project timeframes, cost and required section sizes may also influence the decision making process. Ultimately, the specification of suitable timber requires consideration of a wide range of factors including technical requirements, environmental and commercial considerations.

Section 2.1 details a step-by-step, risk-based methodology that can be used to help identify the most suitable timbers for different marine and freshwater applications.

2 Step-by-step methodology

The step-by-step methodology presented in Section 2.1 has been developed with a range of marine and freshwater structures in mind. The methodology, and all recommendations in this guide, are aimed specifically at timber for constructional purposes in Use Classes 3, 4 and 5 as defined in EN 335: 2006 Part 2. These Use Classes are the starting point of the step-by-step methodology, as they are linked to hazards and risks that may exist. It should be noted that Use Classes 1 and 2 relate to internal uses of timber and are therefore not relevant in the context of this guide.

Use Class 3: A situation in which the timber is not under cover and not in contact with the ground. It is either continually exposed to the weather or is protected from the weather but subject to wetting. The timber is exposed to decay fungi that can cause pockets of rot. Examples include: decking (incl. pontoons), parts of a jetty structure above the Mean High Water Springs (MHWS) level or 1-2 year water level for rivers.

Use Class 4: A situation in which the timber is in contact with the ground or fresh water and is permanently exposed to wetting. The timber is exposed to decay fungi and soft rot fungi which exacerbate erosion. Examples include: moorings, navigation structures, parts of landings, piers, jetties and stages that are immersed, fenders, lock gates and slipways.

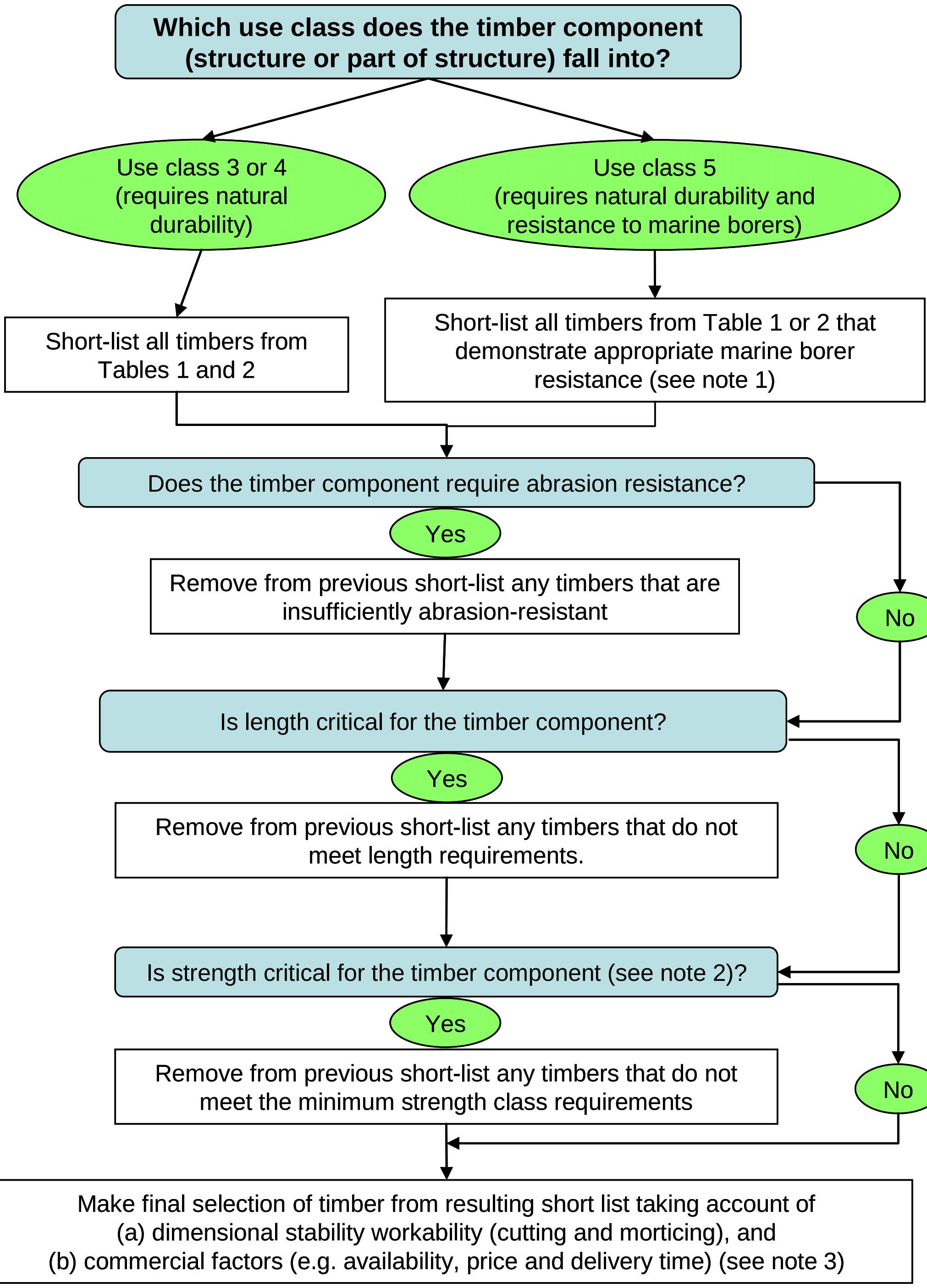
Use Class 5: A situation in which the wood or wood-based product is permanently exposed to salt water. The timber is exposed to decay fungi that can cause pocket rot, soft rot fungi and attack by marine borers. Examples include: parts of groynes, parts of slipways (incl. decking), parts of landings, piers, jetties and stages that are immersed, fenders and lock gates.

It may not be necessary to protect against all biological risks listed in the Use Classes as they may not be present or economically significant in all service conditions in all geographic regions. However, in the absence of local knowledge or experience that indicates to the contrary, a precautionary approach should be adopted. Information about the risks present at different localities may be obtained from authoritative sources such as TRADA (Timber Research and Development Association) or BRE (Building Research Establishment).

When using the methodology detailed in Section 2.1, reference should be made to data contained in Tables 1, 2 and 3 in Section 3, and Annexes 3 and 4.

It should be noted that the methodology may need to be applied more than once for any given application, as the individual components of a structure may require different functional performance or material attributes. For example, in relation to a beach groyne, piles and planking may need to be considered separately by applying the methodology twice, as typically length is less of an issue in relation to planking, and a lower strength class may also be required for planking compared to that needed for the piles

2.1 Flow diagram illustrating step-by-step methodology



Notes:

1. In the absence of any recent data (post 1960's), it is assumed that the risk of attack by marine borers does not vary around the UK coastline unless local track record demonstrates otherwise, i.e. timbers should be selected that demonstrate resistance to both shipworm and gribble.

2. Timber selections may vary within structure depending on the requirements – section by section basis; e.g. there could be strength-critical and non strength-critical elements to the structure.

3. Contact timber suppliers prior to specification of any single species for use in projects to check market/forest conditions and stock availability.

2.2 Examples of application – the methodology in practice

EXAMPLE 1: Marine structure - beach groynes

This worked example uses a hypothetical but realistic scenario that could easily relate to a situation where abrasion and marine borer resistance are critical, such as on the south coast of the UK. The purpose of the worked example is to illustrate how the methodology should be used, and how a risk-based approach to specifying timber can result in the consideration of lesser used species. Reference should be made to data contained within Tables 1, 2 and 3 (Section 3) and also Annexes 3 and 4.

Beach groynes comprise vertical piles and horizontal planking between each pile. The material attributes required of piles and planking are different, so in this instance the methodology has been applied twice.

Piles (refer to flow diagram of step-by-step methodology).

Q1: Which Use Class does the timber component fall into?

A1: Use Class 5

Shortlist of timbers: All timbers in Tables 1 and 3 that exhibit marine borer resistance, i.e. Angelim Vermelho, Cupiuba, Okan, Tali, Greenheart, Ekki, Yellow Balau, Opepe, Basralocus, Garapa, Massaranduba, Piquia, Sapucaia, Souge and Timborana

Q2: Does the timber component require abrasion resistance?

A2: Yes – the beach is assumed to be shingle

Shortlist of timbers: Angelim Vermelho, Okan, Tali, Greenheart, Ekki, Basralocus, Garapa, Piquia, Sapucaia, Souge, Timborana (i.e. Cupiuba, Yellow Balau, Opepe and Massaranduba removed from list as they are less resistant to abrasion than Greenheart)

Q3: Is length critical for the timber component?

A3A: Yes – lengths *in excess* of 10m may be needed

Shortlist of timbers: Greenheart or Basralocus (i.e. all others removed as not available in lengths exceeding 10m)

OR

A3B: Yes – lengths *up to* 10m may be needed

Shortlist of timbers: Angelim Vermelho, Okan, Tali, Greenheart, Ekki, Basralocus, Garapa, Piquia, Sapucaia, Souge and Timborana

Q4: Is strength critical for the timber component?

A4: Yes – as piles will be driven into ground

Shortlist of timbers (if *in excess* of 10m lengths required): Greenheart (D70) (i.e. Basralocus removed as no strength data available)

OR

Shortlist of timbers (if *up to* 10m lengths required): Greenheart (D70), Ekki (D70), Angelim Vermelho (D60), Okan (D40), Tali (D35) (i.e. Basralocus, Garapa, Piquia, Sapucaia, Souge and Timborana removed as no strength data available)

FINAL OPTIONS:

Greenheart - if lengths *in excess* of 10m required

Angelim Vermelho, Okan, Tali, Greenheart, Ekki - if lengths *up to* 10m required

(NB: may also need to consider dimensional stability, workability or commercial considerations at this point)

Planking (refer to flow diagram of step-by-step methodology)

Q1: Which Use Class does the timber component fall into?

A1: Use Class 5

Shortlist of timbers: All timbers in Tables 1 and 3 that exhibit marine borer resistance, i.e. Angelim Vermelho, Cupiuba, Okan, Tali, Greenheart, Ekki, Yellow Balau, Opepe, Basralocus, Garapa, Massaranduba, Piquia, Sapucaia, Souge and Timborana

Q2: Does the timber component require abrasion resistance?

A2: Yes – the beach is assumed to be shingle

Shortlist of timbers: Angelim Vermelho, Okan, Tali, Greenheart, Ekki, Basralocus, Garapa, Piquia, Sapucaia, Souge and Timborana (i.e. Cupiuba, Yellow Balau, Opepe and Massaranduba removed from list as they resistant to abrasion than Greenheart)

Q3: Is length critical for the timber component?

A3: No – lengths of up to 6m will generally suffice

Shortlist of timbers: As for Q2 as all timbers are available in lengths of at least 6m

Q4: Is strength critical for the timber component?

A4: Yes, but not to the same degree as for piles

Shortlist of timbers: Angelim Vermelho, Okan, Tali, Greenheart and Ekki (i.e. Basralocus, Garapa, Piquia, Sapucaia, Souge and Timborana removed from short list as no strength data)

FINAL OPTIONS:

Angelim Vermelho, Okan, Tali, Greenheart, Ekki

(NB: may also need to consider dimensional stability, workability and commercial considerations at this point)

EXAMPLE 2: Freshwater structure - landing stage

This second worked example of the step-by-step methodology uses a hypothetical but realistic scenario that could easily relate to a project along a river in the UK. Reference should be made to data contained within Tables 1, 2 and 3 (Section 3) and also Annexes 3 and 4.

A landing stage comprises vertical piles and horizontal decking. The material attributes required of piles and decking are different, so the methodology has been applied twice.

Piles (refer to flow diagram of step-by-step methodology)

Q1: Which Use Class does the timber component fall into?

A1: Use Class 4

Shortlist of timbers: All timbers in Tables 1 and 3, excluding Souge and Douglas Fir which are only moderately durable

Q2: Does the timber component require abrasion resistance?

A2: No – in this instance, the river is slow flowing and the risk of abrasion is low

Shortlist of timbers: As for Q1, i.e. all timbers in Tables 1 and 3 excluding Souge and Douglas Fir

Q3: Is length critical for the timber component?

A3A: Yes – lengths *in excess* of 10m may be needed

Shortlist of timbers: Greenheart or Basralocus (i.e. all others removed as not available in lengths exceeding 10m)

OR

A3B: Yes – lengths *up to* 10m may be needed

Shortlist of timbers: As for Q2, i.e. all timbers in Tables 1 and 3, excluding Souge and Douglas Fir

OR

A3C: No – lengths of up to 6m will generally suffice

Shortlist of timbers: As for Q2, i.e. all timbers in Tables 1 and 3 excluding Souge and Douglas Fir

Q4: Is strength critical for the timber component?

A4: Yes – as piles will be driven into ground

Shortlist of timbers (if *in excess* of 10m lengths required): Greenheart (D70) (i.e. Basralocus removed as no strength data available)

OR

Shortlist of timbers (if *up to* 10m lengths required): Greenheart (D70), Ekki (D70), Yellow Balau (D70), Angelim Vermelho (D60), Cupiuba (D50), Opepe (D50), Karri (D50), Eveuss (D50), Okan (D40), Tali (D35), Oak (D30) (i.e. all others timbers removed as no strength data available)

FINAL OPTIONS:

Greenheart - if lengths *in excess* of 10m required

Greenheart, Ekki, Yellow Balau, Angelim Vermelho, Cupiuba, Opepe, Karri, Eveuss, Okan, Tali or Oak - if lengths *up to* 10m required

(NB: may also need to consider dimensional stability / workability / commercial considerations at this point)

Decking (refer to flow diagram of step-by-step methodology)

Q1: Which Use Class does the timber component fall into?

A1: Use Class 3

Shortlist of timbers: All timbers in Tables 1 and 3, excluding Souge and Douglas Fir which are only moderately durable.

Q2: Does the timber component require abrasion resistance?

A2: No

Shortlist of timbers: All timbers in Tables 1 and 3 excluding Souge and Douglas Fir

Q3: Is length critical for the timber component?

A3: No – lengths of up to 6m will generally suffice

Shortlist of timbers: As for Q2 as all timbers are available in lengths of at least 6m

Q4: Is strength critical for the timber component?

A4: No

Shortlist of timbers: As for Q2 (i.e. all timbers in Tables 1 and 3 excluding Souge and Douglas Fir)

FINAL OPTIONS:

All timbers listed in Tables 1 and 3, excluding Souge and Douglas Fir – select a lesser used species if possible and avoid over-specification

(NB: may also need to consider dimensional stability, workability and commercial considerations at this point)

3 Technical information

Table 1 summarises the technical properties of the five lesser used timbers that were selected for strength testing. Table 2 presents the species-specific characteristic strength values of these five timbers that were obtained during the strength test programme. Table 3 summarises the properties of the other thirteen lesser used species that comprised the long list of candidate timbers. Technical properties other than strength, marine borer and abrasion resistance have been obtained by reference to the Prospect Wood Database. Further information regarding technical properties is given in Appendix II of the Technical Report[3] which underpins this guide.

[3] http://www.trada.co.uk/techinfo/research/

Table 3.1 Performance of five HS grade (BS 5756) lesser used species of timber benchmarked against Greenheart and Ekki

Species	Resistance to fungal decay	Resistance to shipworm[4]	Resistance to gribble[4]	Bending Strength		Modulus of elasticity		Density		Abrasion[4]	Shrinkage on drying		Movement in service	Typical maximum length available (m)	Typical maximum section size held in stock (mm)
		(benchmarked against Ekki/ Greenheart)[5]	(benchmarked against Ekki)[6]	$f_{m,k}$ (N/mm²)	Strength class	$E_{m,mean}$ (N/mm²)	$E_{m,05}$ (N/mm²)	ρ_{mean} (kg/m³)	$\rho_{k,05}$ (kg/m³)	Benchmarked against Greenheart[7]	Plane	Dimensional stability			
Greenheart [8]	**Very durable**	**Resistant**	**Resistant**	**70.0**	**D70**	**20000**	**16800**	**1080**	**900**	**Resistant**	**Tangential**	**Large**	**Medium**	**12**	**400 x 400** [9]
											Radial	**Large**			
Ekki [8]	**Very durable**	**Resistant**	**Resistant**	**70.0**	**D70**	**20000**	**16800**	**1080**	**900**	**Better**	**Tangential**	**Large**	**Large**	**10** [10]	**230 x 230** [9]
											Radial	**Large**			
Lesser used species															
Angelim Vermelho [11 12]	*Very durable*	*Comparable*	*Comparable*	*60.0*	*D60*	*17000*	*14300*	*840*	*700*	*Comparable*	*Tangential*	*Fairly large*	*No data*	10 [10]	*300 x 300* [9]
											Radial	*Fairly large*			
Cupiuba [11 12]	*Durable*	*Comparable*	*Better*	*50.0*	*D50*	*14000*	*11800*	*780*	*650*	*Worse*	*Tangential*	*Medium*	*Large*	10 [10]	*300 x 300* [9]
											Radial	*Large*			
Eveuss [11 12]	*Very durable*	*Comparable*	*Worse*	*50.0*	*D50*	*14000*	*11800*	*780*	*650*	*Better*	*Tangential*	*Large*	*No data*	10 [10]	*250 x 250*[13]
											Radial	*Large*			
Okan [11 12]	*Very durable*	*Comparable*	*Comparable*	*40.0*	*D40*	*11000*	*9400*	*700*	*590*	*Comparable*	*Tangential*	*Small*	*No data*	10 [10]	*300 x 300* [9]
											Radial	*Medium*			
Tali [11 12]	*Very durable*	*Comparable*	*Comparable*	*35.0*	*D35*	*10000*	*8700*	*670*	*560*	*Better*	*Tangential*	*Small*	*Small*	10 [10]	*300 x 300* [9]
											Radial	*Small*			
Reference species															
Yellow Balau [11]	Durable	Comparable	Better	70.0	D70	20000	16800	1080	900	Worse	Tangential	Large	Small	10 [10]	300 x 300 [9]
											Radial	Large			
Opepe [11]	Very durable	Comparable	Comparable	50.0	D50	14000	11800	780	650	Worse	Tangential	Medium	Small	10 [10]	300 x 300 [9]
											Radial	Medium			
Karri [11]	Durable	Worse	Comparable	50.0	D50	14000	11800	780	650	Comparable	Tangential	Large	Large	10 [10]	300 x 300 [9]
											Radial	Large			
Oak [11]	Durable	Worse	Comparable	30.0	D30	10000	8000	640	530	Better	Tangential	Large	Medium	10 [10]	300 x 300 [9]
											Radial	Fairly large			
Douglas Fir [11, 14]	Moderately durable	Worse	N/a	24.0	C24	11000	7400	420	350	Comparable	Tangential	Small	Small	10 [10]	300 x 300 [9]
											Radial	Small			
Purpleheart	Durable	Worse	Worse	N/a	N/a	N/a	N/a	N/a	1000	Comparable	Tangential	Medium	No data	10 [10]	300 x 300 [9]
											Radial	Medium			

Notes:

a. Angelim Vermelho, Cupiuba, Eveuss, Okan and Tali were much stiffer than predicted by their strength class, as detailed in Table 2. This should give engineers confidence to use the strength class values detailed in Table 1 without reduction for Service Class 3, since the structures are less likely to suffer from excessive flexure.

b. NOTE: Typical lead times for specialist order if required sizes not in stock: South America 4 – 5 months: West Africa 3 months.

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4 Refer to Annex 2 for more detailed results summarising the respective trials
5 Greenheart and Ekki perform comparably.
6 Ekki selected as benchmark because performance slightly inferior to Greenheart
7 Greenheart selected as benchmark because performance slightly inferior to Ekki
8 Strength classes obtained from BS EN 1912: 2009
9 Larger section sizes up to 450mm x 450mm may be available by specialist order. Check with suppliers.
10 Lengths up to 10m are available by specialist order although 6m tends to be the maximum length commonly held in stock. Check with suppliers.
11 Strength classes and characteristic values as defined in BS EN 338: 2003
12 Refer to Table 2
13 Eveuss is typically available as smaller section sizes than other timbers
14 Unless used as groyne planking, Douglas fir should be preservative treated in accordance with the requirements detailed in BS 8417 for the intended end use of the timber

Table 3.2 Characteristic values as obtained from test data using BS EN 384 for five HS grade (BS 5756) lesser used species of timber

Species	Bending Strength	Modulus of elasticity		Density	
	$f_{m,k}$ (N/mm²)	$E_{m,mean}$ (N/mm²)	$E_{m,05}$ (N/mm²)	ρ_{mean} (kg/m³)	$\rho_{k,05}$ (kg/m³)
Angelim Vermelho	60.4	22084	18551	1082	1012
Cupiuba	53.1	21414	17987	822	729
Eveuss	51.0	20998	17638	1019	981
Okan	47.3	19318	16227	998	898
Tali	40.5	17200	14448	815	672

Note: Engineers usually design structures using the strength class system as this removes the need to specify a specific timber species, and simplifies procurement. However, engineers may use the characteristic values for the species/grade combination where additional strength properties of the species are desirable for bespoke applications. Values for properties not detailed in Table 2 must be taken from the allocated strength class as detailed in Table 1 - values for the other properties may be found in EN 338. This approach can encourage the use of lesser species and even favour their specification.

Table 3.3 Performance of thirteen lesser used species of timber benchmarked against Greenheart and Ekki

Species	Resistance to fungal decay	Resistance to shipworm [15] (benchmarked against Ekki/ Greenheart)[16]	Resistance to gribble [15] (benchmarked against Ekki)[17]	Mean density (kg/m³)	Resistance to abrasion [15] Benchmarked against Greenheart[18]	Shrinkage on drying: Plane	Shrinkage on drying: Dimensional stability	Movement in service	Typical maximum length (m)	Typical maximum section size (mm)
Benchmark Species										
Greenheart	**Very durable**	**Resistant**	**Resistant**	**1080**	**Resistant**	**Tangential**	**Large**	**Medium**	**12**	**400 x 400** [19]
						Radial	**Large**			
Ekki	**Very durable**	**Resistant**	**Resistant**	**1080**	**Better**	**Tangential**	**Large**	**Large**	**10** [20]	**230 x 230** [19]
						Radial	**Large**			
Newly tested species										
Basralocus	Very durable	Comparable	Comparable	720 - 840	Comparable	Tangential	Large	Medium	10 [21]	300 x 300 [19]
						Radial	Medium			
Cloeziana	Durable	Worse	Comparable	No data	Comparable	Tangential	No data	No data	10 [20]	300 x 300 [19]
						Radial				
Dabema	Durable	Worse	Comparable	600 - 840	Comparable	Tangential	Fairly large	Medium	10 [20]	300 x 300 [19]
						Radial	Medium			
Garapa	Durable	Comparable	Comparable	840 - 960	Comparable	Tangential	Fairly large	No data	10 [20]	300 x 300 [19]
						Radial	Medium			
Massaranduba	Very durable	Comparable	Comparable	960 - 1080	Worse	Tangential	Fairly large	Medium	10 [20]	300 x 300 [19]
						Radial	Large			
Mora	Durable	Worse	Comparable	960 – 1080	Comparable	Tangential	Large	Large	10 [20]	300 x 300 [19]
						Radial	Large			
Mukulungu	Durable	Worse	Worse	840 – 1080	Comparable	Tangential	Large	Large	10 [20]	300 x 300 [19]
						Radial	Large			
Niove	Durable	Worse	Better	840 - 1080	Comparable	Tangential	No data	Small	10 [20]	300 x 300 [19]
						Radial	No data			
Piquia	Durable	Comparable	Better	840 – 1080	Comparable	Tangential	Large	Large	10 [20]	300 x 300 [19]
						Radial	Large			
Sapucaia	No data	Comparable	Comparable	No data	Comparable	Tangential	Fairly large	No data	10 [20]	300 x 300 [19]
						Radial	Medium			
Souge [22]	Moderately durable [22]	Comparable	Comparable	840 - 1080	Better	Tangential	Medium	Large	10 [20]	300 x 300 [19]
						Radial	Medium			
Tatajuba	Durable	Worse	Comparable	720 – 840	Comparable	Tangential	Fairly large	Small	10 [20]	300 x 300 [19]
						Radial	Medium			
Timborana	Durable	Comparable	Comparable	960 -1080	Comparable	Tangential	Fairly large	Medium	10 [20]	300 x 300 [19]
						Radial	Small			

NOTE: Typical lead times for specialist order if required sizes not in stock: South America 4 – 5 months: West Africa 3 months.

[15] Refer to Annex 2 for more detailed results summarising the respective trials
[16] Greenheart and Ekki perform comparably.
[17] Ekki selected as benchmark because performance slightly inferior to Greenheart
[18] Greenheart selected as benchmark because performance slightly inferior to Ekki
[19] Section sizes up to 450mm x 450mm may be available by specialist order. Check with suppliers.
[20] Lengths up to 10m are available by specialist order although 6m tends to be the maximum length commonly held in stock. Check with suppliers.
[21] Lengths in excess of 10m available
[22] For use only as groyne planking

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Annexes

Annex 1 Information on marine borers

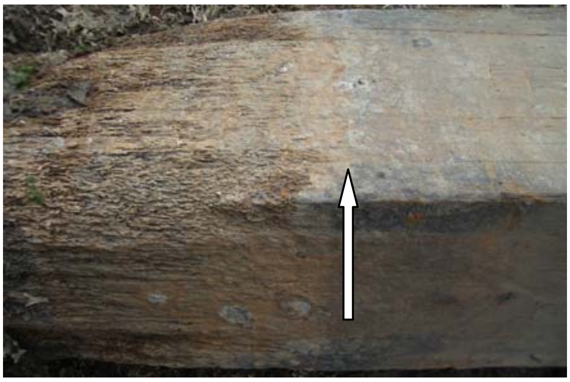
Gribble

Gribble are wood boring crustaceans, generally 2 to 4mm in length, pale grey in appearance and just about visible to the human eye when timber is inspected *in situ*. In contrast to the static conditions favoured by shipworm, adult gribble inhabit the surface of the timber and are fully mobile. Attack by gribble tends to be superficial and results in the creation of an extensive network of galleries at or just below the wood surface. These tend to be 1mm to 3mm in diameter with regularly spaced openings to allow respiration. Photographs 1 and 2 illustrate the typical appearance of gribble and the damage associated by the animal.

The animals tend to concentrate at the intertidal zone. Gribble tend to be sensitive to their environment. They can cause significant damage in harbours and estuarine environments, where there is less risk of abrasion. However, where structures are exposed to the full force of the sea and where there is a high risk of mechanical abrasion, gribble find it difficult to establish large populations. This is because the abrasive nature of the environment destroys the galleries. In such instances, gribble tend to be restricted to the sheltered parts of structures, particularly where joints are formed as these act as a suitable refuge for the animals

Photograph 1: Scanned electronmicrograph of gribble. Courtesy L Cookson. CSIRO

Photograph 2: Wasting of timber pile caused by gribble attack. Note that there is no attack below the sea bed line (arrowed)



Shipworm

Shipworm found around the UK coastline tend to be members of the Teredinidae family. They have a soft worm-like body with two shells or valves at the front of the animal which enable it to bore into timber. The animal remains in the same tunnel throughout its life and does not emerge from the timber. It will continue to bore alongside its neighbours until the timber is more or less destroyed and breaks apart.

The posterior part of the animal maintains contact with the external seawater environment via a fine hole about 1mm to 2mm in diameter. This hole is the only external sign that shipworm have colonised a timber component which makes surveying for shipworm using non-destructive techniques extremely difficult *in situ.*

Photographs 3 and 4 illustrate an example of shipworm extracted from a Douglas fir bearer of the Barmouth viaduct and typical damage to a Douglas fir pile.

Photograph 3: Example of shipworm extracted from a Douglas fir bearer of the Barmouth viaduct within the intertidal zone of the estuary mouth of the River Mawddach, Gwynedd. Note the soft tubular body and the bulbous head comprising the bivalve shell

Photograph 4: Example of the typical damage that shipworm can cause to timber. This is a section of Douglas fir removed from a bridge located on the River Ystwyth, Gwynedd.

Annex 2 Summary of marine borer and abrasion resistance trials

Resistance to gribble

Figure 1 shows the average pellet production rate per day over a 28 day period for candidate timber species on the long list, compared with Ekki. Higher pellet production by gribble (pellets per day) means a higher feeding rate and hence a lower resistance of the timber to gribble attack.

KEY

(green)	Performed better than Ekki
(yellow)	Comparable performance to Ekki
(orange)	Performed worse than Ekki

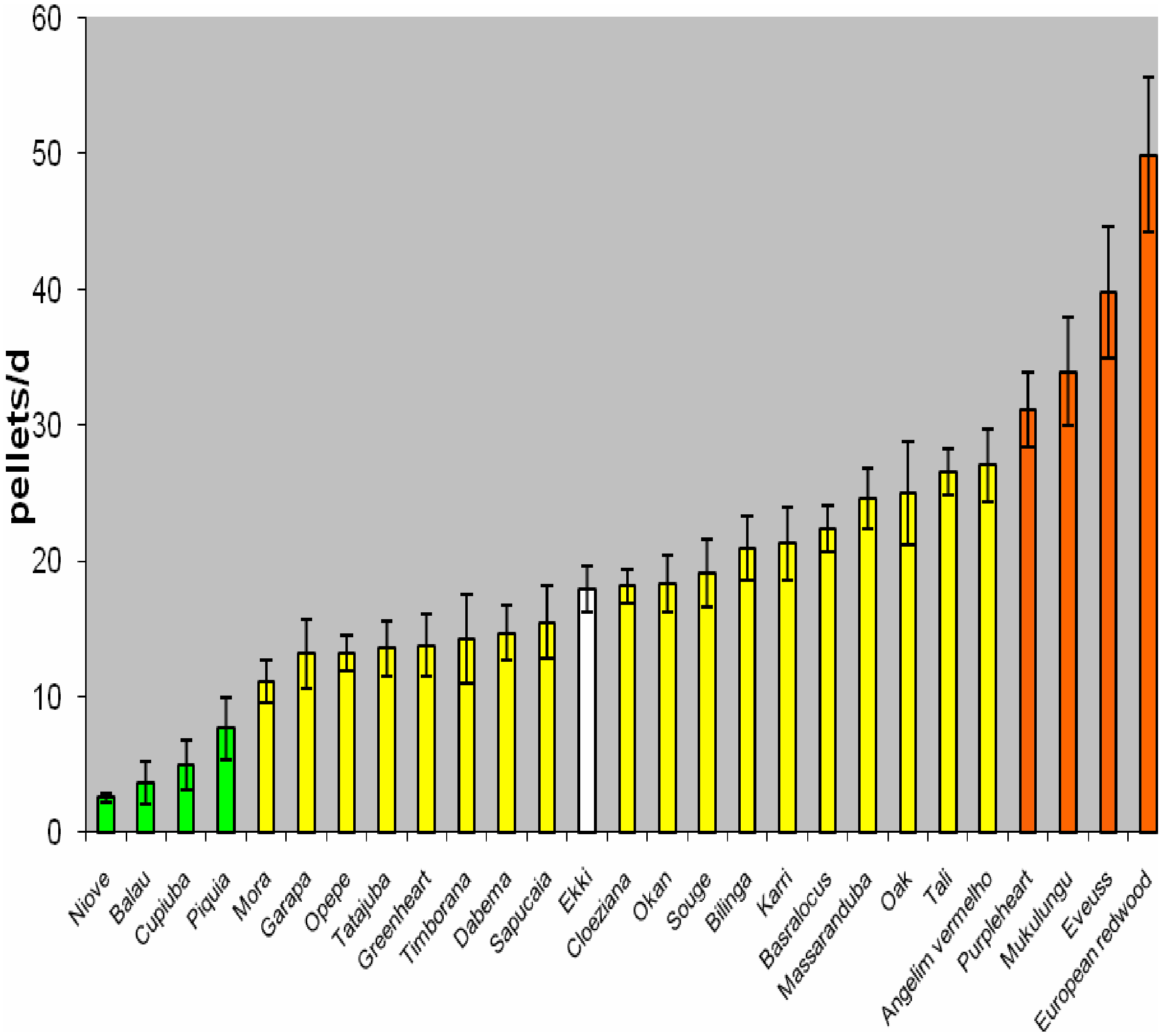


Figure 1: Comparison of daily feeding rates (mean ± Standard Error) against Ekki.

Resistance to abrasion

Figure 2 shows the average volume loss after 160,000 cycles for the candidate species on the long list compared with Greenheart.

KEY

(green)	Performed better than Greenheart
(yellow)	Comparable performance to Greenheart
(orange)	Performed worse than Greenheart

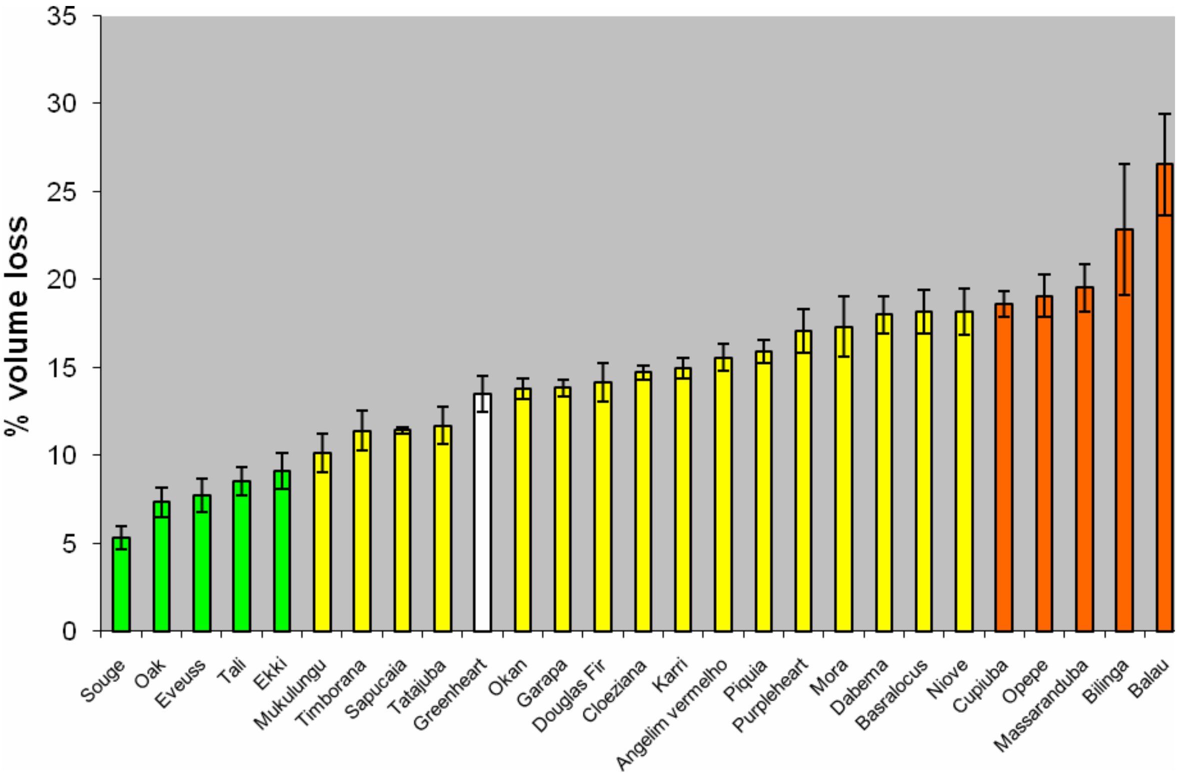


Figure 2: Average volume loss (mean ± Standard Error) after 160,000 cycles for the candidate species compared with Greenheart.

Resistance to shipworm

Figure 3 shows the mean visual assessment ratings for attack by shipworm during the marine exposure trial over an eighteen month period.

KEY

(blue)	Performance after six months exposure
(red)	Performance after twelve months exposure
(green)	Performance after eighteen months exposure

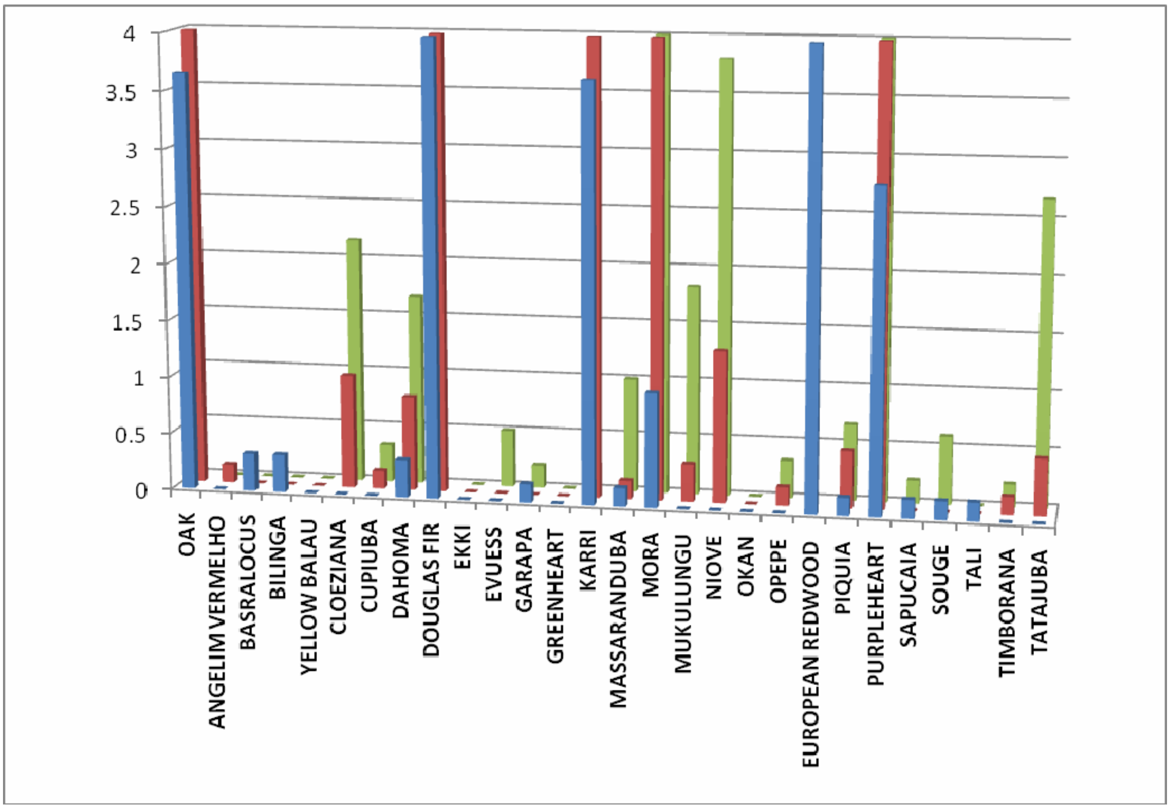


Figure 3: The comparative performance of the candidate timbers against attack by shipworm expressed as a mean visual assessment rating.

The visual assessment categories for determining attack by shipworm are presented below. These were based upon a continuous non-linear scale. For each candidate timber, the visual assessment ratings for each test sample were added and the result divided by the number of test samples to yield a notional average rating.

Numerical assessment category	Amount of attack caused by shipworm (teredinids) as percentage of board volume.
0	No attack.
1	Minor attack. Single or a few scattered tunnels not covering more than 10% of the specimen areas as it appears on X-ray film.
2	Moderate attack. Tunnels not covering more than 25% of the specimen area as it appears on X-ray film.
3	Severe attack. Tunnels covering between 25% - 50% of the area of the specimen as it appears on X-ray film.
4	Failure. Tunnels covering more than 50% of the area of the specimen as it appears on X-ray film.

Annex 3 Machining and workability properties

Timber Species	Performance comparison	Blunting	Sawing	Machining	Mortising	Workability (hand tools)
Angelim Vermelho	Vs. Greenheart	Equal	Worse	Better	Hard to mortice. Same as Ekki. Harder than Greenheart	Difficult to work across the grain. Comparable to Greenheart and Ekki and harder than Oak
	Vs. Ekki	Equal	Worse	Better		
	Vs. Oak	Worse	Worse	Worse		
Cupiuba	Vs. Greenheart	Worse	Equal	Equal	Easier to mortice than Greenheart & Ekki. Same As Oak.	Comparable to oak and easier to work than Ekki and Greenheart
	Vs. Ekki	Better	Better	Better		
	Vs. Oak	Better	Worse	Better		
Okan	Vs. Greenheart	Better	Better	Better	Harder to mortice than Oak but easier than Ekki and Greenheart	Difficult to work across the grain. Comparable to Greenheart and Ekki and harder than Oak
	Vs. Ekki	Equal	Better	Better		
	Vs. Oak	Worse	Equal	Better		
Eveuss	Vs. Greenheart	Equal	Better	Equal	Hard to mortice. Equal to Greenheart. Easier than Ekki. Harder than Oak	Difficult to work across the grain. Comparable to Greenheart and Ekki and harder than Oak
	Vs. Ekki	Equal	Equal	Equal		
	Vs. Oak	Worse	Worse	Worse		
Tali	Vs. Greenheart	Better	Better	Better	Easier to mortice. Easier than Greenheart and Ekki. Same as Oak	Comparable to oak and easier to work than Ekki and Greenheart
	Vs. Ekki	Better	Better	Better		
	Vs. Oak	Equal	Worse	Better		

Annex 4 Typical availability of section sizes and their typical end uses

Timber species	**Section sizes (mm) as imported or produced Thickness x width**	**Length (mm)**	**Typical uses**	**Comments**
Angelim Vermelho	25x 100x150x200 40x 100x150x200x250x300 50x 100x150x200x250x300 80x 100x150x200x250x300 100x 120x150x200x250x300 150x 150x200x250x300 200 x200x250x300 250 x250x300 300 x300 (boxed heart)	Lengths typically available from 1,000mm to 6,000mm in multiples of 500mm.	Decking Riverworks (piling, toe boards, etc) Lock gates Structural beams and groyne planking Piles and beams Fendering Sheetpiling	Lengths of up to 6,000mm are usually available from stock. Section sizes of 450mm x 450mm and lengths of up to 9,0m may available as custom orders. Typical procurement times for the delivery of a custom order can take 4 to 5 months and will depend on the volume of timber required for the scheme, section sizes and yearly rain patterns at the forest source
Cupiuba	25x 100x150x200 40x 100x150x200x250x300 50x 100x150x200x250x300 80x 100x150x200x250x300 100x 120x150x200x250x300 150x 150x200x250x300 200 x200x250x300 250 x250x300 300 x300 (boxed heart)	Lengths typically available from 1,000mm to 6,000mm in multiples of 500mm.	Decking Sheetpiling Structural beams and groyne planking Piles and beams	Lengths of up to 6,000mm are usually available from stock. Section sizes of 450mm x 450mm and lengths of up to 9,000mm may available as custom orders. Typical procurement times for the delivery of a custom order can take 4 to 5 months and will depend on the volume of timber required for the scheme, section sizes and yearly rain patterns at the forest source

NOTE: The information presented above was supplied by Ecochoice Ltd, UK agents for Reef Hout BV, specialist suppliers of FSC certified timbers for civil and marine applications. It should be noted that this information is considered representative of the market at the time of undertaking the research. The timbers are also commercially available from other UK suppliers.

Annex 4: Typical availability of section sizes and their typical end uses (continued)

Timber species	Section sizes (mm) as imported or produced Thickness x width	Length (mm)	Typical uses	Comments
Eveuss	25x 100x150x200 40x 100x150x200x250 50x 100x150x200x250 60x 100x150x200x250 80x 100x150x200x250 100x 120x150x200x250 150x 150x200x250 200 x200x250 250 x250	Lengths typically available from 1,000mm to 6,000mm in multiples of 500mm.	Decking Structural beams and groyne planking Piles and beams	Lengths of up to 6,000mm are usually available from stock. Section sizes of 450mm x 450mm and lengths of up to 10,000mm may available as custom orders. Typical procurement times for the delivery of a custom order can take 4 to 5 months and will depend on the volume of timber required for the scheme, section sizes and yearly rain patterns at the forest source
Okan	25x 100x150x200 40x 100x150x200x250x300 50x 100x150x200x250x300 60x 100x150x200x250x300 80x 100x150x200x250x300 100x 120x150x200x250x300 150x 150x200x250x300 200 x200x250x300 250 x250x300 300 x300 (boxed heart)	Lengths typically available from 1,000m to 6,000mm in multiples of 500mm.	Fendering Lock gates Sleepers Structural beams and groyne planking Footbridge bearers Piles and beams Riverworks	Lengths of up to 6,000mm are usually available from stock. Section sizes of 450mm x 450mm and lengths of up to 11,000mm may available as custom orders. Typical procurement times for the delivery of a custom order can take 4 to 5 months and will depend on the volume of timber required for the scheme, section sizes and yearly rain patterns at the forest source

Timber species	Section sizes (mm) as imported or produced Thickness x width	Length (mm)	Typical uses	Comments
Tali	25x 100x150x200 40x 100x150x200x250x300 50x 100x150x200x250x300 60x 100x150x200x250x300 80x 100x150x200x250x300 100x 120x150x200x250x300 150x 150x200x250x300 200 x200x250x300 250 x250x300 300 x300 (boxed heart)	Lengths typically available from 1,000mm to 6,000mm in multiples of 500mm.	Decking Handrails Fendering Footbridge bearers Structural beams and groyne planking Piles and beams Riverworks	Lengths of up to 6,000mm are usually available from stock. Section sizes of 450mm x 450mm and lengths of up to 11,000mm may available as custom orders. Typical procurement times for the delivery of a custom order can take 4 to 5 months and will depend on the volume of timber required for the scheme, section sizes and yearly rain patterns at the forest source

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