Technical Report

PD 344/05 Rev.2 (I)

Assessment of the resistance of 15 lesser used timbers from Guyana to abrasion and attack by *Limnoria quadripunctata* Holthuis

Commercial in Confidence

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by e-mail

Contents

Summary

The following report describes two laboratory tests that assess performance of 15 Lesser Used Species (LUS) of timber, listed in Table 2 (in report) against the two benchmark species, ekki and greenheart against abrasion and attack by the marine wood borer *Limnoria quadripunctata*. Ekki and greenheart were selected as benchmarks since they are already employed for marine application in the UK.

A summary of the performance of the LUS relative to the benchmark species is summarised in Table 1.

Table 1 Summary of the performance of the LUS and benchmark species

Treatment	Exposure to *Limnoria*	Exposure to abrasion
Timber species that performed significantly better than ekki	None	None
Timber species that performed significantly worse than ekki	muneridan dalli iteballi futui Scots pine*	darina iteballi kurokai wadara limonballi suya fukadi muneridan dalli futui
Timber species that performed significantly better than greenheart	burada Black kakaralli	None
Timber species that performed significantly worse than greenheart	dalli iteballi futui Scots pine*	limonballi muneridan suya dalli futui

*used as a control to validate the vigour of the test organisms.

Whilst no species performed better than ekki with respect to marine borer and abrasion testing, 2 species performed better than greenheart in the marine borer test and 5 species performed as well in terms of abrasion resistance.

1 Introduction

On 5th July 2007 a telephone conference was conducted between Mr Luvindra Sukhraj of the Forest Products Marketing Council of Guyana and Dr Andrew Pitman and Miss Natalie Furbank of TRADA Technology (TRADA).

The purpose of the telephone conference was to discuss the conclusions of a desktop study of 15 Lesser Used Species (LUS) from Guyana, which was conducted by TRADA on behalf of the Guyana Forestry Commission in the early part of 2007.

The telephone conference identified the need to test these 15 LUS for abrasion resistance, marine borer resistance and natural durability against fungi, using standard tests in order to assist in marketing these species in the UK and Europe.

On the 25th July 2007 TRADA Agreement TC//F07096 Part 2 was sent to the Guyana Forestry Commission outlining the methods used to investigate abrasion resistance, marine borer resistance and natural durability assessment.

This agreement was signed by Mr James Singh, Commissioner of Forests, Guyana Forestry Commission and returned to TRADA dated 24th August 2007 and was taken as formal notification for work to proceed.

The timber samples that were required for testing arrived at the TRADA site on 7th January 2008.

This report summarises the methods used to assess abrasion resistance and resistance to the marine wood borer *Limnoria quadripunctata* and provide findings. This work was undertaken between January and May 2008.

2 Scope of Work

- **Marine Testing**

  - Abrasion testing for all species.

    The abrasion testing will be benchmarked against two other species commonly employed for marine construction in the UK, greenheart and ekki.

  - Marine borer testing against *Limnoria* spp.(*Limnoria*)for all species in the laboratory.

    The marine borer testing will be benchmarked against two other species commonly employed for marine construction in the UK, greenheart and ekki. Scots pine is used as a control to validate the vigour of the test organisms.

- **Natural Durability Testing for Terrestrial Applications**

  - Natural durability testing for 10 species

Natural durability testing will be benchmarked against beech as a control. The test will be carried out using a recommended European Standard EN350-1 'Durability of wood and wood-based products – Natural durability of solid wood – Guide to the principles of testing and classification of the natural durability of wood'.

3 Background Information

During the telephone conference with the Guyana Forestry Commission on 5th July 2007, the role of the Environment Agency (EA) in the UK was discussed. The EA is government agency responsible for maintaining a large number of man-made structures within the marine and freshwater environment around the UK including those constructed using wood. The EA have expressed interest in the outcome of research to source sustainable supplies of naturally durable timbers which could be used for these applications.

The EA has a strict timber procurement policy which goes beyond the current UK Government requirements. The Agency's timber purchasing policy requires that all softwood and temperate hardwood is either FSC (Forest Stewardship Council), PEFC (Programme for the Endorsement of Forest Certification Schemes), SFI (Sustainable Forest Initiative), CSA (Canadian Standard Association) or MTCC (Malaysian Timber Certification Council) certified (Category A evidence[1]).

In relation to tropical hardwood, FSC / PEFC / MTCC / SFI / CSA certified timber must be purchased wherever possible. However, if certified timber does not exist, then other forms of evidence (Category B evidence[2]) which demonstrate legality, sustainability and chain of custody must be obtained.

Current guidance on UK Government timber procurement states that suppliers and contractors should have available documentary evidence demonstrating the timber supplied is at a minimum from legal sources, and if possible, from sustainable sources. Evidence should include full chain of custody from the forest source(s) to the end user.

Therefore, the key differences between UK Government policy and Environment Agency policy are as follows:

- The Environment Agency has a stated a preference for Category A evidence whereas the UK Government treats Category A and B equally.
- The Environment Agency includes sustainability as a minimum requirement

More information about the UK Government's approach to timber procurement is available from the Central Point of Expertise on Timber Procurement (CPET) which has been set up by the Department for Environment, Food and Rural Affairs www.defra.gov.uk (Perscomm Meaden 2007).

The marine environment is challenging for all construction materials, but timber suffers remarkably little from the effects of the salt content of seawater compared to, for example, concrete and steel (Cragg 1996). In addition, timber's resilience and favourable strength to weight ratio, and the relative ease of fabrication and repair, make it an attractive construction material for decision makers to design with, and specify.

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1 i.e. forest certification scheme

2 e.g. other evidence such as supply chain and forest source verification

Timber, particularly species from tropical forests, have been used for marine and fresh water engineering in the UK for centuries and has many applications, ranging from coastal defences such as groynes and sheet piling systems to structures including wharves, jetties, piers and navigation aids such as dolphins (Brazier 1995).

Within the UK marine and fresh water engineering industry, there is a demand for strong, durable, cost-effective and environmentally acceptable construction materials. Since timber is a renewable resource, it is the environmentally acceptable choice particularly if it is recycled or obtained from well-managed forests.

However, increasing timber costs, the poor track record of some timber species, the perceived increase in marine borer populations and the requirement for timber to meet stringent procurement rules are some of the negative factors that influence decision makers when trying to specify timber for these applications.

Furthermore, the recent legislation changes have prevented the use of certain types of preservative treated wood for marine applications, which has restricted timber species that can be used (Williams *et al* 2004A).

The restriction on the use of preservative treated wood in the sea has led to pressure to use naturally durable timber species. However, this sector of the construction industry is conservative and there is a reluctance to specify timber species without a proven track record of performance in these applications.

Brazier (1995) summaries the desirable material properties of timber for use in the marine and fluvial environments as being:

1. Dense, to withstand the scouring action of the waves

2. Strong, especially in bending

3. Stiff, to withstand impact

4. Durable in fresh water against fungal attack and against marine borers and fungal attack in the marine environment. If the timber is not classified as naturally durable it must be permeable and capable of receiving preservative treatment.

5. Available in large sections of 300mm x 300mm or greater and, often, lengths up to 15m.

Historically, in the UK, the combination of the above factors has resulted in a fairly short list of tropical hardwoods being used. Therefore, the designer has almost always chosen a dense, naturally durable species of timber with a proven track record, such as greenheart or ekki, although a few other dense tropical hardwoods such as balau, opepe and jarrah have also been used. The chief disadvantage of this conservatism is that commercial exploitation of such a narrow range of species have accelerated depletion of these species from forests and inflated the price of certain timber species extracted from tropical forests. Taking a holistic view of the timber trade, this makes profitable forestry and sustained yield management increasingly difficult to achieve (Williams *et al* 2004A)

It is the great variety of timbers available from tropical forests that makes them so valuable for industrial applications but at the same time presents an enormous challenge in their use (Brazier 1995). Marketing LUS and encouraging the specifier to use an unfamiliar species has always tested the timber industry and this has been seen very clearly in the use of timber for marine construction. Suppliers into this conservative market place have, and continue to introduce new species. However, there is often considerable end-user resistance to these lesser-used species by designers, as their technical properties are not fully appreciated.

Two of the principal obstacles in using lesser-known species are that, either there is limited confidence in the pedigree of the technical information about these species, or little is known about their resistance to marine borer attack. It should be borne in mind that a high level of natural durability in the terrestrial environment does not necessarily guarantee robust marine performance (Cragg 1996 and Williams *et al* 2004B). A questionnaire survey undertaken by Williams *et al* (2004A) identified that the four most important material attributes for timber for use in marine engineering were:

1. Resistance to marine borers
2. Strength
3. Impact resistance
4. Abrasion resistance

Whilst the piling/driveability characteristics of some species may be established by experience gained within the UK and overseas, the driveability characteristics of other species can only be determined through pilot studies. There are obvious limitations with pilot studies as only limited numbers of candidate species could be assessed and the costs of such pilot studies may limit the scope of these pilot trials. It may be possible to devise a laboratory investigation whereby the energy absorption characteristics of candidate species may be studied. The form of the test would involve the energy absorption characteristics of the candidate species being established and compared against the benchmark species greenheart and ekki, with particular focus on the comparison between the candidate species and greenheart. This is because greenheart has excellent piling characteristics on account of the bole being cylindrical and available in long lengths as opposed to tapered boles which is a common feature of some of the larger tropical trees such as ekki and purpleheart for example.

The last comprehensive UK coastline survey to establish the risk posed by marine borers was undertaken by Hall and Saunders (1967) in the 1960's. Since the 1960's a cleaner marine environment and reported increases in sea temperature can only favour an increase marine borer incidence. In the absence of new information regarding marine borer presence around the UK coastline, where known to be reliable, local knowledge and experience should be used in conjunction with the outputs from this research and development programme when choosing the 15 LUS tested.

Fast track laboratory screening trials were devised by Borges *et al* (2003) and Sawyer and Williams (2005) to assess the feasibility of determining marine borer resistance and abrasion resistance in a reliable cost effective manner. BS EN 275:1992 'Wood preservatives. Determination of the protective effectiveness against marine borers' specifies that a five year test period is required to assess whether timber is suitable for use in the marine environment. However, five years is a long period of time to screen performance and the tests described in EN 275 do not assess abrasion resistance.

Both laboratory trials employed in this study were developed to identify poor performing timbers so that they can be excluded from longer, more expensive and time consuming exposure trials. Species that do not perform well in fast track laboratory tests for both abrasion and marine borer resistance will be excluded from longer term marine exposure trials.

Williams (2004B) compared results of longer term marine exposure trials with results of Borges *et al* (2003) fast track laboratory trials and found there was a good correlation, therefore validating the fast track laboratory test. It should be noted that the results of both Williams and Borges were based on performance of *Limnoria* spp. only and not on timber species performance to *Toredo* (shipworm).

No abrasion resistance standard for marine applications exists. A literature review undertaken by Sawyer and Williams (2005) showed that a field trial was conducted by Oliver and Woods (1959) between 1953 to1959 who examined abrasion resistance of species exposed to shingle wear. The species tested and findings were not available for review. The problem with this field exposure approach is the time required to make meaningful comparisons.

Assessment of abrasion resistance in marine field exposure trials is difficult to study owing to variability of weather and site conditions. Existing laboratory methods bear little resemblance to the effects of marine abrasion. Furthermore, although test methods that assess timber properties such as the Janka hardness test can provide an indication of abrasion resistance, this is carried out using dry test material. The study undertaken by Sawyer and Williams (2005) is the basis for the laboratory method to assess abrasion resistance of the 15 LUS from Guyana against the benchmark species ekki and greenheart.

It is proposed that timber species which perform well in both laboratory trials are selected for further marine exposure trials. Species that demonstrate appropriate performance following marine exposure trials can then be selected for full strength testing at a later date in accordance with guidelines detailed in BS EN 408: 2003 '*Timber structures – structural timber and glued laminated timber. Determination of some physical and mechanical properties'*.

4 Materials and Methods

4.1 Timber species

The timbers selected for the testing (see Table 2 below) were selected by the Guyana Forestry Commission. TRADA understands that the timber is widely available in Guyana. TRADA was supplied with 10 boards from each of the 15 LUS. Each board was heartwood from separate randomly selected individual trees.

Table 2 Timber sample names and reference codes

Commercial Name	Botanical Name	Reference Code
Limonballi	*Chrysophyllum pomiferum* Eyma	LM
Black Kakaralli	*Eschweilera sagotiana* Miers.	BK
Muneridan	*Qualea rosea* Aubl.	MU
Burada	*Parinari campestris* Aublet.	BU
Iteballi	*Vochysia surinamensis* Stafl.	IB
Darina	*Hymenolobium flavum* Kleinh.	DA
Fukadi	*Buchenavia fanshawei* Exell & Maguire	FU
Tonka Bean	*Dipteryx odorata* Willd.	TO
Wadara	*Couratari guianensis* Aubl.	WA
Itikiboroballi	*Swartzia benthamiana*	IT
Morabukea	*Mora gongrijpii* Kleinh.	MB

Commercial Name	Botanical Name	Reference Code
Futui	*Jacaranda copaia* Aubl.	FT
Suya	*Pouteria speciosa* (Duckle) Baehni	SU
Dalli	*Virola surinamensis* (Rol) Warb	DL
Kurokai	*Protium decandrum* Aublet.	KU

4.2 Marine Borer Testing

4.2.1 Preparation of test materials

Specimens of *Limnoria quadripunctata* Holthuis were obtained from a laboratory culture in blocks of European redwood sapwood (*Pinus sylvestris*) maintained in running seawater at temperatures close to those of the source seawater in Langstone Harbour near Portsmouth, UK. The blocks were moved to a seawater tank at 20°C for one week prior to the test. Twenty-four hours before the experiments took place cloths were draped over the blocks to create anoxic conditions to induce the animals to leave their burrows. Individual animals were then transferred with a fine sable brush or fine forceps into 5ml of seawater in each chamber well of the cell culture box.

Timber test sticks measuring 20mm x 4.5mm x 2 mm were prepared from the 15 LUS and reference species. Heartwood was used in all cases except for the control wood species (European redwood) for which sapwood was used.

The vigour and health of the animals was assessed and confirmed by observing feeding rates on the sapwood blocks prior to the starting the trials. Confirmation of comparatively high feeding rates on the European redwood sapwood blocks validated the trial (see Photograph 1 in Appendix).

Each cell culture box contained 12 chambers (see Photograph 2). Twelve sticks per lesser used species were exposed to *Limnoria*. One stick from each of 10 sample boards supplied for each species was selected. Two additional sticks from the sample populations were selected at random from the 10 boards of each species. Prior to experimentation, the sticks were leached in seawater for one week (see Photograph 3), with a change of water after 3 days. This was to ensure that any water soluble extractives were leached from the blocks as would occur in the marine environment. Individual sticks were placed in 4mls of seawater in each chamber of the cell culture box (see Photograph 4) measuring 20mm in diameter. The cell culture chambers were kept in the laboratory under ambient lighting conditions at 20±2°C.

One *Limnoria* was placed into each chamber and the numbers of faecal pellets produced in each chamber were counted every 3 days (see Photograph 5). The rationale behind this laboratory test is that faecal pellet production rate matches feeding or ingestion rate closely. The data was transformed into a daily rate of faecal pellet production.

Results were presented as average feeding rates and compared against the two benchmarking species, ekki (see Photograph 6), greenheart and European redwood sapwood.

Statistical analysis using analysis of variance (ANOVA) was carried out to identify:

1. Timber species that performed significantly better than ekki
2. Timber species that performed significantly better than greenheart
3. Timber species that performed significantly worse than ekki
4. Timber species that performed significantly worse than greenheart

Faecal pellet counts were square root transformed before analysis and residuals were examined to ensure that the requirements for normality of distribution and equality of variances were met with transformed data. The variation in pellet production rates between different wood species was examined with a one way ANOVA and the species with rates that differed significantly from the rates on ekki and greenheart were identified using Dunne's post hoc test.

4.3 Abrasion Testing

4.3.1 Preparation of test materials

Abrasion testing was undertaken on 15 LUS from Guyana. The test simulated the wave action and debris impact that timber surfaces are exposed to when submerged in seawater. The results will identify the timber species that should be subjected to further long-term testing in field trials.

Each of the species supplied were cut to produce two 'matched' adjacent blocks of dimensions 75mm wide by 80mm long and a thickness 'as supplied', which was nominally 25mm two layers of the matched blocks to measure 50mm in thickness. Each block was marked with its reference number and the two blocks were then secured with a single wood screw (see Photograph 7).
In this way, the sample identification number was protected from abrasion. Finally, each block assembly was drilled centrally with an 8mm hole for securing to the test frames.

Blocks were immersed in running sea water for four weeks until saturated with seawater (see Photograph 8). Moisture meter checks indicated that all blocks were above fibre saturation point (30%) at a depth of 5mm, but it is acknowledged that full saturation would require a longer immersion time.

Since the moisture content of wood influences strength and subsequently the abrasion resistance of timber, it is important that the exterior of the timber was above fibre saturation point to properly simulate the timber when submerged in seawater.

Immediately prior to testing, the volume of the blocks was measured by displacement in a Eureka can. Fresh water displaced was weighed directly (see Photograph 9).

4.3.2 Test apparatus used to expose blocks.

The test apparatus was an adapted Los Angeles aggregate fragmentation resistance tester (see Photograph 10). This comprised a heavy robust steel drum that can be sealed so as to be watertight. The speed of rotation was 33 rpm. At this speed the shingle rolls smoothly around the drum, over and under the test frames holding the timber samples and is not carried around the drum and fall on the blocks. If this were to occur, the abrasion caused is more likely caused by impact damage rather than rubbing abrasion. A counter accurately recorded the number of revolutions.

The six test frames were fabricated from medium carbon steel and constructed to ensure that the faces of the wood blocks were perpendicular to the moving shingle. They also allowed shingle to flow under and over the blocks.

From the ten samples of each species, six were selected at random. These were then bolted to the exposure frames in a random order, although the position of each block was noted so as to determine whether position on the frame affected rate of abrasion. Five species were tested during each test run; with a further frame containing the control or reference species which were ekki, greenheart and Douglas fir cut to the same dimensions (see Photograph 11).

The testing regime used an initial charge of 25kg of 20mm shingle with 15 litres of seawater. The shingle was obtained from a local builder's merchant that uses the same source of supply. Although literature reviews have failed to find evidence that sea water contributes to abrasion, it was felt that the test should simulate field conditions in this respect and seawater rather than freshwater was used.

After 80,000 revolutions, the shingle was removed and the drum thoroughly washed. Fresh shingle and sea water was loaded and the machine run for a further 80,000 revolutions. In this way, each test took 5 days (see Photographs 12 and 13).

At the end of the test, all blocks were thoroughly washed to remove surface contaminants (see Photograph 14) and stored under water to prevent drying. Finally, the volume of the blocks was determined by the displacement of water using a Eureka can.

Percentage loss of volume for each test block was determined using the following equation:

$$\textbf{Percentage Loss in Volume (\%)} = \left(\frac{\textbf{Initial Volume} - \textbf{Final Volume}}{\textbf{Initial Volume}} \right) \times 100$$

Photographic records were kept of each test block. The surface texture of the blocks was noted at the end of the test on a scale of 1 to 5. A low number on the scale indicates a very smoothly worn surface, whereas a high number 5 indicates a very rough, coarse surface.

The orientation of growth rings was also noted in case that was a significant factor.

The oven dry density of every board of every species supplied was measured as density was calculated using the following equation:

$$\textbf{Density} = \frac{\textbf{Oven Dry Weight}}{\textbf{Green Volume}}$$

Green volume was measured when the samples were above fibre saturation point.

5 Results

5.1 Marine Borer Testing

Results presented in Table 3 show comparative feeding rates listed against the two benchmark species, ekki and greenheart. The sapwood of European redwood was used as a control to validate the experiment. Comparatively high daily feeding rates observed on sapwood confirmed the vigour of the test organisms and validated this laboratory trial.

Table 3. Comparison of feeding rates on the LUS with ekki and greenheart

	mean pellets/d	% reduction compared with ekki	% reduction compared with greenheart
Burada	17.7	14.1	47.0
Ekki	20.6	0.0	38.3
Black kakaralli	22.2	-7.9	33.4
Tonka Bean	24.2	-17.4	27.6
Kurokai	25.5	-23.9	23.6
Mora Bukea	26.1	-26.9	21.7
Wadara	27.3	-32.5	18.3
Muneridan	31.5	-53.3	5.4
Greenheart	33.3	-62.1	0.0
Dalli	47.7	-131.7	-42.9
Iteballi	53.3	-159.0	-59.8
Futui	59.0	-186.8	-76.9

A - in Table 3 indicates the LUS performed worse than the benchmark species. A + indicates a better performance expressed as a % reduction in daily faecal pellet production rate.

From Table 3 (above) and Figure 1 (below) we see that none of the species performs significantly better than ekki and that 4 species, not including greenheart, perform significantly worse than ekki.

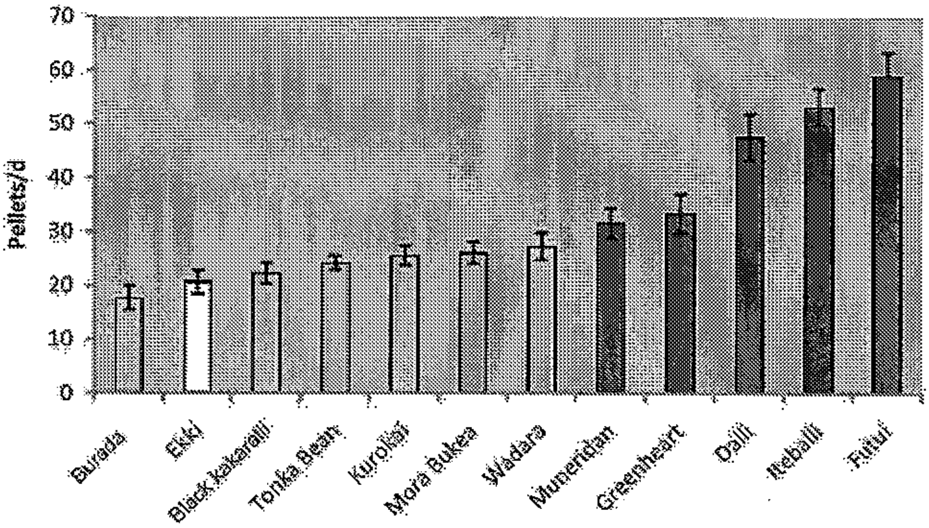

Figure 1. Comparison of feeding rates expressed in terms of faecal pellets produced per day (mean ±SE) on the LUS and ekki. Significantly higher rates of production when compared with ekki are shown in red (one way ANOVA of square root transformed rates with Dunnet's post comparison with a control).

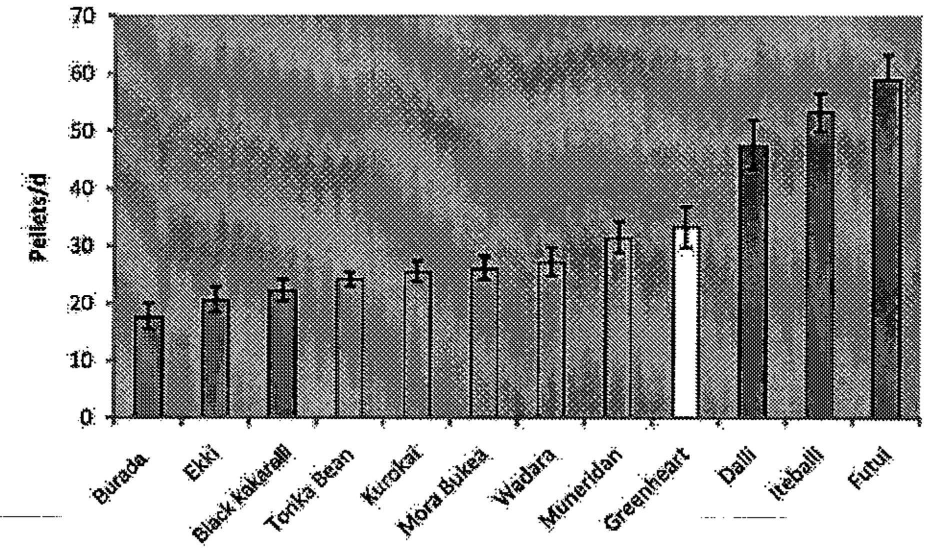

Figure 2. Comparison of feeding rates expressed in terms of faecal pellets produced per day (mean ±SE) on the LUS and the greenheart. Significantly lower rates of production when compared with greenheart are shown in green and significantly higher rates shown in red (one way ANOVA of square root transformed rates with Dunnet's post comparison with a control).

From Table 3 (above) and Figure 2 (above) 2 of the LUS (burada and Black kakaralli) perform significantly better than greenheart, 5 perform as well as greenheart and 3 LUS perform significantly worse than greenheart (dalli, iteballi and futui).

Since greenheart is already accepted for use for marine applications then a total of 8 species have the potential for use in marine construction if *Limnoria* resistance is considered.

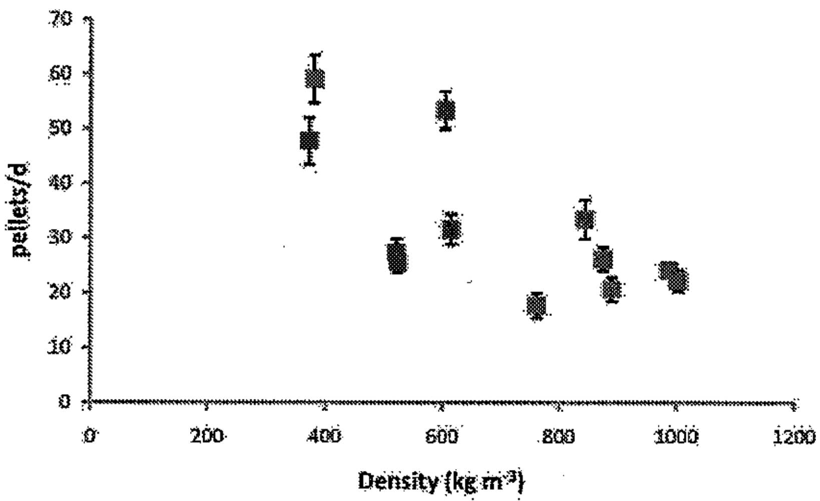

Figure 3. Correlation between density of the timbers tested and feeding rate expressed in terms of faecal pellet production.

It can be seen in Figure 3 that, in general, there is a negative correlation between the increase timber species density and the *Limnoria* feeding rate.

5.2 Abrasion Testing

Table 4 makes a comparison of % volume loss between the 15 LUS and the two benchmark species greenheart and ekki.

Table 4. Comparison of abrasion rates for LUS with ekki and greenheart

	mean % volume loss	% reduction compared with ekki	% reduction compared with greenheart
Black kakaralli	8.3	25.8	38.7
Ekki	11.2	0.0	17.4
Mora Bukea	11.8	-5.8	12.6
Burada	13.2	-18.1	2.4
Itikiboroballi	13.5	-20.7	0.3
Greenheart	13.5	-21.0	0.0
Tonka Bean	15.1	-35.3	-11.8
Douglas Fir	16.3	-45.6	-20.3
Darina	17.4	-55.4	-28.4
Iteballi	17.5	-56.3	-29.1
Kurokai	17.9	-60.0	-32.2
Wadara	18.5	-65.3	-36.6
Limonballi	18.9	-69.3	-39.9
Fukadi	19.1	-70.6	-41.0
Muneridan	19.4	-73.0	-42.9
Suya	27.5	-145.5	-102.9
Dalli	33.6	-199.9	-147.8
Futui	38.5	-244.5	-184.7

Figures 4 and 5 (below) summarise the losses in the LUS, ekki and greenheart during abrasion testing.

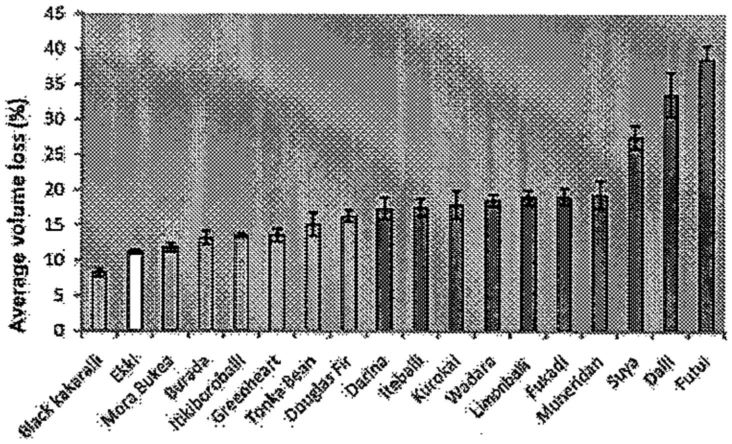

Figure 4. Comparison of abrasion (mean volume loss ±SE) of the LUS with ekki (above). Significantly higher abrasion rates are shown in red: no significantly lower rates were measured (one way ANOVA with Dunnet's post hoc comparison with a control).

From Table 4 and Figure 4 it can be seen that none of the test species performed significantly better than ekki during the abrasion testing. Of the 15 LUS tested 10 performed significantly worse than ekki and 6 performed as well as ekki.

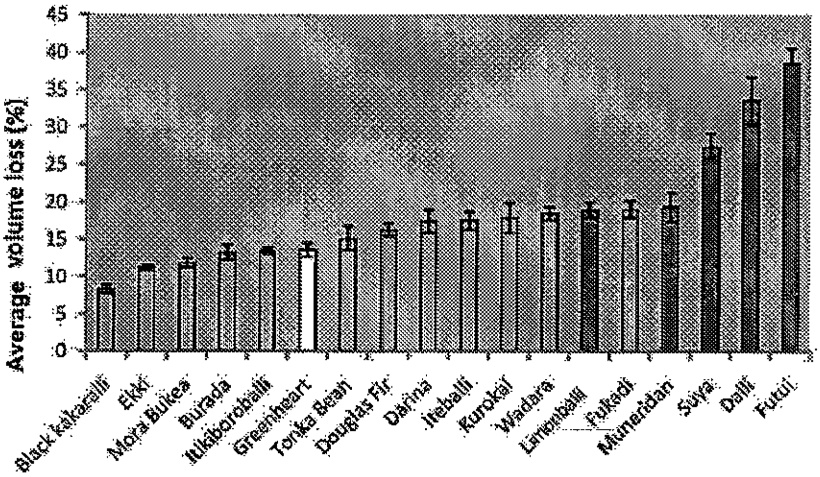

Figure 5. Comparison of abrasion (mean volume loss ±SE) of the LUS with greenheart (above). Significantly higher abrasion rates are shown in red: no significantly lower rates were measured (one way ANOVA with Dunnet's post hoc comparison with a control).

From Table 4 and Figure 5 it can be seen that none of the test species performed significantly better than greenheart during the abrasion testing. Of the 15 LUS tested 5 performed significantly worse than greenheart and 11 performed as well as greenheart.

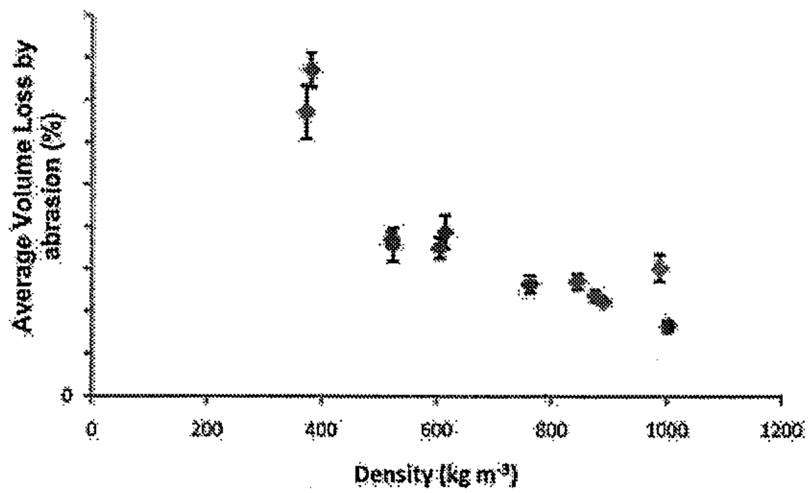

Figure 6. Correlation between density of the timbers tested and abrasion resistance expressed in terms of volume of sample lost over the testing period.

It can be seen from Figure 6 that there is, a negative correlation between increasing density and volume of wood lost by abrasion. There is less wood lost by abrasion in high density timbers.

6 Discussion

6.1 Marine Borer Testing

Control of crustacean wood borers has proved particularly problematic, with *Limnoria* proving capable of attacking preservative-treated wood (Cragg, 2003) and timbers that are otherwise naturally durable (Pitman *et al.*, 1997). A variety of methods have been used to evaluate the resistance of novel preservatives and potentially durable timber species to *Limnoria* (Becker 1955; Richards & Webb, 1975; Rutherford *et al.*, 1979; Cookson 1990, 1996; Cookson & Woods, 1995).

Apart from the topical application tests of Rutherford *et al.*, these experiments were relatively long-term (up to one year) laboratory evaluations of the degradation of test samples. Field test methods are even more protracted with the European Standard BS EN 275 requiring a minimum of five years of observations.

The fast track laboratory screening programme used in this study has been shown to provide reliable data regarding *Limnoria* resistance. The rationale behind this laboratory test is that faecal pellet production rate must match feeding or ingestion rate quite closely. It is much easier to measure than wood loss by ingestion and weight loss.

Previous research undertaken by Borges *et al* (2003) and Williams *et al* (2004B) demonstrated that *Limnoria* resistance in fast track laboratory method correlates well with *Limnoria* resistance longer term marine trials showing that it is reliable.
However, resistance to *Limnoria* does not necessarily mean the species is also resistant to *Teredo* spp. (hereafter known as shipworm). For this reason species that perform well in the laboratory should be further tested at a site where there is a high risk of shipworm attack. Those species that perform well against both marine borer types can then be used with confidence in EU waters.

There is no reliable laboratory screening trial that can assess the resistance of timber species to shipworm.

Black kakaralli, mora bukea, burada, kurokai, wadara and Tonka Bean performed as well as ekki in the *Limnoria* resistance testing. TRADA would recommend further long term testing in the marine environment for these species.

Black kakaralli and burada performed better than greenheart in the *Limnoria* resistance testing. Mora bukea, kurokai, wadara, muneridan and Tonka Bean performed as well as greenheart in the *Limnoria* resistance testing. Based on these results TRADA would recommend further long term testing in the marine environment for these species.

When the data in Figures 2 and 5 are compared (greenheart used as the benchmark species) it can be seen that whilst muneridan performs comparatively with greenheart when challenged with *Limnoria*, it performs significantly worse than greenheart when exposed to shingle abrasion. This indicative result is of interest as it suggests that it may possible to design marine structures by performance. In other words, where there is a known risk of *Limnoria*, this species could be comparable to greenheart. However, where abrasion is considered to be the most significant service hazard, greenheart may be a more appropriate timber species to specify.

Previous work described by Borges *et al* (2003) and Williams *et al* (2004B) describes the assessment of marine borer resistance whereby the rationale behind the laboratory testing was *'if it fails in the lab then it will fail in the sea'*. However, this rationale was only applied to marine borer resistance and took no account of abrasion resistance. The cross referencing of abrasion resistance and *Limnoria* resistance has focussed on the most visible observations described above. This data suggests that it may be possible to specify timber for use in the marine environment by understanding the service conditions and hazards the timber will be exposed to and recognising the hazard the timber has to counter and withstand in service. For example, if the primary hazard is one of abrasion, then *Limnoria* resistance may not be so critical as the abrasion of the timber in service may prevent the establishment of large colonies of *Limnoria*.

Selection of timber by understanding service requirements and service hazards may provide a means to introduce lesser-used timber species from the 15 LUS list (see Table 2) into marine and freshwater constructions in the UK. Selection by this means should be undertaken on a pilot study basis so that confidence in new species can be gained.

We have often referred to the initial rationale behind the development of the laboratory screening trials for *Limnoria* resistance as being summarised as '*if it fails in the lab it will fail in the sea*'. This statement can be qualified as there may be exceptions to this rule. *Limnoria* is ubiquitous around the UK coastline. However, the organism favours sheltered, warmer coastal environments. It follows that the risk of *Limnoria* infestation is lower on exposed areas of the coastline where there is a high risk of abrasion. Limited pilot studies using abrasion resistant species that are significantly less resistant to *Limnoria* than ekki and greenheart, in non-critical applications may provide the mechanism to test the idea that it may be possible to design with and specify timber where service conditions and risk factors are fully understood.
The specification of LUS will require a holistic approach where in addition to considering marine borer resistance, abrasion resistance and strength other factors need to be considered. Availability may be seasonal and the prices of the species may be subject to fluctuation. Furthermore, the section sizes and working characteristics such as ease of driveability of timber piles may influence choice.

6.2 Abrasion Testing

During the comparative abrasion resistance trials it was observed that the rate of attrition of the shingle was quite rapid, producing fine mud that had lubricant properties. In the marine environment this mud would rapidly wash out to sea. The effect of lubricating mud could reduce the efficacy of the test. This was mitigated by removal of the mud and recharging the abrasion vessel with fresh shingle on a regular basis.

Previous experiments have suggested that the abrasion process may comprise simple rubbing of shingle over the surfaces and impact from stones thrown against the surfaces of the wood. This weakened wood may then abrade more easily. Earlier experiments (Sawyer and Williams 2005) noted how the impact was sufficient to cold forge the steel support frames. In the sea both forms of abrasion may occur, particularly in storm conditions.

It is difficult to relate the number of cycles in the experiment to service conditions. Around British coasts we may expect wave intervals of 10 to 15 seconds. Larger ocean waves may have longer intervals but dissipate more energy on breaking. Most movement of shingle occurs in the zone where the waves are breaking and disturbing the shingle. Shingle may be thrown up and then drawn back by the receding wave. Since the point at which a wave breaks varies with the height of the tide, it follows that any one piece of wood will only be affected by shingle abrasion for a short period each tide and then only when wave energy is sufficient to disturb the shingle. It should be noted that on sandy shores, sand can be disturbed quite easily and held in suspension producing abrasion conditions that may be significant. So far we have worked on a worst case scenario and therefore challenged the LUS with shingle.

The abrasion tests exposed the timber samples to 160,000 revolutions. If we assume that timber *in situ* is exposed to 10 waves every minute, it follows that the structure will be exposed to 360 waves per hour. We can make a further assumption that a given locus of the structure will be exposed to wave abrasion for 1 hour per tide. Therefore 160,000 revolutions is equivalent to 450 tides.

On the basis of these assumptions and in the absence of other information, the test of 160,000 cycles would therefore equate to about 450 tides. It is unlikely that all waves will have sufficient energy to subject the structure to abrasion with every wave cycle. Therefore, we have to make another assumption that the waves will only generate abrasive conditions for 33% of the time. This would then equate to 1350 tides or about 675 days.

The abrasion tests described in this report have condensed 675 days in service (almost two years) into a 5 day test period. However, it should be borne in mind that direct comparisons to exposure *in situ* are difficult to make and the assumptions detailed above could be viewed as theoretical.

Notwithstanding the above, the laboratory trial described in this report does provide a means to predict comparative performance of lesser-used timber species when exposed to shingle abrasion.

Since all species were exposed to the same substrate for the same period of time under identical conditions then abrasion resistance could be directly compared.

Laboratory screening provides a valuable, cost effective mechanism to assess the potential of new species.

Black kakaralli, mora bukea, burada, itikiboroballi and Tonka Bean performed as well as ekki in the abrasion resistance testing. TRADA would recommend further long term testing in the marine environment for these species.

Black kakaralli, mora bukea, burada, itikiboroballi, kurokai, darina, wadara, iteballi and Tonka Bean performed as well as greenheart in the abrasion resistance testing. TRADA would recommend further long term testing in the marine environment for these species.

Although the abrasion resistance testing was designed with marine applications in mind it may be able to identify abrasion resistance for other applications such as decking and flooring etc.

7 Conclusions

1. The feeding rate observed on the European redwood sapwood samples confirmed the vigour and good health of the *Limnoria* colony used in this trial which validates our test results.

2. During the laboratory screening trials, ekki performed better than greenheart when challenged with *Limnoria* resistance and during abrasion resistance trial.

3. None of the test species performed significantly better than ekki when challenged with *Limnoria* under laboratory conditions though 6 species performed as well.

4. Muneridan, dalli, iteballi, futui and Scots pine performed significantly worse than ekki when challenged with *Limnoria*.

5. Burada and Black kakaralli performed significantly better than greenheart when challenged with *Limnoria*.

6. Dalli, iteballi, futui and Scots pine performed significantly worse than greenheart when challenged with *Limnoria*.

7. In abrasion trials, no candidate timber performed significantly better than ekki, although 5 LUS performed the same as ekki. Ten timber species performed significantly worse than ekki.

8. In abrasion trials, no candidate timber performed significantly better than greenheart, although 9 LUS performed the same as greenheart. 5 timber species performed significantly worse than greenheart.

9. This phase of the research and development programme presents initial data pertaining to *Limnoria* and abrasion resistance. These trials form the basis of a research programme that should drive the incremental development of confidence in using timber species elected from the list of 15 LUS into the UK marine and freshwater construction industry. Data pertaining to shipworm resistance still needs to be collated and analysed.

10. Although the tests provide specific properties it is important to consider the combined properties of the LUS when selecting timber for marine applications.

8 Recommendations

The following species, listed in Table 5, performed as well as, or better than ekki and greenheart in *Limnoria* and abrasion resistance trials. TRADA recommend that all of the species listed in Table 5 are exposed in longer term marine trials in EU waters where they would be exposed to a complete range of marine wood degrading organisms including shipworm and marine micro-organisms. Data from the current trial and the marine exposure trial could then be used for marketing purposes and TRADA could assist with reviewing this material and completing a market research study.

Table 5 Shows the LUS that performed well in both trials

	***Limnoria* Testing**				**Abrasion Testing**			
	ekki		greenheart		ekki		greenheart	
LUS	Better	Same	Better	Same	Better	Same	Better	Same
burada		✓	✓			✓		✓
Black kakaralli		✓	✓			✓		✓
Tonka Bean		✓		✓		✓		✓
kurokai		✓		✓				✓
mora bukea		✓		✓		✓		✓
wadara		✓		✓				✓
muneridan				✓				
itikiboroballi						✓		✓
darina								✓
iteballi								✓

9 Authorisation

	Issued by:	Under the authority of:
Signature:		
Name:	Natalie Furbank	Dr Andrew Pitman
Title:	**Technical Consultant**	**Manager – Site-based Services**

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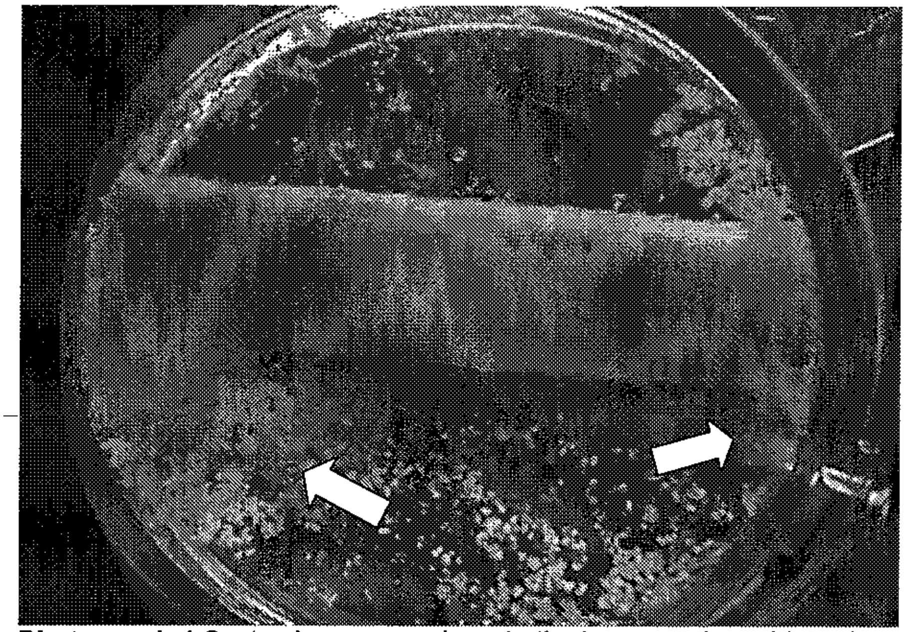
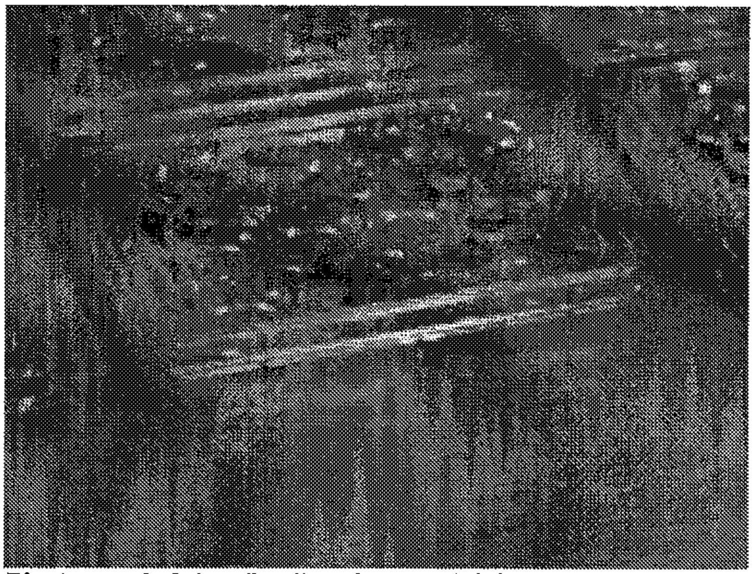
Appendix

Photographs

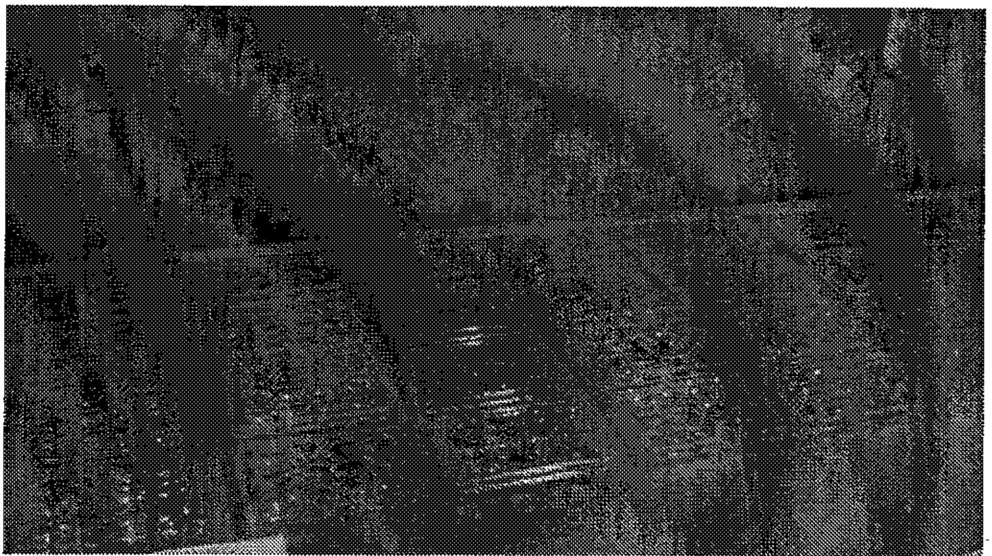


Photograph 1 Scots pine sapwood - note the large number of faecal pellets around the stick (arrowed) which indicated the healthy vigour of the *Limnoria* following 3 days feeding

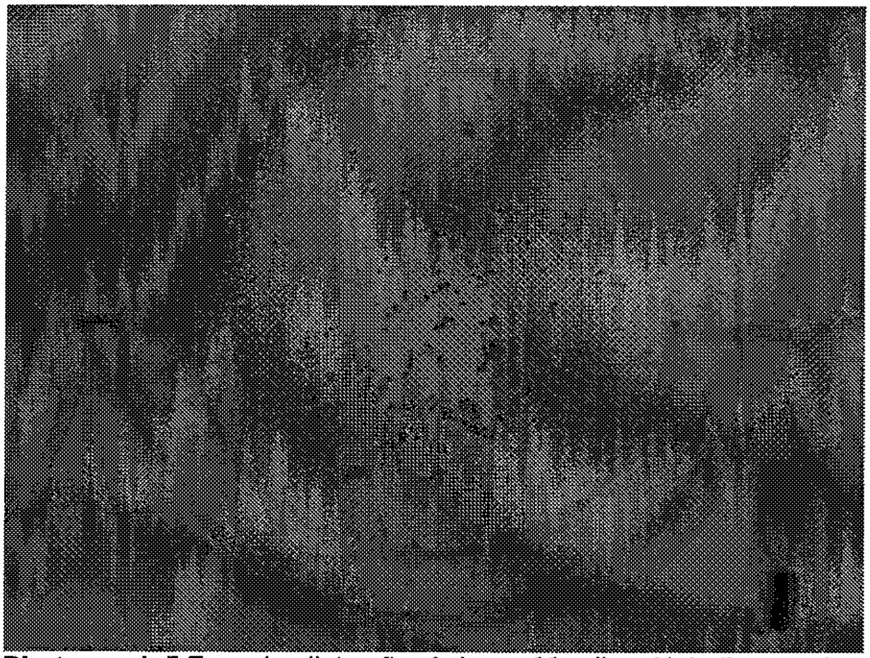


Photograph 2 A cell culture box containing 12 chambers

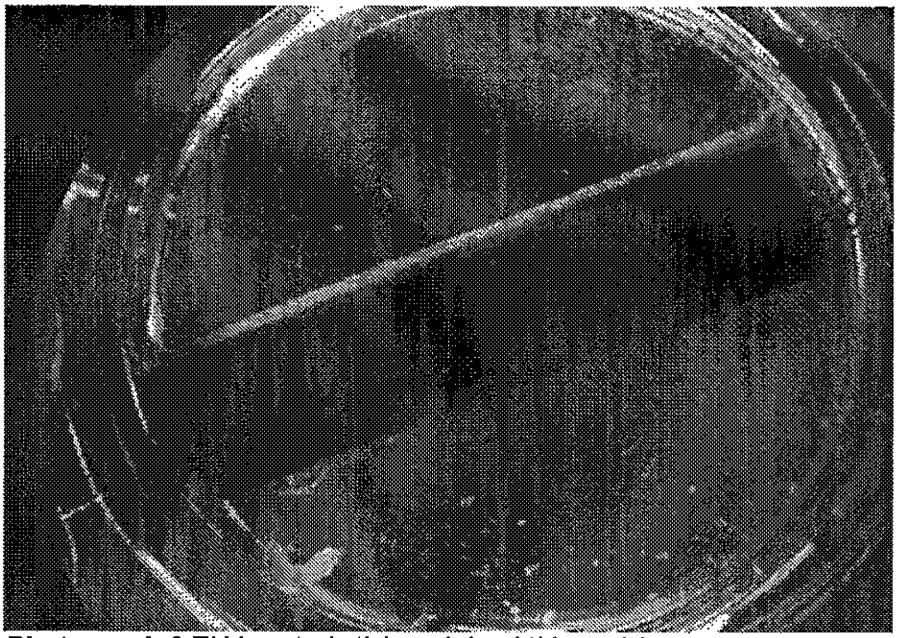
Photograph 3 Show samples being soaked in sea water



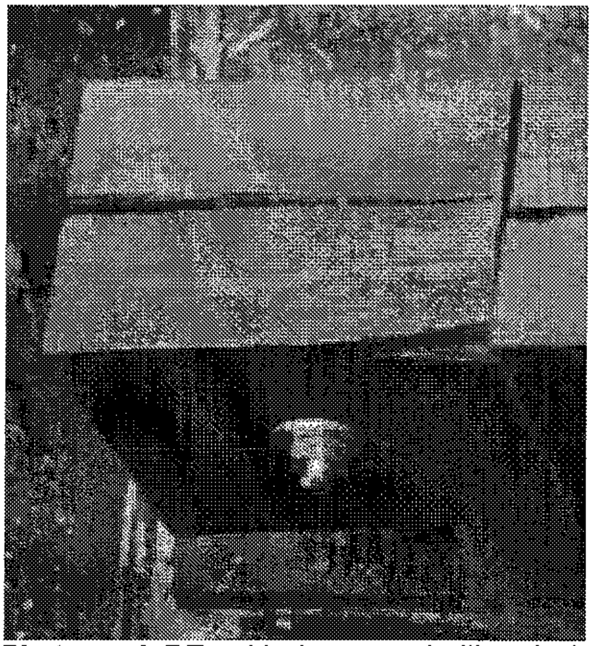
Photograph 4 Trial in progress illustrating the cell culture dishes with 12 cells per candidate timber species



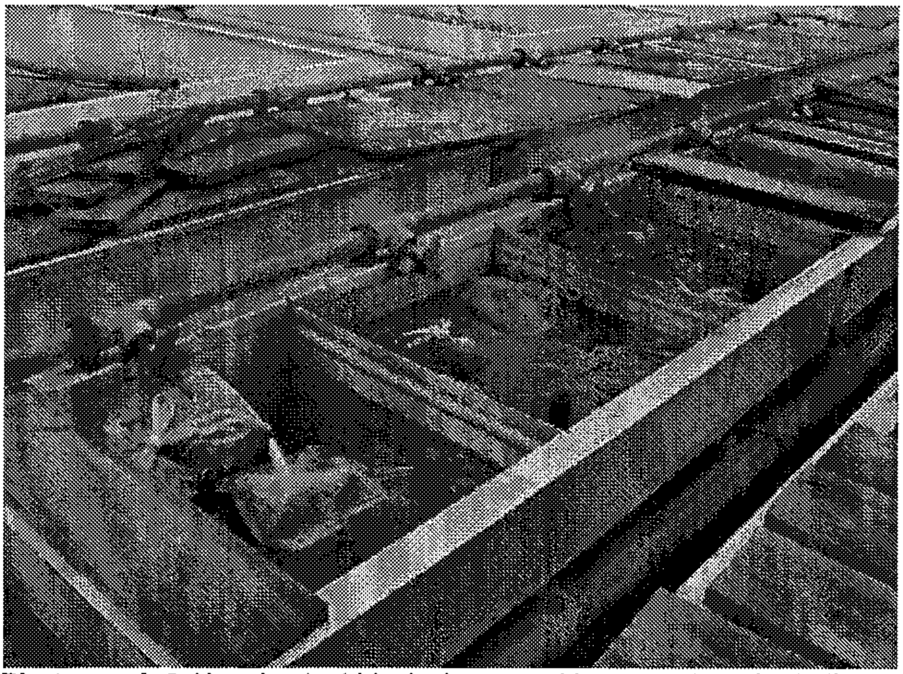
Photograph 5 Faecal pellets after 3 days of feeding. Note the wood block removed



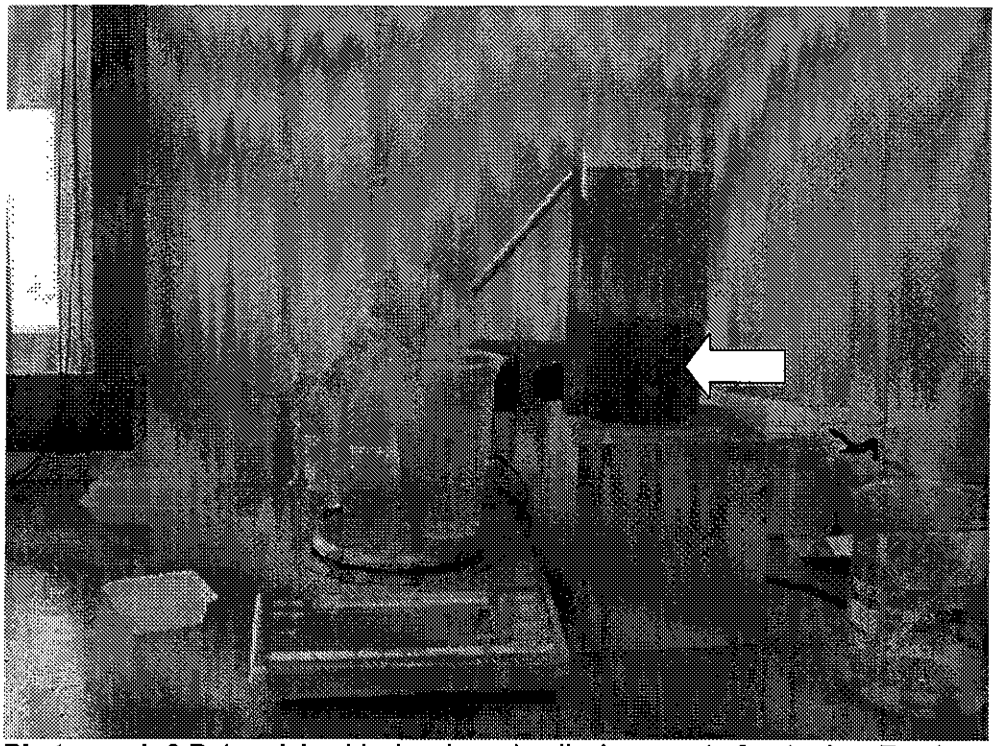
Photograph 6 Ekki control stick and dead '*Limnoria*'



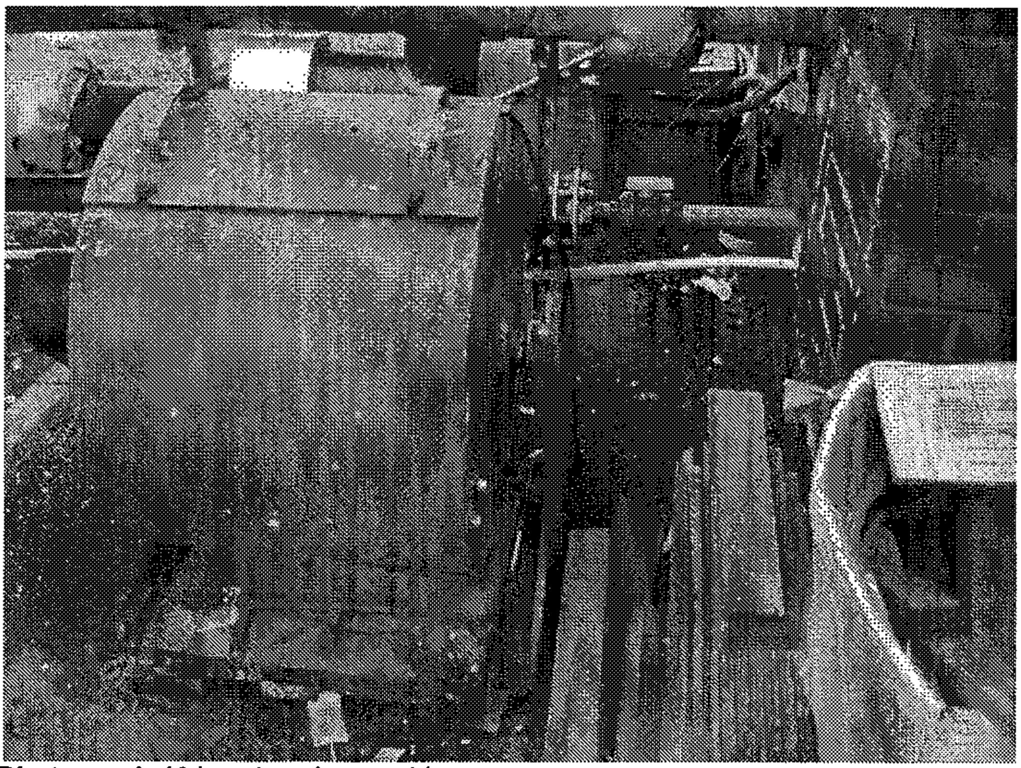
Photograph 7 Two blocks secured with a single wood screw. The sample identification number was then protected from abrasion as far as possible.



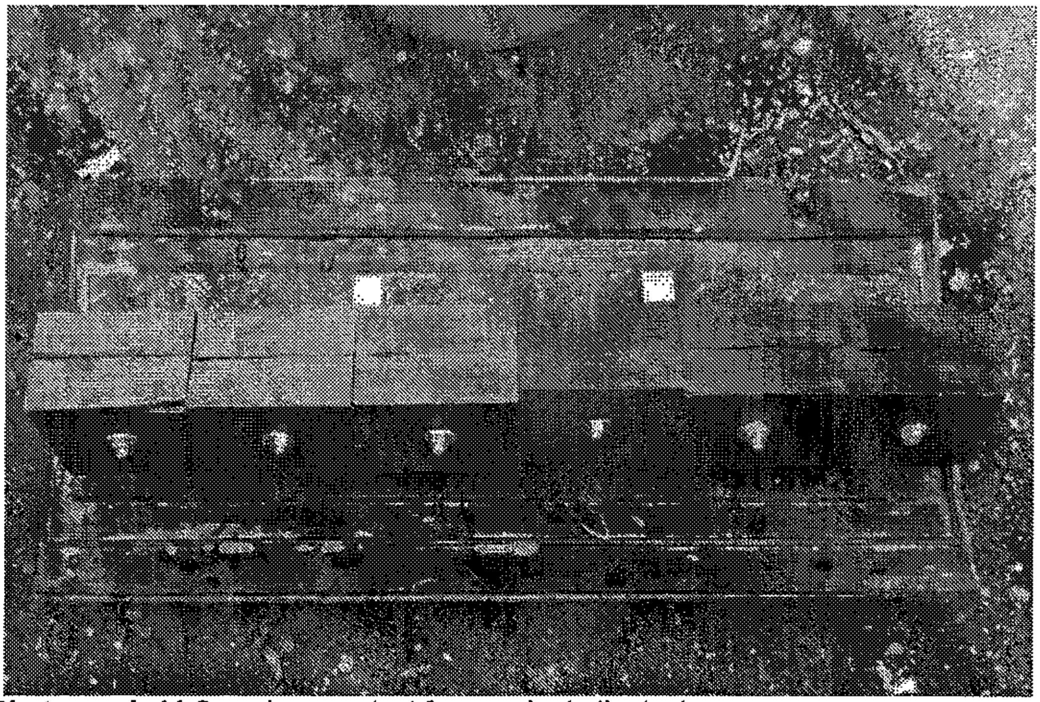
Photograph 8 Abrasion test blocks immersed in sea water prior to the test in order to saturate them



Photograph 9 Determining block volume by displacement of water in a Eureka Can. Arrow shows test block



Photograph 10 Los Angeles machine



Photograph 11 Samples on a test frame prior to the test

Figure 12 Inside the drum after 80,000 revolutions. Note the 'mud-like' breakdown product

Photograph 13 Inside the test drum after 80,000 revolutions and flushed out showing blocks fixed *in situ*.

Photograph 14 Blocks at the end of 80,000 revolutions. Arrows show the rounded arrises as a result of wear.