CONSIDERATIONS FOR GRADING SPECIES COMBINATIONS. GENERAL REMARKS ON SCENARIOS AND REQUIREMENTS.

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ABSTRACT: This paper discusses the situations in which timber species might be combined in commercial combinations, and the considerations relating to strength grading work. It is expected that more species combinations will be developed in the years to come, as the timber value chain diversifies. However, it is not clear how the grading standards and associated procedures should best adapt to cover situations where there is no long-standing industry experience. This paper presents some considerations and examples, with the aim of assisting people doing grading work in taking informed, safe steps based on their knowledge of the resource. This paper gives examples from the European standards, and mostly temperate species, but the principles are general.

KEYWORDS: Wood properties, strength grading, species combinations, standards, taxonomy, growth conditions

1 INTRODUCTION

The species of tree from which timber comes is an important consideration for strength grading, since it is part of what influences the wood properties, and the grading process required. For practical convenience (or necessity), species are commonly grouped into species combinations. There are many such species combinations in common and long-standing use. However, the matter of what "species" means exactly, as far as the grading standards are concerned, is not entirely clear. This means that the requirements and considerations for forming new species combinations are also unclear.

There is an increasing need for new species combinations, as hitherto lesser-used timber species come to market. Lesser-used species might be included as a new minor component of an already established species combination, or form a new combination with other relatively lesser-used species. Common species might also be combined in new ways, and familiar species combinations might be created from new growth areas, or be graded by methods that work on new principles.

Continued advances in tree breeding, hybridisation and clones add further complexity since they represent differences below the species level. Taxonomy is also not completely stable for some species, which may be regarded as varieties, subspecies or separate species by different authorities, and consequently be recognised differently in different countries. This raises the question of what a species combination even means.

In future, it is expected that some of what is currently monoculture plantation forestry will move to more diverse and intimate species mixtures for changing forest management objectives, such as climate resilience. It is also expected that species that were previously coming from logging of natural forests will instead come from plantations. Such things change the resource, even though the species is the same.

There is also growing need to be able to assess the strength of timber *in-situ* and grade timber from building deconstruction, where identification might only be possible to a list of likely species.

These give cause to reflect on the purpose of species combinations, the way they should be handled by the standards, and the way that industry can adapt to a changing resource.

It is first important to recognise that, for timber strength grading, the concept of "species" serves a different purpose than it does for botany.

2 NEED FOR SPECIES DISTINCTION

The species is one of the key determinants of timber properties. For structural timber, the important aspects are the species influence on strength, stiffness and density, averages, standard deviations, and correlations. Importantly, this includes the correlations of grade determining properties like strength, with the criteria used for grading (whether that is by visual grading or machine). Density and stiffness could be directly assessed for each piece non-destructively, but strength will always depend on predictive models.

The growth conditions are also key determinants of timber properties, and this interacts with the species and the within-species variation. The phenotype (the resulting timber) is a combination of the genotype and the environment:

- Phenotype, *e.g.*
  - Tree size and log shape
  - Knots (size, distribution, etc.) and ring width

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- Wood properties
- Genotype, *e.g.*
  - Species
  - Seed provenance
  - Tree selection or genetic improvement
- Environment, *e.g.*
  - Site: soil, climate, wind, temperature, seasons, *etc.*
  - Management: forest type, spacing, pruning, thinning, age at felling, *etc.*
  - Pests, diseases, storms, fires, *etc.*

These complex interactions are the reason why timber strength grading is necessarily linked to species and growth area, and may also change over time.

For example, knots indicate timber strength because of their influence on grain deviation within the sawn timber, but the knots are also determined by growth conditions, which additionally influence wood strength in other ways. The tree's branching results from a combination of genetics and environment, which are things that also change other aspects of the wood microstructure on account of the different biomechanical needs of the tree.

For timber strength grading, it is therefore not possible to completely separate the concept of species from the concept of growth area. It can also connect with timber sizes, since certain cross-sections and lengths come from differently sized trees, which have different growth conditions.

The genotype–environment interaction is part of the reason why it is common in the trade to distinguish between, for example, French oak and English oak as if they were different species, but not necessary to make a distinction between the oak species within these resources: *Quercus robur* and *Q. petrea*. This is also part of the reason why, even after significant research effort toward the aim, there has been little harmonisation of visual strength grading standards in Europe [1,2]. Strength grading across very broad sets of species has been shown to be possible within certain limits, but not completely independently of species due, especially, to the effect of knots when present [3].

3 THE CONCEPT OF SPECIES

For structural timber, unless appearance, durability or some other species aspect is an additional criterion, the species *per se* is less important than the declared structural properties. Indeed, a key concept of general strength class systems such as in the European Standard EN338 [4] is that timber can be specified with almost no regard to its species.

In that sense, the limitation of species in strength grading performs a similar role to the limitation of growth area. These two things are part of what determines how the timber should be graded, and what design properties can be obtained. Indeed, a fine distinction of species may well be a way of indirectly being more specific about growth area within countries that have varied growth conditions.

The taxonomy of trees is done by botanists, rather than timber engineers. Family, genus and species are assigned based on the morphology of the tree's features and, more lately, from genetic sequencing. For wood properties, a fine distinction between species may be of no consequence, but it can also be the case that differences below species level do affect the grading enough that they need to be accounted for. This could be because the subspecies or variety is different because of the growth conditions it has naturally adapted to, or because cultivars, seed provenance or clones have been chosen because of their desirable timber characteristics.

Even the matter of strict botanical species is not necessarily clear cut, and since there is no single central authority on taxonomy, even being specific about species can be tricky; especially when historical trade names and documents do not correspond exactly to the latest botanical state-of-the-art.

Therefore the concept of species in timber grading is not the same as the botanical one. In timber grading we might refer to *Handroanthus* (a genus in taxonomy) and *Pinus nigra* subsp. *nigra* (a subspecies level distinction) both as a "species", and *Larix decidua*, *Larix kaempferi* and *Larix*×*marschlinsii* as a "species group" (even through the hybridisation of larch is something of a spectrum).

We might even include some other aspect into our concept of species that is to do with the growth conditions. In Europe, machine control grading gives us one example in having a distinction between *Pinus pinaster* and *Pinus pinaster* trees at least 40 years old (Xyloclass F machine settings Table 21-2 [5]).

Less obviously, growth conditions maybe the reason we need to make some subspecies level distinctions, such as for the various types of *Pinus nigra* that appear in European grading rules and standards (see below). This also gives us another example: The description of *Pinus nigra* and *Pinus nigra* subsp. *laricio* each as a "species", and a mixture of *Pinus nigra* subsp. *laricio* and *Pinus nigra* subsp. *nigra* as a "species group".

It is not always clear how best to control species in structural timber grading, and in many respects it might be helpful; to regard all timber as a kind of mixture, even if nominally the same species.

4 THE DESCRIPTION OF A SPECIES COMBINATION

A species combination can be specified at different levels:

1) Listing at genus level.
2) A specific list at species level, but regarded as if a single species
3) A specific list at species level, regarded as a combination of species
4) A list with items below species level, such as subspecies, variety or clone.

A specification at genus level might be more restricted than it first appears, since the way the trade operates might limit in other ways. It is also the case that a list of species might be a long one and it is common to combine species that are only distantly related genetically. As an example, Figure 1 shows a phylogenetic diagram ending in species

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and species combinations that appear in European strength grading documents, and Table 1 lists the species combinations. These are not exhaustive since there are additional items in national standards.

In practice, these four ways of describing a species combination are not completely distinct since taxonomy can differ. It is also the case that a specification of a single species, might be regarded as mixture of below species level distinctions. For example, in the European grading system *Pinus sylvestris* is not sub-divided (except by growth area) but it could be considered as a mixture of *P. sylvestris* var. *sylvestris, P. sylvestris* var. *lapponica, P. sylvestris* var. *hamata, and P. sylvestris* var. *elicinii.* Europe also has (non-native) *Pseudotsuga menziesii* var. *glauca* and *P. menziesii* var. *menziesii*, but the two are covered under a single listing of *Pseudotsuga menziesii*, and for timber strength grading the benefit of distinguishing varieties taken out of their native growth conditions is, anyway, questionable.

For timber grading, the matter of whether a resource should be treated as a species combination or not should be about the considerations that can affect grading, and not strict botanical taxonomy, which has no concern to wood properties. This can mean treating a single species as if it was a combination of elements, or ignoring botanical distinctions that are of no consequence to the timber.

5 SOME EXAMPLES

In the most recent draft of the European Standard EN1912 [6], the standard which lists assignments to strength classes (design values) from visual grading, pine from France is specified as a group with the exception of *Pinus pinaster*. This is because the available test data showed that this species (from France) graded less well (had lower design properties) than the other pines (when done to the French visual grading standard). Since it would be possible for a batch of timber to be of a single pine species it was necessary to either exclude *P. pinaster*, or lower strength class assignment (design values) to the level of *P. pinaster*. The first option was chosen as the better compromise for the industry.

The standard EN1912 [6] also lists a very specific entry for poplar from France, *Populus×canadensis* cv 'Robusta', 'Dorskamp', 'I 214', 'I 4551' due to the high level of variability across the poplar cultivars in the country. However, thanks to extensive additional testing, settings for machine control grading with several machines [5] were approved in 2019/20 for the very general species description: *Populus spp.*

Larches readily hybridise where they meet naturally, and where they are planted. This makes strict distinction by species unachievable in some situations. There are machine grading settings for *Larix sibirica* under the European system [5] but also confusion with *Larix gmelinii* (in [7]) with which it hybridises in Siberia and with no distinct line between the two. Some botanists also recognise a species *Larix sukaczewii* separately from *L. sibirica* on the basis of morphological differences that others regard as environmental rather than phylogenetic. In cases like this, the species distinction and growth area distinction are hard to separate.

The latest draft of EN1912 [6] also includes an entry for fir from Türkiye, which combines *Abies cilicica* with *Abies nordmanniana*. However, since some botanists regard the sub-divisions *A. nordmanniana* subsp. *equi-trojani* and *A. nordmanniana* var. *bornmuelleriana* as species in their own right (*Abies bornmuelleriana and Abies equi-trojani*) it is not clear cut whether the combination of Caucasian and taurus fir from Türkiye is two species or four.

6 KINDS OF MIXTURE

It is also necessary to take into account the possible different kinds of species combination, which include:

1) Intimate mixtures in the forest, which are not practical to separate in the wood value chain. The wood is processed, graded and sold as a mix. Batches of processed timber might be expected to contain reasonably consistent ratios of the different species components (although it may not be possible to know this).
2) The species are separate in the forest, but harvested at the same time. They could be separated, but there are commercial reasons not to. The species are processed, graded, and sold as a mixture. Batches might contain quite varied ratios of components, because logs of different species are not so well mixed as in case (1).
3) The species are separate in forest, and are not harvested at same time. Species are processed as individual species but graded on common basis and sold as species combinations for market convenience. Batches contain very varied ratios of components because the species are only combined later in the process.
4) The species are separate in the forest, and not harvested at same time. They are processed and graded as individual species but sold under a species combination for market convenience. Batches of timber are generally always not a mixture when graded, but they could be mixed by merchants and end users.
5) Species are processed and sold separately, but under a common grading process which covers a number of different species.

7 CONSIDERATIONS FOR MIXTURES

7.1 Before strength grading

In the case when sawmills have some choice as to whether or not to process logs of different species together, there are several practical factors to consider including whether the species are similar for debarking, sawing and drying. The way the sawmills process the timber will have an effect on the species mix in the packs of graded timber, but even if the species are well mixed in production, the packs are likely to be less mixed, due to the number of boards that come from individual logs ending up together.

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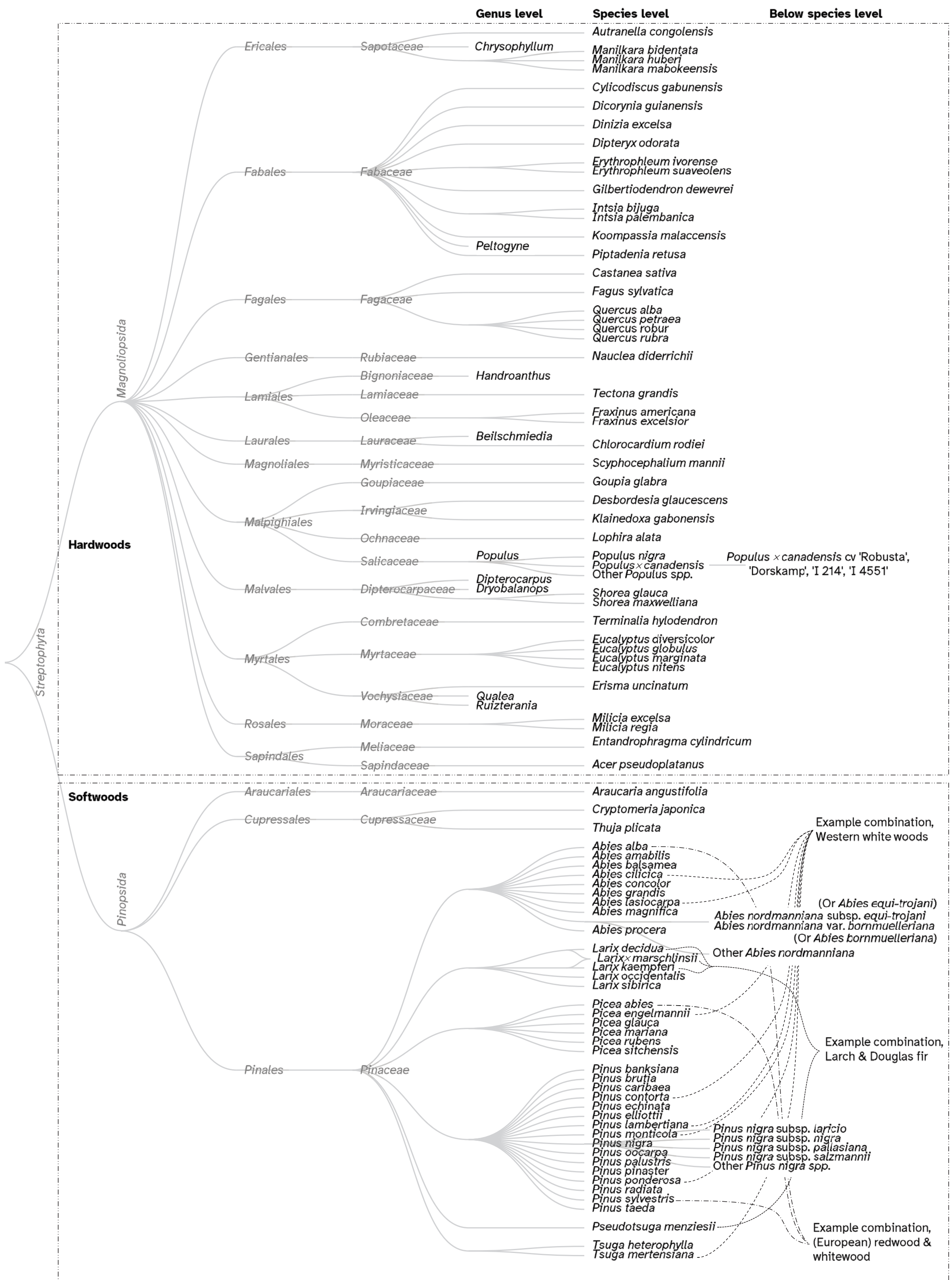

Figure 1: *Phylogeny of species mentioned in European standards [7,8] and machine control grading settings tables [5]*

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Table 1: *Example: list of species combinations referenced in European standards [7,8] and machine control grading settings tables [5]*

Genus level as if a single species	
Temperate	
Poplar spp.	Poplars
Tropical	
Qualea spp., Ruizterania spp. *	Mandio (gronfolo)
Chrysophyllum spp. (syn. *Gambeya spp*)	Longhi
Dipterocarpus spp.	Keruing
Dryobalanops spp.	Kapur
Beilschmiedia spp.	Kanda
Handroanthus spp.	Ipé (Ebene verte)
Peltogyne spp.	Amarante (Purpleheart)
A species list as if a single species	
Temperate	
Quercus petraea, Quercus robur	European oak
	Tropical
Erythrophleum ivorense, Erythrophleum suaveolens	Missanda (Tali)
Intsia bijuga, Intsia palembanica	Merbau
Milicia excelsa, Milicia regia	Iroko
Shorea glauca, Shorea maxwelliana	Balau (bangkirai)
A species list as a species combination	
Temperate	
Abies alba, Picea abies	Spruce & fir whitewood
Abies alba, Picea abies, Pinus sylvestris	Redwood & whitewood
Abies amabilis, Abies concolor, Abies grandis, Abies magnifica, Abies procera, Tsuga heterophylla	Hem-fir
Abies balsamea, Abies lasiocarpa, Picea engelmannii, Picea glauca, Picea mariana, Picea rubens, Pinus banksiana, Pinus contorta, Pinus ponderosa	S-P-F (spruce-pine-fir)
Abies balsamea, Abies lasiocarpa, Picea engelmannii, Pinus contorta, Pinus lambertiana, Pinus monticola, Pinus ponderosa, Tsuga mertensiana	Western white woods
Abies nordmanniana, Abies cilicica, Abies bornmuelleriana, Abies equi-trojani	Caucasian and taurus fir
Larix decidua, Larix × marschlinsii, Larix kaempferi	Larch (European, Japanese and hybrid)
Larix decidua, Larix × marschlinsii, Larix kaempferi, Pseudotsuga menziesii	Larch and Douglas fir
Larix occidentalis, Pseudotsuga menziesii	Douglas fir-larch
Manilkara bidentata, Manilkara huberi	Balata Franc (Massaranduba)
Picea abies, Picea sitchensis	British spruce
Picea abies, Pinus sylvestris	Norway spruce and Scots pine
Pinus caribaea, Pinus oocarpa	Caribbean pitch pine
Pinus echinata, Pinus elliottii, Pinus palustris, Pinus taeda	Southern pine
Pinus elliottii, Pinus taeda	Loblolly pine and slash pine
Pinus nigra, Pinus pinaster, Pinus sylvestris	Pines
Pinus nigra subsp. *laricio, Pinus nigra* subsp. *nigra*	Austrian & Corsican pine
Pinus nigra subsp. *laricio, Pinus nigra* subsp. *nigra, Pinus sylvestris*	French pine (not including maritime)
Pinus nigra subsp. *laricio, Pinus sylvestris*	British pine

* EN13556 [8] does not include *Ruizterania*

7.2 During strength grading

The considerations during strength grading depend on the kind of grading, in particular:

- For machine grading, the nature of the things the machine assesses, and how those are combined in the particular indicating property model used for those settings.
- For visual grading, the features possible to assess, how they are quantified (especially knots and ring width) and the grade limits.
- The grade determining properties of the different species (particularly the means, standard deviations and correlations).
- The strength class (design value) requirements, the combination of strength classes being graded, and the particular grade determining property (if any) that is limiting the grading.

Some species influences might not be immediately obvious. For example, the standard EN14081-1 [8] requires visual grading standards to have a rule about ring width or density, with ring width intending to function as a predictor of density when it is not directly measured. However, the kind of species affects this (the transition of earlywood to latewood in softwoods and the ring porous / diffuse porous spectrum for hardwoods), as well as influencing how easy it is to assess ring width. It also interacts with growth condition effects as ring width is also connected to geographical origin and to radial position in the log. Depending on how important ring width is in a particular visual grading scenario, it may or may not limit the possible species combinations.

In the case of grading to a single strength class with near 100% yield the considerations to do with species and grading method may not be so important, especially if the grade limiting property is not the strength. But generally speaking, for effective grading, the species would ideally have similar grade limiting properties, which correlate in a similar way with the grading criteria. Properties that are not grade limiting need not correlate in a similar way with the grading criteria. The degree to which this affects the grading of species combinations depends on both the grading method and the target strength classes (design values).

It is commonly expected that the difference between the species in a combination are ideally of similar variation seen within a single species (within the growth area), but this is not an easy requirement to quantify.

In the case of machine grading, it is also important that the species can be graded with the same indicating property adjustments for moisture content, temperature, cross-section size and machine operating speed.

When grading is controlled via testing in production (known as output control in Europe) the effect of species is only accounted for if the feedback to machine settings is fast enough to adapt to any large deviation in species mix ratio. Measures to separately check individual species in the production testing can mitigate this.

The European strength grading system does not prohibit a species combination that combines both hardwoods and softwoods, although such a thing would need to be based on the "softwood" strength classes due to the secondary properties. It is already the case that lower density hardwoods like *Populus*, *Castanea sativa* and *Eucalyptus nitens* can be given "softwood" strength class assignments.

7.3 After strength grading

Strength grading ensures the key mechanical and physical properties for structural use, but there are still practical considerations such as similar treatability with preservatives and similar workability from the user perspective (finishing, gluing, moisture movement, dead knots, resin pockets, need for pre-drilling etc), especially for use in laminated timber products. Product and usage standards might also have specific restrictions based on species.

To a certain extent there needs to be similar appearance for market acceptability, and similar average density (for predictable self-weight, handling, drilling etc). However, in the European system, the grading is only concerned with a minimum characteristic (5th percentile) density and the mean density is not explicitly controlled.

If the different species are distinguishable as sawn timber, the grading should still be safe even if the end user or merchant separates them for some reason.

8 VERIFICATION OF GRADING

Whether or not species should be included as a specific aspect of the grading verification calculation (and sampling for the testing) depends on the situation. If the species cannot be distinguished before, during and after grading in real production, it is usually appropriate not to treat species separately in the verification. However, it is still necessary to consider how similar those species are to allow for the expected variation in the mixture from sawmill to sawmill and timber pack to timber pack. For that reason, if species can be distinguished in sampling it is advisable to do so.

If species can be distinguished, it is prudent to check each species individually. In the framework of machine control grading in Europe [9] this could be done by creating additional verification samples in a similar manner to the geographical ones. An example of this is provided in an accompanying paper [10].

A full separate check on species is expensive in test data, and if species differences are thought comparable to growth area differences, it may be appropriate to treat the addition of a species to an existing grading route in a similar way to the route for an already included species to an extended growth area.

When it is not economic to do a large enough testing programme to fully resolve the uncertainty, the grading assignment should be correspondingly conservative. It is not enough that a resource as whole grades correctly since it is packs of timber that are used in structures, and grading must work correctly at that level whatever

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realistic separation of the species has occurred before, during or after grading.

There are two additional ways in which fully separate grading verification calculations could be combined, although since they require a large amount of testing they are less useful for bringing minor species to market:

1) Separate calculations but with the same indicating property model and thresholds (or visual grading rule and assignment) so that the grading process can be common.
2) Separate calculation and also different grading settings (or visual grading rules), but the graded timber marked and sold as a combination for market convenience.

9 RECOMMENDATIONS

It is recommended that national grading experts work to develop a framework for establishing grading assignments for new species combinations, rather than develop requirements for sampling and verification on an *ad hoc* basis as new grading reports are prepared. This would make it clearer for those developing the grading assignments, and also help to ensure that relevant considerations are accounted for from the planning stage. Nevertheless, it will still be necessary to be able to adapt this framework as more information is revealed through experience. Whatever the approach, it would be important that it is not subservient to strict botanical taxonomy, but rather use taxonomy as part of the way that the resource is defined.

Developing the grading assignments by treating each species (or other relevant resource division) separately is the most robust approach, but requires a very large dataset and it is not always practically possible to distinguish the individual species during the grading development work, while still maintaining the overarching requirement for the sampling to be representative of the resource. The best course of action depends on the context both before and after grading.

For new grade combinations, and lesser-used species, it may be advantageous to also include a mean or upper percentile density to allow for fact that actual density may be considerably higher than the declared value, in order to avoid over-weight problems for handling and transport.

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