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CONSIDERATIONS FOR GRADING SPECIES COMBINATIONS. THE EXAMPLE OF DOUGLAS FIR WITH LARCH IN IRELAND AND UK

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ABSTRACT: This paper examines the grading of Douglas fir (*Pseudotsuga menziesii*) and larch (*Larix* spp.) as a strength grading species combination for the growth area formed by Ireland and the UK. The two genera produce higher timber quality than Sitka spruce (*Picea sitchensis*), the main commercial timber species in the two countries. Developing this species combination may increase the volume of timber available for the market, making these species more commercially attractive to sawmills, particularly if there are common settings that can be used for either species whether mixed in production or not. Simultaneously, the paper examines the challenges of mixed species grading within the framework of the European standard EN14081 for machine control grading, as the requirements for combining species are not clearly defined. More than 1600 pieces are used for this study. The results found that the ranges of modulus of elasticity, strength and density of both species are similar, but special considerations are required to ensure the safe grading of the timber.

KEYWORDS: Wood properties, Strength grading, Douglas fir, Larch, Species combination, Standards

1 INTRODUCTION

The main timber species grown in Ireland and UK is Sitka spruce (*Picea sitchensis* (Bong.) Carrière). Commercially, it is common to refer to it as "British spruce", WPCS [1], a long-standing commercial combination where Sitka spruce is often mixed in the forest and the sawmills with Norway spruce (*Picea abies* (L.) H.Karst). The amount of each species in the mixture depends on the relative volumes available in the forests, which varies geographically. The overall percentage of Norway spruce is low but nevertheless a batch with 100% Norway spruce could be processed and sold as British spruce. The mixture is possible because the grade determining properties (GDPs) are similar. This paper will focus on GDPs as those primary properties determined for grading on the usual bending strength basis, namely modulus of elasticity (MOE), strength and density. The wood of the two species also has practically identical visual appearance and is not separated in production. Such industry practise species combinations are not uncommon, but this is also potentially a way to combine lesser used conifers with an established species, or grade lesser conifers together, as a convenient route to market.

There are many other species combinations in use. For example, Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western larch (*Larix occidentalis* Nutt.) are graded together as a species combination, WPSM [1], as well as a part of other species combinations in North America. The properties of both species are somehow similar, and can be mixed for selling [2, 3] following grading rules of different agencies, like WCLIB, WWPA or NLGA. The combination is commonly used for glulam in the US [2].

Although western larch is not grown commercially in Europe, in Ireland, larches and Douglas fir are currently the second and third largest timber species in terms of forest area after spruces [4]. In Great Britain, larch is the third largest timber species, and Douglas fir is the fifth [5]. In 2018 and 2020, as part of the WoodProps programme at the University of Galway, machine grading settings were developed for Douglas fir [6], PSMN, and larch (WLAD: European larch (*Larix decidua*), hybrid larch (*Larix x eurolepis*) and Japanese larch (*Larix kaempferi*)), separately [7], for the grading area formed by Ireland and the United Kingdom (UK). Douglas fir and larch produce higher timber quality than British spruce and it would be desirable to have more material available on the market. However, the relatively small and dispersed volume of these species in Ireland may not always make grading these species on their own attractive to sawmills.

New construction projects in Ireland are now using locally grown Douglas fir (Figure 1). An option to concentrate the timber volume and increase the use of the local timber resources currently available is a combined approach for production and marketing. For this, it is desirable to have common machine grading settings that could be used for either WLAD or PSMN whether mixed in production or not.

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Figure 1: *Viewing tower at the Avondale Forest Park in Ireland built with locally grown Douglas fir. Source: WIEHAG GmbH.*

There is very little literature on how to develop machine control grading settings for a mixture of two or more species. Regarding the sampling for testing, the standard EN14081-2 [8] says that when species are graded together without being differentiated, the sampling should be representative of the species proportion. The standard thus leaves open the question as to whether the approach should be different if the species are more commonly differentiated, but desired to be graded by a common process. The standard also states that the species within a species combination need to be "sufficiently similar", but it does not explain how to satisfy this requirement.

In order for timber to be graded under the European machine control system, the thresholds (settings) for the machine indicating properties (IPs) are calculated based on their predictive relationship to the GDP values, as determined by a large testing programme. The characteristic values for strength and density are the lower 5th percentiles and for MOE the mean. It would be expected that when populations of different species have similar GDP mean and variances, characteristic values, and correlations with the grading parameters, the species can be graded together as species combination. However, the fact that the relationships between the GDPs can be similar in two species (falling within the confidence intervals), does not guarantee that the relationship between a grading machine's IP and all the GDPs is also similar. Likewise, it is worth knowing what would happen if, in the effort to study "sufficiently similar" samples, timber of higher or lower characteristics is overlooked.

This paper examines the grading of the species combination PSMN with WLAD for the first time in Europe, in particular for the grading area formed by Ireland and the UK, while suggesting an appropriately cautious approach to develop machine settings of species combinations within the scope of EN14081.

2 MATERIALS AND METHODS

2.1 MATERIALS

The study uses timber from normal production runs in sawmills sampled from across the Republic of Ireland and the United Kingdom. As usual for grading work, specification was given to each sawmill that the timber provided should be unsorted for quality, except for the removal of any pieces that fail visual override criteria as described by EN 14081-1 [1, 9]. The sampling also included timber from research studies in the two countries, considered representative of the timber in production. A total of 704 pieces of PSMN and 899 of WLAD were available and split into four verification samples per genus (Table 1) for the analysis, where A to D correspond to PSMN and E to H correspond to WLAD.

Table 1: *Pieces sampled by cross-section size and source.*

Size (mm^2)	Sample	WLAD	PSMN
35x75	H	96	-
37x75	B	-	70
45x100	A, D	-	277, 109
47x100	E, F,	166, 126,	
"	G, H	126, 60	
50x100	C, D	113, 75	-
47x150	E	17	-
75x150	F, G, H	80, 80, 94	
76x225	B	-	60
100x275	F, G	27, 27	

2.2 METHODS

The pieces were tested at the University of Galway using a Zwick/Roell 500 kN Servo Hydraulic testing machine, and at Edinburgh Napier University using a Zwick Z050 universal testing machine. The tests followed the requirements of the European standards EN408 [10] and EN384 [11]. For WLAD, local MOE was used to calculate the settings, whereas for PSMN, global MOE and the correction to shear free MOE (Clause 5.3.2 of EN 384:2016+A2:2022, E_0=1.3 x $E_{global,u=12\%}$ - 2690 N/mm^2) was applied. The choice of one or the other moduli of elasticity influences the grading yields, particularly when MOE limits the allocation to a strength class [12, 13]. MOE and density were adjusted to 12% moisture content and strength to 150 mm depth in accordance with EN384 [11]. The moisture content of every specimen was determined using the oven drying method, or estimated by moisture meter [14]. The symbols and units used in this paper are listed in Table 2.

Table 2: *Symbols and units.*

Symbol		Units
Bending strength, adjusted to 150 mm width		
f_{mean}	Mean	N/mm^2
f_k	5th percentile	N/mm^2
Bending modulus of elasticity, parallel to grain, MOE		
$E_{0,mean}$	Mean, at 12% mc	kN/mm^2
Density		
ρ_{mean}	Mean, at 12% mc	
ρ_k	5th percentile, at 12% mc	

In order for timber to be graded, the dynamic modulus of elasticity (MOE_{dyn}) was chosen as the IP. This IP was developed through modelling using non-destructive acoustic properties as predictor variables of the GDPs. The methodology for the calculation of IP thresholds, or "settings", followed the requirements in EN14081-2:2018+A1:2022, from the calculation of the optimum grading to the determination of the cost matrix using Annex C. However, this paper focuses on the specific issue of verification for new settings of the whole sample and verification samples, with the aims of investigating how settings can distinguish the upper-grade timber from the lower-grade timber taking species into account, and providing a good practice example for future work on grading of species combinations.

As per the existing approach, in the first step, the calculation sought to determine the lowest IP value that defined a population whose characteristic values met those of the target grade. Secondly, a check was carried out to ensure that that each of the eight verification samples studied (EN14081-2:2018+A1:2022 states that the whole sample must be divided into at least four) achieved at least 90% of the characteristic values of strength and density of the target grade and 95% of the required mean modulus of elasticity. Strictly speaking, these two steps would suffice to verify the grading settings according to the current procedure in EN14081-2. However, developing grading settings must ensure that the assignments are safe beyond the calculations required by the standards. There are questions unanswered when developing grading for a species combination: What happens if one sample is noticeably better or worse than the others? How many samples there must be for each species? What happens if the grading of the species is limited by a different GDP? Can the two species be safely graded separately but using the same settings? In order to address those questions, in particular to ensure that the grading is safe, an additional (not specified by EN14081-2) requirement was added. This was implemented so that the settings fully satisfied (100%) the required strength class values of the GDPs for Douglas fir and larch separately to explicitly confirm correct grading of each species alone. In fact, EN14081-2 does suggest the verification procedure to be applied on non-geographical subsets of the whole, when there is reason to be cautious. This approach is also similar to the expansion check carried out for expansion of existing settings to a larger setting area.

3 RESULTS

3.1 GPDs of UNGRADED TIMBER

The properties of the timber (ungraded) are summarised in Table 3. The moisture content at the time of grading varied between 9.8% and 25.9%, with a mean of 15.3%. The moisture content at the time of testing varied between 8.8% and 22.8%, with a mean of 13.5%. Overall, WLAD had slightly higher strength and density values than PSMN, but lower modulus of elasticity. However, sample A had the highest GDP values of all, and certainly much higher than the rest of PSMN values. This large variation is likely the result of microsite factors and differences in forest management, and it must be understood that this variation can occur in a sawmill and is therefore important to include it in the sampling. In fact, the results are comparable to data reported for PSMN from the UK [15], and data collected within the GradeWood project by BRE (unpublished). The two genera produce higher timber quality than Sitka spruce [7, 16] and the GDPs are comparable enough between themselves producing yields above 80% for the strength class C18 investigated in this paper as shown in Table 3.

Table 3: *Summary of properties by sample.*

	Sample	f_{mean}	f_k	$E_{0,mean}$	ρ_{mean}	ρ_k
PSMN	A	50.4	29.2	13400	561	481
	B	27.8	14.1	8980	454	394
	C	34.3	17.1	8960	453	360
	D	28.7	11.5	8410	452	376
	PSMN	38.0	15.4	10550	495	397
WLAD	E	41.9	21.7	9400	483	405
	F	37.7	22.0	9560	497	404
	G	38.9	20.3	10100	499	415
	H	43.6	25.7	10500	532	426
	WLAD	40.5	22.5	9920	504	410
	All	39.4	19.0	10200	500	405

Figure 2 shows the relationships between the three GDPs and the distribution of values as density plots. The results show that both species have comparable values of GDPs, with a slightly wider distribution of values of the GDPs in PSMN as previously mentioned. The figure also shows that the correlations between density and strength and density and stiffness are stronger in PSMN (orange) than in WLAD (green).

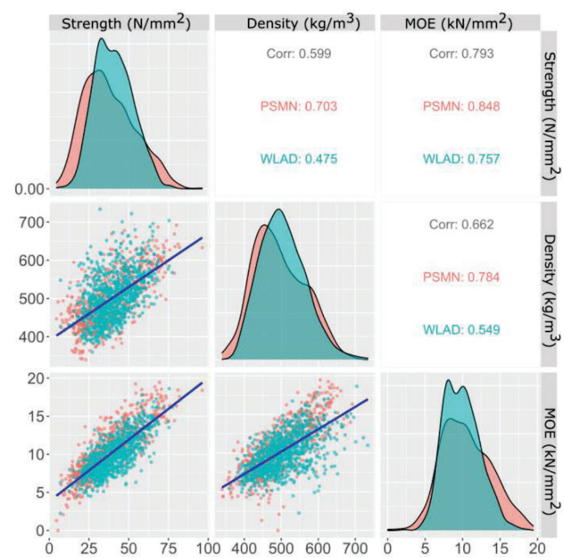

Figure 2: *Distribution of the GDPs and Pearson correlations.*

The optimum grading for the entire population was C20, that is, the one that results from using the values of the destructive tests instead of those based on the IP. For this purpose, the 0.95 factor was applied to the required characteristic value $E_{0,mean}$, and 1.12 to f_k (for non-portable grading machines). However, it can be observed that PSMN on its own would only achieve C18, largely penalised by the low characteristic strength value of sample D. WLAD on the other hand, would achieve C22. Previous studies analysing these datasets in part or in full, reported that the grading of PSMN was in general limited by strength [6], whereas WLAD was typically limited by

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MOE [17]. This can be observed in Figure 3 and Figure 4, which illustrate the grading for strength and MOE respectively using MOE_{dyn} as IP. The y-axis represents the characteristic values (f_k and $E_{0,mean}$, respectively), where the lowest value corresponds to the characteristic value of the whole population. Each successive point corresponds to the characteristic value as the ranked board values increase. Thus, f_k and $E_{0,mean}$ typically increase while the yields decrease until the board/s with the highest strength and stiffness, respectively, are reached. Figure 3 shows that the characteristic value of strength for PSMN is lower than that of WLAD for most of the sample. Roughly 60% and 75% of PSMN and WLAD, respectively, are below the 10.5 kN/mm^2 threshold. However, the characteristic value of MOE for PSMN is higher for almost the entirely range of MOE_{dyn} values (Figure 4).

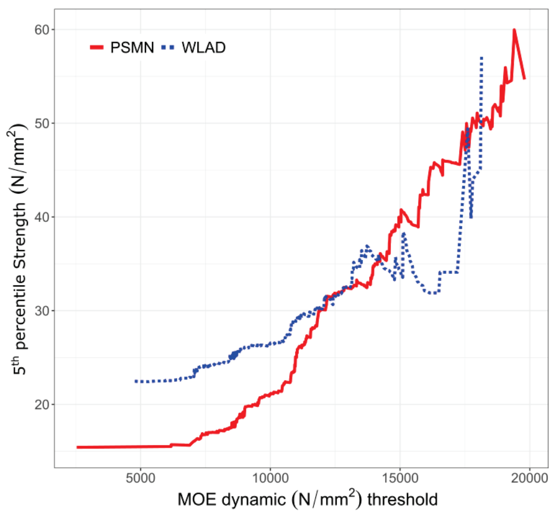

Figure 3. *Timber grading for strength using MOE_{dyn}*

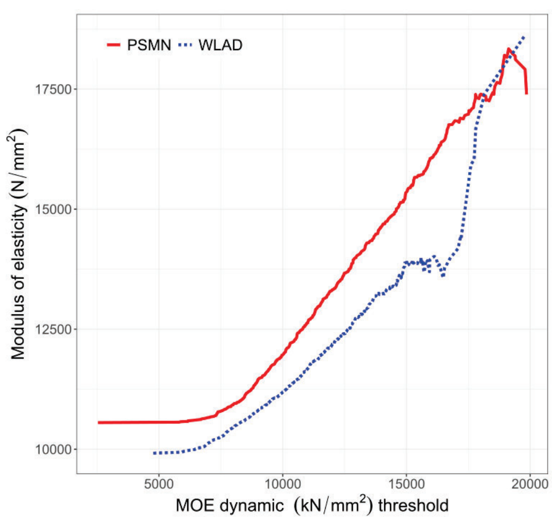

Figure 4. *Timber grading for MOE using MOE_{dyn}*

For the development of grading settings it is typically the limiting GDP that is modelled as priority. In the current dataset, the limiting GDP is different for each species. There is therefore the risk of grading an entire population of PSMN, as part of the species combination with WLAD, based on an IP that predicts MOE (for which the correlation with MOE_{dyn} is typically higher than for strength or density) and that may result in graded timber that does not meet the requirements for strength. For comparison with the derivation of machine settings for a single species, this scenario would be an analogous situation where the required characteristic values of the three GDPs must be met for the whole sample.

Although superficially similar, there are meaningful differences in the species combination that presents, a priori, a great challenge when it comes to develop the grading settings. For this reason, an additional requirement, not required by the letter of the standard but required by the spirit, was added, where it was required to also verify that the settings satisfied 100% the required strength class values of the GDPs for each species separately to confirm correct grading of each species alone.

3.2 CALCULATION OF SETTINGS

The timber of both species was non-destructively assessed with the Viscan Plus (Microtec s.r.l. – GmbH). This device measures the natural frequency of vibration in the longitudinal direction of a board, and together with density enables calculation of dynamic modulus of elasticity MOE_{dyn} using Equation (2):

$$MOE_{dyn} = \rho\ (2Lf)^2\ \text{N/m}^2 \qquad (2)$$

where ρ is the wood density (kg/m^3), L the length of the specimen (meters) and f the first mode resonance frequency (Hz) at which the stress wave propagates.

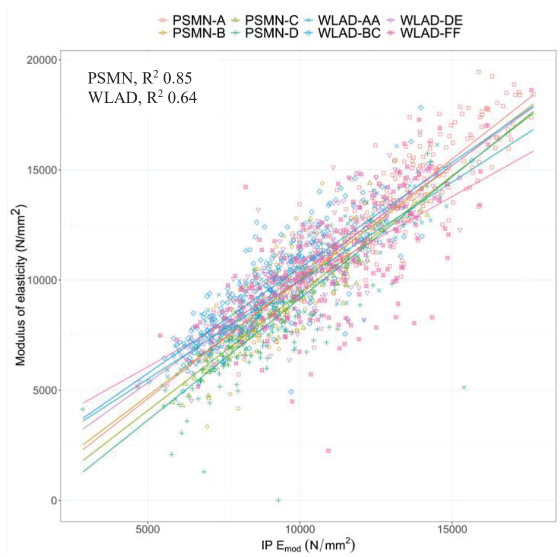

Figure 5: *Relationship between modulus of elasticity and IP by sample (R^2 0.42 to 0.88, overall 0.75)*

The strongest correlation of the IP was with modulus of elasticity (Figure 5), followed by density (Figure 6) and strength (Figure 7). The IP generated by MOE_{dyn} is closely related to the static MOE, therefore the stronger correlation is expected. By species, MOE_{dyn} explained 85% of the variation in MOE of PSMN and 64% of WLAD. In all the cases, MOE_{dyn} was more strongly related to the GDPs of PSMN than of WLAD.

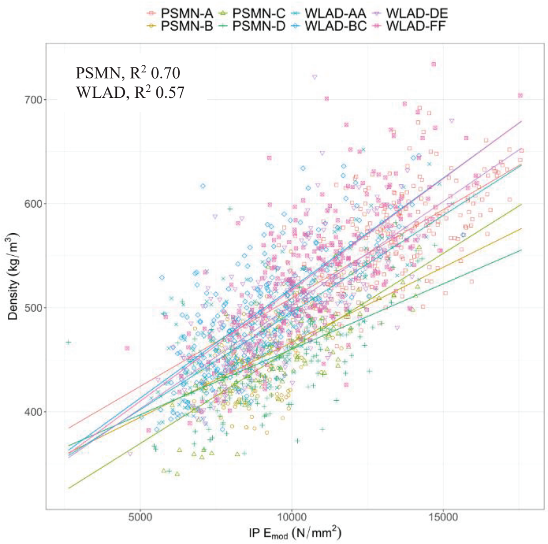

Figure 6: *Relationship between density and IP by sample (R^2 0.19 to 0.65, overall 0.58).*

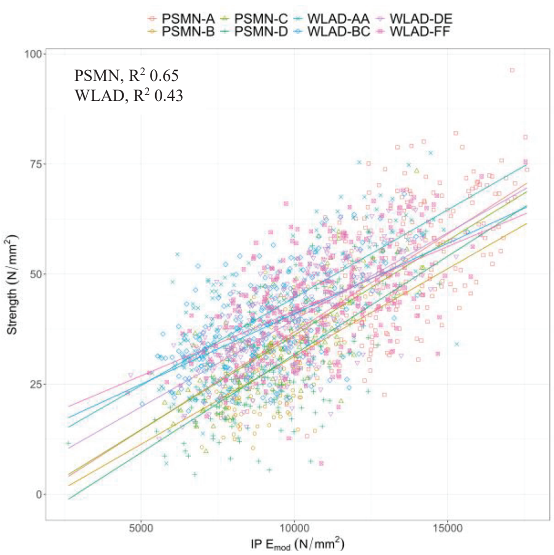

Figure 7: *Relationship between bending strength and IP by sample (R^2 0.22 to 0.56, overall 0.49).*

For grading, the analysis addressed initially the strength class combination C18/C14/reject. The setting must ensure that the whole population assigned to a grade must achieve 100% of the required strength class values of the GDPs. As well as that, at least 90% of the required target value for strength and density and 95% of stiffness must be met for each subsample.

In the first step, the settings for the upper grade was calculated. The first challenge was to find the threshold that would satisfy the requirements of the upper grade for subsamples B and D of PSMN. These samples had the lowest values for strength, and due to the large differences in GDP values between subsamples, it was possible that satisfying the requirements as a whole population was far from satisfying those of each subsample. This issue however, is not specific to the grading of a species combination.

Table 4 shows that the ratios between the derived characteristic values of the whole population and the required strength class values were 100% satisfied. The ratios for the eight subsamples (results not shown) also satisfied the requirements (90% of the target value for strength and density and 95% of stiffness). Under the current specifications of EN14081-2, the derived settings would be within the requirements of the standard. However, the strength of the PSMN population graded as C14 did not achieve 100% of the required value, 12.5 N/mm^2, of the strength class. Since the number of boards graded as C14 in samples A, B and C was less than 40, the parametric method was used to calculate f_k, which as Figure 3 shows is subjected to large fluctuations for a small number of pieces. To satisfy the species requirement it was not possible to simply increase the C14 setting, and that of the higher grade C18 had to be increased in beforehand so that more pieces were assigned to C14. As a result, the number of rejected pieces increased by 0.8 % points. Table 4 also shows settings for the combination C18/batten14. Batten14 is a user-defined strength class with characteristic values of: f_k = 14 N/mm^2; $E_{0,mean}$ = 7.5 kN/mm^2 and ρ_k = 330 kg/m^3 [7]. The peculiarity of this grade is that f_k is the same as in C14, but $E_{0,mean}$ and ρ_k are higher. This combination aimed to investigate how the higher requirement for $E_{0,mean}$ may influence the grading of WLAD. However, without the additional requirement, it was PSMN that did not achieve 100% of $E_{0,mean}$. On the contrary, WLAD, even though limited by MOE, achieved 100% of the GDPs without the additional requirement.

Table 4: *Ratios between the derived characteristic values, of the whole population and of species, and the required strength class values (re for MOE, rf for strength, rd for density).*

Strength Class	*Sample*	re	rf	rd
C18	ALL	1.28	1.33	1.32
C14	ALL	1.12	1.23	1.33
R	ALL			
C18	PSMN	1.32	1.14	1.29
C14	PSMN	1.02	0.91	1.25
R	PSMN			
C18	WLAD	1.25	1.60	1.38
C14	WLAD	1.18	1.67	1.38
R	WLAD			
Strength Class	*Sample*	re	rf	rd
C18	ALL	1.29	1.34	1.32
Batten14	ALL	1.06	1.19	1.18
R	ALL			
C18	PSMN	1.33	1.16	1.29
Batten14	PSMN	0.99	1.01	1.10
R	PSMN			
C18	WLAD	1.26	1.61	1.38
Batten14	WLAD	1.11	1.69	1.21
R	WLAD			

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In order to investigate further the effect of the additional species requirement, the analysis for this paper also calculated the settings for C18/reject for the total sample less:

1) the best and worst quality samples;
2) the best quality sample, PSMN-A;
3) the worst quality sample, PSMN-D

Table 5 summarises the resulting yields under the three cases, and the following grading of the remaining pieces. Using the eight samples (case 0), the lowest C18 setting that satisfied the requirements of the whole and verification samples also met the requirement for each species alone. Excluding the best and worst samples (case 1), it was necessary to increase the C18 setting so that PSMN as a whole achieved 100% of the required strength class values. Consequently, the overall yield dropped considerably. Excluding the best subsample (case 2), again PSMN did not achieve 100% unless the additional requirement was applied. As expected, if the setting was calculated excluding the worst subsample (case 3), the setting value was considerably lower, and the overall yield increased. However, this practice would not make grading safe as the strength ratio reached for the otherwise not included PSMN-D was only 81%. EN14081-2 contains a verification procedure for checking that existing settings are grading correctly in a particular location. This requires that the graded timber being checked achieves at least 90% of f_k and ρ_k of the target grade and 95% of the required $E_{0,mean}$. That check would fail for PSMN-D.

As well as that, EN14081-2 requires knowledge and experience to be applied when designing the sampling strategy, and states that *if weak areas* (i.e., low quality) *are known, they should be taken into account accordingly*. While it may be tempting to remove or avoid sampling low performing data from the calculation on the grounds that it is different, it would certainly be incorrect to do so. In the previous version of EN14081-2:2012 [18], the verification checks were applied differently, so that the required characteristic values for each grade were achieved for the total sample less one geographical sample in turn. In that procedure the mean setting could not be more than 15% different from the most conservative setting or otherwise the setting had to be adjusted by 15% towards the mean value. It was realised that this procedure becomes ineffective as more samples are included in the settings calculation even though, as illustrated above, there can be significant issues with individual samples. In revising the standard, the verification checks were made more robust and explicit in their function. The standard also states that the same procedure can be used to check non-geographical samples that are suspected to be different. The standard mentions cross-section size as the example, but it is valid also for species. It is therefore recommended to apply the species check to ensure that the grading is safe.

One might also wonder whether to group the dataset by species and country, resulting in four samples, which is the minimum verification samples required in the standard. This approach gave the lowest rejects for C18/reject, 45 boards over the whole population. However, in view of the results shown in Table 5, it may be advisable from a safety point of view to consider at least four samples per species. Since EN14081-2 requires at least one hundred specimens per sample, four samples per species leads to at least 800 specimens for a combination of two species. This will provide a larger dataset to analyse, and more variability of the timber source than the 450 specimens given in the standard as the minimum number required for deriving settings. In developing grading settings, the first objective must always be safety of grading and it is sometimes necessary to do more than the minimum required by the standard, and accept some loss in yield, in order to achieve that.

Table 5: *Pieces allocated to C18/reject under different cases and the subsequent grading of the remaining pieces without (No Sp. Req.) and with the additional species requirement.*

Case		Samples	PSMN	WLAD	Reject
0	No Sp. Req. Sp. Req.	ALL	605	688	310
1	No Sp. Req.	a)	231	810	101
		PSMN-A & D	442	-	19
	Sp. Req.	a)	193	679	270
		PSMN-A & D	406	-	55
2	No Sp. Req.	b)	329	688	309
		PSMN-A	276	-	1
	Sp. Req.	b)	316	673	337
		PSMN-A	273	-	4
3	No Sp. Req. & Sp. Req.	c)	507	810	102
		PSMN-D	166	-	18

The study here presented used a machine that uses MOE_{dyn} for grading, a relatively simple case due to the direct link between the IP and GDPs. The additional check by species may become more important when grading timber using characteristics such as knottiness. Knots are related to GDPs in a much more complicated way with differences in species and growth conditions. The IPs determined by grading machines using knottiness are typically obtained through linear regression between the knots (and density) and the GDPs on all available test data. If one of the species has small knots compared to the other(s), and is widely represented in the sampling used to develop the settings (which EN14081-2:2018 specifies should broadly similar to that in practice), the influence of the knot characteristics on the model will be less, which may benefit other species with larger knots in the combination.

4 CONCLUSIONS

This paper has shown that it is possible to grade PSMN -Douglas fir- with WLAD -larch- together as a species combination for the grading area formed by Ireland and the UK. In doing so, this paper also outlines an approach to develop machine grading settings for species combinations. In particular, it includes an additional check (in line with EN14081-2, but not required by it) so that the required characteristic values of the target grade are fully satisfied for the two (or more) species within the combination. The additional requirement aims to ensure that the grading is safe, particularly if the species are graded separately. It is shown that while larch and Douglas-fir look superficially very similar in their properties and grading, there are some meaningful differences. Further, it is shown that as long as differences are accounted for, the strength grading of the species combination can still be safely achieved. The disadvantage is that it requires an even larger testing programme than normal, and the ability to separate the species in testing.

Having common settings that can be used for Douglas fir and larch, whether mixed in production or not, is an advantage both economically and from a logistical point of view to sawmills and may increase the volume of timber available for the market, making these species more commercially attractive for processing.

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