RESPONSE TO “ON NOTICE” QUESTIONS

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ECONOMICS REFERENCES COMMITTEE INQUIRY INTO NON-CONFORMING BUILDING PRODUCTS

HEARING IN ADELAIDE ON MONDAY 31ST JULY 2017

THE UNIVERSITY of ADELAIDE

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Questions & Responses

1. What regulations are in existence for wood imports into Australia and who has responsibility for those? Who has responsibility for compliance?

Imports of wood products into Australia are covered by three separate Acts, these are the *Environment Protection and Biodiversity Conservation Act 1999*; the *Biosecurity Act 2015*, and; the *Illegal Logging Prohibition Act 2012*. The requirements of these in terms of species and origin information, along with details of responsible parties are given in table 1.

With respect to building regulations, wood products are not regulated at the point of import for their compliance to building codes. Buildings must comply with the National Construction Code (NCC) but according to the website of the NCC[1] "Administration of the NCC is the responsibility of the States and Territories under their various building and plumbing Acts and Regulations."

According to Andrew Dunn, CEO of the Timber Development Association[2], the responsibility for final compliance to building code rests with Certifiers and Surveyors. Although a range of voluntary certification schemes exist that include product compliance testing, there are no mandatory requirements to prove compliance at import. Where products are considered compliant or not based on their species identity (durability, fire-resistance etc…) there are no mechanisms currently in place that require demonstration that an imported wood product is, in fact, the species that was tested and shown to have those compliant properties.

2. Is there a problem with imports and, if so, what is the extent of the problem?

Globally, there is a significant problem with illegal logging, which can involve a range of practices including species substitutions. In 2012, the global rate of illegal logging was estimated to be 30-50%, and up to 90% in some tropical areas[3]. It is highly likely that a proportion of that illegal timber is imported into Australia – the Australian Government certainly thinks so, as evidenced by the *Illegal Logging Prohibition Act*, *2012*. Empirical data regarding the extent of the problem of illegal wood products entering Australia are difficult to come by, although results from a handful of pilot studies in our laboratories that have looked at products from a small range of suppliers, have revealed that the global average of 30-50% seems to ring true in Australia. For an example of data from the perspective of non-compliance to building codes, we refer to the submission of the Engineered Wood Products Association of Australasia (EWPAA, submission 12) which details what it calls "alarming levels of non-compliance of mostly imported product". Andrew Dunn, CEO of the Timber Development Association[4] described "imports as the real problem" with regards to building

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[1] http://www.abcb.gov.au/NCC/About
[2] http://www.tdansw.asn.au/
[3] Nellemann C, INTERPOL Environmental Crime Programme, eds. 2012. Green Carbon, Black Trade: Illegal Logging, Tax Fraud, and Laundering in the World's Tropical Forests: A Rapid Response Assessment. United Nations Environment Programme, GRID-Arendal.
[4] http://www.tdansw.asn.au/

compliance issues in timber. Further market testing across a broad range of timber imports would be required to more accurately assess the extent of the problem.

Table 1. Details of regulations that cover wood imports into Australia

Legislation	Date	Amendments	Responsible Department	Requirements for species	Requirements for origin	Responsibility for compliance
Environment Protection and Biodiversity Conservation Act (including Regulation)	1999	Amended and in force on 1 July 2016	Department of the Environment and Energy (policy), Department of Immigration and Border Protection (enforcement at the border)	For species listed on the CITES appendices: species name (unless all species within a higher taxonomic rank are listed on the appendices of CITES, e.g. the genus *Dalbergia* (rosewood and palisander) in which case that higher taxonomic rank only is required).	For species listed on the CITES appendices: Country of origin in order to establish permit requirements dependant on which CITES appendix the species is listed.	Importer
Biosecurity Act (including Regulation and BICON)	2015	Amended and in force on 18 May 2017	Department of Agriculture and Water Resources (policy), Department of Immigration and Border Protection (enforcement at the border)	The existence of plant material must be declared but there are no specific details regarding what information about that plant material is required. However, instructions on BICON (Australian Biosecurity Import Conditions) state that "Botanical Name" is required.	The existence of plant material must be declared but there are no specific details regarding what information about that plant material is required	Importer
Illegal Logging Prohibition Act (including Regulation)	2012	Amended and in force on 1 July 2015	Department of Agriculture and Water Resources (policy), a community protection question is included in the import declaration made to the Department of Immigration and Border Protection at the border. However, regardless of the answer, the goods will be imported as long as all other entry requirements are met. The Department of Agriculture and Water Resources may then follow up at their discretion	Due diligence: "The requirements may include…the kind, origin and details of harvest of raw logs". "An importer must...obtain as much...information...as it is reasonably practicable for the importer to obtain. The information is the following: (a) a description of the regulated timber product, including: (i) the type of product, and the trade name of the product; and (ii) the common name, genus or scientific name of the tree from which the timber in the product is derived"	Due diligence: "The requirements may include…the kind, origin and details of harvest of raw logs". "An importer must...obtain as much...information...as it is reasonably practicable for the importer to obtain. The information is the following: (b) the country, the region of the country and the forest harvesting unit in which the timber in the product was harvested; (c) the country in which the product was manufactured"	Importer

3. I think you've already alluded to a common problem that we've heard about in this committee, which is fraudulent certificates of compliance. That's an issue for timber as well, is that right?

Wood products coming in to Australia are not required to hold a certificate of compliance to particular building codes. EWPAA, submission 12 compares certified and non-certified products with respect to compliance and found that significantly less certified products were non-compliant compared to uncertified products (but certified products did still contain some non-compliant products). However, EWPAA does not recommend mandatory certification as this has not provided a solution in the electrical and plumbing sectors where the incidence of fraudulent certificates has risen. We believe the situation will be the same with timber, for both structural compliance certification and sustainability certification, the incentive to circumvent compliance requirements and produce fraudulent certificates will only grow should they be made a legal requirement in the absence of independent verification through product testing.

4. Could you take on notice how your technology would fit in within this compliance regime?

The United Nations Office on Drugs and Crime (UNODC) have published a Best Practice Guide for Forensic Timber Identification, the writing of which was coordinated by Dr Dormontt with input from an Expert Group consisting of global leaders in the fields of timber science and law enforcement, including Prof Lowe. The Guide sets out how timber identification can best be incorporated into law enforcement practices[5] and also provides a Law Enforcement Best Practice Flow Diagram for Timber[6] for use by front line agents. In addition, we have authored two scientific papers in recent years that examine the options for independent identification of timber and consider how these scientific approached can be applied to timber supply chains, both through law enforcement and industry compliance[7,8]. These publications are provided in Annex 1. Given that there are no current import requirements for timber compliance to building code, the existing *Illegal Logging Prohibition Act 2012* requirements potentially offer an opportunity for independent species/origin verification. Results from these tests could be then be used to support demonstration of compliance to both the *Illegal Logging Prohibition Act 2012* requirements and to the NCC (where species ID is relevant to NCC compliance). Species testing for timber is particularly important where compliant properties such as fire-resistance and durability are determined on a species by species basis. For more complex engineered timber products, species testing can support compliance demonstration but should be used, as appropriate, in conjunction with structural performance testing.

[5] Dormontt E.E. for the United Nations Office on Drugs and Crime (2016) Best Practice Guide for Forensic Timber Identification, Publishing and Library Section, United Nations Office, Vienna, Austria. https://www.unodc.org/documents/Wildlife/Guide_Timber.pdf

[6] Dormontt E.E., Dubois J.F. for the United Nations Office on Drugs and Crime (2016) Law Enforcement Best Practice Flow Diagram for Timber, Publishing and Library Section, United Nations Office, Vienna, Austria. https://www.unodc.org/documents/Wildlife/Timber_Flow_Diagram.pdf

[7] Lowe AJ, et al. 2016. Opportunities for improved transparency in the timber trade through scientific verification. BioScience 66: 990-998. See Annex 1.

[8] Dormontt EE, et al. 2015. Forensic timber identification: It's time to integrate disciplines to combat illegal logging. Biological Conservation 191:790–798. See Annex 1.

5. **What government assistance do you say would be needed to take your research from the academic domain—although I note it is being used, as you've just said—and use it for widespread enforcement?**

The University of Adelaide houses the Advanced DNA, Identification and Forensics Facility (ADIFF), which is a global leader in the development of timber identification methods. However, transfer of these cutting edge approaches into a routine and cost-effective service offering for government and industry testing requires investment. Resources are needed to further equip laboratory capability, build reference databases, undertake a risk analysis of major Australian timber supply chains, assess the level of compliance and identify those supply chains which are most at risk, develop training programs for relevant government and industry stakeholders, and work with government and industry to develop and implement best practise testing protocols to screen and secure Australian timber supply chains. The investment required is AU$7.35 million. We have developed a brief proposal outlining the requirements that can be found in Annex 2.

6. **That raises the question of whether we need to revisit the Australian legislation. Could you take that on notice as to being in sync with best practice legislation overseas?**

Legislation similar to the *Illegal Logging Prohibition Act, 2012* (ILPA) exists in the United States of America (*The Lacey Act, amended 2008*) (Lacey) and in the European Union (*European Union Timber Regulations, 2010*) (EUTR). Key components of these are compared in table 2 (taken from Lowe *et al*. (2016)[9], Annex 1). The Legislations are broadly the same, with EUTR and ILPA having a greater focus than Lacey on the requirement for due diligence regardless of eventual legality status of the wood. ILPA has an exemption for consignments below the value of AU$1000 whereas Lacey and EUTR have no such exceptions. With regards to “deemed to comply” products, neither Lacey nor EUTR consider any certified products to automatically fulfil due diligence or legal compliance requirements (with the exception of FLEGT VPA licences in the European Union, which are in fact bilateral trade agreements rather than certification schemes). Currently, Australia is considering relaxing ILPA requirements to increase the value threshold up to $10,000 and to allow some third party certified products to be deemed to comply. We strongly advise that this is not consistent with best practice overseas. Further, with respect to enforcement of legislation, both the USA and several countries within the European Union (Germany, UK and Denmark) now routinely use scientific testing of wood products to independently verify compliance with the law. Australia is well placed to follow this lead by supporting routine independent scientific testing of their wood imports.

We do not have the expertise to comment on best practice legislation overseas for the regulation specifically of building products.

[9] Lowe AJ, et al. 2016. Opportunities for improved transparency in the timber trade through scientific verification. BioScience 66: 990-998. See Annex 1.

Table 2. A comparison of legislation designed to address demand-side factors in the illegal timber trade

	Legislation (year enacted)			
	Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act (1992).	**Lacey Act (1900, amended 2008).**	**EU Timber Regulation (2010).**	**Illegal Logging Prohibition Act (2012).**
Jurisdiction	Canada	United States of America	European Union	Australia
Regulated plant products	Any wild species of the plant kingdom (kingdom Plantae) including any seed, spore, pollen, tissue culture or any other part or derivative of any such plant whether living or dead.	Any wild member of the plant kingdom, including roots, seeds, parts, and products thereof, and including trees from either natural or planted forest stands.	Any timber product prescribed in the annex to the EU Timber Regulation (2010).	Any timber product prescribed by Schedule 1 of the Illegal Logging Prohibition Amendment Regulation (2013).
Prohibited actions with respect to illegal timber	Unlawful to import any plant that was taken, possessed, distributed or transported in contravention of any law of any foreign state. Unlawful to knowingly possess a plant that has been imported or transported in contravention of the Act for the purpose of transporting from one province to another or exporting it from Canada. Also unlawful to knowingly furnish any false or misleading information or make any misrepresentation with respect to any matter in the Act.	Unlawful to import, export, transport, sell, receive, acquire, or purchase in interstate or foreign commerce any plant taken, possessed, transported or sold in violation of any law or regulation of any State, federal, tribal, or any foreign law that protects or regulates plants. Also unlawful to make or submit any false record, account or label for, or any false identification of any plant.	Unlawful to place any timber on the EU market for the first time that has been harvested illegally under the law of any foreign nation. Unlawful to fail to conduct due diligence on timber products placed on the EU market for the first time. Unlawful to trade timber products on the internal market without keeping records of suppliers and customers.	Unlawful to knowingly, intentionally or recklessly import or process illegally logged timber. Unlawful to import any timber or timber products without appropriate certification, licensing and proof that the timber has not been harvested illegally under the law of any foreign nation. Unlawful to process raw logs, without appropriate certification and proof the timber has not been harvested illegally.
Required level of plant identification	Common name and, if known, its scientific name (genus and species).	Scientific name (genus and species).	Trade name, type of product, common name, and where applicable full scientific name (genus and species).	The common name, genus or scientific name (genus and species) of the tree from which the timber in the product is derived.
Required specification of plant origin	Country of harvest.	Country of harvest.	Country of harvest (and where applicable, region and concession of harvest).	The country, the region of the country and the forest harvesting unit in which the timber in the product was harvested and manufactured.

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Annex 1. Publications from Professor Lowe and Dr Dormontt relating to timber identification and legal compliance

Lowe AJ, et al. 2016. Opportunities for improved transparency in the timber trade through scientific verification. BioScience 66: 990-998.

Dormontt EE, et al. 2015. Forensic timber identification: It's time to integrate disciplines to combat illegal logging. Biological Conservation 191:790–798.

These documents can be found on the following pages.

Opportunities for Improved Transparency in the Timber Trade through Scientific Verification

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In May 2014, the Member States of the United Nations adopted Resolution 23/1 on "strengthening a targeted crime prevention and criminal justice response to combat illicit trafficking in forest products, including timber." The resolution promotes the development of tools and technologies that can be used to combat the illicit trafficking of timber. Stopping illegal logging worldwide could substantially increase revenue from the legal trade in timber and halt the associated environmental degradation, but law enforcement and timber traders themselves are hampered by the lack of available tools to verify timber legality. Here, we outline how scientific methods can be used to verify global timber supply chains. We advocate that scientific methods are capable of supporting both enforcement and compliance with respect to timber laws but that work is required to expand the applicability of these methods and provide the certification, policy, and enforcement frameworks needed for effective routine implementation.

Keywords: certification, illegal logging, scientific verification, timber trade, wood identification

Forests are important sources of timber, nontimber forest products, and other ecosystem services; tropical forests alone harbor more than half of the world's plant and wild animal species and store about 247 billion metric tons of carbon (Saatchi et al. 2011). Illegal logging is a major cause of forest degradation and subsequent loss (Burgess et al. 2012) estimated to account for between 15%–30% of the global trade in timber and worth US$30–$100 billion annually, including processing (Nellemann and INTERPOL 2012). In tropical regions, illegal logging rates are thought to be even higher, with 50%–90% of timber likely to be illegally sourced (Nellemann and INTERPOL 2012). The consequences of these illegal activities are realized economically, socially, and ecologically. Legitimate concession holders, governments, and local communities are denied vital revenue; armed conflict and corruption are promoted; and regional biodiversity assets and ecosystem services are degraded (Sikor and To 2011, Reboredo 2013).

Illegal logging for the international timber trade is predominantly a response to the external demand for wood products generated by consumer nations; therefore, efforts to curb the practice must address these demand drivers in addition to targeting illegal operations on the ground (Johnson and Laestadius 2011). In attempts to stem such international demand, legislation in Canada (1992), the United States (2008), the European Union (2010), and Australia (2012) now prohibits the importation of timber products harvested or traded in contravention of applicable foreign laws (table 1). Importantly, in each legislation, all actors in the timber supply chain (except the final consumer) are responsible for ensuring the legality of the timber they purchase and must declare the identification and geographical origin of the timber in question. US legislation requires the declaration of the full scientific name (genus and species), whereas the remainder only require trade names, common names, or genus where the full scientific name is unknown. This approach can be problematic in determining legal status because most environmental protection laws are applied at the species level. Legislation in the United States and Canada require only that the country of origin be declared for traded timber, whereas legislation in the European Union requires the region and concession of harvest "where applicable," and Australia requires region and harvesting unit information in all cases. In addition to these declaration requirements, legislation in the European Union and Australia requires buyers to fulfill requirements for due diligence and provide evidence that the timber has not been illegally sourced. Legislation designed to address

BioScience 66: 990–998.
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Table 1. A comparison of legislations designed to address demand-side factors in the illegal timber trade.

	Legislation (year enacted)			
	Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act (1992)	**Lacey Act (1900, amended 2008)**	**EU Timber Regulation (2010)**	**Illegal Logging Prohibition Act (2012)**
Jurisdiction	Canada	United States	European Union	Australia
Regulated plant products	Any wild species of the plant kingdom (kingdom Plantae), including any seed, spore, pollen, tissue culture, or any other part or derivative of any such plant, whether living or dead.	Any wild member of the plant kingdom, including roots, seeds, parts, and products thereof, and including trees from either natural or planted forest stands.	Any timber product prescribed in the annex to the EU Timber Regulation (2010).	Any timber product prescribed by schedule 1 of the Illegal Logging Prohibition Amendment Regulation (2013).
Prohibited actions with respect to illegal timber	Unlawful to import any plant that was taken, possessed, distributed, or transported in contravention of any law of any foreign state. Unlawful to knowingly possess a plant that has been imported or transported in contravention of the Act for the purpose of transporting from one province to another or exporting it from Canada. Also unlawful to knowingly furnish any false or misleading information or make any misrepresentation with respect to any matter in the Act.	Unlawful to import, export, transport, sell, receive, acquire, or purchase in interstate or foreign commerce any plant taken, possessed, transported, or sold in violation of any law or regulation of any state, federal, tribal, or any foreign law that protects or regulates plants. Also unlawful to make or submit any false record, account, or label for—or any false identification of—any plant.	Unlawful to place any timber on the EU market for the first time that has been harvested illegally under the law of any foreign nation. Unlawful to fail to conduct due diligence on timber products placed on the EU market for the first time. Unlawful to trade timber products on the internal market without keeping records of suppliers and customers.	Unlawful to knowingly, intentionally, or recklessly import or process illegally logged timber. Unlawful to import any timber or timber products without appropriate certification, licensing, and proof that the timber has not been harvested illegally under the law of any foreign nation. Unlawful to process raw logs without appropriate certification and proof that the timber has not been harvested illegally.
Required level of plant identification	Common name and, if known, its scientific name (genus and species).	Scientific name (genus and species).	Trade name, type of product, common name, and, where applicable, full scientific name (genus and species).	The common name, genus, or scientific name (genus and species) of the tree from which the timber in the product is derived.*
Required specification of plant origin	Country of harvest.	Country of harvest.	Country of harvest (and, where applicable, region and concession of harvest).	The country, the region of the country, and the forest harvesting unit in which the timber in the product was harvested and manufactured.

Note: Wording is taken from the appropriate legislation and amended for clarity and relevance where required. The provisions described here are in addition to national provisions for the regulation of trade in species listed in the appendices to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

demand-side factors is in addition to laws governing the regulation of trade in endangered species, as is required by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Nonstate market driven certification schemes have been developed in response to growing consumer demand for sustainable wood products and requirements to demonstrate compliance with timber regulations. Certification is obtained through initial assessment of compliance against a set of principles, criteria and indicators followed by periodic audits. Although it is difficult to fake compliance with standards of forest management and harvesting operations, the chain of custody of products along supply chains are vulnerable. Substitution or inclusion of prohibited timber, over harvesting, exclusion of sales from financial records and mixing of certified and noncertified timber (Johnson and Laestadius 2011), present risks to the integrity of all certification schemes. So although the enactment of legislation and the development of nonstate market-driven certification schemes provide a framework for addressing illegal trade, practical tools with which to independently verify the compliance of specific products are urgently required by governments, certification bodies, traders, and even consumers. In May 2014, the Member States of the United Nations recognized this need through adoption of Resolution 23/1 on "strengthening a targeted crime prevention and criminal justice response to combat illicit trafficking in forest products, including timber" (UNODC 2014). The resolution included the promotion of the development of tools and technologies that can be used to combat illicit trafficking of timber. Without the routine application of such verification tools, there can be little realistic expectation of demand-side initiatives significantly curbing the rates of illegal logging.

Current approaches to timber supply-chain verification

Standards relating to the legal and sustainable harvest of timber focus on prescribing what can be logged, where, how much, by whom, and at what time. How timber is processed post-harvest can also be a consideration, because certified and noncertified products generally must be kept separate. Currently, compliance is determined primarily through paper-based systems involving the issuing of licences and certificates. Documentation typically includes declarations of activity such as forest inventories and felling forms, log production reports, invoices, transport documents, sales reports, and various tally and balance sheets designed to capture the flow of timber in and out of various points in the supply chain. Supply chains are verified through the examination of this documentation and through physical inspections. These inspections may be part of a routine process to fulfill requirements for certificate issuance; applied *ad hoc*, such as in the case of customs inspections; or form part of external or internal audit procedures, such as those required by forest certification schemes. The nature of these inspections will usually include counting of products and identification of the type of material. However, the accuracy and granularity afforded by this identification process depends on the methods used. In most cases, identification is achieved by visual examination and is only able to verify the trade grouping, or genus level, not individual species designation. Furthermore, this identification cannot confirm the geographic origin, specific individual, or age of the timber, all characteristics that can have a bearing on the compliance of the timber in question.

Reliance on paper-based methods alone leaves room for fraudulent activity. Documentation can be forged, or genuine documentation can be inappropriately associated with illegal timber. Efforts to implement more robust tracking systems using barcodes and electronic tagging go some way to ameliorating these risks (Seidel et al. 2012). However, the basic problem remains: Without a verification technique that derives from the timber itself rather than some externally affixed marker or associated paperwork, the system will always be vulnerable to the inclusion of illegal or otherwise non-compliant material. In order to genuinely verify that standards have been met, independent identification of the genus, species, geographic origin, specific individual, and, in some cases, the age of timber are required, based on characters inherent to the timber itself (Dormontt et al. 2015).

Scientific methods for timber supply-chain verification

Science can provide the means to identify timber, but it is not a trivial task. Timber does not have the most common diagnostic morphological features used for plant identification, such as flowers, fruits, and leaves. Therefore, the definitive scientific verification of timber has to rely solely on characteristics inherent in the wood itself. Various methods such as wood anatomical analysis (Wheeler and Baas 1998, Gasson et al. 2011), phytochemical analysis (Pastore et al. 2011, McClure et al. 2015), isotopic analysis (Kagawa and Leavitt 2010, Krüger et al. 2014), DNA barcoding (Lowe and Cross 2011, Jiao et al. 2015), and DNA profiling (Lowe et al. 2010, Jolivet and Degen 2012) are used to determine timber identity. Each method has a particular suite of circumstances in which it is most appropriate, can usually provide a specific level of identification, and varies somewhat in associated costs (box 1, table 2). For example, traditionally used wood anatomy can generally only identify timber to genus but requires no preliminary information about the sample and is one of the cheapest methods, making it a particularly useful "first pass" at identification (table 2; Gasson 2011). Similarly, DNA barcoding can be used on unknown material to establish genus and species but relies on the existence of appropriate genetic barcode reference data for the species and related groups in question (Parmentier et al. 2013) and has a higher associated cost (table 2). Conversely, DNA profiling, while having a similar cost to DNA barcoding (table 2), can identify the exact genetic individual, but the species identity must be known in advance. DNA profiling is therefore an ideal tool for the tracking of individual logs (box 2; Lowe et al. 2010) but inappropriate for genus or species identification of a completely unknown sample or for use in clonally propagated species.

Scientific verification opportunities within the timber supply chain

The modern timber trade is characterized by complex global networks spanning multiple locations within producer nations and multiple consumer countries, making the challenge of monitoring and policing especially difficult. There are, however, discrete points along supply chains that present opportunities for routine scientific verification (figure 1). In most forests, standard management practices produce detailed inventories of standing trees. The collection of reference material to act as a benchmark for subsequent independent, scientific, supply-chain verification could be incorporated into the inventory process.

Once harvested, individual trees are uniquely marked according to their taxon and place of harvest; timber is transported to log yards and then cut in saw mills, where illegal wood can be added to otherwise legal consignments. The routine scientific verification of a match between timber harvested from a legal concession or plantation and that which passes through a log yard and saw mill could identify illegal augmentations of timber loads. A method that facilitates the individualization of trees is most suitable here, such as DNA profiling (box 2; Lowe et al. 2010). Genus and species identification can also be important, such as through wood anatomical (Gasson 2011, Ruffinatto et al. 2015) or chemical analyses (Musah et al. 2015), particularly if there are protected taxa in the area. Effective scientific verification at the beginning of the supply chain would have the greatest impact on any downstream illegal timber trade, with the potential to cut it off at the source.

After cutting, timber is processed. This processing may be no more than preparing consignments for domestic sale or may involve exportation to an intermediary country for further processing (and often mixing with timber from other sources) before re-exportation for sale. Timber processing

Box 1. The scientific basis of the main methods for timber identification.

Scientific verification can be achieved through the application of one or more of the following methods for timber identification. All methods rely on reference specimens of known species from which reference data can be derived and compared with unknown samples to determine an identification. The existence and availability of reference materials and derived data varies between methods (Dormontt et al. 2015).

Wood anatomy

Wood anatomy is concerned with the arrangement of the internal structures of timber, which are determined primarily by genetics and, to a lesser extent, by environment. Combinations of anatomical characters are diagnostic for particular taxonomic groups and can be used for identification. Identification relies on the comparison of unknown samples with reference specimens at the macro- and microscopic levels (Carlquist 2001).

DNA

Small changes in the genetic code accumulate over generations, resulting in greater differences between the DNA sequences of distantly related compared with closely related individuals. By reading the DNA sequence at particular parts of the genome, individuals can be assigned to a particular group (i.e., species, population) on the basis of similarities and differences in their DNA compared with reference data. Success can be limited by the technical challenges inherent in extracting and amplifying sufficient DNA from timber (Lowe and Cross 2011, Jiao et al. 2015).

Mass spectrometry

Mass spectrometry can be used to measure the mass-to-charge ratios of ionized chemical compounds. The specific compounds and relative amounts found within timber are determined by both genetic and environmental factors, and the resulting chemical fingerprints can be analyzed to facilitate the clustering of groups such as species or populations from particular geographic areas. Unknown samples can be analyzed in the same way and identified by the group(s) with which the derived data clusters (Musah et al. 2015).

Near-infrared spectroscopy

By measuring the absorption spectra of timber when exposed to near-infrared electromagnetic energy, near-infrared spectroscopy provides information on both the chemical and physical structure of wood. Appropriate multivariate analyses can be applied to determine the identity of an unknown wood sample when compared with a reference database of spectra from possible taxa (Pastore et al. 2011).

Stable isotopes

Elements exist in various naturally occurring stable isotopes, the ratios of which can vary depending on certain climatological, geological, and biological conditions. As compounds containing these isotopes are synthesized by trees, the isotopic fingerprints of species in particular areas can be used to identify the geographic origin of unknown samples. Stable isotope analysis typically requires the combined assessment of multiple stable isotopes to provide the required granularity for useful geographic origin identification (Horacek et al. 2009).

Radiocarbon

Carbon occurs naturally as the radioactive isotope ^{14}C (“radiocarbon”), as well as the stable isotopes ^{12}C and ^{13}C. Radiocarbon decays naturally to ^{14}N. By measuring the ratio of radiocarbon to the stable carbon isotopes, it is possible to calculate a “radiocarbon age” of timber. During the early 1960s, levels of ^{14}C in the upper atmosphere were augmented through nuclear-bomb testing producing a spike in calibrations (the “bomb curve”), which can be used to date recent material (Uno et al. 2013). Accurate calculation requires two samples of different ages (such as different tree rings within a piece of timber). The results reveal the age of the individual tree rings tested, but this may not equate to the felling date if the outermost tree rings were not present in the sample (del Valle et al. 2014).

represents an important point for scientific verification, particularly in highly convoluted supply chains (figure 1), in which information on the origin of products postprocessing can be easily lost or obscured. Depending on the type of processing, all methods able to determine some aspect of timber identity (i.e., genus or species; source region, box 3; individualization, box 2; and age) could be useful to confirm the origin(s) of processed timber, although genus or species and source region would likely be the most relevant.

The point of export presents another opportunity for effective routine scientific verification of timber; individualization to match back to a legal source is still a feasible option (box 2), and genus and species identification remain valuable. Identifying the geographic origin becomes important here, because much illegal timber is smuggled across porous land and sea borders and then used to augment otherwise legal shipments bound for export. By verifying the geographic origin of timbers at the point of export, such as through the application of population genetics (Jolivet and Degen 2012) or stable isotope analysis (box 3; Kagawa and Leavitt 2010), illegal additions to otherwise legal timber loads could be detected.

Currently, the point of import provides the most robust existing infrastructure where verification tools could be routinely applied through established customs and quarantine procedures, and legislation designed to address

Table 2. Methods for scientific timber verification.

Method	Identification capacity	Prior information required	Technical expertise required	Technical infrastructure required	Approximate cost for application of test	Complementary techniques	Biases in applicability
Wood anatomy	Genus, sometimes species	None	Professional wood anatomists working with highly trained ground staff	Access to xylarium collections and associated tools for wood anatomical analyses	Less than US$100	Can complement all other methods by determining genus	None
DNA	Genus, species, geographic origin, individual (separate tests)	For genus and species identification, none. For geographic origin and individualization, species information required	Professional molecular biologists	Access to DNA databases and laboratories	US$100–$300	Can identify genus and species for chemical methods, can augment geographical origin identification from chemical methods	Taxonomically understudied and speciose groups are harder to distinguish and often lack adequate reference data. Geographic origin and individualisation capabilities only exist for a handful of species to date, spread across the northern temperate and equatorial tropical regions of the world
Mass spectrometry	Genus, species, geographic origin	Suspected genus required to identify correct reference data comparison	Professional chemists	Access to chemical profile databases and mass spectrometry equipment	Less than US$100	Can identify genus and species for other chemical methods	Limited reference data collected to date, focusing on a select few genera of primarily CITES listed tropical taxa
Near infrared spectroscopy	Genus, species, geographic origin	Suspected geographic origin required to identify correct reference data comparison	Professional chemists working with highly trained ground staff	Access to near-infrared spectral databases and spectroscope	Less than US$100	Can identify genus and species for other chemical methods	Limited reference data collected to date, focusing on a select few South American taxa
Stable isotopes	Geographic origin	Species	Professional chemists	Access to stable isotope profile databases and mass spectrometry equipment	US$100–$400	Can augment geographical origin identification from DNA methods	Limited reference data collected to date, focusing on a range of South–East Asian and Central African species
Radiocarbon	Age	None	Professional chemists	Access to radiocarbon calibration data and associated mass spectrometry equipment	US$300–$400	Can be used with other methods that identify species to determine whether the timber pre-dates requirements	Can only provide a date for the section of wood sampled. Where this does not include the outermost ring of the tree, felling date cannot be determined

demand-side factors (table 1) is often enforced first here. Customs authorities generally employ sophisticated risk analyses to determine which shipments deserve further scrutiny (e.g., particular transit routes, companies with a history of noncompliance, typical smuggling modus operandi), but most often lack the practical tools and knowhow required to obtain identification results for timber. Because points of import generally deal with shipments originating from multiple global destinations, linking any one log back to an individual tree would likely be prohibitively challenging (the proverbial "needle in a haystack"), but records of previous individual matching results could still provide valuable information. Genus, species, and geographic origin verification will all be important for determining a shipment's compliance. Import and export permit requirements (mainly CITES) can change depending on the age of timber; therefore, the independent verification of age, such as through radiocarbon dating (del Valle et al. 2014), can be used to identify where illegal timber was incorrectly claimed to pre-date legislation. Wood anatomy, mass spectrometry, and DNA identification have all been used successfully to identify timber at the Port of

Box 2. Case studies demonstrating the use of genetic individualization in timber verification.

Genetic individualization is the process of using the unique genetic profile of an individual to distinguish it from all others (excluding clones). The method is used extensively in human forensics to identify the origin of biological material. In timber identification, genetic individualization techniques can be used to verify whether shipments contain the same individuals at different points in the supply chain or whether there has been substitution or augmentation. Alternatively, the same techniques can be used to match timber evidence to the scene of illegal logging crimes. The technique is best suited to high-value timber, for which testing costs represent a lower fraction of the overall value of the timber and volumes and species diversity are typically low.

Genetic individualization to verify compliance in certified supply chains

In 2009, the International Tropical Timber Organization supported a project to evaluate the effectiveness of DNA verification of the chain of custody in CertiSource certified supply chains of Merbau timber (*Intsia* spp.) in Indonesia (Lowe et al. 2010, Seidel et al. 2012). Specimens were taken from logs at point of harvest in Papua and again on arrival at sawmills in Java. Genetic individualization was undertaken on a sample of matched specimens. The study revealed a DNA amplification success rate of between 59.2% (forest) and 41.9% (sawmill) and concluded that ongoing implementation of the system could be achieved at an affordable cost to industry. The application of scientific verification in this example can be used to demonstrate well-managed supply chains, and where mismatches are discovered, it can highlight weaknesses that can be further investigated by auditors.

Genetic individualization to identify illegal logging in US National Forest

In 2012, the US Forest Service uncovered sites of illegal logging of Bigleaf Maple (*Acer macrophyllum*) in the Gifford Pinchot National Forest. Timber off cuts from a nearby sawmill were seized as evidence. In a World Resources Institute–funded project, DNA markers (Jardine et al. 2015) and a subsequent DNA database were developed for the species that would provide individualization results suitable for admission to the US court system in support of a Lacey Act conviction (see table 2 for more information on the Lacey Act). The resulting database was used to test the evidence and revealed a highly significant match. All four defendants pleaded guilty in 2015–2016. Research continues into reducing costs (see table 2 for cost details of the various methods) to enable the use of DNA verification in Bigleaf Maple supply chains, as well as for law-enforcement purposes.

Rotterdam, and radiocarbon analyses have been sought but were ultimately deemed unnecessary because of other factors (Anton Huitema, CITES Officer at the Port of Rotterdam, personal communication, 2 July 2016). Unfortunately, the specifics of these cases cannot be published at present because of ongoing investigations and pending prosecutions.

Point of sale is the final stage at which the scientific verification of products can be employed, and the appropriate technologies are the same as for the point of import. Verification at the point of sale allows traders and consumers to ensure that they are making legal and informed purchasing decisions, as well as provides an opportunity for the collection of broad and accurate information on the true extent of illegal or noncompliant timber sales.

Requirements for implementation

The implementation of a global system of scientific timber supply-chain verification requires an integrated approach from policymakers, certification bodies, law-enforcement agencies, and industry. A concerted effort from the scientific community is also required to advance the development and forensic validation of identification technologies, to expand the scope of existing capabilities (more species, more geographic areas), and to continue to innovate in order to drive down costs. Certification systems have so far provided the only means through which consumers can make informed choices about wood product origins. However, the success to date of such schemes seems to present an unfortunate irony: The greater the consumer demand for certified products and the higher the prices consumers are often willing to pay (Aguilar and Vlosky 2007), the greater the incentive for unscrupulous actors in the supply chain to defraud the system and reap the financial benefits of appearing to sell genuine certified products. Independent scientific verification embedded within existing certification schemes would provide the tools for certification bodies to police their supply chains, identify and exclude fraudulent products, and protect the integrity of their brand. Certification in other primary industries, such as fishing, has already begun to make such changes (MSC 2015), but beyond the pilot project of DNA verification of CertiSource products (box 2), timber certification schemes have so far steered clear of embedding scientific verification into their operating procedures.

Promotion of the value of independent scientific verification is required to generate consumer demand and create a market advantage for verified products. However, the risk of affecting consumer confidence by undertaking such an awareness campaign presents a conundrum: Will certification schemes be brave enough to take the next step towards integrating scientific verification? The potential rewards are significant. New standards of supply-chain transparency and integrity can be set, and a first mover's advantage see consumers preferentially supporting the certification scheme(s) that employ independent scientific verification. The detection and prosecution of illegal timber trading would subsequently increase, and the degradation of the world's natural resources through illegal logging would

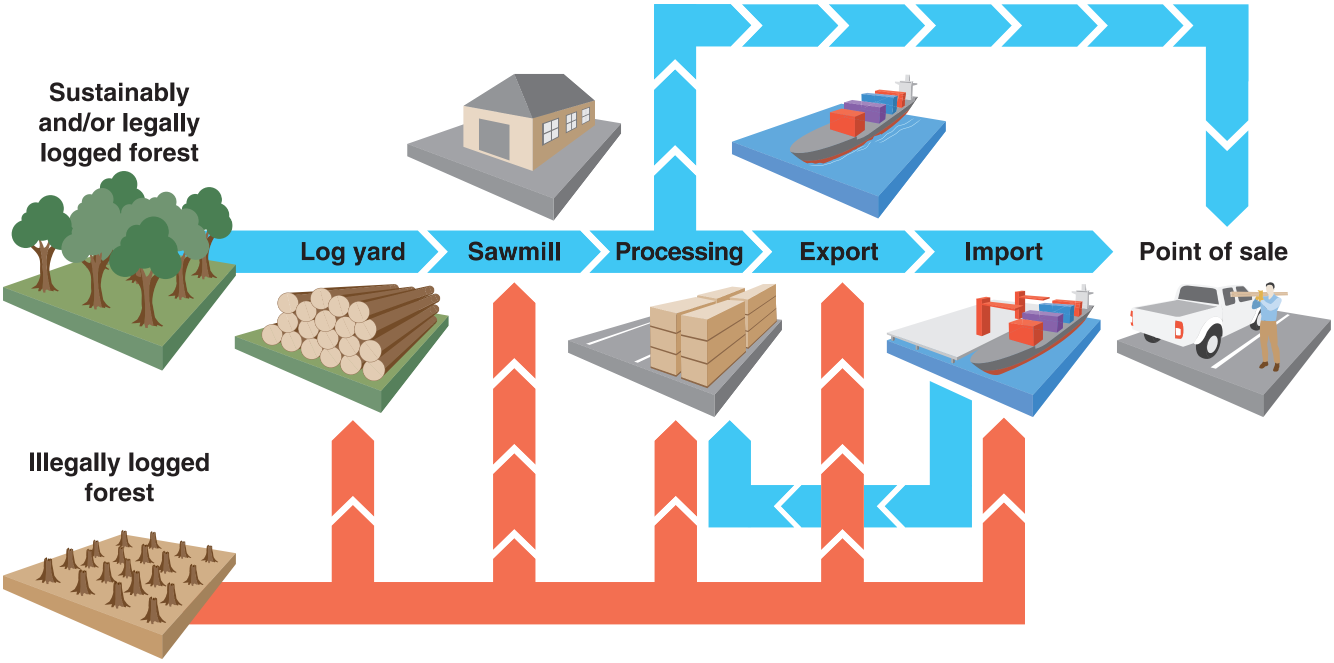

Figure 1. A schematic representation of the timber supply chain. Sustainably and/or legally harvested timber originates from appropriately managed logging concessions and is moved along the supply chain to log yards, saw mills, and processing plants. Products are then moved from processing to the point of sale or are exported for processing and reimported (often through multiple countries) before reaching the final point of sale. At each stage, illegally sourced timber products can enter the supply chain. A range of scientific technologies (visual, chemical, and genetic) exist that can be used to verify the legality of timber products at each stage of the supply chain.

slow. We call on certification schemes worldwide to make such a change.

Governmental policy is crucial in any effort to implement meaningful change in global trade. The enactment of legislation designed to curb illegal logging and associated product demand goes a long way toward addressing this need (table 1), but how legislation is translated into meaningful policy requires careful consideration. It is through policy that governments can commit to supporting these requirements, and we encourage governments to consider how the routine scientific verification of timber can be supported through public policy to strengthen anti-illegal logging legislation and potentially create incentives for the support of certification schemes that fulfill legal compliance requirements while using scientific verification. In this way, overall standards of sustainability may be improved (Auld et al. 2010). The scientific basis of many of the existing methods of timber identification has resulted from basic and applied forestry research, the ongoing support of which should also be prioritized by governments.

The routine use of timber-identification technologies by law-enforcement personnel policing trade routes would dramatically increase the rates of detection and prosecution of illegal logging crimes. However, implementation presents significant challenges: Distinguishing between legal and illegal timber is extremely difficult and requires access to experts and/or specialized tools. Law-enforcement agencies need to develop relationships with appropriate experts, raise awareness of the importance and availability of such resources, and train staff to select and acquire samples for testing. Given that timber is only a small part of their remit, the resources to provide such support are likely beyond the reach of many law-enforcement agencies. Coordinated international efforts to address these needs present a potential solution. The International Consortium on Combating Wildlife Crime, a collaborative effort involving five intergovernmental organizations—the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), INTERPOL, the United Nations Office on Drugs and Crime (UNODC), the World Bank, and the World Customs Organization (WCO)—has convened an expert group, hosted by UNODC, bringing together customs and law-enforcement personnel, scientists, and legal professionals working on timber crime–related issues (UNODC 2015). The resulting guide, to be published this year, will detail how to acquire robust timber-identification outcomes.

Any implementation of routine timber-identification methods urgently requires increased investment and needs to direct effort towards the development and validation of scientific tests. Currently, the scientific basis of identification

Box 3. A case study of the use of stable isotopes to identify the geographic origins of timber.

In 2011, The World Wide Fund for Nature Germany published a report including details of the development of a stable isotope test to identify the geographic origins of teak (*Tectona grandis*). In the study, researchers analyzed 420 reference samples from across Indonesia, Myanmar, Laos, Vietnam, Papua New Guinea, India, Ghana, Brazil, Costa Rica, Panama, and Honduras using the stable isotope ratios of hydrogen, carbon, nitrogen, sulphur, and strontium (Förstel et al. 2011). The assignment accuracy (assessed by a "leave-one-out" approach) ranged from 33% to 100%, with most country assignments exceeding 80% success. A subsequent blind test was able to correctly verify or refute claimed geographic origin in 11 out of 12 unknown teak samples (92%).

methods has been established, but the capacity for affordable routine testing in a wide range of taxa is generally lacking (Dormontt et al. 2015). A major impediment to the development of such tests is the paucity of taxonomically robust reference material from which identification methods and data can be derived. The current trend for reduced investment in collection-based science (Funk 2014) further impedes efforts to increase the pool of available timber-identification tests.

Outlook

Illegal logging is a complex global issue associated with a range of economic, social, and environmental drivers. The international scale of the problem demands an international response. Cooperation between timber producing, processing, and consuming nations is required and coordinated investment (both public and private) in scientific infrastructure. The technologies exist to encourage and enforce legal compliance, as well as improve sustainability, transparency, and consumer choice in the timber trade. Much work is still required, however, to expand the applicability of the available scientific verification methods and provide the policy, certification, and enforcement frameworks needed for effective routine implementation.

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Discussion

Forensic timber identification: It's time to integrate disciplines to combat illegal logging

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ABSTRACT

The prosecution of illegal logging crimes is hampered by a lack of available forensic timber identification tools, both for screening of suspect material and definitive identification of illegally sourced wood. Reputable timber traders are also struggling to police their own supply chains and comply with the growing requirement for due diligence with respect to timber origins and legality. A range of scientific methods have been developed independently with the potential to provide the required identification information, but little attention has been given to how these tools can be applied synergistically to support the legal timber trade. Here we review the use of visual identification methods (wood anatomy, dendrochronology), chemical methods (mass spectrometry, near infrared spectroscopy, stable isotopes, radio-carbon), and genetic methods (DNA barcoding, population genetics/phylogeography, DNA fingerprinting) each with potential application to forensic timber identification. We further highlight where future research and development are required to identify illegal logging crimes using these methods and suggest ways in which multiple methods can be used together to answer specific identification questions. We argue that a new integrated field of forensic timber identification should be a global investment priority, for which the ongoing collection, curation and taxonomic study of appropriate reference material is a critical part. Consideration of the specific legal requirements for method development and the application of identification methodologies to criminal evidence are also imperative to achieve robust scientific support for illegal logging crime prosecutions and prevention.

1. Introduction

Deforestation represents a massive threat to global biodiversity with illegal logging and the associated trade in illegally sourced wood products a significant contributor to the continuation of unsustainable deforestation rates. International efforts to combat the problem consist primarily of the enactment of laws designed to discourage the trade in illegally sourced timber, and prohibit or limit

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the trade of specific species or those from specific areas. Trade restrictions are imposed primarily through the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) which lists species in one of three appendices depending on the degree of protection required. Appendix I is the most restrictive and prohibits trade in taxa threatened with extinction, trade is only permitted in exceptional circumstances; Appendix II lists species which are not currently at threat of extinction, but require controlled trade to avoid over-utilisation and future extinction threats; Appendix III lists species that are controlled in at least one country which requests assistance in trade control from other signatory countries. In addition to CITES, consumer countries increasingly prohibit the importation of any timber not obtained in accordance with the laws of the country of origin, e.g. Canadian Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act (1992); US Lacey Act (amended 2008); EU Timber Regulation (2010); and Australian Illegal Logging Prohibition Act (2012).

Abraham Lincoln once said "Law without enforcement is just good advice" and currently this is the status quo in most parts of the world with regards to illegal logging legislation. With the best of intentions, law makers have set enforcement officers an impossible task; to seize illegal wood products and prosecute illegal logging crimes, without in most cases the means to identify timber to a level of certainty acceptable for admission to a court of law. The push for more sustainable forestry practises also comes from within the industry, with reputable traders eager to comply with new laws, but similarly facing the daunting task of policing their own supply chains without the scientific tools to independently verify the origin of their wood products. One of the key problems is that timber products do not generally possess the diagnostic features required for plant identification (i.e. the leaves, flowers and fruits of the tree) and hence reliable identification is extremely challenging. Identification questions most often begin with the taxonomic identity of a product (i.e. from which genera or species does the timber originate?). Questions of geographic region of origin often follow as some species are only trade-restricted from certain areas of their distributional range but not others (e.g. some species listed in CITES Appendix III). In this context, 'region' refers to a specific geographic area, which may or may not be synonymous with a country or recognised subdivision within. The age of a specimen can also be important, as timber harvested prior to legislation is often exempt. Finally individual identification is sometimes sought, to link timber products to the original tree, either as part of supply chain verification systems or to identify theft.

Table 1
Screening methodologies for forensic timber identification.

	Macroscopic wood anatomy	Microscopic wood anatomy	Machine vision	Near infrared spectroscopy	Detector dogs
Identify genus	Yes	Yes	Yes	Yes — depending on suite of taxa used to train the model	No
Identify species	Occasionally	Occasionally	Occasionally	Yes — depending on suite of taxa used to train the model	Yes
Approximate cost per sample for screening	<\$1 USD — cost for knife blades	<\$100 — cost for making slides and professional wood anatomical expertise	<\$1 — identifications are achieved at the cost of the power to operate the machine	<\$1 — identifications are achieved at the cost of the power to operate the machine	<\$10 — cost of maintaining a dog
Speed of initial ID	Minutes to hours (depending on experience)	Days (if sending to external wood anatomy lab)	Minutes	Minutes	Minutes
Equipment requirements for application as screening tool	Knife, hand lens	Microscopy preparation and observation tools	Machine vision camera and database link	NIRS machinery and database link	Dog and handler
Training requirements for use as screening tool	Extensive and ongoing in order to be reliable. Front line staff can obtain proficiency	Extensive and ongoing, only professional wood anatomists can perform reliably	Minimal, only initial training on operation, maintenance and updating required	Minimal, only initial training on operation, maintenance and updating required	Dog requires extensive training (many months)
Reference material requirements	Electronic databases, ID guides	Access to microscopic wood anatomy examples through microscope slides and electronic databases	Central database loading of microscopic wood anatomy examples from wood specimens	Regional specific database loading of reference spectra obtained from wood specimens	Examples of wood specimens from the desired suite of taxa plus lookalikes
Development potential as screening tool	Fair — easiest method to provide materials for, but has the greatest risk of failure to provide correct identification when employed by non-expert	Poor — most reliable method to provide initial identification but number of trained anatomists very low, and training can take decades	Excellent — if fully functional could provide fast and accurate IDs for law enforcement	Good — if fully functional could provide fast and accurate IDs for law enforcement; must be pre-loaded with region specific species data.	Good — number of species limited by dog capacity; could be added to remit of other contraband detector dogs
Current use as screening tool	Only method in general use	Currently used by some major customs organisations.	Not currently used beyond pilot studies	Not currently used beyond pilot studies	Currently used in pilot studies and by some major customs organisations
Obstacles to implementation as screening tool	Delivery of accessible training materials and high staff turnover on the front line	Low numbers of trained wood anatomists and difficulties with accessing their services	Production and roll out of equipment and incorporation of reference material into database	Cost of equipment and incorporation of reference material into regional specific databases	Access to reference material and training programmes
Research needs for application as screening tool	Analysis of effectiveness of current training provisions, new models for training delivery	Discrimination between closely related taxa, new models of access to expertise e.g. remote provision identification using high quality microscopic photography	Analysis of effectiveness in identification of larger suite of taxa, usability in front-line context	Analysis of effectiveness in identification of larger suite of taxa, usability in front-line context	Assessment of potential to discriminate regional differences within taxa, development of training guide

Table 2
Diagnostic methodologies for forensic timber identification.

	Wood anatomy	Machine vision	Dendro-chronology	Mass spectrometry	Near infrared spectroscopy	Stable isotopes	Radio-carbon	DNA barcoding	Population genetics/phylogeography	DNA fingerprinting
Identify genus	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No
Identify species	Occasionally	Occasionally	No	Yes	Yes	No	No	Yes	Occasionally	No
Identify provenance	Occasionally	Unknown	Occasionally	Yes	Yes	Yes	No	Occasionally	Yes	No
Identify individuals	No	No	Yes	No	No	No	No	No	No	Yes
Determine age	No	No	Yes — where growth rings are present	No	No	No	Yes	No	No	No
Approximate cost per sample including expertise	<$100	<$1	<$100	<$1–$100 — depending on the mass spectrometry method used	<$100	$100–400	$300–400	$100–$300	$100–$300	$100–$300
Speed of process	Minutes–days	Seconds–minutes	Hours–days	Minutes–days depending on the mass spectrometry method used	Seconds–minutes	Several days	Several days	Several days	Several days	Several days
Prior information requirements	None — but suspected region of origin can be helpful	None — but suspected region of origin can be helpful	species	Suspected genus	Broad region of origin	Species	None	None — but suspected taxa can be helpful	Genus for species ID, species for regional ID	Species
Equipment requirements	Microscopy preparation and observation tools	Machine vision camera and database link	Macroscopy equipment	Mass spectrometer and equipment for isolating extractives (if required)	Near infrared spectroscopy machinery and database link	Light gas isotope ratio mass spectrometer and elemental analyser	Liquid scintillation counting and accelerator mass spectrometry equipment	Molecular biology laboratory	Molecular biology laboratory	Molecular biology laboratory
Reference material requirements	Access to microscopic wood anatomy examples through microscope slides and electronic databases	Central database of scientific reference images processed for automated classification	Tree ring series data derived from reference tree cross-sections from specific areas	Heartwood samples from multiple individuals of the desired taxa and potential lookalikes	Regional specific database loading of reference spectra obtained from wood specimens	Wood samples from the desired species with various tree rings	None	Leaf, cambium or wood samples from the desired taxa and potential lookalikes	Leaf, cambium or wood samples from multiple individuals from across the range of the species	Leaf, cambium or wood samples from multiple individuals from across the range of the species
Current use	The most commonly and extensively used method for genus ID	Used predominantly in a research context and in pilot implementation projects	Used occasionally to match wood coming from same tree or to determine antique verses modern origin of timber	Used extensively for identification of some taxa (e.g. *Dalbergia*)	Used extensively for assessment of wood properties Currently used in pilot studies for identification	Used extensively for origin check in agricultural products and used in proof of concept studies and pilot tests for timber	Used extensively for age determination in a wide range of materials, limited application to timber at present	Used extensively for species identification in a wide range of taxa, limited application to wood at present	Used predominantly in a research context and in pilot implementation projects	Used extensively for individual identification in humans and other taxa, limited application to wood at present
Obstacles to implementation	Training of sufficient numbers of wood anatomists, maintenance of reference collections	Incorporation of reference material into database, classification models robust for global context vs. regional models	Collection of tree ring series data for important taxa in areas of interest	Development of reference databases for additional taxa of interest	Development of reference databases for additional taxa of interest	Development of reference databases for additional taxa/areas of interest	No significant obstacles to implementation	Development of discriminating barcodes that work on DNA extracted from wood	Development of genetic markers and reference databases that discriminate areas and taxa of interest	Development of genetic markers and reference databases that discriminate individuals in taxa of interest
Research needs	Discrimination between closely related taxa, forensic validation of methods	Development of global scientific image reference collection, uncertainty quantification and probabilistic model development	Accuracy of dating, provenancing and individual ID, forensic validation of methods	Forensic validation of methods for additional taxa	Development of reference databases, forensic validation of methods	Development of reference databases, forensic validation of methods	No specific research needs with regards to timber	Development and forensic validation of DNA barcoding methods	Development and forensic validation of discriminating genetic markers and reference databases	Development and forensic validation of discriminating genetic markers and reference databases

Several separate scientific disciplines have turned their attention to the problem of timber identification (Tables 1 and 2); the most established of these is the study of wood anatomy — which provides taxonomic characterisation based on the internal structure of timbers. Other identification methods include various forms of visual, chemical and genetic analysis. However, these methods vary quite considerably in terms of the granularity of identification that is afforded, which is also dependent on taxonomic group. In addition, the prior information required and the cost of analysis also varies widely (Tables 1 and 2). Due to the disparate nature of the various disciplines, and the relative infancy of many of the specific identification techniques, there has been very little synthetic work to date which seeks to assess the current state of the art (but see Wiedenhoeft and Baas, 2011).

Methods for tracking timber based on non-inherent features of wood are currently the most commonly used and can provide complementary information to assist with illegal timber investigations. These methods include simple measures such as the use of painted identification marks and paper based certificates but also range to more sophisticated measures that present significant problems for those seeking to commit fraud, such as the use of physical barcoding tagging systems and radio frequency identification (RFID) tags (Seidel et al., 2012). However, for forensic diagnostic timber identification, only those methods which rely only on inherent wood characteristics (such as anatomy, chemistry and genetics) can provide reliable identification outcomes to support the law; it is these specific methodologies that are the subject of the current paper.

Here we review the various scientific methodologies that have potential for use as forensic timber identification tools and consider how multiple approaches could be integrated to answer a range of identification questions. Our treatment of each approach is necessarily brief, but intended to provide an overview and direct the reader to more in-depth material where desired. We also explore some of the issues pertinent to all identification methods, such as the availability and taxonomic integrity of reference material, and the steps required to take academic research into the forensic arena.

Timber identification was historically a branch of wood technology, but is now generally considered to be part of the broad fields of wildlife forensics and forensic botany. However, wildlife forensics focuses almost exclusively on animals, and forensic botany on the use of plant identification to solve crimes, usually where traces of plant material are found at the scene of a crime and can be used to link back to the perpetrators. Forensic botany rarely focusses on illegal logging, in which the trees themselves are the victims of criminal activity. This gap between policy requirement and scientific application has been highlighted by a recently convened expert working group on the subject, brought together by the United Nations Office of Drugs and Crime (UNODC). Given the scale of illegal logging and urgent need for practical timber identification solutions, we contend that the interdisciplinary field of forensic timber identification should be established as a specific research and investment priority.

2. Science for timber identification

2.1. Visual methods

2.1.1. Wood anatomy

Timber identification has traditionally been provided by wood anatomists through the examination of the internal structure of wood (see Carlquist, 2001 and references therein for information on the history of wood anatomy as a discipline). As anatomical characters can be influenced by both genetic and environmental factors, combinations of characters can be used to differentiate taxa. Standard anatomical characters are described according to the terminology of the International Association of Wood Anatomists (Richter et al., 2004; Ruffinatto et al., 2015; Wheeler et al., 1989) and identification obtained through comparison to reference materials. Analysis can be undertaken at both the macroscopic and microscopic scale, but microscopic examination is usually required to achieve a diagnostic identification. Wood anatomical analysis can generally only achieve identification to the genus level (Gasson, 2011). Automated wood anatomical analysis ('machine vision') through the use of sophisticated image capture and processing algorithms is a new area of research showing much promise for timber identification (Hermanson and Wiedenhoeft, 2011), and could potentially facilitate identification to the species level in some cases, thanks to the system's sensitivity to variations that are not easily observable or interpretable to the human eye. However, in order for the system to achieve such discriminatory power, reference material requires integration into the image database such that the natural variations in wood structure of specific taxa are captured. A concerted global effort to incorporate images of the world's xylaria would dramatically improve the system's utility.

Wood anatomical analysis is the most frequently used method for taxonomic identification, both on the front-line for screening purposes, and in the laboratory for diagnostic identification. Screening is most commonly undertaken by front-line officers themselves, with the assistance of various identification aides which describe the macroscopic structure of specific timbers that can be observed with basic magnification (i.e. a hand lens). These materials typically take the form of posters (e.g. Groves, 2003; White et al., 2003a,b), manuals (e.g. Miller and Wiedenhoeft, 2002; Wiedenhoeft, 2011) and interactive databases (e.g. Coradin et al., 2010; Koch et al., 2011; Richter et al., 2002). Machine vision of anatomical features also potentially offers excellent prospects as an automated tool that could be used for screening purposes, but currently requires additional investment, research and development before being a realistic option for front-line law enforcement (Table 1).

2.1.2. Dendrochronology

The science of dendrochronology is another visual method with the potential for use in forensic timber identification. Dendrochronology focuses on the study of periodic growth rings laid down by (predominantly temperate) tree species. Individual rings contain information on the environment at the time of growth and the sequence of rings can provide a valuable record of the conditions at the time. Dendrochronology is typically applied to elucidate past climates but also has the potential provide an age and provenance of trees (Speer, 2010). The ability to correctly assign provenance using dendrochronology is probably limited, although it has been successfully used to identify the origins of archaeologically important timbers (Haneca et al., 2005). The approximate felling date of a tree can potentially be determined if timber products possess the outer most growth rings and bark (e.g. Wolodarsky-Franke and Lara, 2005; Yaman and Akkemik, 2009), but error margins can be substantial and therefore problematic (Jones and Daniels, 2012). Individual identification is also a possibility, as growth rings can be 'matched' where they line up between pieces of wood from the same individual, although how consistent these patterns are across the entire trunk length of a tree is as yet unclear. Visual dendrochronological analyses are occasionally applied to forensic timber identification and we suggest further research into their potential utility be undertaken. However, given that the majority of illegally logged timber originates from tropical areas, where distinct growth rings are rare, dendrochronology is likely to have limited application globally. Chemical dendrochronological analyses can also provide valuable information, and are considered in Section 2.2.4.

2.2. Chemical methods

Analyses of wood chemistry can in many cases provide information on timber identification that cannot otherwise be determined by visual means. Trees and other plants synthesise compounds termed phytochemicals that are often specific to their species or higher taxonomic groups (e.g. Julkunen-Tiitto, 1989; Venkatar, 1972). Recent work has shown that intra-specific variation can also be detected in some species by some chemical analyses (Espinoza et al., 2014). Specific isotopes incorporated into phytochemicals can also give information on plant provenance and age (e.g. Krüger et al., 2014; Rummel et al., 2010).

2.2.1. Mass spectrometry

Assessment of phytochemicals laid down in heartwood can be undertaken using mass spectrometry and statistical analyses of the resulting chemical profiles. Depending on natural variation present in the various taxa assessed, and the relative degree of chemical change over time with wood processing and use, identification to a range of taxonomic levels may be possible and have been illustrated in several recent publications focusing on timber analysis. For example, Cabral et al. (2012) used venturi easy ambient sonic spray ionization mass spectrometry (V-EASI-MS) to distinguish *Swietenia macrophylla* from six other visually similar but taxonomically distant timber species. Within the genus *Dalbergia*, Kite et al. (2010) used liquid chromatography mass spectrometry (LC–MS) to distinguish the CITES listed *Dalbergia nigra* from 15 other congeners, and similarly Lancaster and Espinoza (2012a) and Espinoza et al. (2015) used direct analysis in real time and time-of-flight mass spectrometry (DART–TOFMS) to distinguish between 12 *Dalbergia* species and eight lookalike species. Most recently, McClure et al. (2015) were able to successfully distinguish Madagascan *Dalbergia* from African and Asian *Dalbergia*. Other work using the DART–TOFMS system has successfully distinguished between two oak species (Cody et al., 2012), and between *Aquilaria* species and 25 other fragrant woods (Lancaster and Espinoza, 2012b).

Phytochemical analysis using mass spectrometry methods presents an excellent option for future routine forensic timber identification. Results can be obtained quickly and, excluding initial equipment costs, cheaply. Presently there are only a handful of taxa for which the necessary method development has been undertaken, and we suggest that increasing this number should be an urgent priority.

2.2.2. Near infrared spectroscopy

Phytochemical properties can also be assessed using near infrared spectroscopy (NIRS) which characterises wood absorption spectra when exposed to near infrared electromagnetic energy. NIRS is used extensively for wood property elucidation, but much less frequently for taxonomic identification (see Tsuchikawa, 2007; Tsuchikawa and Schwanninger, 2013 for reviews). For timber identification, NIRS has been capable of discriminating between species of different genera (Braga et al., 2011; Pastore et al., 2011; Russ et al., 2009), congenerics of the genus *Quercus* (Adedipe et al., 2008), and between different geographic provenances of *Picea abies* (Sandak et al., 2011). The relative simplicity of the required machinery and speed of use makes NIRS technology another excellent option for screening tools, but further research and development are required, particularly to build up chemical profile databases and the statistical methods that can be applied to classify taxonomic differences.

2.2.3. Detector dogs

Another option for phytochemical screening is via the use of detector dogs trained in the specific identification of particular timber species. Dogs are able to positively identify the scents of various illicit materials and are commonly used to screen shipments for drugs, explosives and other contraband. In 2010, a pilot project was initiated to assess the feasibility of training detector dogs to identify specific timbers. The team were able to successfully train two dogs to detect bigleaf mahogany and Brazilian rosewood and distinguish them from other similar timbers. The dogs achieved a 90% success rate after five months training (Braun, 2013).

2.2.4. Stable isotopes

Analysis of stable isotopes within timber can inform on geographic provenance identification. As phytochemicals are synthesised, they incorporate specific stable isotopes relative to their availability in the surrounding environment, and this in turn is influenced by various factors related to climate and geology. By utilising one or more informative stable isotopes, commonly including the bioelements (carbon, hydrogen, oxygen, nitrogen) (Fry, 2007) and other elements such as sulphur (Thode, 1991) and strontium (Capo et al., 1998; Rummel et al., 2010; Voerkelius et al., 2010), an isotopic signature of a given area can be determined.

The application of stable isotope analyses to forensic timber identification has been reported in a number of high profile 'grey literature' publications. In 2010, documentation resulting from an international conference on genetic and isotopic fingerprinting methods was published (Gesellschaft für Internationale Zusammenarbeit), looking at stable isotope analyses in *Tectona grandis*, three species of *Swietenia*, *Entandrophragma cylindricum* and *Milicia excelsa*. In 2011 WWF published a project report giving further details of the ability of stable isotopes to distinguish geographic regions of *T. grandis* and *Swietenia* (Förstel et al., 2011). In 2013, the Environmental Investigation Agency reported on their investigation into illegal logging of oak, ash, linden and elm hardwood from the Russian Far East, where stable isotope analysis was used to determine the origin of wood being prepared for export to US and EU markets. In the peer reviewed scientific literature, Horacek et al. (2009) described the use of stable isotopes to successfully distinguish Siberian from European larch, and Kagawa and Leavitt (2010) achieved extremely fine spatial resolution when provenancing pinyon pines in the south-western United States using carbon isotopes from multiple tree rings in conjunction with dendrochronological data (see Section 2.1.2). Stable isotope analysis is generally gaining momentum as an established forensic tool, particularly in the food and drinks sector (Meier-Augenstein, 2011), and timber identification can benefit from its broader utility to provenance questions.

2.2.5. Radiocarbon

As well as occurring in various stable isotopic forms, carbon also exists as radioactive ^{14}C, otherwise known as radiocarbon, with a half-life of 5730 ± 40 years (Godwin, 1962). ^{14}C decays naturally to ^{14}N, a stable isotope of nitrogen. Formation of ^{14}C occurs predominantly in the upper atmosphere through natural processes and after oxidation to CO_2, ^{14}C is mixed throughout the earth's various carbon pools. Carbon sequestered by plants is fixed from atmospheric CO_2 via photosynthesis, and at that point ceases to be exchanged with the environment and decays predictably to ^{14}N. By measuring the ratio of ^{14}C to ^{12}C, correcting for mass dependent fractionation and comparing to known standards, the radiocarbon age of organic material can be calculated (Ramsey, 2008). Radiocarbon ages have been converted into calendar ages based on data sets derived from independently dated tree ring and marine samples (McCormac et al., 2004; Reimer et al., 2004). In the early 1960s the levels of ^{14}C in the atmosphere were substantially increased due to nuclear bomb testing creating the 'bomb curve' in ^{14}C calibrations (Hua, 2009; Hua et al., 2013), and allowing radiocarbon dating of modern samples to within a few years (Currie, 2004). Radiocarbon dating can be used as a forensic timber identification method to determine the age of timber samples when applicability of legislation may be in doubt and is being used increasingly for forensic purposes (Uno et al., 2013; Zoppi et al., 2004). For example, CITES legislation is primarily concerned with timber that enters trade after the listing of particular species. Radiocarbon analysis can determine whether a tree was felled prior to or after the implementation of legislation, although this can be challenging when the outer growth rings of a tree are absent in the timber sample and the date of timber harvest is close to the date of legislation implementation.

2.3. Genetic methods

Analysis of the genetic code of tree species allows assignment of individuals to different groups based on shared ancestry or the relative frequency of different genes. As the genetic code is inherited, individuals with more recent shared ancestry are more similar genetically, compared with more distantly related individuals. Genetic analysis can provide species level identification (or higher taxonomic groups such as genera and families), most commonly achieved through DNA barcoding approaches. Geographic region of origin identification within species can be determined using population genetics or phylogeographic analyses, and individual level determinations can be made using DNA fingerprinting (Lowe and Cross, 2011).

2.3.1. DNA barcoding

DNA barcoding seeks to identify the species of an individual based on variation at specific gene regions (Hebert et al., 2003). In animals, the mitochondrial cytochrome oxidase (CO1) gene region has been adopted as the global standard. In plants, two chloroplast gene regions maturase K (*mat*K) and ribulose-bisphosphate carboxylase (*rbc*L) are currently used as standard, but can only distinguish ~70% of plants, and usually require analysis of additional local barcode regions for species level identification (CBOL Plant Working Group, 2009). The potential application of DNA barcoding for timber identification has been demonstrated using the Internal transcribed spacer (ITS) gene region in the mahogany family (Muellner et al., 2011). CITES listed *Aquilaria* species have also been distinguished from other closely related species using a combination of ITS1 and the *trn*L-*trn*F intergenic spacer (Jiao et al., 2014). A large study aiming to develop a reference library of the Indian tropical evergreen forests successfully assigned sapwood samples to the correct species using the standard barcoding markers (Nithaniyal et al., 2014).

One of the greatest challenges of DNA barcoding in timber is that DNA extracted from wood is generally of poor quality, and it is often not possible to sequence the large fragments associated with the standard barcoding regions, meaning that shorter informative regions need to be developed to attain successful identification via DNA barcoding. In a recent study, (Jiao et al., in press) demonstrated successful extraction of DNA from wood up to 80 years old, but with a corresponding reduction over time in the length of the DNA barcoding regions that could be successfully amplified. DNA barcoding has been criticised in the past for seeking to circumvent the need for basic taxonomy when used for species discovery, however its use in specimen identification is widely accepted (Will et al., 2005). Successful identification outcomes via DNA barcoding are more limited when applied to taxonomically understudied clades containing closely related species (Meyer and Paulay, 2005), and is likely due to problems associated with accurately determining the levels of sequence variation within and between species. The utility of DNA barcoding for forensic identification purposes is gaining recognition and is expected to continue to rise in popularity as capabilities increase and costs of sequencing come down (Iyengar, 2014; Linacre and Tobe, 2011). The existence of extensive online sequences databases add to the future utility of this method for forensic timber identification, such as the Barcode of Life initiative (Ratnasingham and Hebert, 2007) whose BOLD database at the time of writing contains over 58,000 species with barcode sequences from the conifers and angiosperms (both woody any non-woody).

2.3.2. Population genetics and phylogeography

Population genetics and phylogeographic approaches can be used to determine the geographic provenance of individual trees (i.e. differentiation between regions or populations within a species), based on the existence of spatial genetic structure within natural populations, which can usually be found at both local and regional scales (Degen et al., 2001; Hardy et al., 2006). Spatial genetic structure describes the natural phenomenon whereby more proximate individuals of a species are more closely related genetically to one another than individuals further away. By screening multiple individuals from across the range of a species with suitable genetic markers, genographic maps can be developed which can be used to assign unknown individuals back to their area of origin (Deguilloux et al., 2003, 2004; Dutech et al., 2003; Lowe et al., 2004; Petit et al., 1997). The same principal can be used to assign individuals to their correct species group or to identify hybrids (Duminil et al., 2006; Neophytou, 2014), something which can be important in law as hybrids are often exempt from legislation.

Degen et al. (2013) successfully assigned unknown samples of *S. macrophylla* to their country of origin using population genetic approaches and similarly positive results were achieved for geographic regional assignment of *Neobalanocarpus heimii* in Peninsular Malaysia (Tnah et al., 2010, 2009). Successful assignment to relatively small concessional level areas (tens of kilometres) has also been demonstrated in *E. cylindricum* (Jolivet and Degen, 2012). DNA analysis for population genetics and phylogeography is similarly affected by low DNA quality and analyses typically experience a significant drop in amplification success when used with DNA extracted from timber (e.g. Degen et al., 2013; Jolivet and Degen, 2012).

2.3.3. DNA fingerprinting

DNA fingerprinting, otherwise known as individualisation, is the main application of genetic methods to human forensic work (Jobling and Gill, 2004), and uses genetic markers that vary between individuals but show low differentiation between populations (Budowle and van Daal, 2008). By comparing an individual DNA fingerprint to a large enough representative reference sample database, it is possible to calculate the likelihood of an identical profile being generated from an unrelated individual. These probabilities are usually extremely small, leading to the general acceptance of DNA fingerprinting as high quality forensic evidence. Microsatellites are typically used in human and animal forensic cases but often produce poor amplification success in DNA from timber. Single nucleotide polymorphisms (SNPs) are a viable alternative for use with degraded material (Boonyarit et al., 2014). DNA fingerprinting can be complicated in plants due to the occurrence of polyploidy (Masterson, 1994), which makes result interpretation more complex.

DNA fingerprinting could, in principal, be used to link seized wood material back to the stumps of illegally felled trees, although this application is yet to be reported in the scientific literature. Of greater potential utility perhaps, this technology can be used to verify intact chain of custody for routine trade, by matching samples taken at different points in the supply chain. This principal has been demonstrated by Lowe et al. (2010) for *Intsia palembanica* in Indonesia and similar services are beginning to be offered by commercial supply chain consultancies, enabling timber traders to verify the integrity of their own supply chains. This capacity is the major strength of DNA fingerprinting, as it is the only forensic timber identification technology with the potential to independently trace timber products as they travel along the often convoluted global supply network that characterises the modern timber industry. If more products were routinely and reliably traced from their point of origin, most of the subsequent timber identification requirements would be circumvented (Gasson, 2011).

3. Synthesis

3.1. Integrating methodologies

No one scientific methodology is capable of addressing all diagnostic forensic timber identification questions (Table 2). The only option for a functioning forensic timber identification system is to combine methodologies where required, to achieve the desired identification outcome. How to develop such a system, given the disparate nature of the methods and their availability, presents a significant challenge requiring high level international collaboration and coordination, as well as substantial financial support. The majority of timber producing countries, where law enforcement (and therefore timber identification) needs are greatest, are developing nations without the resources to tackle these issues independently.

Most diagnostic methods aside from wood anatomical analysis require identification to at least the genus level before suitable parameters for the various tests can be selected, and even in cases where this is not strictly required scientifically (e.g. radiocarbon dating, Section 2.2.5, Table 2) the genus and species level identification will still usually be required information to assess whether a specific law has been broken. The great strength and utility of identification via wood anatomy is that completely unknown samples can be quickly identified to the genus level, facilitating further analysis downstream to achieve additional identification information in a way that is faster and cheaper than any other method that can identify genus (Table 2).

In order to develop the specific diagnostic forensic questions, the following five identification options should be considered in turn: Genus; species; geographic region of origin; age; individual. During forensic question determination, law enforcement should consider which options apply to their specific identification requirements. Genus level identification should always be the required starting point and the further options of species, geographic region of origin, age, or individual can be then be selected as required. Once a set of hierarchical forensic questions have been defined, appropriate methodologies capable of answering the various questions can be assessed for availability and suitability of the specific tests required (Table 2). Where multiple methods can address the same question, it may be possible to improve accuracy by utilising both. For example, samples of *M. excelsa* and *E. cylindricum* species from Cameroon were mapped simultaneously using both stable isotope and population genetic approaches. Combined results correctly identified whether ~94% of blind samples came from their declared provenance, a success rate greater than that achieved by either method independently (Gesellschaft für Internationale Zusammenarbeit, 2010). Decisions regarding the combination of multiple methods will need to be made on a case-by-case basis, with due consideration to the costs and timings involved.

3.2. Utility of available methods now and into the future

Tables 1 and 2 summarise the available methods for screening and diagnostic timber identification, and assess their relative requirements in terms of future research, cost of application, and status with respect to current usage. There is currently a substantial gap between the potential and realised application of most of the methodologies. Wood anatomical analysis and radiocarbon dating are the only mature disciplines capable of being applied in all cases. Unfortunately, the granularity afforded by wood anatomical analysis is not sufficient for a lot of identification requirements and its application is limited by the number of skilled anatomists available to provide testing services. Radiocarbon dating can be reliably applied to any material, however without the means to identify the species of a sample, radiocarbon information may prove useless in most cases as it is not clear what law may have been breached. The other chemical and genetic methods described in this paper show great promise for future application to a wide range of identification questions, providing much greater resolution than that afforded by wood anatomy. Currently however, the range of taxa that can be identified with these methods is very limited and so their global application is presently minimal.

3.3. Reference collections

All forensic timber identification methodologies require reference material in the form of heartwood for their development, with the exception of genetic analyses which can utilise other plant material such as leaves and cambium to acquire DNA profiles. Heartwood can be obtained directly from a felled tree or from a living tree through coring. Heartwood reference materials are curated in xylaria and to enable correct taxonomic identification, should be collected along with a voucher specimen from the same tree.

Kew Gardens keep a record of xylaria worldwide, the Index Xylariorum, which presently show 83 operational wood collections, and a further 80 which have now been either closed, or absorbed into other collections (Lynch and Gasson, 2010). Although combining collections is not necessarily a bad thing, it usually comes as the expense of professional expertise, where fewer wood anatomists curate larger collections. Given the time required to reach the level of proficiency required for forensic timber identification purposes, time is most definitely of the essence. The greatest barrier to the establishment of a system relying on wood anatomy as an essential first step is the paucity of appropriate wood anatomical expertise worldwide — a deficit which can only be addressed by appropriate recognition, investment and long-term support of wood reference collections and the training of new wood anatomists.

Reduced investment in wood collections and associated staff cut backs are part of a broader trend of reduced support for collection-based science (Funk, 2014), classically termed the 'taxonomic impediment' (de Carvalho et al., 2007, 2005). The knock-on effect of this deficit for forensic timber identification is much more than just a dearth of available wood anatomists. In reality, most methodologies are not ready for forensic use, or where they are, it is only to answer a very narrow suite of specific identification questions. In order to move towards the development of a broader set of forensic timber identification tools, researchers must have access to high quality, taxonomically validated reference collections.

New requirements for forensic timber identification tools arise each time a timber species is listed on the CITES appendices. At present, no consideration is given to the availability of identification tools when new listings are made, and there are no requirements for signatories of the convention to provide reference material or facilitate its acquisition. We contend this presents an unacceptable arrangement, whereby sole responsibility for reference material collection falls to underfunded xylaria. Adding to these difficulties is the paucity of taxonomic clarity in many groups of timber species; without solid taxonomic foundations, it is not possible to develop the required forensic identification tools.

3.4. Transition from research to forensic tool

The final hurdle in the roll-out of any forensic timber identification tool is meeting the strict legal requirements for evidence suitable for presentation in a court of law. These requirements are qualitatively different from those that apply to the acceptance of research into scientific journals, although publication of a method in a peer reviewed periodical is an essential part of the process. The specific challenges are reviewed in detail by Ogden et al. (2009) with respect to DNA forensics, but the general principles apply to all methods. Methods must be subject to extensive validation studies (Peters et al., 2007; SWGDAM, 2012), which assess the ability of tests to achieve the desired outcomes, and characterise the limits within which a test performs as required. Once a test has been forensically validated, it must be applied with due consideration to the requirements for secure chain of custody of evidence (Khan et al., 2010) and in a facility that meets best-practice standards for quality control and quality assurance (Visschedijk et al., 2005). Accreditation of tests and facilities to ISO/IEC 17025 is a means to ensure that these standards are met; however acquiring accreditation is a difficult and expensive process. The development of an externally administered proficiency testing programme is an alternative means of assuring quality which may present a more realistic short term goal for forensic timber identification methodologies at present. For the techniques presented here, only wood anatomy has a significant body of case law as precedent, much of which is in the US court system, dating back to the 1930s.

4. Conclusions

Although a broad range of scientific disciplines boast methodologies suitable for forensic timber identification, they share many of the same underlying requirements, challenges and opportunities for advancement through integrated research and investment efforts. In particular, we highlight the need for improved access to appropriate reference materials to enable effective tests to be developed. Historically, progress towards the development of timber identification tools has proceeded independently in each discipline, often with a sense of competition between proponents of the various methodologies, and a pervading reluctance to accept the validity and future potential of alternative approaches. The tide however, is changing. Several large projects have been undertaken assessing the utility of combining approaches (in parallel or sequentially) to best answer the identification question at hand. In this regard Germany presents a leading example with the Thünen Centre of Competence on the Origin of Timber combining wood anatomy, genetics and forest economics in many collaborative projects, along with stable isotope laboratories and NGOs. The United Nations has also turned its attention to the global requirements for forensic timber identification tools, with the Office on Drugs and Crime (UNODC) convening an expert meeting in December 2014, bringing together the world's experts in the various scientific methods along with law enforcement personnel (UNODC, 2015). A UNODC guidance document on forensic timber identification is expected to be published 2015/2016. We hope this represents an important step in the international community's involvement in furthering the cause of forensic timber identification requirements. There is now a growing acceptance and enthusiasm for the idea that no one method can be a panacea; a future where illegal logging crimes can be routinely prosecuted with robust scientific supporting evidence can only be realised through a synergistic approach to the identification challenges we currently face.

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THE UNIVERSITY of ADELAIDE

Annex 2

Proposal for:

The Southern Hemisphere Centre of Excellence for DNA Identification of Timber

at The University of Adelaide

Professor Andrew Lowe & Dr Eleanor Dormontt

The Advanced DNA, Identification and Forensics Facility, The University of Adelaide, Australia

[redacted]

Executive Summary

Timber is notoriously difficult to identify in trade, which presents serious challenges to enforcement of the *Illegal Logging Prohibition Act (2012)* and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Timber compliance with building regulations is also difficult to determine without accurate species identification. Improved capacity to identify timber in trade would benefit Australia's anti-illegal logging efforts both at home and abroad, and would support improved compliance to building codes.

Here The University of Adelaide proposes the establishment of the semi-commercial Southern Hemisphere Centre of Excellence for DNA Identification of Timber, building on the existing capabilities of the Advanced DNA, Identification and Forensic Facility based in Adelaide.

DNA tests can be used to identify the type, species and point of origin of timber products, and the University of Adelaide's Professor Andrew Lowe and Dr Eleanor Dormontt are global leaders in the development and application of this technology. There is a significant opportunity to access the estimated $26.53M total available market in Australia for timber identification services as well as broader global markets, whilst supporting improved compliance and enforcement of Australian legislation.

Through investment in the Southern Hemisphere Centre of Excellence for DNA Identification of Timber, Australia can cement its position as an innovative front-runner in the fight against illegal and non-compliant timber, with robust scientific verification backing up legislation.

The Braggs Building at the University of Adelaide, home of the Advanced DNA, Identification and Forensic Facility (ADIFF). Credit: University of Adelaide

The problem

Misidentification and species substitution is pandemic in global timber supply chains including Australia. Depending on the region and specific supply chain, between 30-90% of timber is either not the species, or not from the point of origin it is claimed to be[1]. The value of the global illegal timber trade is thought to be between US$30-100 billion per annum[1].

Australia's response to this scourge has been the *Illegal Logging Prohibition Act (2012)* which makes it a criminal offense to trade in illegally harvested timber. The *Act* requires that traders undertake appropriate due diligence efforts to minimise the risk of illegally sourced timber entering Australian supply-chains. Similarly, as Party to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Australia is obligated to restrict trade in certain species according to their status on the CITES appendices. There are currently over 600 timber species listed on CITES.

Rainforest in Sri Lanka. Credit: Samantha Gunasekara

Illegal logging is not just a problem overseas. Australian sandalwood for example is routinely logged illegally from Western Australia, which the Forest Products Commission describes as having caused "significant disruption to the markets and reputation of the Western Australian sandalwood industry" as well as impacting on the sustainability of the resources and the industry.[2] With increasing consumer concern for illegal logging, and other countries now enacting or planning to enact similar legislation to the *Illegal Logging Prohibition Act* (e.g. USA, EU, Canada, Japan, Korea) there is increasing pressure for traders of legitimate Australian timbers to have the means to demonstrate the legality of their products.

Unfortunately, the species and point of origin of timber is very challenging to identify from the wood alone which leads to most due diligence and identification efforts relying on accompanying documentation rather than on the characteristics of the timber itself[3]. Reliance on paper-based systems alone to verify legality are inherently vulnerable to fraud and cannot pick up instances where species have been miss-identified early on in the supply chain and issued with legitimate (yet erroneous) certificates[4]. The outcome of misidentification (or a lack of any attempt at identification) in timber supply chains can go beyond an increase in illegal wood in the market.

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[1] Nellemann C, INTERPOL Environmental Crime Programme, eds. 2012. Green Carbon, Black Trade: Illegal Logging, Tax Fraud, and Laundering in the World's Tropical Forests: A Rapid Response Assessment. United Nations Environment Programme, GRID-Arendal.
[2] www.fpc.wa.gov.au/sandalwood/illegal-harvesting
[3] Dormontt EE, et al. 2015. Forensic timber identification: It's time to integrate disciplines to combat illegal logging. Biological Conservation 191:790–798.
[4] Lowe AJ, et al. 2016. Opportunities for improved transparency in the timber trade through scientific verification. BioScience 66: 990-998.

Since timber is commonly used in construction, significant problems can arise when incorrect species are used as structural properties can be inappropriate and non-compliant.

Durability is an example of where the species of timber is a critical determinant. Australian Standard AS 5604 provides natural durability ratings for a large number of species, Class 1 rated species are the most durable and Class 4 rated species the least durable. These ratings can vary significantly between timbers that are biologically very closely related. A case in point - balau timber has a rating of 1, meaning it has a probable above-ground life expectancy of greater than 40 years. In contrast, light red meranti has a rating of 4, meaning its life expectancy is between zero and seven years. Both of these timbers are dipterocarps and members of the *Shorea* genus, a mix up between these types of timbers could equate to a difference in durability of greater than 30 years.

Dipterocarp in Kalimantan, Indonesian Borneo. Credit: Eleanor Dormontt

The Solution

DNA testing can be used identify timber accurately and could simultaneously support Australia with the following:

- Compliance with, and enforcement of, the *Illegal Logging Prohibition Act (2012)*
- Fulfilment of obligations under the CITES convention to regulate trade in over 600 timber species
- Demonstration of legality and authenticity of Australian timber products for both domestic and international markets
- Improved conformance of timber products for the building trade

The University of Adelaide houses the Advanced DNA, Identification and Forensics Facility, which is a global leader in the development of DNA timber identification methods. The $8 million facility was built by The University of Adelaide in 2014 and has since been equipped through $0.5 million in contributions from the following:

- The Australian Research Council's Linkage Infrastructure, Equipment and Facilities Scheme
- The University of Adelaide's Environment Institute
- Flinders University
- The Australian Museum
- The South Australian Museum
- The Australian Genome Research Facility
- The Department of Environment, Water and Natural Resources
- Australia New Zealand Policing Advisory Agency
- Double Helix Tracking Technology Pte Ltd

A range of research and development activity by the group has been supported through $2 million in research funding from diverse sources awarded to researchers, including:

- The Australian Research Council's Linkage Projects Scheme
- The German Government (in collaboration with The Thünen Institute's Centre of Competence on the Origin of Timber)
- The International Tropical Timber Organisation
- Australian Centre for International Agricultural Research
- The World Resources Institute (in collaboration with The US Forest Service and Double Helix Tracking Technology Pte Ltd)
- The Department of State Development

Laboratory of the Advanced DNA, identification and Forensic Facility (ADIFF) at the University of Adelaide. Credit: University of Adelaide

The Current Opportunity

There now exists a compelling opportunity to develop a semi-commercial venture to provide routine and cost-effective service offerings for government and industry testing of timber. A 2015 Commercialisation Development Report by CtechBA, commissioned by The University of Adelaide, identified a total available market of $26.53M per annum in Australia. There is also a large potential global market, with only one other organisation (The Thünen Institute in Germany) having a similar capability to the Facility in Adelaide. The University of Adelaide has an excellent collaborative relationship with The Thünen Institute, evidenced by a Memorandum of Agreement working in the DNA timber identification field.

The successful venture would position Australia as the Southern Hemisphere Centre of Excellence for DNA Identification of Timber and would further strengthen capacity building efforts to improve legality standards in the region's major timber producing countries through collaborative research, training and development initiatives. Collaborations in the region currently exist with industry, academic and government agencies from China, Japan, Indonesia, Singapore, Myanmar, Thailand, Lao PDR, PNG and Solomon Islands. Further afield, relationships exist with the USA, UK, Germany, Peru, Brazil, Costa Rica, Bolivia, French Guiana, Ghana, Kenya, Ivory Coast and Cameroon.

Global interest in timber legality and scientific methods of verification have increased markedly over the past 3-5 years, with many initiatives utilising the knowledge and skills of Dr Dormontt and Professor Lowe, including:

- Successful prosecution of both international and domestic cases under the revised *Lacey Act (2008)* legislation in the USA (the latter was supported by DNA evidence from The University of Adelaide)

- Production of The United Nations Office on Drugs and Crime Best Practice Guide to Forensic Timber Identification (coordinated by Dr Dormontt with input from an expert group including Professor Lowe)
- Adoption by CITES of decisions to include more timber species than ever in their appendices and to support improved timber species reference collections to facilitate the development of identification tests (the latter drafted and presented to the CITES Plants Committee by Dr Dormontt)
- Investment in the Global Timber Tracking Network from the German Government (Professor Lowe is a founding member and Dr Dormontt now actively participates in their working groups)

Professor Lowe and Dr Dormontt working with law enforcement on an illegal logging investigation. Credit: Ron Malamphy

The proposed venture has the opportunity to leverage the global reputation of Professor Lowe and Dr Dormontt in the area of DNA timber identification and provide a world-leading research and service delivery offering to the Southern Hemisphere.

Initial contact has been established with the following organisations which may serve as customers and collaborators, and The University of Adelaide is currently exploring these opportunities:

- The Australian Government Department of Agriculture and Water Resources
- The Australian Government Department of Immigration and Border Protection
- The Australian Government Department of the Environment and Energy
- The Australian Timber Importers Federation
- The Australian Furniture Association
- The Australian Forest Products Association
- Simmonds Lumber Pty Ltd
- Double Helix Tracking Technologies Pte Ltd

Vision:

The Southern Hemisphere Centre of Excellence for DNA Identification of Timber, based at The University of Adelaide provides a suite of DNA timber testing products tailor made to suit the needs of the Australian Government, industry and international partners. The Centre is a semi-commercial venture that undertakes cutting-edge research and development activities alongside service provision, providing best-practice leadership in the growing sector of scientific timber verification. Through research and service provision, capacity building activities and engagement with stakeholders, the Centre cements Australia's reputation as a world leader in timber identification and the reduction of trade in illegally logged timbers.

The work of the Centre supports improved compliance with, and enforcement of, the *Illegal Logging Prohibition Act*; provides capacity to better fulfil Australia's obligations under CITES and to verify the compliance of timber products for construction; and value-adds to Australian timber products both nationally and internationally.

Mission:

Improved compliance and transparency in timber supply chains through the integration of independent scientific testing to verify species and region of origin to support Australia's interests both nationally and internationally.

Objectives:

To realise the potential societal benefits, commercial opportunities, and to develop a financially self-sustaining program, resources are needed in several key areas:

1. Increased laboratory capability
2. Reference database augmentation
3. Risk analysis of timber supply chains
4. Development of tailored service offerings that meet the needs of industry and government
5. Education, training and marketing programs for government and industry stakeholders

Project activities and outputs:

1. Equip the service lab at the University of Adelaide to provide cost-effective, high-throughput identification of timber products on a fee-for-service, semi-commercial basis. The research equipment at the current Advanced DNA, Identification and Forensic Facility will be upgraded for full scale service provision. Funding will also provide support for technical staff for the facility for 3 years until the fee-for-service framework allows the lab to operate self-sustainably.

2. Build the reference database required to verify species claims for all timber traded in Australia and verify region of origin claims for the most important timber imports. Up to ten samples of each species will be used to develop DNA barcoding markers that can provide species identification from timber and processed wood products. The markers will be tested in real world supply chain scenarios and validated by blind tests. For the most important imported timber species, multiple samples from across their production range will be sampled. DNA markers will be developed and used to screen these collections to develop geographically specific profiles for each of the target species, which can be used to verify origin claims. The markers will be tested in real world supply chain scenarios and validated by blind tests.

3. Undertake a risk analysis of major Australian timber supply chains, using DNA markers to assess the level of compliance and identify those supply chains which are most at risk from substitution and misidentification. Working with government, NGOs and industry, major timber supply chains into Australia will be systematically sampled and tested for species and region of origin compliance providing a unique a comprehensive picture of compliance in Australia and facilitating further targeted activities aimed at reducing non-compliance.

4. Develop service offerings for the application of DNA methods to verify the origin claims made by timber producers and traders. Through engagement with industry and government stakeholders, a suite of tailor-made service offering will be developed that meet the needs of the potential customer base and provide a cost effective and commercially attractive product.

5. Develop a marketing strategy, educational tools and provide training workshops on 'Tree genetic reference databases and applications to timber source verification and market access' for relevant government and industry stakeholders to stimulate business and improve compliance and enforcement efforts in Australia and overseas.

Budget and Timeline (indicative):

Activity	Budget	Timeframe
1. Increased laboratory capability - Equip and staff a scientific service lab at University of Adelaide	Equipment and consumables $900,000 3 staff $1,200,000	Years 1-3
2. Build a DNA identification database for use to verify species and region of origin claims in Australian timber supply chains	$3,250,000	Years 1-3
3. Undertake a risk analysis of major Australian timber supply chains to identify those most at risk from substitution and misidentification	$1,200,000	Years 2 and 3
4. Develop service offerings for the application of DNA methods to verify the origin claims	$400,000	Years 2 and 3
5. Develop a marketing strategy, educational tools and provide training workshops	$400,000	Years 1-2
Total	**$7,350,000**	**3 years**