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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

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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

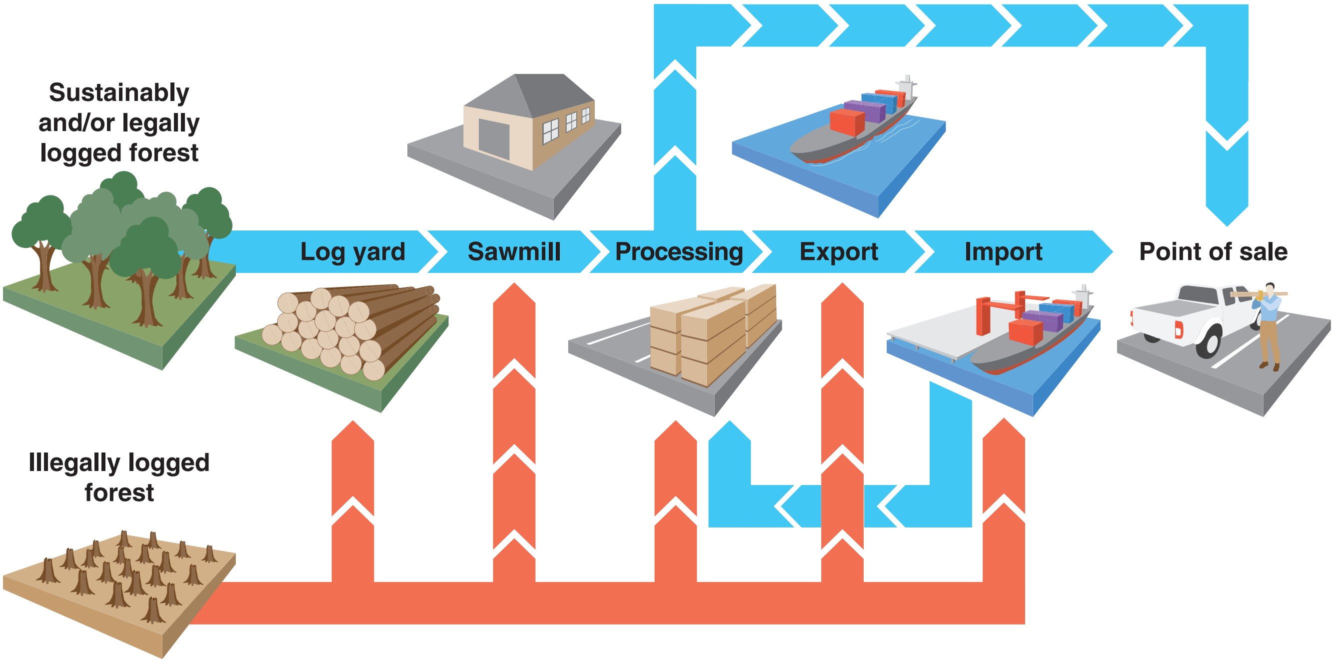

Figure 1. A schematic representation of the timber supply chain. Sustainably and/or legally harvested timber originates from appropriately managed logging concessions and is moved along the supply chain to log yards, saw mills, and processing plants. Products are then moved from processing to the point 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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