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# From Paper Trails to DNA Barcodes: Enhancing Traceability in Forest and Fishery Certification

## ABSTRACT

*Governments and industries are familiar with private sector or third-party driven natural resource and agriculture certification schemes, like the Forest Stewardship Council (FSC) process. These schemes affect products including organics, fair trade coffee, fisheries, olive oil, cheese, milk, herbs and many more. In practice these schemes attempt to control attributes of final retail products through supply chain verification of a specific product, or process qualities that involve consumer product labeling and certification of chain of custody product and process control procedures. All are difficult and costly to administer. It is necessary to monitor and inspect each step of lengthy supply chains. These schemes ensure the quality and purity of final products in the face of omnipresent dangers and incentives for producers to evade quality standards and adulterate products or processes. Many schemes operate more or less on a self-regulatory basis where producers agree to honor third-party certification of supply chain operators who, typically, are infrequently inspected. This system periodically gives rise to various forms of product and process quality scandals. New technologies linked to genomics, proteinomics, metabolomics and transcriptomics that involve cellular level identifiers in specific products show promise in improving both the quality and cost of regulatory oversight of many certification efforts. They enable rapid, low-cost confirmation of the origins and purity of many goods often without the need for intermediate supply-chain monitoring and inspection. This article describes*

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*the state-of-the-art of 'omics*[1] *technologies and discusses the advantages and limitations of these techniques in the areas of natural resource and agricultural certifications.*

## I. INTRODUCTION: TRACEABILITY, THE ACHILLES HEEL OF EXISTING AGRICULTURAL AND NATURAL RESOURCE CERTIFICATION PROCEDURES

Product certification generally involves following that product from the point of production or collection, to the point of consumption. Certificates of quality are typically delivered by a third-party. Two important areas dealing with certification are: (i) the type of minimum standards that the product must meet, and; (ii) the trust that consumers can place in the ability of the certification body to deliver both unbiased, and technically valid results. Certification can be helpful to both the producers and the consumers of a product, and can serve a variety of societal and environmental goals. These include the development of sustainable production methods, the control of the quality of both production processes and final products, and the protection of human and animal health. A complete tracing process ensures that every important step between harvesting a resource and that resource's consumption is tracked. For example, tracking seafood begins with recording fish catches at the moment of capture, and continues when the product is landed and sold to a distributor. When the fish arrives at the processing centre, another step is recorded and is followed by data regarding the now-processed product (fish fillets for example) being sold to a retailer, its transportation and arrival.

Product and process certification has become an important addition to natural resource and agricultural regulation. Consumers and citizens have demanded product process attributes—like sustainability, and ethical treatment of workers and animals—in addition to earlier concerns for product quality and purity.[2] Consumers increasingly expect access to mounting product and process information to make their purchasing de-

1. "Omics" is the shorthand that is used in the field to describe the broad (albeit interconnected) field of proteomincs, genomics, metabolomics, etc.

2. Benjamin Cashore et al., *The Future of Non-State Authority on Canadian Staples Industries: Assessing the Emergence of Forest Certification*, 26 POL'Y AND SOC'Y 71, 73 (2007); Mark Woolfe & Sandy Primrose, *Food Forensics: Using DNA Technology to Combat Misdescription and Fraud*, 22 TRENDS IN BIOTECH. 222, 226 (2004); J D McKean, *The Importance of Traceability for Public Health and Consumer Protection*, 20 REV. - OFF. INT. EPIZOOT. 363, 364 (2001); Jennifer L. Jacquet & Daniel Pauly, *Trade Secrets: Renaming and Mislabeling of Seafood*, 32 MARINE POL'Y 309, 310 (2008); Benjamin Cashore, *Legitimacy and the Privatization of Environmental Governance: How Non–State Market–Driven Governance Systems Gain Rule–Making Authority*, 15 GOVERNANCE 503, 506 (2002).

cisions. Many third-party certification processes have developed in areas such as forestry, fisheries, and for many agricultural products to provide this information to consumers and regulators.[3]

Such schemes targeting quality, adulteration, and purity are very common in the food and agricultural sectors.[4] They also exist in a variety of other food areas, including organic food standards and genetically modified food labeling. These schemes extend to non-food areas as well, such as natural resource products. These schemes also extend to concerns such as the preservation of old-growth and tropical timber harvesting, or rare animal or plant species exploitation.[5]

In addition to concerns for preventing environmental degradation and health risks, there are concerns for the transparency of certification processes. Product and process fraud have arisen.[6] Increasing the amount of accurate information on consumer products through certification is by no means an automatic or unproblematic process.[7] Most certification schemes are difficult and costly to administer because of the manner in which—using existing goods-testing technologies—each step in lengthy, ambiguous product supply-chains must be monitored and inspected to ensure final products retain their original characteristics, and are not altered, blended or substituted at different points in the chain.[8] It is extremely complex to administer such systems, and it is difficult to ensure that 'certified' standards are actually met in practice.[9] It is also difficult to establish the credibility of the many certifying entities.[10]

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3. Gabriele Jahn, Matthias Schramm & Achim Spiller, *The Reliability of Certification: Quality Labels as a Consumer Policy Tool*, 28 J. CONSUMER POL'Y. 53, 59 (2005).

4. IOANNIS S. ARVANITOYANNIS, *Wine Authenticity*, *in* FOOD AUTHENTICITY AND TRACEABILITY 426-456 (2003).

5. A. HOLST-JENSEN, *Advanced DNA-Based Detection Techniques for Genetically-Modified Food*, *in* FOOD AUTHENTICITY AND TRACEABILITY 575-594, 577 (2003); BENJAMIN CASHORE, COMPETING FOR LEGITIMACY: GLOBALIZATION, INTERNATIONALIZATION, AND THE POLITICS OF ECO-FORESTRY CERTIFICATION (GREEN LABELING) IN THE US AND CANADIAN FOREST SECTORS (1999); Benjamin Cashore, Graeme Auld & Deanna Newsom, *Forest Certification (Eco-Labeling) Programs and their Policy-Making Authority: Explaining Divergence among North American and European Case Studies*, 5 FOREST POL'Y AND ECON. 225, 226 (2003).

6. Anne Maruchek et al., *Product Safety and Security in the Global Supply Chain: Issues, Challenges and Research Opportunities*, 29 J.OPERATIONS MGMT. 707, 709 (2011).

7. Dan Klooster, *Environmental Certification of Forests: The Evolution of Environmental Governance in a Commodity Network*, 21 J. RURAL STUDIES 403, 415 (2005).

8. Jorge Verissimo Pereira, *The New Supply Chain's Frontier: Information Management*, 29 INT'L J. INFO. MGMT. 372, 372 (2009).

9. Friederike Albersmeier et al., *The Reliability of Third-Party Certification in the Food Chain: From Checklists to Risk-Oriented Auditing*, 20 FOOD CONTROL 927, 928 (2009).

10. Graeme Auld & Lars H. Gulbrandsen, *Transparency in Nonstate Certification: Consequences for Accountability and Legitimacy*, 10 GLOBAL ENVTL. POL. 97 (2010); Magnus Boström, *How State-Dependent is a Non-State-Driven Rule-Making Project? The Case of Forest Certification*

A critical issue for many natural resource and agriculture product and process certification schemes is the capacity of certifying agencies to trace the origins of products, and product components, accurately through the many steps required to get a product to market in a modern industrial production process.[11] Because production and supply chains often cross multiple national and administrative borders on various continents, it is very difficult to trace a product or its components. In many instances, certifiers lack the ability to track product contents and processes back to their origins; the opportunities for error or fraud are many.[12] While systems, such as Hazard Analysis and Critical Control Point (HACCP) regulation, are broadly used to prevent the contamination of food and pharmaceutical products—by biological, chemical, and physical hazards—they can do little to prevent intentional misrepresentation and are not designed to account for environmental product process concerns.[13]

"Traceability" is thus a critical weak link in the entire certification process.[14] Traceability is also an issue in areas like the trade in endan-

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*in Sweden*, 5 J. ENVTL. POL'Y & PLANNING 165 (2003); MICHAEL DILLON & MICHAEL THOMPSON, *Developing and Implementing an Effective Traceability and Product Recall System*, *in* FOOD AUTHENTICITY AND TRACEABILITY 496-506 (2004).

11. Auld & Gulbrandsen, *supra* note 10; Grant H. Shackell, *Traceability in the Meat Industry – The Farm to Plate Continuum*, 43 INT'L J. FOOD SCI. AND TECH. 2134 (2008).

12. Sally Eden, *The Work of Environmental Governance Networks: Traceability, Credibility and Certification by the Forest Stewardship Council*, 40 GEOFORUM 383, 384 (2009); Sally Eden & Christopher Bear, *Third-Sector Global Environmental Governance, Space and Science: Comparing Fishery and Forestry Certification*, 12 J. ENVTL POL'Y & PLANNING 83, 87 (2010); Kari Tove Elvbakken, Per Lægreid & Lise Helleb Rykkja, *Regulation for Safe Food: A Comparison of Five European Countries*, 31 SCANDINAVIAN POL. STUDIES 125 (2008); Jahn, Schramm & Spiller, *supra* note 3, at 69.

13. DAVID DEMORTAIN, STANDARDISING THROUGH CONCEPTS: SCIENTIFIC EXPERTS AND THE INTERNATIONAL DEVELOPMENT OF THE HACCP FOOD SAFETY STANDARD, 7 (2007), *available at* http://eprints.lse.ac.uk/36138/.

14. While a variety of definitions exist for traceability, Alessandro Arienzo, Christian Coff & David Barling, *The European Union and the Regulation of Food Traceability: From Risk Management to Informed Choice?*, *in* ETHICAL TRACEABILITY AND COMMUNICATING FOOD 23-40, 28 (Christian Coff et al. eds., 2008); DAWN TRAUTMAN, TRACEABILITY A LITERATURE REVIEW (2008)., the two most common are those taken from the EC regulation 178/2002 and the 2004 definition of the Codex Alimentarius Commission. The Codex Alimentarius Commission defined traceability as "the ability to follow the movement of a food through specified stage(s) of production, processing and distribution." As McKean *The importance of traceability for public health and consumer protection*, 20 REV. - OFF. INT. EPIZOOT 363-371, 363 (2001). defined it in the meat industry, traceability involves 'the ability to maintain a credible custody of identification for animals or animal products through various steps within the food chain from the farm to the retailer'. Such a traceability system requires identification and record keeping that starts at birth, and continues into the marketplace. This is the same principle that is applied to 'Chain of Custody' in forensic science, which guarantees the

gered species or the prevention of deforestation.[15] Heavily processed products—fish filets, meat cuts, or wood planks—typically appear on store shelves or factory lots where certified and uncertified products are indistinguishable from each other save for a nominal certification label.[16] Given the price premiums often adhering to such a label, this situation could easily lead to fraud or misrepresentation; a situation for which, until recently, both consumers and regulators had little recourse. The recent discovery that purportedly Marine Stewardship Council (MSC) certified Chilean sea bass were, in fact, not that fish, coupled with the finding that 15 percent of the actual Chilean sea bass samples had been fished outside of certified areas, demonstrates the vulnerability of current certification schemes.[17]

Recent advances in genomic science offer a series of tools, which can help provide a safeguard against attempts to circumvent certification safeguards. This article focuses on the potential use of such techniques—notably 'DNA barcoding' and other kinds of 'marker' technologies—in supply chain certification efforts, to expand the latter's existing capacity.[18] While these techniques, like any other, are open to misuse in handling and processing material samples, we draw on case studies of forestry and fishery certification practices to argue this is a much less

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identity and integrity of a specimen by documenting its chronological history from acquisition through analysis to storage for future reference and/or disposal in a way that is legally defensible. The UK Food Agency, for example, has identified functional roles for traceability within food supply chains, to include correction of food safety incidents, to enhance food residue surveillance programmes, to aid risk assessment from food exposure, to enforce labeling claims, to avoid and enforce fraud; to reduce food wastage and to promote enhanced hygiene A. Furness & K. A. Osman, *Developing Traceability Systems Across the Supply Chain*, *in* FOOD AUTHENTICITY AND TRACEABILITY 473-495 (2003).

15. Bhawna Dubey, P.R. Meganathan & Ikramul Haque, *DNA Mini-Barcoding: An Approach for Forensic Identification of Some Endangered Indian Snake Species*, 5 FORENSIC SCI. INT'L: GENETICS 181 (2011); PJ Palsbll, Bérubé M, Skaug HJ, Raymakers C., *DNA Registers of Legally Obtained Wildlife and Derived Products as Means to Identify Illegal Takes*, 20 CONSERV. BIOL. 1284 (2006); Glenn E. Galloway & Dietmar Stoian, *Barriers to Sustainable Forestry in Central America and Promising Initiatives to Overcome Them*, 24 J. SUSTAINABLE FORESTRY 189 (2007).

16. Eden & Bear, *supra* note 12.

17. Elvbakken, Lægreid & Rykkja, *supra* note 12; FRANCO FURGER, *From Genetically Modified Organisms To Synthetic Biology: Legislation in the European Union, in Six Member Countries, and in Switzerland*, *in* WORKING PAPERS FOR SYNTHETIC GENOMICS: RISKS AND BENEFITS FOR SCIENCE AND SOCIETY 165-184 (2007); Peter B. Marko, Holly A. Nance & Kimberly D. Guynn, *Genetic Detection of Mislabeled Fish from a Certified Sustainable Fishery*. 21 CURRENT BIOL. 621, 621 (2011).

18. Boström, *supra* note 10; Lars H. Gulbrandsen, *Explaining Different Approaches to Voluntary Standards: A Study of Forest Certification Choices in Norway and Sweden*, 7 J. ENVTL POL'Y & PLANNING 43, 51 (2005); Mark Rickenbach & Christine Overdevest, *More than Markets: Assessing Forest Stewardship Council (FSC) Certification as a Policy Tool*, 104 J. FORESTRY 143, 146 (2006).

significant risk than found in many present day certification systems. Their use will result in substantial improvements in reliability in many natural resource and agricultural product areas.

This article examines the potential traceability benefits of DNA barcoding through a discussion of the general limitations on traceability in existing certification programs. Part II and III examine the limitations of existing certification schemes in the forestry and fisheries sectors. Part IV briefly discusses of the development of DNA barcoding and other cellular level identifiers. Part V describes how these new technologies may be applied to natural resources such as forest products or fisheries. Finally, Part VI concludes with a discussion of the promise that these developing technologies hold for enhancing the reliability of market driven certification programs.

## II. THE LIMITATIONS OF EXISTING TRACEABILITY SYSTEMS

Most current traceability systems are paper or electronic-based. They typically rely on physical barcodes attached to products and databases ostensibly tracing the products from stage to stage of the production process.[19] Currently, many records are stored by transcribing information into a computer file, a hard copy, or a Personal Digital Assistant (PDA). Many schemes use bar codes, or Radio Frequency Identification Devices (RFID), in which an observer must read the tag or brand and record the number, which is then passed along to the next step in the chain. Each system offers a way to trace products through records kept on the producing site. These systems record changes of ownership during processing and distribution in order to try to ensure a proper chain of custody from field to store.

Each such step, however, provides potential "error points" where the integrity of the traceability trail is only as reliable as the reading and transcription of the data. These systems are subject to tampering, and the insertion of counterfeit goods in place of certified ones, which can be difficult to detect. RFID, for example, allows an electronic reader to upload and update information from a chip implanted in a tag, placed under an animal's skin or introduced into the gut in a protective bolus. Plans exist to extend this technology by linking it to Global Positioning Systems, which could then be used to pinpoint the exact whereabouts of a product in real time. Yet present day RFIDs do not produce a strong enough signal to do this without intermediate transmitters. Smart chips can also incorporate constant monitoring of temperature and humidity.

19. DILLON & THOMPSON, *supra* note 10; (see for example, the "Forest Express" software from Helveta used for this purpose in the forestry sector).

This technology has already been used in a variety of ways. For example the UK-based company, Historic Futures, have used smart chips to trace product history in areas such as clothing.[20] However, any such devices could be removed and re-planted into non-certified animals or products. Furthermore, data can be manipulated: databases, for example, trace barcodes rather than specific products, allowing products to be substituted by simply swapping barcodes. The process of making RFID tamper-proof is itself recent. While it promises to be very secure, it still is too expensive for large areas of the world and other methods—like standard grocery store-style product barcodes that can be too easily scratched, damaged, or altered.[21]

Given the difficulties and costs associated with inspections and monitoring, it is currently very common for many schemes to operate on a largely honorary or self-regulatory system. Despite their technologically sophisticated overlay, producers, distributors, and retailers largely rely on agreements to honor third-party certificates provided by supply chain operators.[22] These actors are typically subject to only infrequent or annual audits and inspections by the certifying body, which are often linked to the design of certification processes rather than to actual product tests.[23]

## III. EXISTING CERTIFICATION EFFORTS IN NATURAL RESOURCE REGIMES: PROBLEMS WITH TRACEABILITY IN FISHERY AND FOREST PROCESSES

Over the last several decades, both the fisheries and the forestry sectors developed numerous certification schemes as fish and forest stocks have become unsustainably exploited. With 80 percent of fish stocks overfished in 2008,[24] and forest lands under similar environmental pressure due to destructive overharvesting,[25] consumer campaigns led

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20. Marc Gunther, *Why Traceability Matters to Supply Chains*, GreenBiz.Com (Last visited May 10, 2009), http://www.greenbiz.com/blog/2009/05/10/why-traceability-matters-supply-chains.

21. Filippo Gandino, Bartolomeo Montrucchio & Maurizio Rebaudengo, *Tampering in RFID: A Survey on Risks and Defenses*, 26 Mobile Network Applications 502, 505 (2010); Mohd Nasir et al., *An RFID-Based Validation System for Halal Food*, 8 The Int'l Arab J. Info. Tech. 204 (2011).

22. Cashore et al., *supra* note 2.

23. Jahn, Schramm, and Spiller, *supra* note 3.

24. Food and Agriculture Organization of the United Nations: Fisheries and Aquaculture Department, The State Of World Fisheries and Aquaculture 2008, 7 (2008).

25. Food and Agriculture Organization of the United Nations: Fisheries and Aquaculture Department, The State Of World's Forests 2009, (2009).

both governments and retailers to implement certification processes to assure consumers of specific product quality. Certification processes have sought to demonstrate attributes, such as the use of sustainable forest practices in harvesting forest products or, the assurance that rare species or habitats have not been exploited or destroyed. Two certification bodies are predominate in these areas: the Forest Stewardship Council (FSC) and the Marine Stewardship Council (MSC).[26]

As forestry certification schemes develop, and are increasingly adopted by companies and governments, the role of non-governmental actors in this area has increased.[27] In the process, certification organizations have sought wider acceptance through the use of scientific tools in their certification and by stressing transparency.[28]

The various certification bodies have different principles, with which they test these forestry operations. For example, the FSC follows ten principles when certifying companies. Companies must comply with: (i) the laws and FSC principles. Companies must respect (ii) tenure, use rights, and responsibilities; (iii) indigenous peoples' rights; (iv) and community relations and workers' rights. Furthermore, (v) benefits from the forest must be equitably used and shared; and the (vi) environmental impact; (vii) management plan; (viii) monitoring and assessment must be properly conducted at all times. Finally, companies must (ix) engage in the maintenance of high conservation value forests, and; (x) of their plantations.[29] The FSC principles are aimed at "locking in" a process of increased efficiency in implementing the basic notions of forestry protection, and at creating a set of basic processes that are highly amenable to tracing. For example, the monitoring and assessment principle is

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26. In the forestry case, the certification of forest products is open to varied models presented often by different organizations. In North America the Canadian Standards Association (CSA), the Sustainable Forestry Initiative (SFI), American Tree Farm System (ATFS), and the Forest Stewardship Council (FSC) are all of relevance. In Europe the FSC is joined by the Programme for the Endorsement of Forest Certification (PEFC) while in the rest of the world the certification process is handled by emerging bodies like the Australian Forestry Standard (AFS), Indonesian Ecolabeling Institute (LEI) or the Brazilian National Forest Certification Program (CERFLOR). However, the only two certification bodies that truly have global reach are the FSC and the PEFC even if the SFI certifies a large portion of US and Canadian forests.

27. Cashore et al., *supra* note 2.

28. Graeme Auld & Gary Q. Bull, *The Institutional Design of Forest Certification Standards Initiatives and its Influence on the Role of Science: The Case of Forest Genetic Resources*, 69 J. ENVTL. MGMT. 47 (2003).

29. Eden & Bear, *supra* note 12, at 86. The PEFC instead works to endorse national forest certification systems working with a broad set of assessments and analyses to ensure that the endorsed systems match the benchmarks for sustainable forest management. PEFC, WHY PEFC IS THE CERTIFICATION SYSTEM OF CHOICE (2010).

designed to overlap all phases of harvesting, and can be used both as a tool by the forestry companies and as a choice and information tool by consumers that desire more sustainable products. In this sense, tracing is embedded in the final certification in more than one way. These advances are significant but the scheme still requires an efficient and tamper-proof traceability system in order to achieve its goals.

The application of these principles is generally nuanced according to the country, and the environmental and climate requirements of local forests. The acid test for forestry certification will be employed not only (or predominantly) in relatively open and transparent forestry operations in North America and Europe, but in highly exploited areas like Brazil and Indonesia, where governments may oppose certification, and corruption and malfeasance in timber licensing and management are pervasive.[30] While developed countries represent the largest majority of FSC certified areas, there is still enormous difficulty in extending the principles of the scheme to developing countries. This has meant that the scheme, originally presented in the early 1990s as a way to reduce the alarming rate of deforestation in developing countries, has remained mostly a promising option.[31] Furthermore, Non-Governmental Organizations allege that some companies—while holding FSC certification—are actually acting outside of the scheme's boundaries, as in the case of SODEFOR in the Republic of Congo.[32] Such circumstances often allow species and location standards to be evaded, or for uncertified products to be substituted for certified ones, at various points in production supply chains.

In the fisheries sector, the MSC is the most important certification body.[33] Fisherie certifications, like many forestry ones, often promote

30. Lars H. Gulbrandsen, *Overlapping Public and Private Governance: Can Forest Certification Fill the Gaps in the Global Forest Regime?*, 4 GLOBAL ENVTL. POL. 75, 94 (2004); Klooster, *supra* note 7, at 417; Dan Klooster, *Environmental Certification of Forests in Mexico: The Political Ecology of a Nongovernmental Market Intervention*, 96 ANNALS OF THE ASS'N OF AMERICAN GEOGRAPHERS 541 (2006); Galloway & Stoian, *supra* note 15.

31. Axel Marx & Dieter Cuypers, *Forest Certification as a Global Environmental Governance Tool: What is the Macro-Effectiveness of the Forest Stewardship Council?*, 4 REGULATION AND GOVERNANCE 408, 411 (2010).

32. Danielle van Oijen, *Forest Certification Scheme Ignores Human Rights Violations in the Congo Basin*, GREENPEACE.ORG (Mar. 27 2012), http://www.greenpeace.org/canada/en/Blog/forest-certification-scheme-ignores-human-rig/blog/39733.

33. Other organizations exist that attempt to provide information about the sustainability of fisheries that work closely with the sales rather than production point, like the Friends of the Sea, or are much more limited in nature than MSC, as is the case with the Japanese Marine Eco-Label initiative or the UK Seafish Responsible Fisheries Scheme. UNITED NATIONS ENVIRONMENT PROGRAM, CERTIFICATION AND SUSTAINABLE FISHERIES, 86 (2009).

eco-labeling of final consumer products. There is little doubt that this has increasingly become an important part of the marketing process in response to consumer demand.[34] MSC has brought together various constituencies from both the public interest sphere—academia, environmental NGOs, and public interest groups—and the commercial sphere—retail, fishermen, and Multinational Corporations (MNCs)—to develop such arrangements.[35] Much like the forestry certification bodies that we have seen above, MSC works on the basis of a broad-spectrum alliance, and has cultivated connections with large fish processing corporations that have been central in demanding certification for the products that they process and sell.[36] The inclusion of the major players in these certification schemes carries both positive and negative connotations. On the positive side, many of these actors are interested in developing at least a sustainable market for higher priced products. This in and of itself is a positive—a demand-driven mechanism that would appear to bode well for environmental conservation and the abatement of health risks. On the other hand, the actual effects on conservation and sustainability have not been nearly as pronounced as they were expected to be.[37] The risk of fraud remains high—both as a real phenomenon and as a public or industry perception—potentially undermining confidence in existing schemes and processes. The chief executive of the MSC, Rupert Howes, stated that

> as the momentum behind the MSC programme increases and market demand for MSC-certified products grows, so too does the incentive for fraudulent use of the MSC ecolabel. DNA testing helps build public confidence in product sourcing and labeling claims. Traceability is an essential business requirement and the MSC will continue to develop systems that help protect our partners' investment, markets and reputation.[38]

Certification in fisheries is more complex than in the forest sector; oceans and rivers within which fish move are typically more difficult to control and monitor. Ownership and management of fish stocks are, therefore, targeted by certifying "a combination of site, species, and fish-

34. BRUCE PHILLIPS & TREVOR WARD, "INTRODUCTION" *in* ECO-LABELLING IN FISHERIES: WHAT IS IT ALL ABOUT?, 1-3 (2003).

35. Eden & Bear, *supra* note 12, at 91.

36. *Id.*

37. Jennifer Jacquet, et al., *Conserving Wild Fish in a Sea of Market-Based Efforts*, 44 ORYX 45 (2010); Jennifer Jacquet, et al., *Seafood Stewardship in Crisis*, 467 NATURE 28 (2010).

38. Rupert Howes, *Forensic Methods Enhance MSC Traceability Program*, FISH INFO. SERVICES (July 16 2010), http://fis.com/fis/worldnews/worldnews.asp?l=e&id=37298&ndb=1.

ing gear, making its object of governance a fluid hybrid of cartography, ecological taxonomy and technology."[39] Thus, the result is the certification of a fishery rather than of a geographical space. Sometimes within such a space, we can find various certified fisheries. These differences play a critical role in the MSC approach, and therefore "the precise assessment of a fishery will vary with the nature of the species, the capture method used, the ecology of the fishery, etc."[40]

Within this scheme some marketing practices are condoned, such as the re-branding of less desirable species. This has led to outcomes such as consumers thinking they are eating a type of sea bass when they order Chilean sea bass, but are really having Patagonian Toothfish. While re-branding can be harmless to consumers' health and safety, if not necessarily to fish-stocks, the mislabeling of fish products is a more serious practice that can lead to a variety of wide-ranging consequences; it is typically illegal in most countries.[41] These consequences—including health risks associated with allergies, food borne illnesses, and high levels of mercury[42] or pesticides,[43] associated with illegal product substitution—are more worrisome byproducts of product fraud and adulteration. In extreme cases—as with the 2007 poisonings due to the presence of mislabeled puffer fish toxins—consumers' lives may be endangered.[44]

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39. *Id.*

40. MSC, Interpreting the MSC Principles and Criteria for Sustainable Fishing (2007). It is important to notice that the MSC approach only deals with naturally occurring fisheries therefore leaving aside the growing sector of fish farming. This leaves outside of MSC certification over a third of world fisheries production, where by far the most important producer is China, followed by India, Vietnam, Indonesia, Thailand and Bangladesh. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS: FISHERIES AND AQUACULTURE DEPARTMENT, YEARBOOK OF FISHERY STATISTICS (2010).

41. REBECCA SMITHERS, *Supermarkets Sold Farmed Fish as Wild*, GUARDIANNEWS.COM (Aug. 17, 2012), *available at* http://www.guardian.co.uk/business/2007/may/04/food.retail (last visited Aug. 18, 2012); Peter B. Marko et al., *Fisheries: Mislabelling of a Depleted Reef Fish*, 430 NATURE 309, 309 (2004); Jacob H. Lowenstein, George Amato & Sergios-Orestis Kolokotronis, *The Real Maccoyii: Identifying Tuna Sushi with DNA Barcodes – Contrasting Characteristic Attributes and Genetic Distances*, 4 PLoS ONE 1-14, 2 (2009); Laura Filonzi et al., *Molecular Barcoding Reveals Mislabelling of Commercial Fish Products in Italy*, 43 FOOD RESEARCH INT'L 1383, 1383 (2010); Dana D. Miller & Stefano Mariani, *Smoke, Mirrors, and Mislabeled Cod: Poor Transparency in the European Seafood Industry*, 8 FRONTIERS IN ECOL. AND THE ENVRT. 517, 519 (2010); Montserrat Espiñeira et al., *Development of a Method for the Genetic Identification of Flatfish Species on the Basis of Mitochondrial DNA Sequences*, 56 J. AGRIC. AND FOOD CHEM. 8954, 8955 (2008).

42. Jacquet & Pauly, *supra* note 2, at 315.

43. Jian-Yang Guo et al., *Organochlorine Pesticides in Seafood Products from Southern China and Health Risk Assessment*, 26 ENVRN. TOXICOL. CHEM 1109, 1109 (2007).

44. Nicole Cohen et al., *Public Health Response to Puffer Fish (Tetrodotoxin) Poisoning from Mislabeled Product*, 72 J. FOOD PROTECTION 810, 810 (2009).

The existing international regulatory and certification system does not help in the process of tackling shortcomings, such as those associated with product substitution.[45] For example, while the Codex Alimentarius[46] of the Food and Agriculture Organization (FAO) sets clear standards for labeling, individual countries are often less open with their practices.[47] Furthermore, while labeling regulation tends to apply to the wholesale end of business, the retailers and restaurants are much less regulated and are capable of substituting inexpensive items for expensive certified menu items. Despite the presence of certification systems, this leaves consumers in a conundrum regarding the source, and therefore the potential health and environmental risks, associated with purchasing or consuming certain products.[48]

Thus, in both the forestry and fishery cases, traceability is key to determining that the final product sold in stores is the one that was certified in the field. This is especially important where certified products enjoy a price premium over non-certified products in stores—a financial incentive for fraud and mislabeling through the substitution of non-certified goods for certified ones.

## IV. ENHANCED TRACEABILITY THROUGH DNA BARCODING

As recent scandals in areas such as dairy and beef products, in a wide variety of countries and settings have shown, existing natural resource and agricultural certification systems remain prone to failure.[49] Until recently, the only way to bolster the efficacy of such schemes was to increase the number and frequency of inspections, placing a great deal of stress on the administrative capacity of certifying bodies and increasing the cost of certification substantially, often beyond the price advantage a certified good might enjoy. Such efforts are often viewed as counter-productive, undermining consumer, producer, and retailer support for such schemes, as well as the trust relationships that underpin most existing certification systems.[50]

45. Jacquet & Pauly, *supra* note 2.

46. The Codex is an international document created under FAO jurisdiction.

47. Eva Roth & Harald Rosenthal, *Fisheries and Aquaculture Industries Involvement to Control Product Health and Quality Safety to Satisfy Consumer-Driven Objectives on Retail Markets in Europe*, 53 MARINE POLLUTION BULLETIN 509, 604 (2006).

48. Jacquet & Pauly, *supra* note 2.

49. Oliver Cerf, *Current Definitions of Risk for Food Safety and Animal Health Allow Risk Assessments to Provide Substantially Different Outcomes*, 28 RISK ANAL. 811, 811 (2008).

50. Line Friis Lindner, *Regulating Food Safety: The Power of Alignment and Drive Towards Convergence*, 21 INNOVATION: THE EUR. J. SOC. SCI. RESEARCH 133, 135 (2008); KEITH HAWKINS & JOHN M. THOMAS, *Making Policy in Regulatory Bureaucracies*, *in* MAKING REGULATORY POL'Y

Recent developments in biotechnology provide several means for overcoming many issues with existing certification processes. Molecular DNA technology in particular has developed rapidly over the last decade, and applied genomics has developed a series of transformative technologies for product and process regulation.[51] These are similar to the well-known advancements in forensic DNA analysis, which have provided a range of new tools to criminal investigation agencies and have enhanced their ability to identify and apprehend criminals.[52] Much of the process is based on genotyping: determining the differences in the genetic make-up of an individual sample by comparing it to reference, or "base-line," background data that is collected from specific plants and animals in specific regions or locales. It is now possible to use molecular markers to trace the origin of many imported products, such as timber, fish, coffee, palm oil, organic foods, GMO foods, meat, and other products. This enhanced traceability can clarify a potential illegal origin, or illegal production practice, for various products—like meat or fish "from farm to store."[53] Additionally, recent events, like the emergence of bovine spongiform encephalopathy (BSE), have fostered the emergence of stricter or more widespread traceability measures.[54]

Legislation and market-based initiatives from around the world have increasingly aimed at ensuring a better, and more uniform, control of the journey that products undertake in increasingly globalized production and consumption chains. These efforts are generally aimed at ensuring that consumer choices correspond to consumer expectations, and attempt to maximize a consumer's ability to influence product content, origins, and production processes. However, maximizing the benefits of these choices requires a better definition of food chain traceability, improved enforcement of attendant regulations and standards, and har-

(Keith Hawkins & John M. Thomas eds., 1989). *See also,* Albersmeier et al., *supra* note 9, at 930. Jahn, Schramm & Spiller, *supra* note 3, at 55.

51. Alison C. Cullen et al., *The Application of Genetic Information for Regulatory Standard Setting under the Clean Air Act: A Decision-Analytic Approach*, 28 RISK ANAL. 877, 880 (2008).

52. Herbert Gottweis, *Regulating Genomics in the 21st Century: From Logos to Pathos?*, 23 TRENDS IN BIOTECH. 118, 121 (2005).

53. Shackell, *supra* note 11, at 2134; E. LARSEN, *Traceability in Fish Processing*, *in* FOOD AUTHENTICITY AND TRACEABILITY 507, 510 (2003); Andrew Cockburn, *Assuring the Safety of Genetically Modified (GM) Foods: The Importance of an Holistic, Integrative Approach*, 98 J. BIOTECH. 79 (2002).

54. Elvbakken, Lægreid & Rykkja, *supra* note 12; R. G. L. Murphy et al., *Review: Animal Identification Systems in North America*, 24 PROF. 277 (2008); A. Regattieri, M. Gamberi & R. Manzini, *Traceability of Food Products: General Framework and Experimental Evidence*, 81 J. FOOD ENG'G 347, 350 (2007).

monizing the practices involved in all of these steps.[55] Increasing, interest in the survival of endangered species,[56] combating food fraud,[57] and expanding our taxonomic horizons,[58] has led to a strong interest in promoting traceability through genetic markers. But until very recently, the regulatory landscape favored a more on-demand approach—in the case of Europe—or even a voluntary one—in the case of the United States.

A critical moment in the process came in 2005, when the European Union and the United States implemented full traceability requirements in their food chains.[59] In 2005, the European Union established a "farm to fork" traceability model.[60] This regulation demands that, even in the absence of a consumer request, food and feed operators within the European Union must be able to establish a full traceable link for their products. This ended the consumer driven on-demand system and implemented a much stronger one.[61]

In the United States, the traceability model was based on a voluntary system until 2005, when the enactment of the Bioterrorism Act made food and feed traceability the new standard.[62] As the technology in the field of DNA barcoding progresses, the options it offers increasingly match the requirements of the increased traceability. Finally, because of the increased reliability and scope of DNA barcoding, in October, 2011 the U.S. Food and Drug Administration (FDA) approved the use of this technology as a tool to prevent the importation of mislabeled seafood into the United States.[63] These moves will encourage the use and dissemination of these technologies, and their integration into existing schemes as both a supplement and substitute for existing procedures and techniques.

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55. Swaroop V. Kher et al., *Experts' Perspectives on the Implementation of Traceability in Europe*, 112 BRITISH FOOD J. 261 (2010).

56. F. Schwägele, *Traceability from a European Perspective*, 71 MEAT SCI. 164, 167 (2005); G.C. Smith et al., *Traceability from a US Perspective*, 71 MEAT SCI. 174, 180 (2005).

57. Woolfe & Primrose, *supra* note 2, at 226.

58. F.O. COSTA & G.R. CARVAHLO, *The Barcode of Life Initiative: Synopsis and Prospective Societal Impacts of DNA Barcoding of Fish*, GENOMICS, SOC. AND POL'Y, AUG. 2007 at 29-30 (2007).

59. Schwägele, *supra* note 56; Smith et al., *supra* note 56.

60. Directive 178/2002 (which came into effect in 2005).

61. Schwägele, *supra* note 56, at 165.

62. Jacquet & Pauly, *supra* note 2, at 310; Natalia Vidal et al., *Chain of Custody Certification: An Assessment of the North American Solid Wood Sector*, 7 FOREST POL'Y AND ECON. 345, 346 (2005); Public Health Security and Bioterrorism Preparedness and Response Act of 2002, Pub. L. No. 107-188, 116 Stat. 594.

63. Single Laboratory Validated Method for DNA-Barcoding for the Species Identification of Fish for FDA Regulatory Compliance, U.S. FOOD & DRUG ADMIN., (Sept. 2011), http://www.fda.gov/Food/ScienceResearch/LaboratoryMethods/ucm237391.htm.

Biological markers can be used to trace an animal from farm to store. More significantly, for future traceability regimes, many products carry a built-in unique genetic identifier or "DNA barcode."[64] This DNA barcode cannot be manipulated and can unequivocally establish a product's identity and origin, without the need for costly intermediate supply chain inspections and monitoring. Recently developed 'omics-based marker technologies provide a promising way to enhance the reliability and effectiveness of certification, at relatively little cost.[65] These technologies, linked to genomics, proteinomics, metabolomics, and transcriptomics all involve the use of cellular level identifiers in specific products, which can be used to confirm their, identity, origins, and purity.[66] Because of the way DNA is inherited, it also offers a means of linking individual animals or plants to their parents or location of origin.[67] When this is coupled with information about expressed traits—e.g., tenderness and marbling in meat—the parts of the DNA that are closely associated with the expressed variation, or even the specific genes controlling such traits, can be determined and certified.[68] They enhance traceability in supply chain oversight in two ways: first, only an original and a final product sample would be required to test to adulteration and substitution, and; second, even where more detailed knowl-

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64. If it is possible to define a short region of a DNA sequence, that consistently divides species, the sequence functions as a species identifier. At present several kinds of DNA-based techniques are available for traceability purposes, however, with very different properties. Common for most such techniques is that they focus on genetic markers. This refers to the explicit expectation that observed variations in genetic makeup of individuals reveal patterns formed by the joint effects of migration, mutation and random genetic drift. Often the genetic patterns have been generated from bottlenecks during glaciations in which case the patterns can reveal a great deal about the geographical origins of specific individuals. In practice, DNA barcoding refers to the capacity of identifying different species by using a small fraction of their DNA sequence Barcode of Life Initiative. In this sense, "the goal of DNA barcoding is also not molecular taxonomy, as it is not intended to replace classical taxonomy. Its purpose is to carry out species identifications so that even non-experts can determine what species might be at hand, and to do so in a rapid and inexpensive manner" G. B. Golding, Robert Hanner & Paul D.N. Hebert, Preface, 9 MOLECULAR ECOL. RES. iv, iv (2009).

65. Marker-Assisted Selection. Current Status and Future Perspectives in Crops, Livestock, Forestry and Fish, (Elcio P. Guimarães et al. eds., 2007). DNA marker technologies have become an important part of modern technological development. They include Marker Assisted Selection. Marianne Benard et al., *Science and Society in Dialogue About Marker Assisted Selection*, 23 J.AGRIC. AND ENVTL. ETHICS 317, 317 (2010); Zhanjiang Liu & J. F. Cordes, *DNA Marker Technologies and their Applications in Aquaculture Genetics*, 238 AQUACULTURE 1, 1 (2004); A. K. Lockley & R. G. Bardsley, DNA-based Methods for Food Authentication, 11 TRENDS IN FOOD SCI. AND TECH. 67, 67 (2000).

66. Woolfe & Primrose, *supra* note 2, at 226.

67. Guimarães et al. eds., *supra* note 65.

68. *Id.*

edge is required in order to correct alterations—as would be the case with tainted food products—this is made simpler and more reliable.

The capacity of DNA barcoding to identify various types of alterations to food and timber, that may not be apparent to the naked eye when these products are processed, is an important advantage in the fight to enforce standards, properly trace products, and implement sustainable methods of resource extraction. Such alterations are very common—for example, when fish are processed into fishsticks, their appearance and identification is altered. Another example is when timber is used with veneers, or other materials, that disguise its appearance. DNA barcoding is thus superior to other techniques designed to enforce standards such as product purity, sustainability, and other factors, which are otherwise unrecognizable.

Wine and olive oil are other good examples. Genomics-based markers can be associated with particular types of olives and grapes, and terroirs[69] can be used to check final products for adulteration using other species or the same species grown in other areas.[70] The same logic and techniques can be applied to many other products. For example, to distinguish between fish raised in fish farms and on the open ocean, or—in the case of tropical timber smuggling—between timber taken from a specific type and location of tree. As one commentator has argued, as the common link in the "gate to plate" continuum, DNA barcoding is becoming a must-have management tool for the future to improve, authenticate, trace, and verify product quality and origin in both forward and reverse.[71] DNA barcoding links both the current handler, and the future one, in the production or retail chain in one continuous, seamless traceability process.[72] This is most often understood as the "one step forward, one step back" model where product information is collected both by the shipping company and by the receiving one.[73]

While the costs of genetic analysis and sampling were once too high to contemplate their large-scale use, costs of DNA sequencing and

69. The word "terroir" refers to the specific climatic, geographical and geological characteristics that impart particular qualities to the products grown in it. It is most commonly applied to wine but it is also used for coffee and tea.

70. Simona Pafundo et al., *Applicability of SCAR Markers to Food Genomics: Olive Oil Traceability*, 55 J. AGRIC. AND FOOD CHEM. 6052, 6053 (2007).

71. Shackell, *supra* note 11, at 2137.

72. Paul D.N. Hebert & T. Ryan Gregory, *The Promise of DNA Barcoding for Taxonomy*, 54 SYST. BIOL. 852, 852 (2005); Paul D.N. Hebert et al., *Biological Identifications Through DNA Barcodes*, 270 PROC. BIOL. SCI. 313, 320 (2003); V. Shneyer, *DNA Barcoding is a New Approach in Comparative Genomics of Plants*, 45 RUSS. J. GENET. 1267, 1272 (2009).

73. INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA [ICES], REPORT OF THE WORKING GROUP ON THE APPLICATION OF GENETICS IN FISHERIES AND MARICULTURE 2009.

other techniques have dropped dramatically in recent years. This promises much more widespread use to enhance certification accuracy and trust, and eliminate fraud and misrepresentation.[74]

## V. THE POTENTIAL IN THE FISH AND FORESTRY SECTOR

Some of the applications for DNA barcoding to date have included quarantine processes,[75] the identification of invasive species,[76] trees,[77] fish,[78] endangered species,[79] and food, among others.[80] DNA

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74. Claire Waterton, *Barcoding Nature: Strategic Naturalization as Innovatory Practice in the Genomic Ordering of Things*, 58 THE SOCIOLOGICAL REV. 152 (2010). DNA barcoding efforts have been particularly well publicized by the Barcode of Life Initiative (BOLI; Waterton, Ellis and Wynne 2010). Today the interest in DNA barcoding is increasing, even as some philosophical questions are raised as to the effect that its application to widespread species recognition would have on the field. The technology faced some early questions and there were also some critiques on whether the technology could deliver on its promises. While the technology has limitations it is easily applicable by non-specialists and it has become increasingly popular. Kirk Fitzhugh, *DNA Barcoding: An Instance of Technology-driven Science?*, 56 BIOSCIENCE 462 (2006); Kipling W. Will, Brent D. Mishler & Quentin D. Wheeler, *The Perils of DNA Barcoding and the Need for Integrative Taxonomy*, 54 SYST. BIOL 844, 849 (2005). The technology faced some early questions Daniel Rubinoff, *Utility of Mitochondrial DNA Barcodes in Species Conservation*, 20 CONSERV. BIOL. 1026 (2006); Daniel Rubinoff, Stephen Cameron & Kipling Will, *A Genomic Perspective on the Shortcomings of Mitochondrial DNA for "Barcoding" Identification*, 97 J. HEREDITY 581 (2006); Kipling W. Will & Daniel Rubinoff, *Myth of the Molecule: DNA Barcodes for Species Cannot Replace Morphology for Identification and Classification*, 20 CLADISTICS 47 (2004); Brendon M.H. Larson, *DNA Barcoding: The Social Frontier*, 5 FRONTIERS IN ECOL. AND THE ENV'T 437 (2007); Lise Frézal & Raphael Leblois, *Four Years of DNA Barcoding: Current Advances and Prospects*, 8 INFECT. GENET. EVOL 727 (2008); Andrew Mitchell, *DNA Barcoding Demystified*, 47 AUSTL. J. ENTOMOLOGY 169 (2008); Torbjrn Ekrem, Endre Willassen & Elisabeth Stur, *A Comprehensive DNA Sequence Library is Essential for Identification with DNA Barcodes*, 43 MOLEC. PHYLOGENETICS AND EVOL. 530 (2007); Natalia V. Ivanova, Alex V. Borisenko & Paul D.N. Hebert, *Express Barcodes: Racing from Specimen to Identification*, 9 MOLEC. ECOL. RES. 35 (2009); Adriana E. Radulovici, Philippe Archambault & France Dufresne, *DNA Barcodes for Marine Biodiversity: Moving Fast Forward?*, 2 DIVERSITY 450 (2010).

75. P. Bonants et al., *QBOL: A new EU Project Focusing on DNA Barcoding of Quarantine Organisms*, 40 EPPO BULLETIN 30, 31 (2010).

76. K.F Armstrong & Shelley L. Ball, *DNA Barcodes for Biosecurity: Invasive Species Identification*, 360 PHILOS. TRANS. R. SOC'Y LOND., B, BIOL. SCI. 1813, 1814 (2005).

77. Mailyn Adriana Gonzalez et al., *Identification of Amazonian Trees with DNA Barcodes*, 4 PLOS ONE e7483 1, 5 (2009).

78. Nicolas Hubert et al., *Identifying Canadian Freshwater Fishes through DNA Barcodes*, 3 PLOS ONE e2490 1, 5 (2008); Radulovici, Archambault, and Dufresne, *supra* note 74, at 450; Rosalee S. Rasmussen, Michael T. Morrissey & Paul D.N. Hebert, *DNA Barcoding of Commercially Important Salmon and Trout Species (Oncorhynchus and Salmo) from North America*, 57 J. AGRIC. FOOD CHEM. 8379, 8379 (2009).

79. Dubey, Meganathan & Haque, *supra* note 15, at 181.

80. P.J. Smith, S.M. McVeagh & Dirk Steinke, *DNA Barcoding for the Identification of Smoked Fish Products*, 72 J. FISH BIOL. 464, 464 (2008).

barcoding holds great promise in forestry and fishery management because it allows both for the control of products in regulatory terms—i.e., enabling the reduction of fraud and mislabeling—and for the insertion of higher levels of consumer choice in the process.

The forestry field is an important area of application for traceability technologies—and potentially for DNA barcoding—because of the size of the industry, its impact on the environment, and the difficulties with earlier efforts at traceability. The development of DNA barcoding for plants lagged behind the establishment of the same technology for animals.[81] In particular, the low rate of sequence evolution in plants' genome hindered the development of effective barcoding, since the range of easily observable variation was smaller.[82] However, research has increasingly improved the capacity of the method in recent years.[83]

Literature still differs, however, regarding the capacity of DNA technology to help in forestry traceability. In a study of Amazonian plants, DNA barcoding was helpful in the identification of juvenile plants and in recognizing errors in previous identification. However, it was rather less efficient for identifying collections; the study authors believed this to be a likely limiting factor in implementing DNA-based tropical plant biodiversity programs.[84] In a different study of Panama forestry plots, however, the technology was found to have a higher than 98 percent success rate in identifying plants.[85] While these studies have an important scientific resonance, the capacity of developing countries to enter and maintain a strong certification scheme that highlights sustainability is limited. On the other hand, the success of schemes—like the MSC—and the policies of some large retailers—like IKEA—to source sustainable products, demonstrate that consumer demand can have important effects on the industry.

In a related study, barcoding was used to identify ferns in U.S. nurseries where some plants were found to be non-native exotic spe-

81. Renaud Lahaye et al., *DNA Barcoding the Floras of Biodiversity Hotspots*, 105 PROC. NATL. ACAD. SCI. U.S.A 2923, 2923 (2008); Mark W. Chase et al., *Land Plants and DNA Barcodes: Short-Term and Long-Term Goals*, 360 PHILOS. TRANS. R. SOC'Y LOND., B, BIOL. SCI 1889, 1889 (2005).

82. W. John Kress & David L. Erickson, *A Two-Locus Global DNA Barcode for Land Plants: The Coding rbcL Gene Complements the Non-Coding trnH-psbA Spacer Region*, 2 PLoS ONE e508 1, 1 (2007).

83. Mark W. Chase et al., *A Proposal for a Standardised Protocol to Barcode all Land Plants*, 56 TAXON 295, 295 (2007). *see also* W. John Kress & David L. Erickson, *DNA Barcoding - A Windfall for Tropical Biology?*, 40 BIOTROPICA 405, 405 (2008).

84. Gonzalez et al., *supra* note 77, at 1.

85. W. John Kress et al., *Plant DNA Barcodes and a Community Phylogeny of a Tropical Forest Dynamics Plot in Panama*, 106 PROC. NAT'L ACAD. OF SCI. 18621, 18622 (2009).

cies.[86] The University of Trieste used a panel of microsatellites to test the origins of 33 commercial cultivars of *C. Arabica*, and thirteen interspecific coffee hybrids collected in America, India and Africa with almost 100 percent success. With respect to timber, however, several experts have noted that DNA markers can be used to identify morphologically similar species, in order to prevent the illegal trade of species protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)—such as Aquilaria and Cedrela species.[87] Barcoding in the North American solid wood sector, however, still has a large unexploited potential: recently it was only the third most used tracking method at 14.2 percent, behind paint daubs at 30.3 percent, and labels at 29.3 percent.[88]

Molecular biology in general, and DNA barcoding in particular, also show a lot of promise in tackling problems in the fishery sector.[89] Fish have been heavily classified in terms of barcoding through the FISH-BOL,[90] and SHARK-BOL projects,[91] and through a variety of regional research projects.[92] In general, DNA tools have great potential in the fight against illegal, unreported and unregulated (IUU) fishing.[93] The development of extensive gene mapping projects for tropical ornamental fishes, and for stocks managed for human consumption, has been the basis of implementing strong traceability and prevention measures to stop unsustainable practices. For example, the capacity to immediately identify non-compliant ornamental fish provides a critical tool for enforcement agencies to limit, or altogether eliminate, the potential profit that is often associated with IUU practices. At the same time, the capacity to identify shark species through DNA barcoding should be an important step in initiating checks on the flourishing, but unsustainable, shark fin market in Asian countries.

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86. Kathleen M. Pryer et al., *DNA Barcoding Exposes Fake Ferns in International Plant Trade*, MOLEC. ECOL. RES. (2010).

87. Lene Rostgaard Nielsen & Erik Dahl Kjær, *Tracing Timber from Forest to Consumer with DNA Markers*, 14 (2008).

88. Vidal et al., *supra* note 62, at 349.

89. Scott C. Baker, *A Truer Measure of the Market: The Molecular Ecology of Fisheries and Wildlife Trade*, 17 MOLEC. ECOL. 3985, 3994 (2008).

90. Robert D. Ward, Robert Hanner & Paul D.N. Hebert, *The Campaign to DNA Barcode all Fishes*, 74 J. FISH BIOL. 329, 331 (2009).

91. Radulovici, Archambault, & Dufresne, *supra* note 74, at 461.

92. W. S. Lakra et al., *DNA Barcoding Indian Marine Fishes*, 11 MOLEC. ECOL. RES., 60, 60 (2011); Robert D. Ward et al., *DNA Barcoding Australia's Fish Species*, 360 PHILOS. TRANS. R. SOC'Y LOND., B, BIOL. SCI 1847, 1847 (2005); Ward, Hanner, & Hebert, *supra* note 90, at 330.

93. Rob Ogden, *Fisheries Forensics: The Use of DNA Tools for Improving Compliance, Traceability and Enforcement in the Fishing Industry*, 9 FISH AND FISHERIES 462, 463 (2008).

Examples of success in this area include DNA barcoding traceability work of Amazonian fish by analyzing catch being sold as Acará and of other species in Brazilian fish markets,[94] for American catfish stocks,[95] and other seafood products.[96] Fisheries that involve endangered species, or those that may rapidly become unsustainable—like the shark fishery—can benefit from DNA barcoding and DNA identification techniques in general.[97] These benefits can accrue on a variety of levels. For example DNA barcoding can help classify endangered species to make management of fisheries more rational,[98] to make it easier to track parts from protected species,[99] and to make it easier to uncover potentially illegal trade.[100] Several fisheries are already benefiting from these activities, from the identification of fins from protected shark species in the international market, to the development of more efficient stock management in Icelandic fisheries.

## VI. CONCLUSION: FROM PAPER TO DNA BARCODING

DNA barcoding, and other marker-related genomics techniques, are increasingly used in agricultural production to trace individual cuts of meat, or to audit conventional meat traceability systems. The science

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94. Alba Ardura et al., *DNA Barcoding for Conservation and Management of Amazonian Commercial Fish*, 143 BIOL. CONSVN. 1438, 1439 (2010); Alba Ardura et al., *Application of Barcoding to Amazonian Commercial Fish Labelling*, 43 FOOD RES. INT'L 1549, 1550 (2010).

95. K. Mickett et al., *Assessing Genetic Diversity of Domestic Populations of Channel Catfish (Ictalurus Punctatus) in Alabama using AFLP Markers*, 228 AQUACULTURE 91, 101 (2003).

96. Milena Maldini et al., *Fish and Seafood Traceability Based on AFLP Markers: Elaboration of a Species Database*, 261 AQUACULTURE 487, 488 (2006).

97. Debra L. Abercrombie, Shelley C. Clarke & Mahmood S. Shivji, *Global-Scale Genetic Identification of Hammerhead Sharks: Application to Assessment of the International Fin Trade and Law Enforcement*, 6 CONSERV. GENET. 775, 775 (2005).

98. Bronwyn H. Holmes, Dirk Steinke & Robert D. Ward, *Identification of Shark and Ray Fins Using DNA Barcoding*, 95 FISHERIES RESEARCH 280, 282 (2009).

99. Jennifer E. Magnussen et al., *Genetic Tracking of Basking Shark Products in International Trade*, 10 ANIMAL CONSERVATION 199, 206 (2007); P.J. Smith & P.G. Benson, *Biochemical Identification of Shark Fins and Fillets from the Coastal Fisheries in New Zealand - Statistical Data Included*, 99 FISHERY BULLETIN 351, 351 (2001).

100. Mahmood S. Shivji et al., *Genetic Profiling Reveals Illegal International Trade in Fins of the Great White Shark, Carcharodon Carcharias*, 6 CONSERVATION GENETICS 1035 (2005). Other applications also exist in this area. DNA barcoding, for example, was found to be extremely promising for the identification of ornamental fish and therefore in the regulation of this very popular trade and indirectly in ensuring that these fisheries are managed sustainably. Dirk Steinke, Tyler S. Zemlak & Paul D.N. Hebert, *Barcoding Nemo: DNA-based Identifications for the Ornamental Fish Trade,* 4 PLoS ONE e6300 1 (2009). Barcodes from sea lice have also been used to trace the path of transmission of the lice from aquaculture farms to wild fish on the BC coast. Mark Hume, *Experts find a Way to Track Onslaught of Sea Lice: DNA Method Traces Illness Spread to Fish*, GLOBE AND MAIL, May 20, 2009, at S1.

behind such techniques is now well known. The potential for their application to the natural resources sphere, however, is just now being recognized. Such applications in some cases require further technological advances—such as the development of hand-held or inexpensive field testing equipment. These advances await demand from regulatory agencies and certifiers in the impacted sectors like forestry and fisheries,[101] or the development of appropriate geographic 'base-line' data on species' origins.[102]

Within this context, a variety of technologies—including RFID, DNA fingerprinting, DNA barcoding, biochemical tools and others—are generally available and can be highly efficient in improving certification efforts, reducing costs, and improving the accuracy of certification schemes. Not every product is equally amenable to DNA barcoding.[103] But where it is, it can help supply chain monitoring systems remain uncompromised over the many steps of the supply chain, and through many form changes, until a consumer purchases a product. It offers the possibility of a built-in traceability verification tool that cannot be removed like a paper barcode, and is not destroyed or altered by production processes.

Scientific work continues to accumulate relevant base-line data, and DNA technology has continued to improve in recent years, showing no sign of slowing down. The cost of equipment, and of taking a DNA sample, is declining rapidly; it is now frequently associated with existing management procedures, such as on farm procedures resulting in a sample of blood being available—e.g., ear tagging or some forms of tail docking.[104] The cost of genotyping DNA samples is also declining rapidly as new genotyping tools come on-stream, and improved techniques provide an increasing amount of information from a single analysis.[105] Such technologies are not foolproof, and the possibility of laboratory fraud or malfeasance is always present. But these technologies will greatly simplify the task of inspecting and monitoring production processes and supply chains for many products, enhancing the reliability of, and confidence of consumers in, resource certification systems.

101. Galloway & Stoian, *supra* note 15, at 204; Baker *supra* note 89, 3994.

102. ICES, *supra* note 73, at 38.

103. Smith, McVeagh, & Steinke, *supra* note 80, at 464. *see also*, C. Shanahan et al., *A Framework for Beef Traceability from Farm to Slaughter Using Global Standards: An Irish Perspective*, 66 COMPUTERS AND ELECTRONICS IN AGRICULTURE 62, 63 (2009).

104. *Id.* at 66.

105. *Id.*