Chemical traceability for high-risk aquaculture supply chains

New research shows that chemical analysis can independently verify the geographic origin of farmed shrimp, including after primary commercial processing. But when the same methods are applied to products on supermarket shelves, a significant majority do not match their declared origin. These findings have direct implications for supply-chain risk, import regulations, certification integrity, and next generation due diligence.

THE INSIGHT SERIES

World Forest ID's Insight series is designed to communicate the outputs of our longform research in a timely manner, by summarizing data snapshots and interim learning. All research is ultimately published in appropriate peer-reviewed journals and citations should reflect full articles wherever possible.

Full article

WHY SHRIMP, WHY NOW

Farmed shrimp is one of the world's most valuable traded seafood commodities, representing around $32 billion[1] in annual trade, with global production approaching 6 million tons annually[2]. Production is concentrated in tropical Asia and Latin America, and shrimp aquaculture has been estimated to occupy up to 1.5 million hectares of coastal lowlands[3]. Major import markets include China, the United States (US), the European Union (EU), and Japan.

Alongside labor abuses and human rights concerns, shrimp farming has contributed to mangrove loss and coastal degradation in several tropical regions. Much of the regulatory and market attention on environmental crime has focused on forest-risk commodities such as timber, palm oil, and soy, as well as on wild-caught fish. Aquaculture products, especially farmed shrimp, present many of the same challenges, but have received less scrutiny.

Shrimp supply chains are long, fragmented, and opaque. Products may be processed multiple times and traded across borders before reaching final markets, making it difficult for regulators, buyers, and traders to confirm origin and conditions within their supply chains. Documentation and certification can provide important information, but relying on these alone gives limited assurance.

Our research took place in two phases. The first, published as a peer-reviewed paper[4], established the scientific foundations of the method and produced an initial set of retail results striking enough to require further investigation. The second expanded the retail sample set into multiple EU markets. This Insight summarizes the findings of both phases.

1. World Wildlife Fund. (2020). Blueprint for future-proofing shrimp supply chains. Published 29 September 2020.
2. Gillett, R. (2008). Global study of shrimp fisheries. FAO Fisheries Technical Paper No. 475. Rome: Food and Agriculture Organization of the United Nations.
3. Páez-Osuna, F. (2001). The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environmental Management, 28(1), 131–140.
4. Deklerck, V. D., Davis, R. P., Rodriguez-Zunino, A., Khongtanakrittakorn, S., Hofem, S., Jungkeit, J., Leyton, A., Osorto-Nuñez, M., Podmore, C., Prior, L., Smith, C. C., & Soule, B. (2026). Shrimp (sub-)national traceability and retail fraud detection using stable isotopes and multi-element profiling. Food Control. Advance online publication.

1. Chemical fingerprinting can verify shrimp origin with very high accuracy

Every shrimp carries a chemical record of where it was farmed. Stable isotope ratios in shrimp tissue reflect the local water, climate, and feed environment, while multi-element profiles reflect the geochemistry of the production area. By combining these two types of analysis and comparing results against a reference database of samples from known locations, the geographic origin of shrimp products can be determined with high degrees of precision.

Using ground-truthed reference samples collected from aquaculture ponds across Ecuador, Honduras, and Thailand, spanning multiple production regions within each country, the peer-reviewed method achieved 99.5% accuracy in determining production location to country level. This was based on hundreds of samples representing dozens of individual ponds, farms and producers. It shows that chemical traceability is no longer experimental, and can provide objective, science-based verification of origin in real-world supply chains.

2. Primary commercial processing does not defeat the method

A central concern of those considering real world use cases is whether post-harvest chemical processing obscures geographic signals. To test this, shrimp of known origin were subjected to standard industry chemical treatments (sodium metabisulfite (SMBS), sodium tripolyphosphate (STPP), and chlorine), replicating the processes shrimp normally undergo before export to Western markets.

Notably these chemically-treated shrimp retained their geographic fingerprint. All treated samples were correctly assigned to their country and sub-national source area.
This indicates that chemical verification is feasible for export-ready and imported products, the point in the supply chain which matters most for regulators and buyers.

FIGURE 1. *Known-origin shrimp remained identifiable after processing*

99.5% matched true origin

KNOWN ORIGIN
REFERENCE SAMPLES

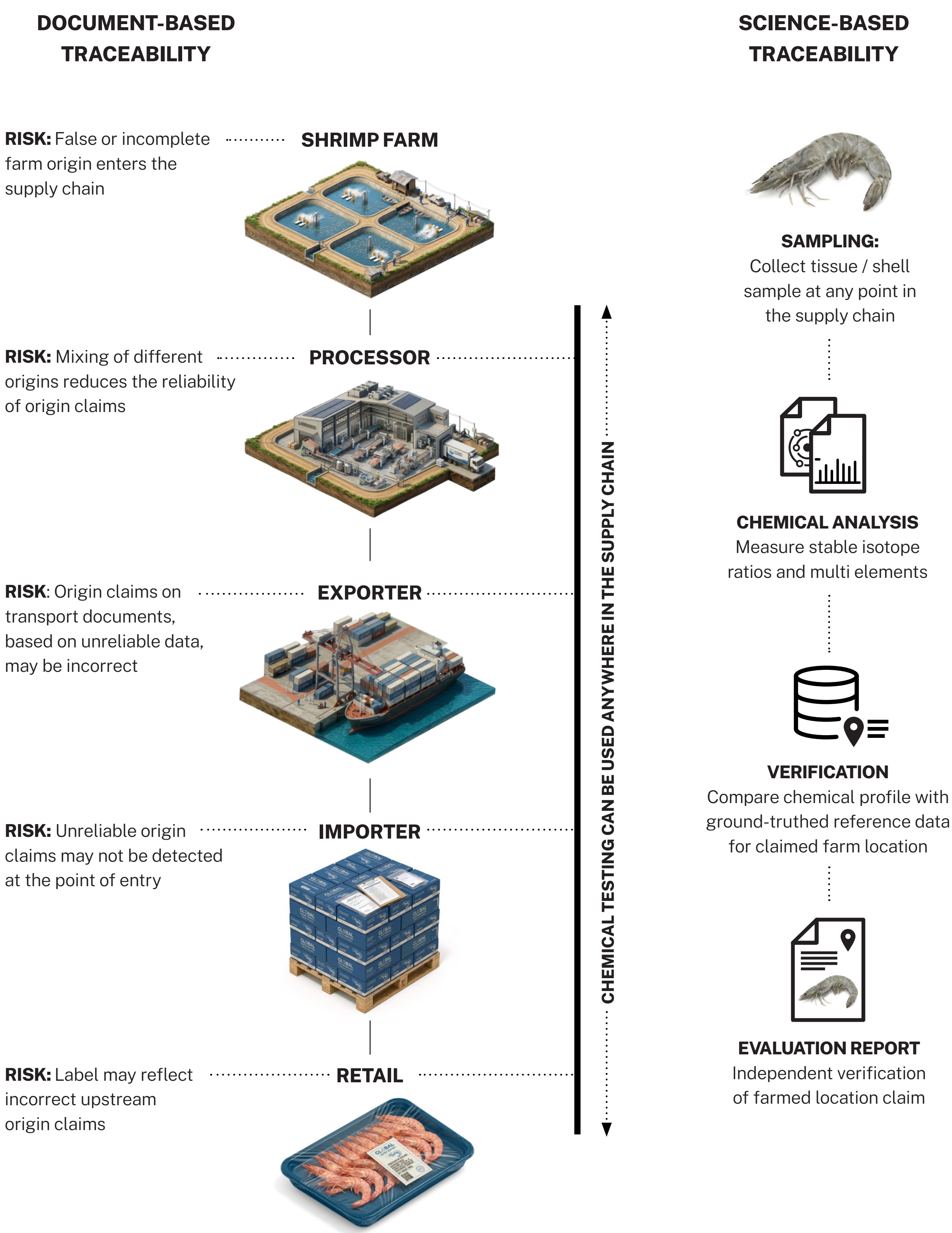
Ground-truthed farm samples
Samples: 375

100% matched true origin

KNOWN ORIGIN
PROCESSED SAMPLES

SMBS, STPP & chlorine treated
Samples: 16

FIGURE 2. *Document-based vs science-based traceability*



3. Sub-national origin can be resolved at environmentally meaningful scales

Beyond country-level classification, the majority of shrimp origin could be distinguished at sub-national scales aligned with watershed catchments, reflecting underlying hydrological and environmental differences rather than administrative boundaries. In Ecuador and Honduras, models successfully determined origin at catchment level, achieving 97% and 95% accuracy respectively. Performance was lower in Thailand (77%), likely reflecting less environmental heterogeneity across the sampled production areas.

This level of resolution is particularly relevant for governance contexts where environmental risk varies within countries. Mangrove conversion, pollution, and labor practices are not uniformly distributed, they are often concentrated in specific production areas. The ability to trace shrimp to catchment allows certifiers and buyers to mitigate the risk of mixing product from variable risk categories in supply chains.

The research shows that the level of geographic detail that can be inferred depends heavily on environmental heterogeneity in the chemical signal, and the availability and coverage of detailed reference data sets. Higher-resolution claims require correspondingly denser sampling.

4. Shell material retains geographic signature

Chemical signals measured in shrimp shell material, specifically the telson (tail fan), closely mirror those found in edible muscle tissue. All telson samples were correctly classified to their country of origin, even when tested against models built from muscle tissue data.

This has a practical implication for enforcement: the telson is typically retained even on many peeled shrimp products, meaning inspectors can test a wider range of products across different points in the supply chain, including inspections where muscle tissue may be highly processed or otherwise unavailable.

Retail sampling results: The majority of products do not match their declared origin

When the peer-reviewed methods were applied to shrimp purchased at retail in Germany, the United Kingdom (UK), and the US, 26 of 31 samples (84%) did not match their declared country of origin. Among certified products (carrying labels from schemes including ASC, BAP, Naturland Organic, or EU Organic) 18 out of 19 samples (95%) did not match their declared origin.

Shrimp labeled as originating from Ecuador or Honduras were overwhelmingly classified as having chemical profiles closer to Thai reference samples. Only shrimp declared as Thai in origin were consistently assigned correctly.

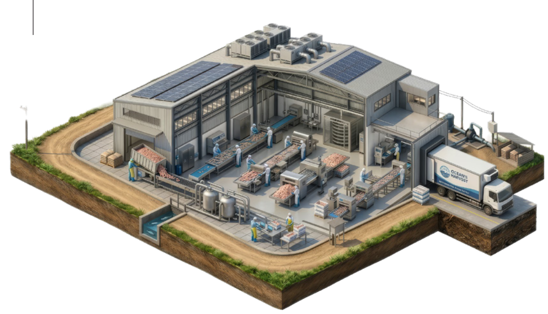
The scale and consistency of the findings warranted further investigation. A second set of retail samples was collected from Austria, France, Germany and the US.

Of the 31 samples tested in the second phase, 21 (68%) did not match their declared country of origin. Certified products showed the same rate with 14 of 21 (68%) samples inconsistent with their declared origin. While this represents an improvement on the original retail figures, a significant majority of samples still do not match their declared origin.

Multiple explanations for these findings were considered and controlled for in the methodology, such as the use of undocumented chemical processes in the supply chain, and the possibility that different shrimp species produce inconsistent chemical signatures. Objective review of the data suggests that the most likely explanation is that the majority of the retail shrimp tested were mislabeled.

FIGURE 3. *Most retail shrimp tested did not match their declared origin*

Percentage of retail products that did not match their declared origin	Percentage of certified retail products did not match their declared origin
84% Mislabeled Phase 1 testing / sample size 31	95% Mislabeled Phase 1 testing / sample size 19
68% Mislabeled Phase 2 testing / sample size 31	68% Mislabeled Phase 2 testing / sample size 21



What this means for policy and governance

Taken together, these findings show that chemical traceability tools are sufficiently mature for real-world application. They cannot replace existing traceability or certification systems, but provide an independent system check that can identify mixing risks in processing hubs and substantially increase integrity.

FOR REGULATORS AND IMPORT CONTROLS.
Chemical verification can be integrated into existing regulatory frameworks, such as the US Seafood Import Monitoring Program, and to extend EU catch certificate requirements as a science-based audit layer. Both retail testing phases demonstrated that the industry faces a substantial mislabeling challenge, and a clear need for objective scientific testing.

The methodology uses standard laboratory equipment and established, market-ready analytical techniques, and costs are comparable to routine food safety testing. Chemical traceability is already widely used in supply chains for cotton and other agricultural products. Rather than creating additional costs for all producers or regions, it enables targeted, risk-based oversight, focusing resources where discrepancies are most likely, while reducing unnecessary burden on lower-risk supply chains.

FOR CERTIFICATION BODIES.
The high rate of origin mismatch among certified retail products is a direct challenge to the credibility of certification as a mechanism for market-based approaches to addressing social and environmental challenges. However, the aim should be to strengthen certification systems through scientific verification, not abandon them. Chemical analysis can serve as an additional assurance layer, allowing certification bodies to demonstrate that their chain of custody claims can withstand scrutiny.

FOR PRODUCER COUNTRIES AND RESPONSIBLE PRODUCERS.
Chemical traceability can also benefit producer countries and responsible producers by enabling objective verification of origin at national and sub-national scales. Compliant producers and regions can differentiate themselves from higher-risk areas using independent evidence, avoiding blanket risk assumptions. Participation in reference sample donation is an opportunity to build credibility and maintain access to increasingly sensitive export markets and investors.

FOR DATA GOVERNANCE.
The accuracy and resolution of chemical verification depends on access to ground-truthed reference datasets. And critically, how these datasets are governed will determine whether the approach can deliver transparency at scale — who owns them, who can access them, and whether they are comparable across laboratories will remain as important as the existence of data itself. Reference data held in proprietary commercial databases serves a narrow set of interests. Reference data stewarded as a public good, with transparent protocols, cross-laboratory comparability, and access for independent verification, can underpin uniquely credible, system-wide traceability. World Forest ID was established to provide a unique non-profit model for building and stewarding these system-critical datasets, supporting the transparency needed to make traceability trustworthy at scale.

Looking ahead

The scientific foundations for chemical traceability of farmed shrimp are established. The priority now is scaling the approach to reflect broader real-world supply chains and regulatory needs. This will require investment in expanded reference datasets, the incorporation of temporal variation as production practices and environmental conditions change, inter-laboratory harmonization, participation from producers and exporting regions, and buy-in from buyers and certification schemes.

While this research focuses on shrimp, the approach has clear relevance for other globally-traded agricultural and extractive commodities, many of which are implicated in illegal and unsustainable deforestation as well as wider environmental and social risk.

Photo: Quang Nguyen Vinh

ACKNOWLEDGEMENTS:
Authors: Catherine Karr-Colque, Independent consultant, Resilio Advisory LLC2. Jade Saunders, Executive Director, World Forest ID. Expert review: Charles (Chip) Barber, Director, Natural Resources Governance & Policy, World Resources Institute. Tara Ganesh, Changing Markets Foundation

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