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SUBSTITUTION, MISLABELING, AND FRAUD IN THE SEAFOOD INDUSTRY

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Abstract

Illicit practices within global seafood supply chains pose major challenges to economic integrity, environmental sustainability, and public health. This paper reviews and integrates recent scientific investigations that examine the scale, drivers, and consequences of deceptive practices in seafood commerce. By combining evidence from species identification, market surveillance, and regulatory enforcement reports, the analysis demonstrates how opaque trade networks facilitate the commercialization of undeclared or illegally sourced aquatic organisms. These activities result in financial losses for consumers and legitimate operators, while simultaneously undermining fisheries governance. From a conservation standpoint, inaccurate product identification conceals the exploitation of threatened stocks and compromises biodiversity protection by distorting catch statistics and management assessments. Additionally, the circulation of incorrectly identified seafood products raises food safety concerns, including exposure to allergens, unexpected toxins and heavy metals, and inconsistent nutritional values. The paper underscores the growing importance of authentication tools, improved traceability technologies, and coordinated international regulatory frameworks. Addressing these interconnected issues requires an integrated approach that links economic oversight, biodiversity conservation, and food safety policies to promote transparency, sustainability, and consumer confidence in the seafood sector.

Key words*: aquatic biodiversity, economic adulteration, ethics, food safety, seafood fraud, supply chain, traceability.*

INTRODUCTION

Food fraud represents a deliberate act of deception carried out for economic gain through the misrepresentation of food products, ingredients, or labeling (Kennedy, 2021). Institutional reports have suggested that food fraud may generate substantial illicit profits globally, although precise estimates remain uncertain due to the covert nature of fraudulent activities (Kennedy, 2021; FDA, 2025).

In the seafood sector, which includes edible species from both marine and freshwater environments, fraud manifests primarily through species substitution, mislabeling, undeclared processing practices, and falsification of origin or production method (Luque & Donlan, 2019; Silva et al., 2021). Due to the high biodiversity of aquatic species, extensive product processing, and the globalization of supply chains, seafood has been consistently identified as one of the food categories most vulnerable to fraudulent practices (Visciano & Schirone, 2021).

Seafood plays a critical role in global food security, providing approximately 15% of animal protein intake and essential micronutrients for billions of people worldwide (FAO, 2024). Global fisheries and aquaculture production has reached unprecedented levels, totaling 223.2 million tons, including 185.4 million tons of aquatic animals and 37.8 million tons of algae. In 2022, global aquaculture production alone accounted for 130.9 million tons, with an estimated value of USD 312.8 billion, representing approximately 59% of total global fisheries and aquaculture production (FAO, 2024).

The European Union seafood market represents a major global hub for fisheries and aquaculture products, with total trade reaching €38.2 billion and 8.1 million tons in 2023, despite a slight decline in traded volumes. The market is characterized by high import dependency, with an estimated self-sufficiency rate of approximately 38%. In 2024, imports amounted to €29.9 billion, dominated by high-value species such as salmon, cod, and tuna (FAO,

2024). This structural dependence increases supply-chain complexity and exposure to fraud, particularly when traceability information becomes fragmented across multiple actors and jurisdictions (Blanco-Fernández et al., 2021).

Seafood fraud generates a wide range of negative consequences that extend beyond direct economic losses. From an economic perspective, fraudulent practices distort market competition, undermine consumer trust, and disadvantage compliant producers and retailers (Donlan & Luque, 2019). From a public health standpoint, mislabeling and species substitution may expose consumers to unexpected allergens, parasites, toxins, or unauthorized additives, particularly in raw or minimally processed products (Cohen et al., 2009; Asatryan et al., 2023). From a conservation and fisheries management perspective, fraudulent labeling obscures the true exploitation levels of fish stocks, masks illegal, unreported, and unregulated (IUU) fishing, and compromises biodiversity protection and stock assessment processes (Kroetz et al., 2020; Blanco-Fernández et al., 2021).

Despite increasing regulatory efforts and the development of advanced analytical tools such as DNA barcoding, metabarcoding, and complementary chemical approaches, seafood fraud remains widespread across global markets (Galimberti et al., 2013; Ahles et al., 2025). Existing studies often address isolated components of the phenomenon, including mislabeling prevalence, analytical detection methods, or regulatory frameworks, but less frequently integrate economic, food safety, and biodiversity dimensions within a single analytical framework. The objective of this review is to synthesize current scientific evidence on the main forms, drivers, and effects of seafood fraud, with particular emphasis on mislabeling and species substitution, detection methodologies, and traceability challenges within global and European seafood supply chains.

MATERIALS AND METHODS

Literature sources and selection criteria

This study is based on a narrative literature review combined with the analysis of official regulatory and monitoring frameworks related to seafood fraud. Scientific publications were identified through targeted searches in major bibliographic databases, including Web of Science, Google Scholar, and Google, focusing on peer-reviewed articles, review papers, and authoritative institutional reports relevant to seafood mislabeling, species substitution, food fraud, traceability, and authentication methods.

The literature search covered publications released primarily between 2010 and 2025, with earlier references included where necessary to provide historical or conceptual context. Search terms included combinations of keywords such as “seafood fraud”, “fish mislabeling”, “species substitution”, “food authenticity”, “DNA barcoding”, “seafood traceability”, and/or “fisheries fraud”. Studies were selected based on their relevance to the objectives of the review, methodological robustness, and contribution to understanding the economic, food safety, and biodiversity-related dimensions of seafood fraud.

Regulatory and institutional data sources

In addition to scientific literature, official documents and datasets from international and European institutions were consulted to contextualize seafood fraud within existing regulatory and control frameworks. These sources included reports and legislative documents from the Food and Agriculture Organization of the United Nations (FAO), the European Commission, and the U.S. Food and Drug Administration (FDA), as well as information from the EU Agri-Food Fraud Network and the Alert and Cooperation Network (ACN). These materials were used to describe regulatory approaches, monitoring systems, and reported fraud patterns, rather than as sources of quantitative experimental data.

Analytical framework

The collected literature and institutional information were analyzed qualitatively and organized thematically. Identified cases and findings were classified according to major categories of seafood fraud (economic fraud, food safety-related fraud, and fraud affecting biodiversity and fisheries management), types of fraudulent practices (e.g., mislabeling, species substitution, undeclared processing), and detection or authentication methods. This integrative approach allowed for a structured synthesis of current knowledge and facilitated

the identification of recurring patterns, knowledge gaps, and challenges associated with seafood fraud across global and European supply chains.

RESULTS AND DISCUSSIONS

Within the European Union regulatory framework, food fraud is defined as any intentional act or omission involving false, incorrect, or incomplete information, or the non-disclosure of required information, that affects the financial interests of the European Union (Directive (EU) 2017/1371). To address the scale and complexity of such practices in the agri-food sector, Regulation (EU) 2017/625 strengthened official control systems and consumer protection against fraud. In this context, food fraud notifications have been formally integrated into the Rapid Alert System for Food and Feed through the iRASFF platform (Regulation (EU) 2019/1715), highlighting the recognized prevalence and regulatory relevance of seafood fraud within European food control systems.

Forms and drivers of seafood fraud

The review of scientific literature and institutional reports indicates that seafood fraud is a multifaceted phenomenon driven by a combination of economic incentives, supply-chain complexity, and information asymmetry between producers, intermediaries, and consumers. High price differentials between species, market demand for premium products, and limited consumer ability to identify fish species, particularly in processed forms, represent key structural drivers of fraudulent practices (Luque & Donlan, 2019; Visciano & Schirone, 2021).

Seafood products are especially vulnerable to fraud due to the biological diversity of aquatic species, the frequency of processing steps such as filleting, freezing, or cooking, and the globalized nature of fisheries and aquaculture trade. As products move through increasingly complex supply chains involving multiple actors and jurisdictions, traceability information may become fragmented or lost, creating opportunities for intentional mislabeling or substitution (Blanco-Fernández et al., 2021). Fraud tends to concentrate downstream in the supply chain, at the level of wholesalers, retailers, and food service establishments, b where information asymmetry is greatest and direct oversight is limited.

Economic fraud and mislabeling

Economic fraud represents the most frequently reported form of seafood fraud and is primarily manifested through species substitution and mislabeling. Substitution typically involves replacing high-value species with lower-value alternatives that share similar sensory characteristics, such as color or texture, allowing fraudulent products to remain undetected by consumers (Donlan & Luque, 2019). Numerous studies have documented higher mislabeling rates in processed products, including fillets and sushi, compared with whole fish, suggesting that these practices are predominantly deliberate rather than accidental (Ahles et al., 2025).

Price differentials play a central role in motivating economic fraud. Species with high market demand but limited supply are more likely to be mislabeled, while abundant and lower-value species are frequently used as substitutes (Luque & Donlan, 2019). An important criterion for assessing the likelihood of fraud is therefore the price gap between the declared species and potential substitute species. Market prices for commercially important groups, such as white fish, vary substantially across Member States and seasonally, creating persistent economic incentives for species substitution, particularly in price-sensitive market segments. This pattern has been highlighted in official communications from the European Commission's EU Agri-Food Fraud Network, which coordinates actions against fish substitution across Member States (European Commission, https://food.ec.europa.eu/food-safety/eu-agri-food-fraud-network/eu-coordinated-actions/fish-substitution_en.).

Empirical evidence indicates that species substitution occurs at multiple stages of the seafood supply chain, with increasing prevalence downstream. Reported substitution rates rise from approximately 40% at the supplier level to 58% at fishmongers and up to 62% in restaurants, where information asymmetry between sellers and consumers is greatest. Bluefin tuna (*Thunnus thynnus*) is among the most frequently substituted species, accounting for up to 73% of documented cases. Seasonal patterns further reveal instances of

reverse substitution during fishing seasons, potentially indicating the laundering of illegally caught products into legal markets (Gordoa & Carreras, 2017).

In food service establishments, economic fraud is further facilitated using generic or ambiguous commercial names that mask underlying species diversity. Umbrella terms are often employed to obscure differences related to fishing area, stock status, price, or production method, limiting consumers' ability to make informed choices. Restaurant settings are particularly vulnerable, as seafood products are typically served in processed forms and consumers rely almost exclusively on menu descriptions. Consistent with this, mislabeling rates reported for restaurants are substantially higher than those observed in retail outlets, reflecting elevated information asymmetry and reduced opportunities for independent verification (Gordoa & Carreras, 2017; Ahles et al., 2025).

Product form strongly influences mislabeling rates. The highest overall mislabeling has been reported for sushi and sashimi products (67.5%), followed by other raw or minimally processed preparations such as ceviche, poke, roe, and seared products (54.7%). Intermediate rates are observed in cooked products (45.9%) and smoked products (29.4%), while substantially lower mislabeling rates characterize dried or jerky products (21.6%) and canned or retort products (16.5%). These patterns indicate that reduced visual identifiability and higher levels of processing significantly facilitate fraudulent practices, whereas standardized industrial processing and labeling requirements act as partial deterrents (Ahles et al., 2025).

Overall, economic fraud through mislabeling and species substitution results in direct financial losses for consumers and distorts market competition by disadvantaging compliant operators who adhere to labeling and traceability regulations. The concentration of fraudulent practices in downstream market segments, particularly within food service establishments, highlights the limits of upstream controls alone and underscores the need for integrated monitoring strategies that combine economic risk indicators, product-specific vulnerability profiling, and targeted enforcement across the entire seafood supply chain.

Food safety-related fraud

Beyond economic implications, seafood fraud raises significant food safety concerns. Species substitution may expose consumers to unexpected allergens, parasites, toxins, or chemical residues, particularly when substituted species have different biological or ecological characteristics from those declared on product labels (Cohen et al., 2009; Asatryan et al., 2023). These risks are amplified in raw or minimally processed products, such as sushi or sashimi, where pathogens or parasites are not eliminated through thermal processing.

Cases of mislabeling involving toxic or allergenic species, including pufferfish containing tetrodotoxin, illustrate the potential severity of food safety fraud when regulatory controls fail (Cohen et al., 2009). Additionally, undeclared additives or treatments used to enhance appearance or extend shelf life may pose further health risks and erode consumer trust in seafood markets. While not all instances of seafood fraud result in direct health hazards, the unpredictability of exposure underscores the importance of accurate labeling and effective authentication systems.

Fraud affecting biodiversity and fisheries management

Seafood fraud also has substantial implications for biodiversity conservation and fisheries management. Mislabeling and species substitution can obscure the true exploitation levels of fish stocks, thereby compromising stock assessments, management decisions, and conservation measures (Kroetz et al., 2020). By enabling products derived from illegal, unreported, and unregulated (IUU) fishing to be sold under false identities, fraudulent practices effectively facilitate the "laundering" of illegally harvested fish into legitimate markets.

A particularly concerning dimension of seafood fraud involves the substitution of semi-wild, threatened, or protected species with non-threatened ones. Several studies have documented cases in which endangered or heavily regulated species are marketed under alternative names to bypass conservation measures and trade restrictions (Muñoz-Colmenero et al., 2017). Iconic examples include Mediterranean bluefin tuna (*Thunnus thynnus*) and European sturgeon (*Acipenser*

sturio), as well as certain shark species sold as swordfish. In the case of bluefin tuna, long-standing illegal fishing pressure has resulted in actual catches exceeding authorized quotas, in some instances by substantial margins, directly undermining international recovery plans for the species.

In commercial seafood markets, molecular authentication methods, particularly DNA barcoding, have proven effective in detecting the fraudulent substitution of high-value species with lower-value alternatives, such as the replacement of cod or grouper with *Pangasius* (Miller & Mariani, 2010) or *Tilapia* (Pardo et al., 2016). These practices not only distort market dynamics but also conceal the exploitation of species subject to stricter management or conservation measures. DNA-based identification has additionally revealed cases in which bluefin tuna has been misidentified in favor of substitute species associated with food safety concerns, including escolar (*Lepidocybium flavobrunneum*), further illustrating the multifaceted consequences of species substitution (Lowenstein et al., 2009).

Evidence further indicates that species substitution often involves products originating from fisheries characterized by weak management frameworks or limited monitoring capacity. Substitutes such as tuna juveniles sold as anchovy, unregulated hake species (*Merluccius polli*), or other high-value taxa have been linked to IUU fishing activities in African waters, pointing to intentional and organized fraud rather than accidental mislabeling (Blanco-Fernández et al., 2021).

Such practices distort catch statistics, mask overexploitation, and shift fishing pressure onto unreported stocks, thereby impeding sustainable seafood production and consumption.

Incomplete or ambiguous labeling represents an additional challenge for fisheries management. Missing or imprecise information regarding species identity, origin, or production method creates uncertainty that hampers the differentiation between sympatric species and prevents accurate stock-specific management (Kroetz et al., 2020). This lack of transparency reduces the effectiveness of conservation measures and complicates enforcement efforts, particularly for species with overlapping distributions or similar commercial designations (Blanco-Fernández et al., 2021).

From a governance perspective, the complexity of seafood supply chains further exacerbates biodiversity-related fraud risks. As products move from producers to traders, processors, wholesalers, and retailers, control over traceability information diminishes, increasing opportunities for substitution and misrepresentation. While fisheries management and resilience research has traditionally focused on harvesting activities and fishers' livelihoods, comparatively less attention has been given to post-harvest sectors (Moonmoon et al., 2025), including processing, logistics, and retail, where fraudulent practices frequently materialize and where biodiversity impacts ultimately become visible (Rice et al., 2024).

Overall, seafood fraud undermines biodiversity conservation by disconnecting market signals from ecological reality. When species are sold under false identities, exploitation levels are underestimated, management responses are delayed or misdirected, and conservation priorities are distorted. These dynamics highlight the need to prioritize control efforts on highly valued and vulnerable species, strengthen species-specific traceability requirements, and integrate fraud detection more explicitly into fisheries management and biodiversity protection frameworks.

Molecular approaches for seafood authentication

The validation of food authenticity relies primarily on the analysis of protein profiles and/or DNA sequences. Protein-based approaches, including immunological assays and electrophoretic or chromatographic techniques such as high-performance liquid chromatography (HPLC) and thin-layer chromatography (TLC), have been successfully applied to fresh or minimally processed products. However, their effectiveness decreases substantially in heavily processed foods, where protein denaturation or degradation limits analytical resolution.

In contrast, DNA-based methods provide higher robustness across a wide range of food matrices, as DNA molecules are generally more stable and can be recovered even from small or degraded biological traces. As a result, molecular

approaches have become central to seafood authentication, particularly in contexts where morphological or biochemical identification is no longer possible (Galimberti et al., 2013).

Among DNA-based techniques, DNA barcoding has emerged as a standard tool for species identification in seafood products (Yang et al., 2024; Burke et al., 2025). This approach typically targets short, conserved mitochondrial markers, most commonly the cytochrome *c* oxidase subunit I (COI) gene in fish, allowing species-level identification through comparison with curated reference databases. DNA barcoding has proven effective for detecting species substitution across a wide range of product forms, including fillets, frozen products, cooked seafood, and sushi, and is widely applied in both research and regulatory monitoring (Galimberti et al., 2013).

Recent reviews indicate that DNA barcoding has expanded beyond single-locus identification to include multi-marker approaches and advanced technologies such as environmental DNA (eDNA) and next-generation sequencing, enhancing species discrimination in complex samples and broadening its applications in molecular authentication and biodiversity monitoring (Odah, 2023; Yang et al., 2024; Rani et al., 2026).

DNA metabarcoding extends the barcoding concept by enabling the simultaneous detection of multiple species within complex or mixed samples. Using high-throughput sequencing and universal primers, this approach allows the identification of entire species assemblages without the need for physical separation of individual components (Zhang et al., 2018; Xiong et al., 2022; Liang et al., 2026). DNA metabarcoding has been increasingly applied to processed seafood products, mixed preparations, and environmental samples, providing valuable insights into biodiversity composition and supporting fraud detection in multi-ingredient products (von Cräutlein et al., 2011; Yang et al., 2024).

From an ecological perspective, DNA barcoding addresses challenges associated with cryptic species complexes, providing evidence that morphologically similar populations may in fact represent distinct taxonomic entities requiring differentiated conservation and management strategies, as demonstrated for scalloped hammerhead sharks *Sphyrna lewini* (Quattro et al., 2013). Moreover, molecular identification remains one of the few effective tools for combating illegal wildlife trade, enabling the detection of protected CITES-listed species in highly processed products such as shark fins and sturgeon caviar (Fields et al., 2018). By exposing species substitution and laundering practices that obscure true exploitation levels, DNA barcoding directly supports biodiversity conservation and strengthens the enforcement of international fisheries management and wildlife protection frameworks.

While DNA-based methods are particularly powerful for species authentication, they do not provide direct information on geographic origin or production methods (Woolfe & Primrose, 2004; Gopi et al., 2018). Consequently, complementary analytical approaches have been explored. Stable isotope analysis has been used to support forensic assessments of catch origin in species such as Atlantic cod, although its accuracy is highly dependent on spatial resolution and baseline characterization (Wilson et al., 2024). Similarly, targeted molecular assays combining mitochondrial and nuclear markers have been applied to distinguish closely related species or detect hybrids, such as in the case of European and American eels, offering effective tools for identifying fraudulent labeling in high-risk markets (Ely et al., 2023; Stein et al., 2021).

More recently, non-molecular techniques such as portable X-ray fluorescence (pXRF) have been proposed as complementary screening tools for fisheries monitoring. By generating rapid, non-destructive elemental profiles, pXRF may support preliminary species discrimination and field-based decision-making, although its application for seafood authentication remains at an exploratory stage and requires further validation (Burke et al., 2025).

Overall, DNA barcoding and related molecular approaches represent core components of modern seafood authentication strategies. Their effectiveness is maximized when integrated with complementary analytical methods, standardized reference databases, traceability systems, and regulatory controls, forming a multi-layered framework for detecting and preventing seafood fraud.

Traceability challenges along the seafood supply chain

Despite advances in analytical authentication, traceability remains a critical challenge in combating seafood fraud. The increasing length and complexity of seafood supply chains, coupled with changing consumer preferences for processed and ready-to-eat products, significantly reduce transparency and complicate enforcement efforts (Luque & Donlan, 2019; FAO, 2024). As seafood products pass through multiple actors and jurisdictions, traceability information may become fragmented or lost, creating structural vulnerabilities that facilitate mislabeling and species substitution (Blanco-Fernández et al., 2021).

Inadequate or incomplete labeling, inconsistent use of commercial and scientific nomenclature, and limited harmonization of traceability requirements across jurisdictions further exacerbate these challenges. Such deficiencies hinder effective monitoring and enforcement, particularly for imported products originating from regions with heterogeneous regulatory frameworks and control capacities (European Commission, 2017; Visciano & Schirone, 2021).

Effective traceability systems therefore require not only technological solutions, such as digital tracking or molecular authentication tools, but also coordinated regulatory frameworks, stakeholder compliance, and enforcement capacity throughout the entire supply chain. To counter information fragmentation along the supply chain, the implementation of Blockchain technologies, as Nicolae et al. (2025) point out, offers a solution through the use of immutable ledgers. They ensure that data entered at the point of origin remains unchanged and verifiable by all actors involved, eliminating the possibility of altering species identification data at critical transfer points and facilitating transparent digital traceability from "ship to plate". Without accurate and complete traceability information, even sophisticated analytical methods may fail to prevent fraudulent products from reaching consumers or to support timely corrective actions (Galimberti et al., 2013; Kroetz et al., 2020). Consequently, strengthening traceability remains central to mitigating the economic, public health, and environmental impacts associated with seafood fraud.

Research limitations

This review is subject to several limitations inherent to its scope and methodological approach. First, the analysis is based primarily on published literature and official institutional reports, which may underrepresent the true extent of seafood fraud due to its covert nature and the likelihood of underreporting. Fraudulent practices that escape regulatory detection or are not documented in peer-reviewed studies are therefore not fully captured.

Second, the reviewed studies show substantial heterogeneity in terms of geographic coverage, sampling design, analytical methods, and product categories. Differences in study objectives, species targeted, market segments investigated, and detection techniques limit the direct comparability of reported mislabeling rates and fraud patterns across regions and time periods.

Third, most available data focus on downstream segments of the seafood supply chain, such as retail and food service establishments, while upstream stages, including harvesting, primary processing, and international trade, remain comparatively underrepresented. As a result, the precise points at which fraudulent practices are introduced into supply chains cannot always be conclusively identified.

Finally, although molecular authentication methods are extensively discussed, this review does not quantitatively compare the performance, cost-efficiency, or scalability of different analytical techniques. The effectiveness of detection tools is therefore evaluated qualitatively rather than through systematic benchmarking.

Challenges in fraud prevention and control

Several persistent challenges hinder effective prevention and control of seafood fraud. A major challenge arises from the complexity and length of seafood supply chains, which often involve multiple intermediaries, cross-border transactions, and heterogeneous regulatory frameworks. As products move from capture or harvest to final consumption, traceability information may become fragmented or lost, creating structural opportunities for mislabeling and species substitution.

Another critical challenge is the lack of harmonization in labeling requirements and

commercial nomenclature across jurisdictions. Inconsistent use of commercial names, incomplete labeling, and insufficient integration of scientific nomenclature reduce transparency and complicate enforcement, particularly for imported products originating from regions with variable control capacities.

From a methodological perspective, while DNA barcoding and metabarcoding provide powerful tools for species identification, they cannot independently resolve questions related to geographic origin, production method, or legality of capture. This limitation necessitates the integration of molecular tools with complementary analytical approaches and regulatory controls, which are not yet consistently implemented.

Enforcement capacity also remains uneven across regions. Limited inspection resources, coupled with the high volume of seafood products traded globally, mean that only a small fraction of products can be subjected to analytical verification. This imbalance between trade volume and control capacity allows fraudulent practices to persist despite advances in detection technologies.

CONCLUSIONS

The fish and seafood sectors represent a particularly vulnerable target for food fraud due to their large trade volume, high economic value, and continuously growing global demand. These characteristics create strong economic incentives for fraudulent practices, while the scale of production and trade limits the proportion of products that can be effectively inspected or analytically verified by control authorities.

This review highlights three major and interrelated dimensions of fish and seafood fraud: economic fraud, public health–related risks, and environmental and biodiversity impacts. While economic fraud primarily affects market transparency and consumer trust, health-related fraud may expose consumers to unexpected hazards, and environmental fraud undermines fisheries management, conservation efforts, and the sustainable use of aquatic resources.

Despite significant advances in analytical detection methods, including DNA barcoding, DNA metabarcoding, and emerging complementary tools such as portable X-ray fluorescence, fraud remains difficult to fully control. The length and complexity of seafood supply chains, often characterized by limited transparency and fragmented traceability from capture or harvest to the final consumer, allow fraudulent practices to persist and evade detection.

Within this context, accurate and standardized labeling remains a cornerstone of effective fraud prevention. The consistent use of country-specific authorized commercial names, complemented by unambiguous scientific nomenclature, would significantly improve product transparency and consumer awareness. Such an approach would facilitate species recognition, support regulatory enforcement, and enhance the effectiveness of analytical authentication methods, thereby contributing to more robust control systems across seafood supply chains.

Mitigating seafood fraud requires an integrated strategy that combines improved labeling practices, strengthened traceability frameworks, targeted analytical controls, and coordinated regulatory enforcement. Through such a multi-layered approach can the economic, health, and environmental impacts of seafood fraud be effectively reduced.

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