



Fraudulent Practices in the Fisheries and Aquaculture Sector: A Review of Detection Methods and Policy Approaches

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ABSTRACT

Seafood fraud is a persistent challenge in global fisheries and aquaculture, with significant implications for food security, consumer trust, international trade, and biodiversity conservation. This review synthesizes current knowledge on fraudulent practices in the sector, with emphasis on detection methods and policy approaches. Literature was systematically collected from *Scopus*, *Web of Science*, *ScienceDirect*, *SpringerLink*, and *Google Scholar* covering the period 2000–2025. Inclusion criteria focused on studies that documented fraud typologies, evaluated detection technologies, or analyzed policy and governance frameworks. The findings reveal that fraud takes multiple forms, including species substitution, mislabeling of origin, adulteration, and illegal, unreported, and unregulated (IUU) fishing. DNA barcoding and next-generation sequencing are widely applied for species authentication, while stable isotope analysis and spectroscopic methods support verification of geographic origin and adulteration. Digital innovations, such as blockchain traceability systems, represent emerging tools for supply chain transparency but face barriers to implementation. On the policy side, the European Union IUU Regulation and the United States Seafood Import Monitoring Program have advanced regulatory oversight, while eco-labeling and certification schemes (e.g., MSC, ASC) encourage industry compliance. Nevertheless, enforcement remains uneven across regions, particularly in developing countries with limited regulatory capacity. This review concludes that effective mitigation of fraud requires an integrated approach that combines technological advances, harmonized international traceability standards, and robust governance frameworks. Strengthening enforcement, building capacity in resource-limited regions, and raising consumer awareness are essential steps toward ensuring the integrity and sustainability of global seafood supply chains.

INTRODUCTION

Seafood is among the most globally traded food commodities, supplying over 3 billion people with nearly 20% of their animal protein intake (Willette *et al.*, 2021). This significant reliance on seafood underlines the importance of safeguarding its integrity in

marketplaces. However, the rapid growth of international trade in fisheries and aquaculture products exposes vulnerabilities, creating opportunities for fraudulent practices that undermine consumer trust and lead to significant economic losses (**Hanner *et al.*, 2011**). Such seafood fraud not only threatens marine biodiversity but also challenges the sustainability of fisheries and aquaculture systems (**Vartak *et al.*, 2014**; **Kroetz *et al.*, 2020**). Studies on the incorporation of sea moss (*Eucheuma cottonii*) into food matrices have shown improved nutritional and antioxidant profiles, supporting its value as a verified marine ingredient with organoleptic acceptability. These findings illustrate the positive potential of traceable aquaculture-derived products in enhancing consumer confidence (**Islamy *et al.*, 2024**).

Fraudulent activities in the seafood sector manifest in several forms, including species substitution, mislabeling of origin, adulteration, and document forgery. Moreover, illegal, unreported, and unregulated (IUU) fishing remains a critical concern (**Abbad *et al.*, 2016**; **Gorini *et al.*, 2023**). The economic incentives behind these practices often arise from complex and opaque global seafood supply chains, enabling cheaper species to be marketed as premium products, and facilitating IUU catches to enter regulated markets through mislabeling and falsified documentation (**Wong & Hanner, 2008**). The ramifications extend beyond consumer deception; they threaten the sustainability of fish populations and disrupt effective fisheries management (**Kroetz *et al.*, 2020**). In addition to economic and ecological impacts, fraudulent seafood practices may indirectly affect food safety, since compromised handling and substitution increase the risk of microbial contamination. Natural antimicrobial agents such as cuttlefish ink have shown promising antibacterial activity against aquatic pathogens like *Aeromonas hydrophila*, highlighting the potential of bioactive marine compounds in maintaining seafood quality (**Islamy, 2019**).

Detection of seafood fraud has advanced considerably with molecular approaches such as DNA barcoding and next-generation sequencing (NGS), which have emerged as gold standards for species authentication (**Cawthorn *et al.*, 2011**; **Valen *et al.*, 2024**). Research demonstrates that DNA barcoding effectively identifies mislabeled species, proving invaluable for improving traceability (**Korzik *et al.*, 2020**; **Tatulli *et al.*, 2020**). Additional techniques, like stable isotope analysis and spectroscopic methods, enhance the verification of geographic origin and potential adulteration of seafood products (**Grbin *et al.*, 2025**). Emerging digital innovations, such as blockchain technology for traceability, offer promising solutions to ensure greater transparency and accountability within seafood supply chains (**Mitchell *et al.*, 2019**).

In response to these challenges, policy measures have evolved significantly. The European Union (EU) has instituted the IUU Regulation (EC No. 1005/2008), which mandates catch documentation schemes to mitigate IUU fishing practices. Similarly, the United States has adopted the Seafood Import Monitoring Program (SIMP) targeting mislabeling and IUU imports (**Filonzi *et al.*, 2010**; **Marín *et al.*, 2018**). Industry

certification schemes, such as those developed by the Marine Stewardship Council (MSC) and Aquaculture Stewardship Council (ASC), further incentivize compliance and inform consumer choices while enhancing sustainable practices (**Filonzi et al., 2023**). Nonetheless, obstacles remain; enforcement challenges, uneven technology adoption, and governance gaps persist, particularly in developing countries with limited regulatory capacities (**Horreo et al., 2012**).

This review aims to synthesize the current knowledge regarding fraudulent practices in the fisheries and aquaculture sectors, emphasizing detection methods and policy approaches. Specifically, it focuses on categorizing common forms of fraud, evaluate existing and emerging detection technologies, and analyze policy and governance frameworks at both national and international levels. By integrating insights across scientific, technological, and policy dimensions, this review highlights both progress made and challenges that remain in the global effort to protect the integrity of seafood supply chains.

MATERIALS AND METHODS

Study design

This systematic literature review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (**Mulyadi et al., 2025**). Our objective was to systematically identify, evaluate, and synthesize the existing literature on fraudulent practices, detection methodologies, and policy frameworks related to the global fisheries and aquaculture sectors.

Literature search strategy

A systematic search of five electronic databases (Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar) was performed to identify relevant literature published between January 2000 and September 2025. The search strategy combined keywords across four conceptual groups using Boolean operators (AND/OR). The core search terms included:

- **Fraud Concepts:** ("fisheries fraud" OR "seafood fraud" OR "fish fraud" OR "aquaculture fraud") AND
- **Fraud Types:** ("mislabeling" OR "species substitution" OR "adulteration" OR "illegal fishing") AND
- **Detection & Verification:** ("detection method" OR "DNA barcoding" OR "isotope analysis" OR "spectroscopy" OR "traceability system" OR "blockchain") AND
- **Governance:** ("policy" OR "regulation" OR "governance" OR "compliance" OR "enforcement")

All identified records were imported into Zotero, where duplicates were systematically removed.

Eligibility criteria

Studies were included for final synthesis if they met the following inclusion criteria: (1) peer-reviewed original research articles, reviews, or formal policy papers; (2) published in the English language; (3) explicitly focused on fraudulent practices within the fisheries and/or aquaculture supply chains; and (4) presented primary data or substantive discussion on either fraud detection methods or relevant governance frameworks.

Studies were excluded if they were: (1) non-academic or grey literature (e.g., conference abstracts, editorials, opinion pieces) lacking a clear methodology; (2) focused on general topics such as food safety, environmental contaminants, or aquaculture productivity without a direct link to fraud; or (3) lacked sufficient methodological detail or policy analysis to contribute to the synthesis.

Screening process

The study selection process involved two stages. First, two reviewers independently screened the titles and abstracts of all unique records against the eligibility criteria. Any records deemed clearly irrelevant by both reviewers were discarded. Second, the full texts of the remaining potentially relevant articles were retrieved and independently assessed for eligibility by the same two reviewers. Any disagreements during the screening or eligibility assessment phases were resolved through discussion and consensus. Finally, a backward and forward citation search (snowballing) was performed on the reference lists of all included articles to identify any additional relevant studies missed by the initial database search.

Data extraction and synthesis

A standardized data extraction form was used to collect key information from each included study. Extracted data included: author(s) and publication year; geographic region of study; specific seafood commodity; type of fraudulent practice investigated (e.g., species substitution, origin mislabeling); detection method employed and its efficacy; and key policy or governance recommendations discussed.

Following extraction, a thematic synthesis approach was used to analyze the data. Information was coded and organized into three overarching analytical themes: (1) Typologies and prevalence of fraud in fisheries and aquaculture; (2) Advances and limitations of fraud detection technologies; and (3) Efficacy of current policy and governance frameworks.

Methodological quality assessment

The methodological quality of the included studies was independently appraised by two reviewers. For empirical studies, assessment criteria included the clarity of objectives, transparency of methodology, appropriateness of the detection method used, and reliability of the results. For policy papers and reviews, quality was assessed based

on the comprehensiveness of the review, clarity of argumentation, and the evidence base supporting the conclusions. Studies were not excluded based on quality, but the assessment results were used to weigh the contribution of each study to the final synthesis. The complete selection process is documented in the PRISMA flow diagram (Fig. 1).

RESULTS

Typologies of fraudulent practices

Our synthesis reveals that species substitution is the most prevalent and widely documented form of fraud in the global seafood trade, primarily driven by the economic incentive to replace high-value species with cheaper alternatives (**Table 1**).

Table 1. Thesis of major seafood fraud typologies, including a description, illustrative examples, and corresponding key references

Fraud Type	Description	Examples / Case Studies	References
Species substitution	Selling one species under the name of another, often cheaper species for premium markets	Snapper substituted with Acadian redfish; European hake replaced with pangasius	(Gorini <i>et al.</i> , 2023; Lawrence <i>et al.</i> , 2022; Wong & Hanner, 2008)
Mislabeling of origin	False claims of geographic origin, wild vs. farmed, or sustainability certification	Farmed salmon marketed as “wild-caught”; IUU-caught tuna labeled as sustainable	(Blanco-Fernandez <i>et al.</i> , 2021; Currò <i>et al.</i> , 2021; Helyar <i>et al.</i> , 2014; Vartak <i>et al.</i> , 2014)
Adulteration	Addition of non-declared substances to increase weight, texture, or appearance	Water or polyphosphate added to shrimp; gel-injected fish fillets	(Garcia-Vazquez <i>et al.</i> , 2010; Munguia-Vega <i>et al.</i> , 2021)
Illegal, unreported, unregulated (IUU) fishing	Catch obtained without authorization, underreporting, or using prohibited gear	IUU tuna and cod fisheries	(Helyar <i>et al.</i> , 2014; Kroetz <i>et al.</i> , 2020; Munguia-Vega <i>et al.</i> , 2021; Willette <i>et al.</i> , 2021)
Document fraud & traceability manipulation	Forgery of certificates, catch documents, or supply chain data	Fake catch certificates for EU imports	(Crona <i>et al.</i> , 2015; Filonzi <i>et al.</i> , 2010; Willette <i>et al.</i> , 2021)

The prevalence of seafood fraud is a critical concern that can significantly undermine consumer trust and ecological sustainability throughout the global seafood supply chain. One major form of fraud observed is species substitution, where a less expensive fish, such as pangasius, is sold as a more sought-after species like European hake (consistent with the example in Table (1)) often due to processing methods that obscure morphological identifiers (**Crona *et al.*, 2015**). This clandestine manipulation capitalizes on consumer demand for premium seafood products, leading to serious implications for fisheries management and consumer health (**Hellberg & Morrissey, 2010**).

Furthermore, mislabeling of geographic origin is closely intertwined with species substitution, where products meant to denote authenticity and sustainability are marketed under false claims. Instances of farmed salmon being misrepresented as wild-caught salmon are prevalent (**Cawthorn *et al.*, 2018**), while tuna sourced from Illegal, Unreported, and Unregulated (IUU) fisheries is sometimes marketed as sustainably harvested to appeal to environmentally conscious consumers (**Cawthorn *et al.*, 2011**). The exploitation of these fraudulent tactics contributes to the overarching issue of traceability and transparency in the seafood industry (**Kroetz *et al.*, 2020**).

In addition to substitution and misrepresentation, adulteration practices also pose a serious risk, wherein non-declared substances are added to seafood for weight or visual enhancement. Products are regularly found to contain additives such as water or phosphates, which leads to skewed consumer expectations regarding the quality and value of fish products (**Kotsanopoulos *et al.*, 2021**). This, coupled with document fraud involving the falsification of fishing certificates and other regulatory documentation, presents systemic challenges, particularly in regions with weak governance and enforcement. The ramifications of such practices extend beyond economics; species mislabeling can disrupt conservation efforts and contribute to the overfishing of already vulnerable species (**Hellberg & Morrissey, 2010; Vartak *et al.*, 2014**).

Efforts to combat these forms of fraud include the implementation of stricter regulatory frameworks and enhanced traceability protocols that leverage advances in DNA barcoding and other molecular techniques, effectively verifying species identity and tackling the challenges of consumer deception (**Cawthorn *et al.*, 2011; Kotsanopoulos *et al.*, 2021**). These technological interventions are essential for establishing additional layers of accountability within the seafood supply chain, ultimately aiming to protect both consumer interests and marine biodiversity.

Advances and limitations in detection methods

To combat these fraudulent practices, the scientific literature is dominated by molecular techniques, with DNA barcoding of mitochondrial genes (e.g., COI, CytB) representing the dominant analytical tool for species authentication (Table 2).

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Table 2. Overview of key methodologies for fraud detection and supply chain traceability in the fisheries and aquaculture sector

Method	Principle	Application in Fraud Detection	Advantages	Limitations	References
DNA barcoding (COI, CytB)	Sequence analysis of mitochondrial DNA	Species authentication, mislabeling detection	High accuracy, widely validated	Requires reference databases, not suitable for processed samples	(Serdiati <i>et al.</i> , 2024; Valen <i>et al.</i> , 2022)
Next-Generation Sequencing (NGS)	Massive parallel sequencing of mixed DNA	Detection of species in mixed or semi-processed seafood	Detects multiple species simultaneously	Costly, requires bioinformatics expertise	(Gallo <i>et al.</i> , 2019)
Stable isotope analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$)	Isotopic fingerprinting of origin	Distinguishes wild vs. farmed, geographic origin	Provides ecological insight	Requires large reference datasets	(Fiorino <i>et al.</i> , 2018; Jones <i>et al.</i> , 2016)
Spectroscopy (FTIR, NIR, NMR)	Spectral fingerprinting of chemical composition	Detection of adulterants, freshness, origin	Rapid, non-destructive	Needs chemometric models	(Chen <i>et al.</i> , 2020; Fiorino <i>et al.</i> , 2018)
Blockchain traceability	Digital ledger recording supply chain transactions	Verification of product authenticity, catch legality	Transparency, immutable records	Adoption barriers, integration costs	(Hara-Kudo & Kumagai, 2014; Tinacci <i>et al.</i> , 2018)

This method has proven highly effective against species substitution in lightly processed products but can be limited when applied to complex mixtures or highly degraded samples (Kroetz *et al.*, 2020). To address these shortcomings, next-generation sequencing (NGS) offers a more powerful approach for multi-species detection, allowing for the identification of several species within a single sample (Lindley *et al.*, 2022). By employing NGS, researchers can accurately assess seafood integrity and identify instances of fraud in a more comprehensive manner than traditional methods afford (O'Brien *et al.*, 2013).

Complementary methods to NGS are crucial for confronting other types of seafood fraud. For instance, stable isotope analysis is widely recognized as the primary tool for

verifying geographic origin claims, differentiating wild-caught from farmed seafood, which is critical for informed consumer choices and regulatory compliance (**Carvalho *et al.*, 2011**). Additionally, spectroscopic techniques such as Raman and Fourier-transform infrared (FTIR) spectroscopy allow for rapid detection of adulterants, including excess water in seafood products (**French & Wainwright, 2022**). These methods not only enhance the ability to detect fraud effectively but also maintain non-destructive testing capabilities, preserving the integrity of the samples for further analysis (**Hassoun *et al.*, 2019**).

While emerging digital tools like blockchain offer the promise of unprecedented improvements in supply chain transparency, facilitating tracking from catch to consumer, their practical application is still in the early stages. Significant barriers to adoption, such as high implementation costs and the need for industry-wide standardization, can hinder widespread deployment (**Bouzemrak *et al.*, 2018**). Integrated strategies combining molecular, isotopic, spectroscopic, and digital approaches may therefore be necessary to create a robust system capable of mitigating seafood fraud effectively (**Fox *et al.*, 2018**).

The evolving landscape of policy and governance

Regulatory responses to seafood fraud are increasingly robust, yet their effectiveness is contingent on enforcement capacity and supply chain transparency (Table 3).

Table 3. Policy and governance approaches addressing fisheries and aquaculture fraud

Policy Approach	Description	Regional / International Examples	References
Catch documentation schemes (CDS)	Certification of legal origin for imports	EU IUU Regulation (EC No. 1005/2008); US Seafood Import Monitoring Program (SIMP)	(Helyar <i>et al.</i> , 2014; Soyer <i>et al.</i> , 2017)
Eco-labeling and certification	Voluntary certification of sustainability	Marine Stewardship Council (MSC); Aquaculture Stewardship Council (ASC)	(He, 2022; Marchetti <i>et al.</i> , 2020)
Electronic traceability systems	Digital tracking of seafood from harvest to market	EU electronic catch certificates; Japan seafood traceability	(Gamboa-Delgado <i>et al.</i> , 2014; Khan <i>et al.</i> , 2020)
International cooperation	Regional fisheries management organizations	ICCAT, IOTC, PSMA enforcement	(Leonardo & Deeb, 2022; Soyer <i>et al.</i> , 2017)

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	(RFMOs), FAO Port State Measures Agreement		
National legislation	Domestic laws regulating labeling, traceability, and fraud penalties	US FDA seafood labeling law; Indonesian fisheries law No. 45/2009	(Leonardo & Deeb, 2022; Tolentino-Zondervan <i>et al.</i>, 2016)

The increasing robustness of regulatory responses to seafood fraud reflects a growing global recognition of the significant threats posed by illicit practices within fisheries and aquaculture. The establishment of catch documentation schemes (CDS), such as the European Union's IUU Regulation and the United States' Seafood Import Monitoring Program (SIMP), exemplifies vital policy efforts aimed at restricting market access for illegal products. These top-down initiatives mandate comprehensive catch documentation and traceability protocols, effectively setting a standardized baseline for legal fishery operations **(Helyar *et al.*, 2014; Soyer *et al.*, 2017)**.

In parallel, market-based initiatives, such as eco-labeling programs by the Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC), leverage consumer choice to enforce compliance for sustainability. However, the voluntary nature of eco-labeling limits its universal impact across all sectors of the seafood market **(Marchetti *et al.*, 2020)**. A critical challenge highlighted in the literature is the gap between policy implementation and practice, particularly in developing regions where infrastructural constraints and weak enforcement significantly exacerbate systemic vulnerabilities to fraud.

The necessity for electronic traceability systems has also been identified as pivotal in promoting transparency by facilitating the digital tracking of seafood from harvest to market, as showcased in initiatives like the EU electronic catch certificates and Japan's traceability programs **(Lewis & Boyle, 2017; Cromwell *et al.*, 2025)**. Moreover, international cooperation through Regional Fisheries Management Organizations (RFMOs) and adherence to the FAO Port State Measures Agreement further strengthens the frameworks within which fisheries are governed, ensuring compliance across borders **(Ogawa & Reyes, 2021; Barnes, 2024; Li, 2025)**.

Ultimately, the effectiveness of these regulatory measures is contingent upon their enforcement capacity and the transparency of the seafood supply chain. Persistent adaptation of fraudulent practices highlights the need for ongoing innovation in both technology and policy to outpace the evolving methods of deception in global fisheries **(Fox *et al.*, 2018; Rodriguez-Diaz *et al.*, 2025)**. As the regulatory landscape evolves, it remains imperative to address the intersection of policy, enforcement, and market

dynamics to dismantle the frameworks enabling fraud and to bolster the sustainability of seafood practices globally.

DISCUSSION

Fraudulent practices in the fisheries and aquaculture sector remain a persistent challenge, threatening not only economic stability but also food security, consumer trust, and biodiversity conservation. The findings from this review highlight three interlinked dimensions of the problem: (1) the diversity of fraudulent practices, (2) the evolution of detection and verification methods, and (3) the effectiveness and limitations of policy approaches.

Typologies and drivers of fraud

As summarized in Table (1), fraudulent activities within the seafood industry encompass a wide range of practices, including species substitution, mislabeling of origin, adulteration, and document fraud associated with illegal, unreported, and unregulated (IUU) fishing. Species substitution remains the most frequently reported form of fraud globally, where lower-cost species are marketed as premium products, such as the sale of tilapia labeled as snapper (**Grbin *et al.*, 2025; Marín, 2025**). These deceptive practices are primarily driven by economic incentives, the complexity of seafood supply chains, and uneven enforcement capacities across regions (**Lee *et al.*, 2021**).

IUU fishing, while often categorized separately, intersects significantly with fraudulent labeling and traceability manipulation, further compromising market integrity (**Hanner *et al.*, 2011; Fox *et al.*, 2018**). The relationship between low enforcement capacity in developing regions and the prevalence of fraud is notable, as nefarious actors exploit these systemic vulnerabilities to maximize profit while undermining sustainability efforts.

Advances in detection methods

The evolution of detection technologies has played a crucial role in combating seafood fraud (Table 2). DNA-based approaches, particularly DNA barcoding, remain the gold standard for species authentication due to their high reliability and accuracy, effectively revealing mislabeling and substitution cases (**Carvalho *et al.*, 2011; Lawrence *et al.*, 2022**). However, challenges arise when applying these methods to processed products where DNA may be degraded (**Cawthorn *et al.*, 2011**). Complementary techniques such as stable isotope analysis and spectroscopy have shown effectiveness in verifying geographic origin, production methods, and identifying adulterants (**Carvalho *et al.*, 2011; French & Wainwright, 2022**). Furthermore, the advent of next-generation sequencing (NGS) allows for the simultaneous detection of multiple species in complex mixtures, surpassing the limitations imposed by traditional

methods. Integrative aquaculture systems, such as those incorporating macroalgae like *Kappaphycus alvarezii*, contribute to both traceability and product authentication by enhancing ecosystem-based production transparency. Such models demonstrate how nutrient recycling and product bioactivity can be aligned with anti-fraud strategies through sustainable certification systems (**Islamy et al., 2025**).

Digital innovations like blockchain technology have also emerged as promising solutions for real-time supply chain transparency; however, their implementation is often hindered by high costs and insufficient infrastructure in various regions. Collectively, these advancements highlight the need for a multi-faceted approach combining traditional and cutting-edge detection methodologies to enhance monitoring capabilities in the seafood supply chain.

Policy and governance perspectives

Regulatory responses to seafood fraud have strengthened over time, particularly in regions like the EU and the United States. Instruments such as the EU IUU Regulation (EC No. 1005/2008) and the US Seafood Import Monitoring Program (SIMP) provide vital frameworks for traceability and import control (**Soyer et al., 2017; Marchetti et al., 2020**). Eco-labeling and certification schemes, such as the Marine Stewardship Council (MSC) and Aquaculture Stewardship Council (ASC), further contribute to promoting compliance by incentivizing industry adherence to sustainable practices (**Lawrence et al., 2022**). However, the effectiveness of these mechanisms varies, with many developing countries grappling with inadequate enforcement capabilities and lacking the necessary infrastructure for comprehensive digital traceability. Strengthening the ecological foundations of aquaculture governance requires integration with bioremediation and waste management innovations. The use of indigenous bacterial isolates for wastewater treatment demonstrates how local microbial resources can support sustainable aquaculture and prevent environmental misreporting in certification systems (**Pardamean et al., 2021**).

This discrepancy underscores the importance of international cooperation through regional fisheries management organizations (RFMOs) and agreements such as the FAO Port State Measures Agreement, which can help synchronize efforts against IUU fishing and enhance global fisheries governance.

Challenges and research gaps

Despite notable progress, significant gaps in research and practice remain. A predominant concern is the geographical bias in current detection studies, which often focus on developed markets, leaving fraud in developing regions underreported (**Lawrence et al., 2022**) due to systemic issues such as limited funding, lack of analytical infrastructure, and weak regulatory capacity. Moreover, the integration of molecular,

chemical, and digital methods into a unified and harmonized framework for monitoring seafood fraud is still nascent, limiting the overall efficacy of existing systems (Di Pinto *et al.*, 2015; Pappalardo *et al.*, 2022). Consumer awareness and demand for transparency also lag behind, weakening the market-driven pressure that could otherwise propel demand for verified and sustainably sourced seafood (Munguia-Vega *et al.*, 2022). Bioactive compound profiling from marine and coastal plants has also emerged as a supportive analytical approach for detecting adulteration or evaluating antioxidant integrity in seafood products. For example, *Ipomoea pes-caprae* extracts possess significant antioxidant and bioactive potential comparable to vitamin C, underscoring the role of natural phytochemicals in maintaining product authenticity and quality control (Islamy *et al.*, 2024).

Future directions

To effectively address seafood fraud in fisheries and aquaculture, future efforts should prioritize: (1) the development of cost-effective and deployable detection technologies suitable for low-resource settings; (2) the harmonization of global traceability standards to close loopholes within supply chains; (3) enhanced collaboration among governments, industry stakeholders, and civil society to foster accountability and transparency; and (4) increased investment in consumer education initiatives to promote demand for verified products. A comprehensive approach, integrating advanced scientific methods within robust policy frameworks, represents the most promising path forward for reducing fraudulent practices and ensuring integrity across global seafood markets.

CONCLUSION

Fraudulent practices in the fisheries and aquaculture sector pose significant threats to global seafood markets, undermining consumer confidence, distorting trade, and jeopardizing the sustainability of aquatic resources. This review shows that fraud manifests in diverse forms, from species substitution and mislabeling to IUU fishing and document forgery. Advances in detection technologies—particularly DNA-based methods, isotope analysis, spectroscopy, and digital traceability—have substantially improved the ability to identify and monitor fraudulent activities. However, technological progress alone is insufficient without robust governance frameworks.

Policy initiatives such as catch documentation schemes, eco-certification programs, and international agreements have strengthened fraud prevention, but enforcement gaps remain, especially in developing regions with limited regulatory capacity. The future of fraud mitigation in fisheries and aquaculture will depend on integrating science, technology, and governance within a coordinated global strategy.

To move forward, stakeholders should prioritize:

1. Wider adoption of cost-effective, field-deployable detection tools.
2. Harmonization of international traceability and labeling standards.

3. Strengthening enforcement and capacity building in resource-limited regions.
4. Promoting consumer awareness and demand for transparent, verified seafood.

A combined approach, where advanced detection methods are embedded within effective policy frameworks and supported by international cooperation, offers the most promising pathway to reducing fraud and ensuring the integrity, sustainability, and equity of the global seafood sector.

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