QUALITY CONTROL OF TRADITIONAL FISH PRODUCTS FROM THE DANUBE DELTA: FROM CONTAMINANT MONITORING TO AUTHENTICITY TESTING

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Abstract

This review examines the quality control of traditional fish products from the Danube Delta, such as smoked Pontic shad and fish roe salads, some of which are protected under EU quality schemes. Scientific literature, EU regulations and good practice guides were analysed to identify the main control parameters and the methods used to assess them. The critical hazards include heavy metals, polycyclic aromatic hydrocarbons generated by traditional smoking, histamine and pathogenic microorganisms, while species substitution, particularly in sturgeon products, raises authenticity concerns. Chromatographic, spectrometric and molecular methods allow the assessment of these parameters, but their application by small-scale producers remains limited. By linking contaminant monitoring with authenticity testing, this review provides an integrated framework for the control of these heritage products.

Key words: *heavy metals, histamine, polycyclic aromatic hydrocarbons, smoked fish, species identification*

INTRODUCTION

Traditional foods are products whose ingredients, recipes or processing methods have been passed down across generations and remain linked to a specific territory and its culture [1]. The Danube Delta is a UNESCO Biosphere Reserve and a Ramsar wetland [2]. A total of 136 fish species, including marine species, have been reported for the Danube Delta Biosphere Reserve, representing more than 70% of Romania's ichthyofauna [3].

The Pontic shad (*Alosa immaculata*) is a wild species that migrates from the Black Sea into the Danube and is caught only during its spawning migration [4]. A recent assessment in the Romanian Danube estimated an exploitation rate of E = 0.68, above the reference exploitation level of 0.50, which the authors interpreted as overexploitation [5]. Three traditional fish products from the region are protected under EU quality schemes: "Scrumbie de Dunăre afumată" and "Salată cu icre de știucă de Tulcea" as protected geographical indications (PGI), and "Salată tradițională cu icre de crap" as a traditional speciality guaranteed (TSG) [4, 6-9]. Such products have a broad consumer base: in a recent survey of 371 respondents, 73.9% reported eating fish roe or roe salad, and expiration date, colour and smell were the most frequently cited selection criteria [10].

Quality control of these products covers compliance with the product specification, freshness indicators and safety hazards [11, 12]. The main chemical hazards are heavy metals, for which elevated cadmium concentrations have been reported in Lower Danube fish, and polycyclic aromatic hydrocarbons (PAHs) formed during traditional smoking [2, 13, 14]. Shad

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The manuscript was received: 13.10.2026
Accepted for publication: 16.11.2026

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belongs to the family Clupeidae and is therefore subject to histamine criteria, and both smoked fish and roe salads are ready-to-eat foods that must meet the *Listeria monocytogenes* criteria [15]. Authenticity is an equally important concern, as genetic and isotopic surveys have revealed mislabelled, counterfeit and illegally sourced sturgeon products in the Lower Danube region [16, 17].

EU hygiene legislation allows derogations for foods with traditional characteristics without relieving operators of their food safety obligations [18]. Chemical contamination and product authenticity in the Lower Danube region have, however, been investigated in separate lines of research [2, 14, 16]. This review therefore examines the main quality and safety control parameters of traditional fish products from the Danube Delta, evaluates the analytical approaches available for contaminant monitoring and authenticity testing, and proposes an integrated assessment framework aligned with European legislation.

MATERIAL AND METHOD

The present work is a narrative review of the scientific literature on the quality control of traditional fish products from the Danube Delta [19]. This approach was selected to allow a critical synthesis of heterogeneous evidence, including analytical surveys, risk assessments, legislation and product specifications [19]. Given the differences in matrices, study designs, analytical methods and reporting units, a quantitative meta-analysis was not considered appropriate.

The literature search was conducted using PubMed and the Directory of Open Access Journals (DOAJ), supplemented by searches on the ScienceDirect and MDPI publishing platforms and Google Scholar. Search terms combined the products and species ("Pontic shad", "*Alosa immaculata*", "smoked fish", "fish roe", "caviar", "sturgeon", "Danube Delta") with hazards and methods ("heavy metals", "polycyclic aromatic hydrocarbons", "dioxins", "histamine", "*Listeria monocytogenes*", "lipid oxidation", "authenticity", "DNA barcoding", "stable isotopes"). Legislation, product specifications, Codex Alimentarius standards, EFSA opinions and official notices of the Romanian National Sanitary Veterinary and Food Safety Authority (ANSVSA) were retrieved from EUR-Lex, the eAmbrosia register and the issuing institutions' websites.

The search primarily covered publications from 2000 to 2026, with priority given to studies published after 2015, while selected earlier foundational publications were retained where necessary [20]. Studies were included if they reported data on fish from the Danube Delta, the Lower Danube or the north-western Black Sea, or addressed hazards, quality parameters or analytical methods relevant to smoked fish, roe products and sturgeon products; comparative studies from other regions were used only where regional data were lacking. Non-peer-reviewed publications were excluded, except for official regulatory documents, institutional reports, conservation communications and food safety notices, as were articles not available in English or Romanian. A total of 53 references were included and organised into six themes: product specifications, physicochemical parameters, chemical contaminants, biological hazards, authenticity and an integrated control framework.

RESULTS AND DISCUSSION

Traditional fish products of the Danube Delta: processing and product specifications

In March 2023, Romania had 73 names registered under EU quality schemes, a small share of the EU total, and the traditional carp roe salad was its only

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registered TSG [21]. The three Danube Delta products were registered under Regulation (EU) No 1151/2012 [22], which was repealed by Regulation (EU) 2024/1143; registered names remain protected, and the product specification remains the reference document for verifying conformity [23]. The main requirements of the three specifications are compared in Table 1 [4, 9, 11].

"Scrumbie de Dunăre afumată" is a whole, dry-salted and cold-smoked Pontic shad made only from wild fish caught in a defined sector of the Lower Danube; the specification states that fish caught outside this area have a low fat content and a heavy parasite load [4]. The salt level is checked by tasting, and the specification sets no limits for salt or moisture [4]. The two roe salads are emulsions of salted roe with sunflower oil, carbonated water and lemon juice; the Tulcea specification excludes synthetic food additives, whereas the carp roe salad specification excludes preservatives, acidifiers, colourants, flavourings, emulsifiers and stabilisers [9, 11].

Table 1 Requirements of the product specifications for traditional fish products from the Danube Delta registered under EU quality schemes

Parameter	Scrumbie de Dunăre afumată (PGI)	Salată cu icre de știucă de Tulcea (PGI)	Salată tradițională cu icre de crap (TSG)	Source
Registration act	Reg. (EU) 2018/1878	Reg. (EU) 2021/898	Reg. (EU) 2021/1723	[6-8]
Raw material	Wild Pontic shad caught in the Danube between Cotul Pisicii and the river mouths, up to the 20 m isobath	Salted pike roe and salted Danube Delta fish roe	Salted carp roe (wild or farmed) and roe of cyprinids, percids and bream	[4, 9, 11]
Link with area	Catching in the defined Danube sector; processing in the Danube Delta Biosphere Reserve and Frecăței commune (Tulcea County)	All production stages in the defined area	No geographical restriction under the TSG scheme	[4, 11, 23]
Main processing steps	Freezing/thawing; dry salting ≤5 days; drying 6-10 h; cold smoking ≤35 °C	Salting and maturing of roe; emulsification	Salting (80 g/kg, ~3 days); maturing 10 days at 14-18 °C; emulsification	[4, 9, 11]
Composition requirements (% of finished product)	Fat ≥11%	Roe ≥29% (pike ≥15%; Delta roe ≤14%); moisture ≤30%; fat ≥63%; protein ≥6.2%; NaCl ≤5%; acidity (citric acid) ≤1%	Roe ≥24.5% (carp ≥12.5%; freshwater roe mix ≥12%); fat ≥63%; moisture ≤30%; NaCl ≤5%; protein ≥4%; acidity ≤1%	[4, 9, 11]
Physical characteristics	250-400 g; 25-30 cm; golden, metallic skin	White to yellowish-white cream with whole pike roe grains	Homogeneous white cream with orange carp roe grains	[4, 9, 11]
Maximum process temperature	35 °C (smoking)	Not stated in the published summary	40 °C (≤3 h, roe pre-treatment)	[4, 9, 11]

Note: *PGI = Protected Geographical Indication; TSG = Traditional Speciality Guaranteed [22].*

Both roe salad specifications set minimum roe contents and physicochemical limits, so identification of the roe species is a direct conformity criterion, whereas smoked shad is defined mainly by weight, length, colour and a minimum fat content

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[4, 9, 11]. None of the specifications describes a step validated as a lethal treatment for vegetative pathogens, so product safety depends on raw material quality, effective salting, temperature control and the prevention of recontamination [4, 9, 20].

Sturgeon products are not registered under EU quality schemes but belong to the same fishing tradition [16]. The Danube sturgeons have been protected under CITES since 1998, and since 2021 Romania has banned the fishing and sale of wild sturgeon indefinitely, so sturgeon meat and caviar on the Romanian market must come from aquaculture or other legal sources [16, 24].

Physicochemical and freshness parameters

For smoked shad, physicochemical quality depends first on the raw material, whose composition changes during the spawning migration (Table 2) [25]. Muscle lipid content decreased from 18.60% at the Sfântu Gheorghe arm to about 17.6% upstream, and the Fulton condition index fell from 1.28 to 1.13, which the authors attributed to the use of fat reserves during migration [25]. These raw-muscle values exceed the 11% minimum fat content of the finished product, but they cannot prove conformity or origin, because processing alters moisture and therefore the relative lipid content [4, 25].

Table 2 Proximate composition of Pontic shad (*Alosa immaculata*) muscle at three sampling stations on the Danube during the 2020 spawning migration

Sampling station	Moisture (%)	Protein (%)	Lipids (%)	Ash (%)	Fulton condition index	Source
Sfântu Gheorghe arm	63.03 ± 2.18	16.56 ± 0.86	18.60 ± 1.91	1.27 ± 0.05	1.28	[25]
Isaccea (river km 103)	63.38 ± 3.49	16.96 ± 1.07	17.62 ± 3.48	1.11 ± 0.09	1.15	[25]
Chiscani (river km 197)	63.17 ± 1.08	17.41 ± 0.59	17.65 ± 1.17	1.26 ± 0.09	1.13	[25]

Note: *Central values ± standard deviation for raw muscle, as reported by the authors (n = 15 per station).*

Salt is the main preservative hurdle in cold-smoked fish and salted roe, and its effect depends on its concentration in the aqueous phase [26]. Because the smoked shad specification sets no limit for salt or moisture, water-phase salt can be measured but not assessed against the specification [4]. For the carp roe salad, the maximum values of 5% NaCl and 30% moisture correspond to about 14.3% water-phase salt, but as both are upper limits, this calculation sets neither a minimum nor a maximum for the finished product [9]. In commercial salted roe products, lumpfish and capelin roe had 2.9-3.1% water-phase salt and pH 5.12-6.28 [27]. The same study found undeclared lactic acid and sorbic acid above the EU maximum level in some products, so analysis of organic acids and preservatives can support conformity checks of the protected salads, provided the results are interpreted together with the ingredients and processing [9, 11, 27].

EU limits for total volatile basic nitrogen (TVB-N) of 25-35 mg N/100 g apply to specified groups of unprocessed fishery products that do not include Clupeidae or Cyprinidae, although operators remain obliged to place only fresh and safe fishery products on the market [12, 28]. TVB-N can still track deterioration during storage: in traditionally hot-smoked trout stored at 2-4 °C, it rose from 10.51 to 19.47 mg/100 g over 30 days [29].

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Lipid oxidation is relevant for smoked shad because of its high lipid content [25]. In Black Sea shad, n-3 polyunsaturated fatty acids decreased after steaming and frying, although cold smoking was not examined [30]. Similarly, thermal processing promotes lipid oxidation and the formation of aldehydes, alcohols and ketones in other PUFA-rich muscle foods such as quail meat [31]. Oxidation is quantified by indices such as peroxide value and p-anisidine value, both used to follow lipid oxidation in cold-stored carp [32]. None of these indices is included in the specifications, and the Codex standard treats rancidity only as a sensory defect [4, 9, 26].

Chemical contaminants

EU maximum levels for the contaminants relevant to the species used in Danube Delta products are summarised in Table 3 [13]. No specific maximum levels exist for roe or roe salads, so compliance depends on the contaminant level of the roe, on processing factors and on the proportion of roe set in the specification [9, 11, 13].

Table 3 EU maximum levels for chemical contaminants relevant to the fish species used in traditional Danube Delta products

Contaminant (unit)	Pontic shad	Pike (Tulcea roe salad)	Carp (carp roe salad)	Sturgeon	Remarks	Source
Lead (mg/kg wet weight)	0.30	0.30	0.30	0.30	Muscle meat	[13]
Cadmium (mg/kg wet weight)	0.050	0.050	0.050	0.050	Higher levels only for some marine species	[13]
Mercury (mg/kg wet weight)	0.50 (species not listed separately)	1.0	0.30 (Cyprinidae)	1.0 (*Acipenser* spp.); 0.50 (*Huso huso*)	1.0 mg/kg entry lists only *Acipenser* sturgeons	[13]
Inorganic arsenic (mg/kg wet weight)	0.10	0.10	0.10	0.10	From 8 October 2025; 0.50 only for listed species (e.g. herring)	[33]
Benzo[a]pyrene / PAH4 (µg/kg)	2.0 / 12.0	Not applicable	Not applicable	2.0 / 12.0 if smoked	No Romanian derogation (Art. 7)	[13]

Note: *PAH4 = sum of benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene and chrysene. Limits for metals refer to the muscle meat of the raw fish, whereas the benzo[a]pyrene and PAH4 limits refer to the smoked product. No product-specific maximum levels have been set for roe or roe salads; for these products, the limits for the ingredients and the provisions of Article 3 of Regulation (EU) 2023/915 on processing factors and ingredient proportions must be considered [13].*

Heavy metals

In 21 adult sturgeons from the north-western Black Sea and the Lower Danube, Zn, Cu and Cd were highest in the liver, and Cd and Cu exceeded the consumption limits applied by the authors in the liver of all three species and in the muscle of stellate sturgeon [14]. These exceedances cannot be equated with non-compliance with the current EU maximum levels, which apply to muscle meat and do not include copper [13]. In Pontic shad from the Serbian Danube,

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muscle had the highest arsenic concentration of the tissues analysed [34]. Cd in the muscle of commercial fish exceeded 0.05 mg/kg between Galați and Tulcea and in Danube Delta lakes [35], and in the Babina-Cernovca sector Cd was found in all eight species at 0.14-0.25 mg/kg [2]. Upstream, near Belgrade, muscle concentrations of carp, silver carp and wels catfish remained below EU limits [36].

These studies differ in species, tissues, analytical methods and reporting basis, and the Babina-Cernovca data were obtained by EDXRF on lyophilised muscle without certified reference materials [2]. Because EU maximum levels refer to wet weight, concentrations measured in dried material must be converted before comparison, and results intended for official control must meet the applicable sampling and analytical performance requirements [13, 37]. Total arsenic values cannot be compared with the inorganic arsenic limits applicable since 8 October 2025, because arsenic speciation was not determined [2, 33]. All these studies analysed raw fish, and none reported contaminants in smoked shad, salted roe or roe salads [2, 14, 34, 35].

Polycyclic aromatic hydrocarbons

The derogation for traditionally smoked fish in Article 7 of Regulation (EU) 2023/915 covers only Latvia, Finland and Sweden, so smoked Danube shad must meet the general limits of 2.0 µg/kg benzo[a]pyrene and 12.0 µg/kg PAH4 [13]. In 15 samples from three Romanian smokehouses, benzo[a]pyrene reached 8.4 µg/kg and PAH4 38.8 µg/kg in fish smoked directly over logs or chips, whereas most samples smoked indirectly were below the limit of quantification [38]. Benzo[a]pyrene was not detected in hot-smoked trout smoked with beech and cherry sawdust [29]. Traditionally smoked freshwater fish from Poland had mean PAH4 contents of 2.73-8.23 µg/kg [39], whereas in Latvia PAH4 values for several smoked fish categories exceeded 12.0 µg/kg, and traditionally smoked mackerel contained 15.30 µg/kg compared with 4.34 µg/kg in industrially smoked mackerel [40]. Smoking conditions and fuel type are therefore important determinants of PAH formation [38, 40]. The shad specification does not define the wood species, the smoke generation method or PAH testing, and no product-specific study reporting PAH levels in smoked Danube shad was identified in the literature reviewed [4].

Dioxins and polychlorinated biphenyls

The combined toxicity of dioxins and dioxin-like PCBs is expressed in toxic equivalents (TEQ) [41]. EFSA established a tolerable weekly intake of 2 pg TEQ/kg body weight in 2018 and lowered it to 0.6 pg TEQ/kg body weight in 2026 using the WHO 2022 toxic equivalency factors; both are health-based guidance values rather than maximum levels in food [41, 42]. Because these compounds accumulate in fat, Pontic shad, with a raw muscle lipid content of 17-19%, is a relevant candidate for monitoring [25]. For non-dioxin-like PCBs, shad as a diadromous species falls under the general limit of 75 ng/g, whereas wild carp and pike fall under the 125 ng/g limit for wild freshwater fish [13]. No data on dioxins or PCBs in these raw materials or products were identified in the literature reviewed [2, 13].

Biological hazards

None of the three products receives a validated lethal heat treatment, so their biological safety depends on raw material quality, salting, the cold chain and hygiene [4, 9, 20]. The applicable criteria are summarised in Table 4 [15, 26].

Histamine is a chemical hazard formed through microbial activity in fish of histidine-rich families such as Clupeidae [15, 43]. EFSA reported no observed adverse effects at intakes of up to 50 mg per meal in healthy individuals, while lower amounts may be relevant for histamine-

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intolerant individuals [43]. Smoked shad is dry-salted and cold-smoked rather than enzyme-matured in brine, so the general EU criterion applies [4, 15]. The shad specification requires the fish to be chilled in ice water immediately after capture, but it sets no histamine testing, and no product-specific histamine data for smoked Danube shad were identified [4].

Table 4 Criteria and control measures for the main biological hazards in traditional Danube Delta fish products

Hazard	Products concerned	EU requirement	Codex guidance (non-binding)	Source
Histamine	Smoked shad (Clupeidae)	n = 9, c = 2; m = 100 mg/kg, M = 200 mg/kg (mean ≤ m; ≤2 units between m and M; no unit > M)	Mean ≤10 mg/100 g; no sample unit >20 mg/100 g	[15, 26]
Listeria monocytogenes	Smoked shad, roe salads (ready-to-eat)	n = 5, c = 0; foods able to support growth: not detected in 25 g throughout shelf life, unless ≤100 cfu/g is demonstrated (from 1 July 2026); foods unable to support growth: ≤100 cfu/g	Prevention of recontamination; storage at ≤5 °C for aerobically packed smoked fish	[15, 26, 45]
Clostridium botulinum	Smoked shad, especially in reduced-oxygen packaging	No microbiological criterion	Within the scope of the smoked fish standard: storage ≤3 °C; in reduced-oxygen packaging, 3-3.5% water-phase salt combined with refrigeration may be required	[15, 26]
Parasites	Smoked shad; salted roe	Products eaten raw or salted, marinated or otherwise insufficiently treated: freezing at −20 °C for ≥24 h or -35 °C for ≥15 h throughout the product (parasites other than trematodes), unless exempted	No live parasites; visible parasites treated as defects	[26, 48]

Note: *n = number of sample units comprising the sample; c = number of sample units that may give values between m and M (histamine) or above the limit (*Listeria monocytogenes*); m and M = limits used to assess the results of individual sample units; cfu = colony-forming units [15].*

Listeria monocytogenes is the main microbiological hazard for ready-to-eat fish products such as cold-smoked fish and roe salads [15, 20]. In the 2010-2011 EU baseline survey, it was detected in 10.3% of ready-to-eat fish samples at the end of shelf life, and 1.7% exceeded 100 cfu/g [44]. From 1 July 2026, foods able to support its growth must comply with absence in 25 g throughout shelf life, unless the producer demonstrates that 100 cfu/g will not be exceeded [45]. Whether a product supports growth depends on its pH, water activity and shelf-life conditions, which the roe salad specifications do not set [9, 11, 15]. In May 2026, ANSVSA published two recalls of herring roe salads from the same Romanian producer after *L. monocytogenes* was detected [46, 47], whereas it was not detected in salted roe products from the

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Italian market [27]. Because brining areas are among the most contaminated sites in smoked fish production, preventing recontamination after salting is a key control measure [20].

The EU sets no microbiological criterion for *Clostridium botulinum* in fish products [15]. The Codex standard identifies storage at or below 3 °C as a control condition, while reduced-oxygen packaging at higher refrigeration temperatures may require additional barriers such as 3-3.5% water-phase salt [26]. Neither the shad nor the carp roe salad specification states a storage temperature for the finished product [4, 9].

Fishery products eaten raw or only salted must undergo a freezing treatment that kills parasites other than trematodes, unless an applicable exemption is fulfilled [28, 48]. The shad specification includes freezing and thawing of the raw fish but specifies no temperature or duration, so it cannot be verified whether this step meets the legal requirement [4, 48].

Authenticity and traceability

For these products, authenticity concerns the identity of the species, wild or farmed origin, and geographical origin [4, 9, 11, 16]. Consumer preference for wild origin can create an economic incentive for misrepresentation: in a Romanian survey, 62% of respondents were willing to pay more for wild than for farm-raised pheasant [49].

The best documented problems in the region concern sturgeon products. Of 27 caviar samples from Bulgaria and Romania, four were mislabelled and six were counterfeits, three of which contained no animal DNA [17]. In 149 caviar and meat samples from the four Lower Danube countries, combined genetic and stable isotope analysis showed that 21% came from illegally caught wild sturgeons, 11.4% were sold in breach of CITES and EU rules, and 32% involved consumer deception [16]. DNA analysis identifies the species, whereas distinguishing wild from farmed fish also requires stable isotope analysis [16]. Mitochondrial markers identify only the maternal species, so hybrid sturgeons, common in aquaculture, require nuclear markers; in 21 caviar batches from the Chinese market, mitochondrial barcoding revealed a mislabelling rate of 33.4% [50]. These findings concern sturgeon products, and their applicability to smoked shad would require validation [4, 16].

For the protected roe salads, no product-specific study on species composition was identified in the literature reviewed [9, 11]. Salting, maturing and emulsification degrade DNA, but in 44 processed fish products a combined mini-barcoding approach identified the species or genus in 93.2% of samples, compared with 20.5% with full-length COI barcodes [51]. Verifying minimum roe proportions would require quantitative methods: droplet digital PCR has quantified rainbow trout in salmon products from 1 to 90%, with a limit of quantification of 0.8% [52], but its application to salted and emulsified roe matrices would require validation [52].

For smoked shad, the specification requires wild fish from a defined sector of the Danube, and fat content alone cannot authenticate this origin [4, 25]. Smoked fish (CN code 0305) falls within the consumer information requirements of Article 35 and Annex I of Regulation (EU) No 1379/2013, including the catch area, whereas prepared roe salads are subject only to general food-labelling rules [53]. Because these labelling requirements are distinct from traceability obligations, verification of the catching area relies mainly on catch and traceability documents and on the controls provided for in the specification [4].

Towards an integrated quality control framework

Control parameters for these products are spread across the product specifications, EU food law and non-binding Codex

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guidance, and some hazards are covered by none of them [4, 9, 11, 13, 26]. Table 5 therefore links each product with its control priorities and the verification approaches proposed in this review.

At the raw material stage, the priorities are proof of the catching area and wild origin of shad, freezing to kill parasites, roe species identification and, given the elevated concentrations reported in some studies, cadmium monitoring [2, 13, 48, 51, 53]. Raw material monitoring does not, however, replace verification of the finished product, for which processing factors and ingredient proportions must be considered [13]. During processing, water-phase salt, time-temperature conditions and the fuel and smoke generation method are the main control points [13, 26, 38]. For small producers, routine controls could include temperature records, salt, pH, water activity, sensory checks and traceability documents, while risk-based laboratory verification of metals, PAHs, histamine, *L. monocytogenes* and species authenticity could be organised collectively through the producers' association [4, 12, 15].

Table 5 Control priorities and recommended verification for the three protected Danube Delta fish products

Product	Control priorities	Recommended verification	Source
Smoked Danube shad (PGI)	Wild origin and catching area; parasites; histamine; PAHs; *Listeria monocytogenes*	Catch and traceability documents; freezing records (−20 °C/24 h or −35 °C/15 h); histamine testing; benzo[a]pyrene and PAH4 in the finished product; temperature records and shelf-life studies	[4, 13, 15, 48, 53]
Tulcea pike roe salad (PGI)	Roe species and minimum roe proportion; *L. monocytogenes*; pH; water activity	DNA mini-barcoding; quantitative PCR methods after matrix validation; pH and aw measurement; microbiological testing against the applicable criterion	[11, 15, 51, 52]
Traditional carp roe salad (TSG)	Composition; roe species; *L. monocytogenes*; physicochemical parameters	Verification against the specification limits; DNA analysis; pH and aw measurement; microbiological testing	[9, 15, 51]

Note: *PGI = Protected Geographical Indication; TSG = Traditional Speciality Guaranteed; aw = water activity; PAH4 = sum of benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene and chrysene [13, 22]. Recommended verification approaches are risk-based proposals and do not replace applicable legal requirements or product-specific validation; the quantitative PCR methods proposed for roe salads require validation before use in conformity control.*

The proposed framework is derived from legislation, product specifications and studies on raw fish or comparable products rather than from an experimentally validated protocol [4, 9, 11, 13]. Its implementation requires product-specific validation, particularly for roe species quantification, microbiological shelf-life assessment and contaminant monitoring in finished products [45, 51, 52].

CONCLUSIONS

Traditional fish products from the Danube Delta combine high cultural and economic value with specific control challenges. Their specifications translate tradition into measurable criteria to different degrees: the two roe salads have explicit composition limits, whereas smoked shad relies mainly on sensory control of salting and smoking.

The review identified three main gaps. First, the available contaminant data come from raw fish, and no product-specific study reporting PAHs, histamine or heavy metals in finished smoked shad was identified, even though the product must meet the general EU limits without derogation.

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Second, product-specific data on the roe species composition, pH and water activity of the protected roe salads remain scarce; species composition determines conformity with the specifications, whereas pH and water activity determine *Listeria monocytogenes* growth potential and the applicable criterion. Third, the specifications omit information needed for safety assessment, such as freezing conditions for parasite control and storage temperatures of the finished products.

Authenticity problems are best documented for sturgeon products, where DNA analysis and stable isotopes have revealed species substitution, counterfeits and illegal wild-caught origin. For the protected products, species identification of roe and documentary traceability of the shad catching area are the most relevant tools. The integrated framework proposed here links contaminant monitoring with authenticity testing along the production chain; applying it requires targeted analytical studies on finished products and clearer measurable parameters in the product specifications.

REFERENCES

1. Trichopoulou, A.; Soukara, S.; Vasilopoulou, E. Traditional foods: A science and society perspective. *Trends in Food Science & Technology* **2007**, *18*(8), 420-427. https://doi.org/10.1016/j.tifs.2007.03.007
2. Oroian, I.; Bulete, BI; Matei, E.; Odagiu, ACM; Burduhos, P.; Oroian, C.; Ștefan, OD; Bordea, D. Assessment of heavy metal contamination, bioaccumulation, and nutritional quality in fish from the Babina-Cernovca Romanian sector of the Danube River. *Foods* **2025**, *14*(19), 3419. https://doi.org/10.3390/foods14193419
3. Năstase, A.; Năvodaru, I.; Cernișencu, I.; Țiganov, G. The fish communities of lake-complexes from Danube Delta Biosphere Reserve (DDBR) in spring-summer and autumn of 2016. *Scientific Annals of the Danube Delta Institute* **2019**, *24*. https://doi.org/10.7427/ddi.24.07
4. European Commission. Publication of an application pursuant to Article 50(2)(a) of Regulation (EU) No 1151/2012 – 'Scrumbie de Dunăre afumată'. *Official Journal of the European Union* **2018**, *C 162*, 28–32. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018XC0508(03)
5. Stroe, DM; Crețu, M.; Tenciu, M.; Dima, FM; Patriche, N.; Țiganov, G.; Dediu, L. Age, growth, and mortality of Pontic shad, *Alosa immaculata* Bennett, 1835, in the Danube River, Romania. *Fishes* **2024**, *9*(4), 128. https://doi.org/10.3390/fishes9040128
6. European Commission. Commission Implementing Regulation (EU) 2018/1878 of 26 November 2018 entering a name in the register of protected designations of origin and protected geographical indications ('Scrumbie de Dunăre afumată' (PGI)). *Official Journal of the European Union* **2018**. http://data.europa.eu/eli/reg_impl/2018/1878/oj
7. European Commission. Commission Implementing Regulation (EU) 2021/898 of 28 May 2021 entering a name in the register of protected designations of origin and protected geographical indications ('Salată cu icre de știucă de Tulcea' (PGI)). *Official Journal of the European Union* **2021**, *L 197*, 67. http://data.europa.eu/eli/reg_impl/2021/898/oj
8. European Commission. Commission Implementing Regulation (EU) 2021/1723 of 22 September 2021 entering a name in the register of traditional specialities guaranteed ('Salată tradițională cu icre de crap' (TSG)). *Official Journal of the European Union* **2021**, *L 344*, 1–2. http://data.europa.eu/eli/reg_impl/2021/1723/oj
9. European Commission. Publication of an application for registration of a name of a traditional speciality guaranteed – 'Salată tradițională cu icre de crap'. *Official Journal of the European Union* **2021**, *C 222*, 31. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0611(03)
10. Toma (Enache), IF; Bololoi, IS; Cristea, C.; Berechet, G.; Nicolae, CG Case study on consumer preferences for fish products: Trends and influencing factors. *Journal of Agroalimentary Processes and Technologies* **2025**, *31*(2), 194–202. https://doi.org/10.59463/JAPT2025.2.7
11. European Commission. Publication of an application pursuant to Article 50(2)(a) of Regulation (EU) No 1151/2012 – 'Salată cu icre de știucă de Tulcea'. *Official Journal of the*

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European Union **2021**, *C 39*, 26. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0204(01)
12. Commission Implementing Regulation (EU) 2019/627 of 15 March 2019 laying down uniform practical arrangements for the performance of official controls on products of animal origin intended for human consumption in accordance with Regulation (EU) 2017/625 of the European Parliament and of the Council and amending Commission Regulation (EC) No 2074/2005 as regards official controls. *Official Journal of the European Union* **2019**, *L 131*, 51–100. http://data.europa.eu/eli/reg_impl/2019/627/oj
13. Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. *Official Journal of the European Union* **2023**, *L 119*, 103–157. http://data.europa.eu/eli/reg/2023/915/oj
14. Onără, DF; Suciu, R.; Holostenco, D.; Tudor, D. Heavy metal bio-accumulation in tissues of sturgeon species of the Lower Danube River, Romania. *Scientific Annals of the Danube Delta Institute* **2013**, *19*, 87–94. https://doi.org/10.7427/ddi.19.12
15. Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. *Official Journal of the European Union* **2005**, *L 338*, 1–26. http://data.europa.eu/eli/reg/2005/2073/oj
16. Ludwig, A.; Jahrl, J.; Congiu, L.; Gessner, J.; Friedrich, T.; Lieckfeldt, D.; Peng, Z.; Boner, M. Poaching and illegal trade of Danube sturgeons. *Current Biology* **2023**, *33*(22), R1184–R1185. https://doi.org/10.1016/j.cub.2023.09.067
17. Ludwig, A.; Lieckfeldt, D.; Jahrl, J. Mislabeled and counterfeit sturgeon caviar from Bulgaria and Romania. *Journal of Applied Ichthyology* **2015**, *31*, 587–591. https://doi.org/10.1111/jai.12856
18. Commission Regulation (EC) No 2074/2005 of 5 December 2005 laying down implementing measures for certain products under Regulation (EC) No 853/2004 of the European Parliament and of the Council and for the organisation of official controls under Regulation (EC) No 854/2004 of the European Parliament and of the Council and Regulation (EC) No 882/2004 of the European Parliament and of the Council, derogating from Regulation (EC) No 852/2004 of the European Parliament and of the Council and amending Regulations (EC) No 853/2004 and (EC) No 854/2004. *Official Journal of the European Union* **2005**, *L 338*, 27–59. http://data.europa.eu/eli/reg/2005/2074/oj
19. Ferrari, R. Writing narrative style literature reviews. *Medical Writing* **2015**, *24*(4), 230–235. https://doi.org/10.1179/2047480615Z.000000000329
20. Food and Agriculture Organization of the United Nations. Report of the FAO Expert Consultation on the Trade Impact of Listeria in Fish Products (FAO Fisheries Report No. 604). FAO. 1999. Available online: https://www.fao.org/4/X3018E/X3018E00.htm
21. Bahaciu, GV; Osman, A.; Nicolae, CG; Dragomir, N.; Tudorache, M.; Custură, I. Analysis of the status of food and drinks protected by geographical indication schemes in Romania and European Union. *Scientific Papers. Series D. Animal Science* **2023**, *LXVI*(1), 377–384. https://animalsciencejournal.usamv.ro/pdf/2023/issue_1/Art51.pdf
22. Regulation (EU) No 1151/2012 of the European Parliament and of the Council of 21 November 2012 on quality schemes for agricultural products and foodstuffs. *Official Journal of the European Union* **2012**, *L 343*, 1–29. http://data.europa.eu/eli/reg/2012/1151/oj
23. Regulation (EU) 2024/1143 of the European Parliament and of the Council of 11 April 2024 on geographical indications for wine, spirit drinks and agricultural products, as well as traditional specialities guaranteed and optional quality terms for agricultural products, amending Regulations (EU) No 1308/2013, (EU) 2019/787 and (EU) 2019/1753 and repealing Regulation (EU) No 1151/2012. *Official Journal of the European Union* **2024**, *L 2024/1143*. http://data.europa.eu/eli/reg/2024/1143/oj
24. WWF Central and Eastern Europe. Conservation success! Fishing for wild sturgeon and selling wild sturgeon products banned indefinitely in Romania. 2021. Available online: https://wwfcee.org/news/conservation-success-fishing-for-wild-sturgeon-and-selling-wild-sturgeon-products-banned-indefinitely-in-romania
25. Savin, V.; Mocanu, E.; Patriche, N.; Tenciu, M.; Savin, C.; Stroe, D.; Popa, D.; Năstase, G. Study on the maintenance status and biochemistry of Pontic shad *Alosa immaculata* (Bennet, 1835)

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during migration. *Scientific Papers: Animal Science Series (Lucrări Ştiinţifice: Seria Zootehnie)* **2020**, *74*, 146–150. https://repository.iuls.ro/bitstreams/6a7764be-21ce-4e2b-b142-548b51ba25a4/download
26. Codex Alimentarius Commission. Standard for smoked fish, smoke-flavoured fish and smoke-dried fish (CXS 311-2013). FAO/WHO. 2013. Available online: https://www.fao.org/input/download/standards/13292/CXS_311f.pdf
27. Vasconi, M.; Tirloni, E.; Stella, S.; Coppola, C.; Lopez, A.; Bellagamba, F.; Bernardi, C.; Moretti, VM Comparison of chemical composition and safety issues in fish roe products: Application of chemometrics to chemical data. *Foods* **2020**, *9*(5), 540. https://doi.org/10.3390/foods9050540
28. Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin. *Official Journal of the European Union* **2004**, *L 139*, 55–205. http://data.europa.eu/eli/reg/2004/853/oj
29. Sava, A.; Uiuiu, P.; Lațiu, C.; Cocan, D.; Muntean, G-C; Papuc, T.; Ihuț, A.; Răducu, C.; Becze, A.; Craioveanu, C.; Munteanu, C.; Constantinescu, R.; Mireșan, V. PAHs, physicochemical and microbiological analyses of trout processed by traditional smoking, in different types of packaging. *Fishes* **2023**, *8*(8), 424. https://doi.org/10.3390/fishes8080424
30. Merdzhanova, A.; Dobreva, DA; Makedonski, L. Comparison of polyunsaturated fatty acid and fat-soluble vitamins content of cooked shad (*Alosa immaculata*). *International Journal of Agricultural Technology* **2016**, *12*(6), 1043–1056. https://li04.tci-thaijo.org/index.php/IJAT/article/view/6692
31. Vlad, TS; Gheciu Pirlea, GM; Ianitchi, D.; Bololoi, SI; Tudorache, M. Behavior of quail meat during thermal processing and technological implications: A review. *Scientific Papers: Animal Science and Biotechnologies* **2026**, *59*(1), 421–433. https://www.spasb.ro/index.php/public_html/article/view/2513
32. Ochrem, AS; Żychlińska-Buczek, J.; Zapletal, P. Carp (*Cyprinus carpio* L.) lipid oxidation during cold storage. *Archives of Polish Fisheries* **2015**, *23*(2), 101–106. https://doi.org/10.1515/aopf-2015-0011
33. Commission Regulation (EU) 2025/1891 of 17 September 2025 amending Regulation (EU) 2023/915 as regards maximum levels of inorganic arsenic in fish and other seafood. *Official Journal of the European Union* **2025**, *L 2025/1891*. http://data.europa.eu/eli/reg/2025/1891/oj
34. Višnjić-Jeftić, Ž.; Jarić, I.; Jovanović, L.; Skorić, S.; Smederevac-Lalić, M.; Nikčević, M.; Lenhardt, M. Heavy metal and trace element accumulation in muscle, liver and gills of the Pontic shad (*Alosa immaculata* Bennet 1835) from the Danube River (Serbia). *Microchemical Journal* **2010**, *95*(2), 341–344. https://doi.org/10.1016/j.microc.2010.02.004
35. Simionov, I-A; Cristea, DS; Petrea, Ș-M; Mogodan, A.; Jijie, R.; Ciornea, E.; Nicoară, M.; Turek Rahoveanu, MM; Cristea, V. Predictive innovative methods for aquatic heavy metals pollution based on bioindicators in support of blue economy in the Danube River basin. *Sustainability* **2021**, *13*(16), 8936. https://doi.org/10.3390/su13168936
36. Milanov, ĐR; Krstić, PM; Marković, VR; Jovanović, AD; Baltić, MB; Ivanović, SJ; Jovetić, M.; Baltić, ŽM Analysis of heavy metals concentration in tissues of three different fish species included in human diet from Danube River. *Acta Veterinaria* **2016**, *66*(1), 89–102. https://doi.org/10.1515/acve-2016-0007
37. Commission Regulation (EC) No 333/2007 of 28 March 2007 laying down the methods of sampling and analysis for the official control of the levels of lead, cadmium, mercury, inorganic tin, 3-MCPD and benzo(a)pyrene in foodstuffs. *Official Journal of the European Union* **2007**, *L 88*, 29–38. http://data.europa.eu/eli/reg/2007/333/oj
38. Mihalca, GL; Tița, O.; Tița, M.; Mihalca, A. Polycyclic aromatic hydrocarbons (PAHs) in smoked fish from three smoke-houses in Brașov county. *Journal of Agroalimentary Processes and Technologies* **2011**, *17*(4), 392–397. https://journal-of-agroalimentary.ro/admin/articole/76642L9_Mihalca_2_Vol.17_4_392-397.pdf
39. Pietrzak-Fiećko, R.; Parol, J.; Kubiak, MS Content comparison of polycyclic aromatic hydrocarbons (PAHs) in traditionally smoked freshwater fish. *Nauka Przyroda Technologie* **2015**, *9*(3), 33. https://doi.org/10.17306/J.NPT.2015.3.33

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40. Mičulis, J.; Valdovska, A.; Šterna, V.; Zutis, J. Polycyclic aromatic hydrocarbons in smoked fish and meat. *Agronomy Research* **2011**, *9*(Special Issue II), 439–442. https://agronomy.emu.ee/vol09Spec2/p09s210.pdf
41. EFSA Panel on Contaminants in the Food Chain (CONTAM). Risk for animal and human health related to the presence of dioxins and dioxin-like PCBs in feed and food. *EFSA Journal* **2018**, *16*(11), 5333. https://doi.org/10.2903/j.efsa.2018.5333
42. EFSA Panel on Contaminants in the Food Chain (CONTAM). Update of the risk assessment of dioxins and dioxin-like PCBs in feed and food. *EFSA Journal* **2026**, *24*(6), e10103. https://doi.org/10.2903/j.efsa.2026.10103
43. EFSA Panel on Biological Hazards (BIOHAZ). Scientific opinion on risk based control of biogenic amine formation in fermented foods. *EFSA Journal* **2011**, *9*(10), 2393. https://doi.org/10.2903/j.efsa.2011.2393
44. European Food Safety Authority. Analysis of the baseline survey on the prevalence of *Listeria monocytogenes* in certain ready-to-eat foods in the EU, 2010–2011. Part A: *Listeria monocytogenes* prevalence estimates. *EFSA Journal* **2013**, *11*(6), 3241. https://doi.org/10.2903/j.efsa.2013.3241
45. Commission Regulation (EU) 2024/2895 of 20 November 2024 amending Regulation (EC) No 2073/2005 as regards *Listeria monocytogenes*. *Official Journal of the European Union* **2024**, *L 2024/2895*. http://data.europa.eu/eli/reg/2024/2895/oj
46. Autoritatea Națională Sanitară Veterinară și pentru Siguranța Alimentelor. Recall notice: Gran Mare herring roe salad, 150 g, lot 981, Listeria monocytogenes. 2026. Available online: https://www.ansvsa.ro/wp-content/uploads/2026/05/Rechemare_Gran_Mare_salata_icre_hering_negro2000_Penny_04.05.2026.pdf
47. Autoritatea Națională Sanitară Veterinară și pentru Siguranța Alimentelor. Recall notice: Herring roe salad with onion, 70 g, lot 1363PB, Listeria monocytogenes. 2026. Available online: https://www.ansvsa.ro/wp-content/uploads/2026/05/Rechemare_Salata_icre_hering_ceapa_70g_Gustari_Pescaresti_Profi_29.05.2026.pdf
48. Commission Regulation (EU) No 1276/2011 of 8 December 2011 amending Annex III to Regulation (EC) No 853/2004 of the European Parliament and of the Council as regards the treatment to kill viable parasites in fishery products for human consumption. *Official Journal of the European Union* **2011**, *L 327*, 39–41. http://data.europa.eu/eli/reg/2011/1276/oj
49. Bordei, IS; Toma, IF; Udroiu, A.; Moise, AE; Geicu-Cristea, M.; Nicolae, CG Study on the influencing factors of consumer choices regarding pheasant meat. *Journal of Agroalimentary Processes and Technologies* **2025**, *31*(2), 227–232. https://doi.org/10.59463/JAPT2025.2.11
50. Hu, Q.; Pan, Y.; Xia, H.; Yu, K.; Yao, Y.; Guan, F. Species identification of caviar based on multiple DNA barcoding. *Molecules* **2023**, *28*(13), 5046. https://doi.org/10.3390/molecules28135046
51. Shokralla, S.; Hellberg, RS; Handy, SM; King, I.; Hajibabaei, M. A DNA mini-barcoding system for authentication of processed fish products. *Scientific Reports* **2015**, *5*, 15894. https://doi.org/10.1038/srep15894
52. Ma, X-Y; Shao, Z-L; Yu, X-P; Wang, Z-L A droplet digital PCR-based approach for quantitative analysis of the adulteration of Atlantic salmon with rainbow trout. *Foods* **2023**, *12*(23), 4309. https://doi.org/10.3390/foods12234309
53. Regulation (EU) No 1379/2013 of the European Parliament and of the Council of 11 December 2013 on the common organisation of the markets in fishery and aquaculture products. *Official Journal of the European Union* **2013**, *L 354*, 1–21. http://data.europa.eu/eli/reg/2013/1379/oj

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