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Mislabeling in seafood products sold on the Italian market: a systematic review and meta-analysis

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1 **Mislabeling in seafood products sold on the Italian market: a systematic review and meta-**
2 **analysis.**

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27 **Abstract**

28 In this study the results of a systematic review and meta-analysis on mislabeling in seafood
29 products sold on the Italian market ~~is-are~~ presented. ~~The aim was especially targeted to answer the~~
30 ~~research question “What is the mislabeling rate occurring at national level in seafood products sold~~
31 ~~on the Italian market?”~~. Scientific papers (SPs), were filtered using pre-determined inclusion criteria
32 and data related to sampling and mislabeling was analyzed. ~~No time limit was set, and the search was~~
33 ~~concluded in June 2022~~. Samples were categorized according to their taxon (species, family order)
34 or generic market group (MG), market form (unprocessed/processed), distribution channel and
35 geographical area. Samples were considered mislabeled when the species found by molecular analysis
36 did not comply the information indicated in the label. The mislabeling rate (m. r.) was weighted on
37 the sample size and provided overall and for each category. In the 51 selected SPs (published from
38 2005 to 2022) the most sampled taxa were fish (83.8%): mackerels, cods, herrings, flatfishes and
39 jacks were the most represented. Unprocessed fillet/slice was the most analyzed market form (61.4%),
40 and samples were especially collected at retails (76.5%). Ten regions were sampled, especially
41 Tuscany and Apulia. The overall weighted m. r. was 28.4% (CI 26%-30%), falling within the m. r.
42 range found at international level (Luque & Donlan, 2019). M. r. over the CI (>30%) were observed
43 in 1) jellyfishes, European perch, European grouper, Atlantic mackerel and samples labelled as
44 “*spinarolo*”, “*baccalà*” or “*palombo*”; 2) Unprocessed fresh, processed salted and highly processed
45 samples; 3) small distribution channel; 4) Southern regions. Significant differences in m. r.
46 concerned taxa, distribution channels and geographical areas. Despite some bias of the SPs may affect
47 the results (lack of sampling plans; poor data on molluscs and crustaceans; no standardization in m.
48 r. interpretation) this is the first systematic review and meta-analysis that, synthesizing evidence
49 providing an accurate characterization on of Italian seafood mislabeling, can support ean direct-policy
50 making official control activities for minimizing frauds impacts.

51

52 **Keywords**

53 Food Frauds, DNA analysis, species substitution, labeling compliance, risk assessment.

54

55 **1. Introduction**

56 In EU Member States, food frauds increased by 85% between 2016 and 2019, and it is expected
57 that the percentage further rise (Visciano & Schirone, 2021). For these reasons, the EU has placed
58 increasing emphasis on the prevention of deceptive practices, and the Regulation (EU) No 2017/625
59 came into force updating agri-food chain control policies and reinforcing protection of consumers
60 against frauds. Also, the definition of food fraud provided by the European Commission was therefore
61 recently revised in the light to the aforesaid Reg. as “*any suspected intentional action by businesses*
62 *or individuals for the purpose of deceiving purchasers and gaining undue advantage therefrom, in*
63 *violation of the rules referred to in Article 1(2) of Regulation (EU) 2017/625* (European Commission,
64 2018). Given the extent of the phenomenon, ‘food fraud notification’ has been also included in the
65 Rapid Alert System for Food and Feed portal (iRASFF) (Commission Implementing Regulation EU
66 No 2019/1715).

67 The European Parliament identified seafood as the second-highest food category at risk for fraud
68 (Kroetz et al., 2020) due to the globalization of supply chains and the introduction of increasingly
69 complex distribution systems. While seafood fraud comes in a variety of forms, mislabeling, meaning
70 “*false claims or distortion of the information reported on the label*” (European Commission, 2018),
71 is perhaps the most concerning (Kroetz et al., 2020; Reilly, 2018; Van Holt, Weisman, Käll, Crona,
72 & Vergara, 2018). Although mislabeling may be unintentional – for instance when several species
73 are handled on the same manufacturing equipment –in most cases it disguises illegal practices that
74 are carried out for financial gain at every stage of the marketing chain (Reilly, 2018). Mislabeling
75 involves the intentional substitutions of high-quality species with less expensive varieties, or farmed
76 versus wild sourcing, or even the selling of fish from Illegal, Unreported and Unregulated (IUU)
77 fishing and the recycling of by-catches or fish waste (Helyar et al., 2014; Hu, Huang, Hanner, Levin,
78 & Lu, 2018; Kroetz et al., 2020; Reilly, 2018). Potential consequences include economic losses,

79 ecological impact, undermining of sustainability efforts and, considering that food labeling is the
80 most important instrument for consumer decision-making and food choice, disrespecting of
81 consumers' religious or ethical reasons. In addition, the illicit presence of toxic species (Giusti et al.,
82 2018) or the omission of ingredients potentially causing allergies (e. g. crustaceans or molluscs) may
83 lead to human health risks (Luque & Donlan, 2019; Pardo, Jiménez, & Pérez-Villarreal, 2016).

84 Therefore, besides the principles of the General Food Law (Regulation EC No 178/2002) and the
85 general provision of food information to consumers (Regulation EU No 1169/2011), specific
86 provisions for the labeling of fishery and aquaculture products were established by the Regulation
87 (EU) No 1379/2013. This Regulation imposes to the Member States to publish a list reporting the
88 official seafood trade names, corresponding to species scientific names, accepted within the national
89 territories. Yet, even where seafood traceability regulations are progressive, mislabeling continues to
90 be documented (Luque & Donlan, 2019).

91 With the development of molecular tools and specifically DNA-testing, also proposed by
92 Regulation (EU) No 1379/2013 to deter operators from falsely labeling catches, studies investigating
93 seafood mislabeling have increased substantially. In many cases, these studies investigated a
94 particular product, geography, or a specific stage within the supply chain. On the contrary, few
95 reviews on mislabeling have been published in the last decade. In addition, most of them tend to be
96 mainly descriptive and do not based on a systematic approach (Golden & Warner, 2014; Pardo et al.,
97 2016; Warner, Mustain, Lowell, Geren, & Talmage, 2016). Systematic reviews, increasingly popular
98 in many other scientific research fields, involve in fact a detailed and comprehensive plan and
99 literature search strategy derived *a priori*, with the goal of identifying all relevant studies on a
100 particular topic (Petticrew & Roberts, 2006; Uman, 2011), and often include a meta-analysis
101 component using statistical techniques to analyze the data from several studies (Petticrew & Roberts,
102 2006; [Mikolajewicz & Komarova, 2019](#)). This kind of literature revision was rarely applied for
103 investigating mislabeling in seafood. Recently, Luque and Donlan published two systematic reviews
104 associated with meta-analysis to characterize global seafood mislabeling (Luque & Donlan, 2019)

105 and exploring its causes using price data from mislabeling studies (Donlan & Luque, 2019). The same
106 approach was then used by Blanco-Fernandez et al. (2021), but only to analyze mislabeling trends in
107 hakes during the last 17 years. In these systematic reviews, outcomes from data analysis were
108 aggregated for more countries (Blanco-Fernandez et al., 2021; Donlan & Luque, 2019; Luque &
109 Donlan, 2019). Therefore, the estimation of the global mislabeling rate may be distorted by the
110 different approach adopted across countries for the definition of the official seafood list at national
111 level. In fact, the “one species one name approach” proposed by Lowell, Mustain, Ortenzi, & Warner
112 (2015) is not always applied and the association between the scientific name and the correspondent
113 trade name greatly varies among countries, even within European territory. For instance, the trade
114 name “anchovy”, that in Italy is univocally associated to *Engraulis encrasicolus* (Italian trade name
115 “*acciuga*” or “*alice*”) (Ministerial Decree n. 19105 of September the 22nd, 2017), is instead associated
116 to all the species of the Family Engraulidae in UK (United Kingdom Department for Environment,
117 Food and Rural Affairs, 2013). Therefore, mislabeling interpretation for anchovy-based product is
118 different between these two countries.

119 In the ~~meta-analysis systematic review~~ performed by Luque & Donlan (2019) it was observed that
120 Italy, together with Spain and US, was the country with the largest number of studies on this topic.
121 Despite this, to the best of our knowledge, no reviews have been performed yet in any EU country.
122 Since Italy is included in the four EU countries with highest seafood consumption (EUMOFA, 2021),
123 an accurate characterization of seafood mislabeling in the national market is crucial to assess the
124 causes and consequences of this practice, and to design solutions to reduce it. In fact, a better
125 understanding of the scale and nature of seafood mislabeling is important for improving ~~regulatory~~
126 ~~efforts~~ making policy and consumer engagement programs aimed at minimizing its societal costs
127 (Kroetz, Donlan, Cole, Gephart, & Lee, 2018).

128 In this study a systematic review and meta-analysis was performed to document mislabeling
129 occurrence in seafood products sold on the Italian market. The aim was especially targeted to answer
130 the research question “What is the mislabeling rate in seafood products sold on the Italian market?”

131 ~~We aim to answer the question “What is the mislabeling rate occurring at national level?” by~~
132 ~~providing an evidence synthesis of all the research performed on this topic to document mislabeling~~
133 ~~occurrence in seafood products sold on the Italian market was performed.~~ Since our review only
134 included studies performed in Italy, it counted on a specific regulatory framework represented by the
135 Italian lists of seafood trade names reported by the Ministerial Decrees of 2002, 2008 and 2017 (the
136 last the one currently in force). Outcomes from this study could also provide a risk assessment
137 according to seafood species, market form, distribution channels and geographical area of collection
138 and could serve for driving more targeted official control activities. Finally, by highlighting and
139 discussing strengths and shortcomings arising from data analysis, this ~~study review~~ can serve to
140 improve the inquiry approach in this research area.

141 **2. Materials and Methods**

142 ***2.1 Bibliographic search and scientific papers collection***

143 The bibliographic search was carried out on three scientific databases (Google Scholar, PubMed
144 and Web of Science) using the keywords “seafood AND (species identification OR DNA OR
145 molecular) AND Italian market AND mislabeling”. The relevance of the retrieved scientific papers
146 (SPs) was assessed based on the title and of the abstract. To make the SPs collection as complete as
147 possible, a snowball search was conducted checking the reference lists of the selected articles, and
148 Google Scholar “cited by” function was also used. No time limit was set, and the search was
149 concluded in June 2022. After deduplication, SPs were considered eligible and included in the study
150 only if 1) represented by peer-reviewed studies (quality assurance); 2) molecular techniques based on
151 DNA analysis (e. g. DNA barcoding or metabarcoding, phylogenetic analysis, multiplex PCR, RFLP-
152 PCR, etc.) were used for species identification; 3) the analysed samples belonged to seafood products
153 sold on the Italian market; 4) the seafood products sample sizes was reported; 5) the seafood products
154 reported information on the generic taxon (fish, mollusc, crustacean, other) and /or trade name
155 (generic or specific, e. g. tuna or Yellowfin tuna) and/or scientific name of the species on the label (e.
156 g. *Thunnus albacares*). In fact, this latter information represents the minimum criteria to make a

157 comparison between the label declaration of the samples (from now defined as “blind samples” –
158 “*bs*”) and the molecular results. In the case of SPs also analysing samples belonging to
159 morphologically identified reference samples (e. g. specimens of known species directly purchased
160 on the market or specially provided by fishermen, research institutes, national Competent Authorities,
161 etc.), only the *bs* were included in the analysis, since the reference samples do not fulfil the scope of
162 the study. On the finally included SPs, information on the years of publication, scientific journals and
163 corresponding author/s affiliation were analysed. Then, information on sampling, namely *bs* number,
164 taxonomic information reported on the label, processing degree, distribution channels and
165 geographical area of collection and data on mislabeling cases were recorded, when reported. All data
166 were registered in an Excel file and analysed as reported in section 2.2. Information on the molecular
167 technique used for species identification will be included in another more technical paper.

168 ***2.2 Analysis of data related to sampling***

169 The *bs* number overall, for each SP and year of publication was calculated. Since most of the SPs
170 did not specify the *bs* collection year/s, we decided to use the SP year of publication to standardize
171 the analysis. Respect to the data relative to taxon, market form and distribution channel, we
172 categorized the *bs* according to definition provided by legislation and official reports. In particular,
173 the taxon (order, family and species) was assigned in accordance with the FAO FishBase/SealifeBase
174 Information System as reported by Regulation (EU) No 1379/2013; the market form was assigned
175 according to the definition of the Regulation (EC) No 852/2004 and based on the European Market
176 Observatory for Fisheries and Aquaculture Products report by EUMOFA (2021); for the distribution
177 channel assignment, the definition provided by the Regulation (EU) No 1169/2011 and Regulation
178 (EU) No 1379/2013 were used. Then, the recorded data were analysed as described in the following
179 sections.

180 *2.2.1 Taxonomic information reported on the *bs* label.* If a specific trade name (in English) that
181 can be unequivocally associated to a single species according to FishBase
182 (<https://www.fishbase.se/search.php>) or SealifeBase (<https://www.sealifebase.ca/>), presented as

183 taxonomic reference sources under Regulation (EU) No. 1379/2013, was declared in the label, the
184 species scientific name was recorded (e. g. “Yellowfin tuna” was recorded as *Thunnus albacares*).
185 Likewise, considering that the trade name of the *bs* were often translated in English from Italian in
186 the analyzed SPs, the Italian official lists of seafood trade names were also in some specific cases
187 consulted. For this purpose, the official list in force in the year of the SP publication was used
188 (Ministerial Decree of March 27th, 2002; Ministerial Decree of January 31, 2008; Ministerial Decree
189 n. 19105 of September the 22nd, 2017). For instance, if the generic trade name “hake”, that in Fishbase
190 is associated to several species, was reported in a *bs* from a SP performed in 2020, it was assumed
191 that, if not differently specified in the SP, it corresponds to the Italian designation “*nasello* or
192 *merluzzo*” (Merlucciidae), reported in the Ministerial Decree n. 19105 of September the 22nd, 2017,
193 which is in force since September 2018. After this preliminary step, the *bs* was first categorized in
194 fish, molluscs (cephalopods or bivalves), crustaceans, and other different taxa and then associated to
195 an order (highest taxonomic rank level) according to FishBase and SealifeBase. For instance, if a
196 label declared “Tuna” or “Yellowfin tuna” or “*Thunnus albacares*”, the *bs* was associated to the order
197 Scombriformes. To simplify the reading for non-expert taxonomists, the order was associated to a
198 generic market group (MG) according to FishBase and SealifeBase (such as “mackerels” in the case
199 of the order Scombriformes). Finally, the *bs* within each MG were further organized into lower
200 taxonomic levels (family and species). Obsolete nomenclatures were substituted with valid ones,
201 according to FishBase and SealifeBase. The *bs* number for each MG, family and species was
202 provided.

203 2.2.2 *Bs market form*. The *bs* were categorized based on their market form in unprocessed and
204 processed according to the definition of the Regulation EC No 852/2004 and EUMOFA, 2021 report;
205 unprocessed *bs* were divided in fresh or frozen, while processed *bs* were further categorized in salted,
206 dried, breaded, smoked, canned (in oil, in sauce, in water, marinated, fermented, pastes), pre-cooked
207 or cooked (fried, baked, boiled) and highly processed seafood preparation (burger, minced, balls,

208 cakes, filling, surimi, etc.). The *bs* number for each market form was provided overall and divided
209 for species, when possible.

210 *2.2.3 Bs distribution channels.* For the distribution channels, it was considered “small distribution”
211 if local retails, fish markets, fish shops, fishmongers, groceries, ethnic shops or other small retailers
212 were involved; “large distribution” in the case of supermarkets, hypermarkets, wholesalers,
213 department stores, fish companies and other large-scale retailer markets; “mass caterers” which
214 includes food businesses such as restaurants, canteens, schools, hospitals and mass caterer enterprises
215 (Regulation EU No 1379/2013); additionally, although not properly involving the *bs* distribution
216 channels, sampling that were performed in the context of “official control” activities were considered,
217 for instances if the *bs* were provided by Border Control Points (BIPs), Port Authorities, Local Health
218 Authorities (LHAs) or anti-adulteration and health unit (NAS). The *bs* collected by official control
219 authorities for only research purposes were also included in this category. The *bs* number for each
220 distribution channel was provided overall and divided for species, when possible.

221 *2.2.4 Bs geographical area of collection.* The geographical areas of *bs* collection were categorized
222 in Northern Italy (Valle d’Aosta, Piemonte, Lombardia, Trentino-Alto Adige, Veneto, Friuli-Venezia
223 Giulia, Liguria and Emilia-Romagna), Central Italy (Latium, Marche, Tuscany and Umbria) and
224 Southern Italy (Abruzzo, Basilicata, Calabria, Campania, Molise and Apulia) and Islands (Sicily and
225 Sardinia). The *bs* number for each geographical area, with details on the region, was provided overall
226 and divided for species, when possible.

227 **2.3 Analysis of data related to mislabeling**

228 *2.3.1 Mislabeling rate calculation.* In the collected literature, mislabeling was usually described
229 as the non-compliance between the species identified by molecular analysis and the trade
230 name/scientific name declared on the product label. However, it was sometimes referred to the lack
231 of one or more labeling information required by legislation. In this study, the *bs* were considered
232 mislabeled only in the first case, when the species found by molecular analysis did not comply the
233 information indicated in the *bs* label. Thus, the formula [(*bs* number showing non-compliance

234 between species identified by molecular analysis and information reported on the label/*bs* number
235 *100] was applied to calculate the mislabeling rate (m. r.). We excluded from the m. r. calculation
236 the *bs* reported by the source as not identified to any level of taxonomy (the outcomes on mislabeling
237 rates were in some cases normalized accordingly). The overall m. r. was weighted based on the sample
238 size of the study, and the relative confidence interval (C.I.) was calculated. The m. r. was also reported
239 for each publication year, taxon, market form, distribution channel and geographical area. Initially,
240 we decide to include the SPs regardless of their *bs* number, also considering that in some cases this
241 information was modified for the study purpose. Despite this, we think that a minimum number of
242 samples is essential to represent the market scenario. Therefore, we only considered data on m. r. for
243 which a number of *bs* ≥ 30 was investigated. To facilitate the discussion, they were categorized
244 according to their distance from the C. I. of the overall weighted m. r. in 1) category A (over the upper
245 value of the CI); 2) category B (within the CI); 3) category C (under the lower value of the CI).
246 Significant results were considered as those associated with $p < 0.05$. If overall significance was
247 observed, pair-wise comparisons were analyzed using χ^2 test. We defined as “expected species” (or
248 higher taxonomic level), the species supposed to be present in the product based on the *bs* label and
249 as “substitute species” (or higher taxonomic level), the true identity of a mislabeled *bs*. We searched
250 “substitute species” against the IUCN Red List of Threatened Species database
251 (<https://www.iucnredlist.org/>) to assess their conservation status and the relative ecologic impact of
252 mislabeling.

253 **3. Results**

254 ***3.1 Bibliographic search and scientific papers collection***

255 Overall, 51 SPs were finally selected (Table 1), published from 2005 to 2022 (except for 2006). ~~In~~
256 ~~general,~~ ~~†~~The number of SPs has started to increase since 2015 ~~in which, also,~~ ~~†~~The highest number
257 of SPs was published ~~in 2015~~ (7 SPs), ~~followed by 2019~~ (5 SPs) ~~and 2016, 2017, 2018 and 2020~~ (4
258 ~~SPs each). From 1 to 3 SPs were published in the other years~~ (Table 1). Many of the selected SPs
259 (n=17; 33.3%) were published in “*Food Control*”, followed by “*Foods*” (n=4; 7.8%) and “*Food*

260 *Research International*”, “*Journal of Agricultural and Food Chemistry*” and “*Italian Journal of Food*
261 *Safety*” (3 SPs each; 5.9% each). ~~One or 2 SPs were distributed in other 17 international journals.~~
262 Overall, researchers from the Departments of Veterinary Sciences were the most involved. ~~The SPs~~
263 ~~corresponding authors were in fact affiliated to the Department of Veterinary Sciences of the~~
264 ~~University of Pisa in 13 cases (25.5%), followed by Department of Biological, Geological and~~
265 ~~Environmental Sciences of the University of Catania (n=9; 17.6%) and the Department of Veterinary~~
266 ~~Sciences of the University of Bari (n=8; 15.7%). Other 17 affiliations were found in the other 21 SPs~~
267 ~~(1-3 SPs for each affiliation)~~-(Table 1).

268 3.2 Analysis of data related to sampling

269 3.2.1 *Bs number (overall, for each SP and year of publication)*. Overall, 3576 *bs* were analysed in
270 the 51 SPs, ranging from 3 to 290 (Table 1). The *bs* number was distributed in the years as reported
271 in Figure 1, and it was generally in line with the number of published SPs; ~~with the highest *bs* number~~
272 ~~was in fact in 2015 (565 *bs*; 15.8%), 2019 (528 *bs*; 14.8%) and 2017 (489 *bs*; 13.7%).~~

273 3.2.2 *Taxonomic information reported on the *bs* labels*. Overall, most of the *bs* belonged to fish
274 (2997 *bs*; 83.8%); mollusc accounted for 360 *bs* (10.1%), of which 263 cephalopods, 95 bivalves and
275 2 not specified, and crustacean accounted for 82 *bs* (2.3%). Additionally, 56 *bs* (1.6%) belonged to
276 Cnidaria (jellyfish) and 1 *bs* (0.03%) to Amphibia (frog). Finally, 14 *bs* (0.4%) were labelled with
277 names referable to vegetables (namely bamboo, mustard tuber, lily flower), even though
278 morphologically recognized ~~by the authors~~ as jellyfish-based products (Armani et al., 2013). The
279 remained 66 *bs* were composed by mixture of fish and molluscs (53 *bs*; 1.5%), molluscs and
280 crustaceans (10 *bs*; 0.3%) and fish, molluscs and crustaceans (3 *bs*; 0.1%). To note that few SPs
281 specifically investigated seafood categories different from fish (n=4; 7.8%); ~~and, usually, non fish *bs*~~
282 ~~were included in more extensive SPs, where also fish were analysed.~~

283 It was possible to allocate 3390 *bs* to 49 MG ~~(based on the order association found in FishBase~~
284 ~~and SealifeBase)~~, of which 5 mixed together (e. g. Porgies/Temperate Basses) (Table SM1), while
285 186 *bs* were not allocated to any MG ~~as their label only reported the term fish, molluscs, crustaceans~~

286 ~~(or their mix) and vegetables.~~ The association between the MG with the respective order is specified
287 in Table SM1. ~~To be noted that in the case of the orders Eupercaria incertae sedis and Carangaria~~
288 ~~incertae sedis, the MG used by FishBase to characterize the families instead of the orders was used,~~
289 ~~given the high number of families included in these orders.~~ Thus, respect to the MG, mackerels with
290 543 *bs* (16.0%), and cods with 513 *bs* (15.1%) were the most numerous collected *bs*, followed by
291 herrings (326 *bs*; 9.6%), flatfishes (313 *bs*; 9.2%), and jacks (195 *bs*; 5.8%).

292 To consider that *bs* belonging to cods were collected during almost all the considered period (14
293 out of 17 years), ~~with the highest number in 2016 (176 *bs*; 34.3% of cods) and 2013 (110 *bs*; 21.4%);~~
294 The collection of *bs* belonging to mackerels was performed during 9 years, ~~and especially~~
295 ~~concentrated in 2010 (233 *bs*; 42.9% of mackerels), 2019 (101 *bs*; 18.6%) and 2017 (76 *bs*; 14.0%).~~
296 The *bs* belonging to herrings, flatfishes and jacks were concentrated in 11 (herrings) or 10 (flatfishes
297 and jacks) years; ~~herrings were especially collected in 2019 (233 *bs*; 71.5% of herrings) and 2015 (61~~
298 ~~*bs*; 18.7%); flatfishes in 2019 (106 *bs*; 33.9% of flatfishes) and 2015 (95; 30.4%) and jacks in 2015~~
299 ~~(80 *bs*; 41.0% of jacks)~~ (Figure 2). In all the years, the number of SPs ranged from 1 to 2, except for
300 cods in 2016 (4 SPs), mackerels in 2018 and 2021, and flatfishes in 2018, with 3 SPs each.

301 Respect to the lower taxonomic levels, 3183 (93.9%) and 2521 *bs* (74.4%) out of 3390 *bs* assigned
302 to MG were allocated to a unique family and to a unique species, respectively (all listed in Table
303 SM1). Overall, 75 families (53 belonging to fish, 9 to molluscs, 12 to crustaceans, and 1 to cnidaria)
304 and 219 species (148 belonging to fish, 46 to molluscs, 24 to crustaceans, and 1 to cnidaria) were
305 found. Among families, Scombridae (540 *bs* out of 3183 *bs* assigned to a unique family; 17.0%) were
306 the most numerous, followed by Gadidae (303 *bs*; 9.5%), Merluccidae (201 *bs*; 6.3%), Xiphiidae (190
307 *bs*; 6.0%), Engraulidae (182 *bs*; 5.7%), Clupeidae (144 *bs*; 4.5%), and Pleuronectidae (121 *bs*; 3.8%).
308 Respect to the species, 276 out of the 2521 *bs* assigned to a unique species were declared as *T.*
309 *albacares* (10.9%), followed by *Xiphias gladius* (160 *bs*; 6.3%), *Clupea harengus* (127 *bs*; 5.0%), *E.*
310 *encrasicolus* (119 *bs*; 4.7%), *Pleuronectes platessa* (97 *bs*; 3.8%), *Perca fluviatilis* (94 *bs*; 3.7%) and
311 *Gadus morhua* (90 *bs*; 3.6%). Other MGs, families and species with *bs* number covering percentages

312 $\geq 0.5\%$ are reported in Figure 3. Twenty-three out of the 219 species found in this analysis (10.5%)
313 were not reported in the Ministerial Decree (list of seafood trade names) in force in the respective SP
314 publication year. To highlight that 10 of them have been subsequently included in the list of the
315 Ministerial Decree that was released later, while the remained 13 are not still not reported.

316 The five more represented associations among MGs, families and species analysis were: 1) MG
317 mackerels, family Scombridae, species *T. albacares*; 2) MG cods, families Gadidae and Merlucciidae,
318 species *G. morhua*, *G. chalcogrammus* and *Merluccius merluccius*; 2; 3) MG herrings, families
319 Engraulidae and Clupeidae, species *C. harengus* and *E. encrasicolus*; 4) MG flatfishes, family
320 Pleuronectidae, species *P. platessa*; 5) MG jacks, family Xiphiidae, species *X. gladius* (Figure 3;
321 Table SM1).

322 **3.2.3 Data on bs market form.** Overall, 2197 out of the total 3576 analyzed *bs* (61.4%) were
323 unprocessed (mainly not whole as fillets or slices) and 1379 *bs* (38.6%) were processed. Among the
324 unprocessed *bs* the percentages of fresh and frozen groups were slightly biased in favor of fresh (36%
325 versus 27%) with a large part of *bs* (37%) for which it was not specified if they were fresh or frozen
326 (Figure 4a). As regards the number of processed *bs*, canned highly exceeded that of the other groups,
327 representing the 43.0% (593 *bs*) of processed *bs* (Figure 4b).

328 The correlation between species (or higher taxonomic level, when the species was not declared)
329 and market form was made for 3313 *bs* out of the overall 3576 (92.6%) ~~since the SPs by Armani et~~
330 ~~al. (2015b), Armani et al. (2016) and Cutarelli et al. (2018), in which 68 bs, 135 bs and 60 bs were~~
331 ~~analyzed, respectively, did not provide this information.~~ Considering this, the *bs* number of each
332 market form were modified accordingly (Table SM2). The highest number of unprocessed fresh *bs*
333 were represented by slices of *X. gladius* or swordfish that covered 17.6% (139 *bs*) of unprocessed
334 fresh *bs* considered in this step; ~~among the other main investigated MGs/family/species associations~~
335 ~~(section 3.2.2), *T. thynnus* (mackerels—Scombridae) was also especially included in unprocessed~~
336 ~~fresh, together with *M. merluccius* (cods—Merlucciidae), and *P. platessa* (flatfishes—Pleuronectidae).~~

337 The highest number of unprocessed frozen *bs* were represented by *Pangasianodon hypophthalmus*
338 (9.4%). To note that most of unprocessed frozen *bs* made of *P. hypophthalmus* (51 out of 54) were
339 analyzed in the SP by Bellagamba et al. (2015), ~~aimed at identifying this species from other closely~~
340 ~~related species, rather than assessing mislabeling in this kind of product. However, considering that~~
341 ~~fillets analyzed were purchased from the market to develop the molecular approach, they were~~
342 ~~considered as *bs* in this study.~~ Among the other main investigated MGs/family/species associations
343 (section 3.2.2), *G. morhua* and *G. chalcogrammus* (cods - Gadidae) were also often collected as
344 unprocessed frozen fillets. All processed canned *bs* was made of species included in the most
345 investigated MGs/family/species associations (section 3.2.2), especially represented by *T. albacares*
346 or tuna (mackerels, Scombridae) (46.1%; n=243), followed by *E. encrasicolus* or anchovy (26.9%;
347 n=142), *C. harengus* (10.4%; n=55) (herrings – Clupeidae) and *Scomber scombrus*/other *Scomber*
348 *spp.* (9.3%; n=49) (mackerels, Scombridae).

349 Likewise, the processed breaded *bs* were especially composed by species belonging to cods, and
350 the genus *Merluccius* spp. was most represented (60.2 %, n=142). Processed salted *bs* were especially
351 composed by “baccalà” (42%; n=86), intended as *G. macrocephalus* or *G. morhua* (cods - Gadidae)
352 according to the Italian lists of seafood trade names. Processed smoked and highly processed seafood
353 preparations were especially made of *C. harengus* (82.4%; n=70) (herrings – Clupeidae) and *G.*
354 *chalcogrammus* (41.2%; n=21) (cods - Gadidae), respectively. More details on species (or higher
355 taxonomic level) sampling for each market form are reported in Table SM2.

356 **3.2.4 Data on *bs* distribution channels.** Most of the *bs* were collected at retail level (2736 *bs* out
357 of 3576; 76.5%), of which 876 (32%) performed in large distribution channels and 238 (8.7%) in
358 small distribution channel, while this distinction was not made for the remained 1622 *bs* (59.3%). Of
359 the 238 *bs* from small distribution channel, 144 (60.5%) were collected in ethnic retailers (especially
360 Chinese communities). Additionally, 413 *bs* (11.7%) were collected at mass caterers (4 of which in
361 ethnic restaurants), and 400 *bs* (11.3%) in the context of official control activities (especially from

362 Border Control Posts, and Porth Authorities). The remained 27 *bs* were collected at small distribution
363 level and from official control activities without further details (Armani et al. 2011).

364 A wide number of species (or higher taxonomic levels) were collected at retail level (small or large
365 distribution), with *bs* labeled as *T. albacares* or tuna as the most numerous (392 *bs*; 14.3% of 2736
366 *bs* collected at retail level). The *bs* declared as *R. esculentum* or jellyfish or vegetables (~~but recognized~~
367 ~~to be jellyfish based products by Armani et al., 2013~~) were the most collected in ethnic retailers (66
368 *bs*; 45.8% out of 144 herein collected). At mass caterers, *bs* labeled as *T. thynnus* or *Thunnus* spp. or
369 tuna were the most numerous (67 *bs*; 16.2% of 413 *bs* herein collected), followed by salmon (61 *bs*;
370 14.8%). To be noted that at mass caterers there were more cases of *bs* labeled with no scientific
371 names. ~~All the 4 jellyfish *bs* were collected in ethnic restaurants (Armani et al., 2013).~~ Finally, the *bs*
372 collected in the context of official control activities belonged to various species, with *T. albacares* at
373 the top (68 *bs*; 17.0% of *bs* from official control activities). More details on species (or higher
374 taxonomic level) sampling for distribution channel are reported in Table SM3.

375 3.2.5 Data on *bs* geographical area of collection. ~~Respect to t~~The geographical area was detailed
376 only for of the sampling, it was detailed for 2475 *bs* out of 3576 *bs* (69.2%); ~~while the other 1101~~
377 ~~(30.8%) were only generically reported as collected on the Italian territory. Thus, 1056 out of 2475~~
378 *bs* (42.7%) were collected in Southern Italy, 870 *bs* (35.2%) in Central Italy, 345 (13.9%) in Northern
379 Italy and 25 *bs* (1.0%) in Islands. Additionally, 139 *bs* (5.6%) were collected in both Northern and
380 Central Italy and 40 *bs* (1.6%) in both Southern Italy and Islands. Ten regions out of 20 were sampled
381 - Emilia-Romagna, Liguria, Lombardia (Northern Italy), Latium, Marche, Tuscany (Central Italy),
382 Apulia, Calabria, Campania (Southern Italy) and Sicily (Islands) – and the region of the sampling
383 was detailed for 2187 *bs* (88.4% out of the 2475 where the geographical area was reported). Tuscany
384 and Apulia, with 864 *bs* (39.5% out of 2187 *bs*) and 808 *bs* (36.9%), respectively, were the most
385 sampled regions. Apulia (76.5% of *bs* in Southern Italy), Tuscany (96.0% *bs* in Central Italy) and
386 Emilia-Romagna (21.2% of *bs* in Northern Italy) were the most sampled region of Southern, Central
387 and Northern Italy, respectively. In Southern Italy and Islands (Sicily), *bs* labeled as *X. gladius* or

388 swordfish were the more sampled (15.3% and 60% of *bs* collected in these geographical areas,
389 respectively). *C. harengus* and *E. encrasicolus* or anchovy were especially sampled in Central Italy
390 (13.4% and 6.4%, respectively) and *P. hypophthalmus* in Northern Italy (15.9%). More details on
391 species (or higher taxonomic level) sampling for each geographical area are reported in Table SM4.

392 **3.3 Analysis of data related to mislabeling**

393 **3.3.1 Mislabeling rate (m. r.) calculated overall and for year of publication.** Overall, 3534 out of
394 the total 3576 investigated *bs* (98.8%) were used to calculate the overall weighted m. r., since *bs*
395 where the taxonomic identity was not achieved (e. g. for technical failures in DNA
396 amplification/sequencing, use of ineffective or poorly discriminating molecular targets, etc.) was not
397 included in the count. Overall, 1005 *bs* were found as mislabeled, with an overall weighted m. r. of
398 28.4%, (95% CI 26 and 30). Thus, the m. r. found in this study were categorized as follows: A) m. r.
399 >30%; B) m. r. from 26% to 30%; C) m. r. < 26%. Categories A and C were further divided in A1
400 (m. r. > 50%), A2 (m. r. from >30% to 50%), C1 (m. r. from 10% to <26%) and C2 (m. r. < 10%).

401 The distribution of the mislabeled *bs* throughout the years with relative m. r. is reported in Table
402 2. The m. r. was not provided for 2005, 2008, and 2009 since a *bs* number <30 was investigated in
403 these years. The higher m. r. (category A1) was observed in 2013 (61.9%), 2010 (54.1%) and 2015
404 (49.7%). The m. r. of these three years were significantly higher respect to the other years (p values
405 <0.05). In general, a decreasing trend in m. r. values was observed since 2016, with m. r. calculated
406 for each year included in C category (C1 or C2), except for 2020 (A1) and 2022 (B) (Table 2).

407 **3.3.2 Mislabeling rate calculated for taxon.** All the m. r. calculated for taxon (species or higher
408 taxonomic level, when the species was not declared) are reported in Figure 5 and Table 3. Within the
409 category A1, there were found: *Rophilema esculentum* or vegetables (merged with *R. esculentum* as
410 morphologically recognized as jellyfish-based products by Armani et al. 2013) (m. r. 93.1%). This
411 type of products was found as especially substituted with the jellyfish *Nemopilema nomurai* (81% of
412 the cases); *Squalus acanthias* or *S. blainville* (the two species that can be associated to the Italian
413 trade name “*spinarolo*” according to both the Ministerial Decree of January 31, 2008 and Ministerial

414 Decree n. 19105 of September the 22nd, 2017) (m. r. 86.7%). These species were found substituted
415 with *Prionace glauca* (Italian trade name “verdesca”) in 100% of the cases; *P. fluviatilis* (m. r.
416 85.1%), particularly substituted with *P. hypophthalmus* and *Lates niloticus* (46.8% and 31.0% of the
417 cases); *T. thynnus* (m. r. 77.8%), substituted with *T. albacares* in 85.6% of the cases; “Baccalà” (m.
418 r. 67.5%), where the species *G. Macrocephalus* or *G. morhua* were especially substituted with
419 *Pollachius virens* (65.4% of the cases); *Epinephelus marginatus* (m. r. 67.1%), substituted with *L.*
420 *niloticus* in 76.4% of the cases; *S. scombrus* (m. r. 64.3%), especially substituted with *S. colias* (77.8%
421 of the cases); *M. merluccius* (m. r. 62.7%), especially substituted with *M. productus*, *M. hubbsi* and
422 *G. chalcogrammus* (28%, 25% and 25% of the cases, respectively); *Mustelus mustelus*, *M. asterias*,
423 *M. punctulatus* (“palombo”) (mislabeling rate 59.6%) especially substituted with *S. acanthias*
424 (41.1%). Particularly low m. r. (category C2) was observed for *Octopus vulgaris* (m. r. 7.3%) and *E.*
425 *engrasicolus* or anchovy (m. r. 6.4%). Only *Sepia officinalis* and *P. glauca* showed m. r. within the
426 overall m. r. confidence interval (category B), with 26.0% and 26.1%, respectively. Beyond the m. r.
427 reported above, the major number of substitution cases (120 out of 987) was observed for *T.*
428 *albacares*, linked to the high number of *bs* overall analysed for this species.

429 Overall, 150 species were found to be used as substitute (Table SM5). By searching them against
430 the IUCN Red List it was found that 11 (7.3%) were “vulnerable”, 6 (4.0%) “endangered” and 2
431 (1.3%) “critically endangered” (Table SM5). Health implications were only highlighted for 2 *bs*
432 labeled as squid but identified as *Lagocephalus* spp., a poisonous pufferfish species banned from the
433 EU market (Armani et al., 2015b). Additionally, two SPs especially highlighted the omission of
434 molluscs in the ingredient list of some surimi-based products (Giusti et al., 2017; Piredda et al., 2022).

435 3.3.3 Mislabeling rate calculated for market form. To calculate the m. r. relative to the market
436 form, 203 *bs* were further excluded from the count since the SPs analyzing these *bs* did not provide
437 this information (Armani et al. 2015b; Armani et al. 2016). Thus, 3331 *bs* was considered and the
438 overall *bs* number of each type of processing degree was modified accordingly (Table 4). The m. r.
439 calculated for each market form is reported in Table 4. Overall, the m. r. appeared slightly higher in

440 unprocessed *bs* (29.2%) respect to processed *bs* (27.2%), although this difference was not
441 significative and both within the overall m. r. confidence interval (category B). Within unprocessed
442 *bs*, m. r. in fresh *bs* (42.2%) is appeared significatively higher respect to frozen (22.5%) (p value
443 <0.0001). Within processed *bs*, m. r. in highly processed seafood preparations (burger, minced, balls,
444 cakes, filling, surimi, etc.) (49.0%) and salted *bs* (42.0%) are significatively higher respect to the
445 other processed *bs* (p values <0.05).

446 *3.3.4 Mislabeling rate calculated for distribution channel and geographical area.* To calculate the
447 m. r. relative to distribution channels, the 3534 *bs* mentioned in section 3.3.1 were used, and the
448 overall *bs* number for each channel was modified accordingly. At retail level, the m. r. was 32.4%
449 (category A2), with significant difference between large distribution (18.8% - category C1) and small
450 distribution (54.2% - category A1) (p value <0.0001). The m. r. at mass caterers (15.0%) and official
451 control activities (14.3%) were both found as significatively lower respect to retail level (p values
452 <0.0001). To calculate the m. r. relative to the geographical area of collection, 2460*bs* were used. To
453 the 2475 *bs* for which the geographical area was detailed (section 3.2.5), 15 *bs* where the taxonomic
454 identity was not achieved were further removed. The m. r. was 43.2% in Southern Italy (category
455 A2), that was found significatively higher respect to Central Italy (12.3% category C1), and Northern
456 Italy (11.6% - category C1) (p values <0.0001). The m. r. observed for Islands was considered not
457 significative as involving a total *bs* number <30.

458 The m. r. categories observed for publication year, species, market form, distribution channel and
459 geographical area are summarized in Table 5.

460 **4. Discussion**

461 *4.1 Years of publication, scientific journals and corresponding author/s affiliations*

462 The distribution trend of publication throughout the years (2005-2022) was characterized by an
463 increasing since 2015, which appeared to be in line with the global one. In fact, Luque & Donan
464 (2019) observed that research on seafood fraud has especially grown with the advent of food forensics
465 (e. g. DNA barcoding), with 51 papers published on the topic in 2015 compared to 4 in 2005.

466 Considering that EU was the territory with most publications on mislabeling (Luque & Donlan, 2019),
467 we can suppose that the enactment of the Regulation (EU) No 1379/2013, which enhanced the
468 application of DNA-testing to tackle falsely labeling practices, may have contributed to the SPs
469 increasing. Note that, in their systematic review that was conducted up to December 2017, the
470 inclusion criteria established by the authors led to the collection of 24 SPs in Italy (Luque & Donlan,
471 2019). In our study, a higher number of SPs (n=32) until December 2017 were included. To comment
472 this, it is necessary to highlight that Luque & Donlan (2019) established specific inclusion criteria to
473 select only papers that could contribute to the statistical estimation of global m. r. Among others, they
474 especially excluded from the analysis cases where mislabeling was related to the strict interpretation
475 of the expected trade name versus the trade name reported on the label. We suppose that this
476 occurrence may be very common if studies from several countries are analyzed simultaneously, since
477 expected trade names correspond to those reported to national official lists, may be extremely
478 different from one country to another. This considered, the inclusion criteria identified in this review
479 could be less stringent, with a higher number of recovered SPs and, consequently, a higher pool of
480 data related to Italy, allowing to achieve a wider look of the national status of mislabeling.
481 Furthermore, the higher number of SPs considered in this study might be recollected to the inclusion
482 of studies originally not exclusively focusing on a mislabeling analysis but rather on the setting of
483 DNA-testing tools for the further labeling check (section 3.2.3).

484 In this review we decided to exclude reports and articles on mislabeling that did not undergo a
485 peer-reviewed process, that in some way can represent a quality control before publication, and we
486 found that many SPs (32%) were published on five journals, namely “*Food Control*”, “*Foods*”, “*Food*
487 *Research International*”, “*Italian Journal of Food Safety*” and “*Journal of Agricultural and Food*
488 *Chemistry*”. In line with this, Luque & Donlan (2019) observed that 40% of the peer-reviewed
489 publications selected in their systematic review were published in only five journals, including “*Food*
490 *Control*”, “*Food Research International*” and “*Journal of Agricultural and Food Chemistry*”,
491 confirming that these three journals are the major depositaries of scientific literature on this topic also

492 at global level. Therefore, the inclusion of SPs published on international journals with high
493 bibliometric indices (Impact Factor, SCImago Journal Rank, Source Normalized Impact per Paper)
494 suggests the impact of studies and the interest of the scientific community on the topic. As regards
495 the “*Italian Journal of Food Safety*”, it is particularly required by Italian researchers as the official
496 journal of the Italian Association of Veterinary Food Hygienists (AIVI) and as such it is suitable as a
497 direct scientific information tool for continuous updating by the competent authority at national level.

498 Overall, research groups from the Departments of Veterinary Sciences were the most involved in
499 the SPs publications, proving that veterinarians possess tools and skills to deal with this topic,
500 especially respect to the knowledge of the legislation framework. Among them, Pisa (FishLab) and
501 Bari Universities are at the top of the list, confirming that these two research units have specific
502 competencies at national level.

503 ***4.2 Sampling: size, publication year, taxon, market form, distribution channel and geographical*** 504 ***area.***

505 A wide *bs* number range (from 3 to 290 *bs*) across the included SPs was observed. Accordingly,
506 also in the systematic review by Luque & Donlan (2109), a highly variable sample size was observed
507 (range: 8-4656; mean=194), as well as in other non-systematic reviews (Golden & Warner, 2014;
508 Pardo et al., 2016; Warner et al., 2016). However, as detailed in the methodological section, only the
509 *bs* collected on the Italian market and not belonging to reference specimens were considered in this
510 study, so that the low *bs* number observed for some SPs may be due to this criterion. For instance, *bs*
511 also collected both in Italy and in other countries were analysed in some SPs (Jerome et al., 2008;
512 Giusti et al., 2019; Paracchini et al., 2019; Pardo et al., 2018). Respect to the overall *bs* number, a
513 literature comparison was only possible by extrapolating data from the non-systematic review by
514 Pardo et al. (2016), since the others did not provide the *bs* number for each country. About 350
515 samples were analysed in Italy from 2010 to 2015 (Pardo et al., 2016). In our study, over a double *bs*
516 number (732 *bs*) were observed for the same period. The noticeable gap in numbers can be plausibly
517 attributed to the fact that Pardo et al. (2016) did not conduct a systematic review, thus a

518 comprehensive literature search was not required. No trend in the number of collected *bs* was
519 observed across years, since the largest *bs* number was related with the largest SPs number.

520 In this study, data regarding taxon, market form, distribution channel were organized according to
521 legislative provision and official reports (section 2.2) with the aim to define a standardized approach.
522 Note that in the case of the market forms and distribution channels, such type of “official”
523 categorization was not adopted by the available reviews on this topic, not even in the systematic
524 review by Luque & Donlan (2019).

525 The analysis of the 219 species found in the included SPs highlighted a progressive evolution and
526 expansion of the Ministerial list in response to the increased product demand and supply variety on
527 the national market. This trend, in accordance with the requirement for a periodic updating of the list
528 delegated to each Member State under Regulation (EU) 1379/2013 (Article 37) had already been
529 described by Tinacci et al. (2019). In the study, specifically, the authors observed a continuous and
530 significant updating of the designations included in each repealing Ministerial Decree till the list
531 currently in application including over 1000 scientific names associated with more than 700 different
532 official trade names. This aspect, among other causes, may be partially due to the contribute of
533 scientific production investigating on seafood authentication and mislabeling assessment, that over
534 the years have increasingly uncovered the presence of new species on the national market. The most
535 iconic case is represented by the inclusion of two jellyfish species (*R. esculentum* and *R. pulmo*) in
536 the Ministerial Decree n. 19105 of September the 22nd, 2017, presumably in consequence of the
537 findings published by Armani et al. (2013).

538 As regard the taxon, fish, which resulted as the most representative in this study, is reported as the
539 most sampled and analysed also at global level (Luque & Donlan, 2019; Pardo et al., 2016; Golden
540 & Warner, 2014; Warner et al., 2016), while other seafood was less investigated. This aspect
541 highlights a considerable gap for a comprehensive knowledge of the national market status in term of
542 mislabeling occurrence, especially considering that other seafood categories are highly consumed in
543 Italy. In fact, mussels, octopus and squids are included in the main commercial seafood in Italy

544 (EUMOFA, 2021). Factually, Kroetz et al. (2018) highlighted that several factors can be considered
545 in the selection of products and species in mislabeling studies. The selection can be conducted in
546 accordance with consumers demand trend but it is usually not planned in relation to national
547 consumption; rather, products already identified from previous studies as being at a certain risk of
548 mislabeling are the target. Hence, it can be inferred that the initial sampling plan can significantly
549 contribute to a bias in the characterisation of the magnitude of the mislabelling rate. However, in this
550 study the sampling of fish in term of MG/family/species and market form seems to be both influenced
551 by the product commercial relevance (at EU and/or national level) and its attitude to be subject of
552 fraudulent substitution practices. We found that unprocessed fillets or slices (fresh or frozen) were
553 more representative respect to processed ones, mainly because in Italy the MG/families/species found
554 as most investigated are especially marketed in this form. Also at global level, fillets and processed
555 products have been reported as the most frequently sampled, with cods, especially Gadidae, found as
556 the most investigated in term of *bs* number (Luque & Donlan, 2019). Within the last decade, cods
557 have especially served as an exemplary case study for highlighting the impact of DNA technologies
558 on the seafood authentication (Naaum, Warner, Mariani, Hanner, & Carolin, 2016). This MG
559 represents in fact the main group of exported species worldwide among fish (FAO, 2020a) and it
560 accounts for more than one fifth of the apparent consumption of fishery and aquaculture products in
561 EU, which is mainly supplied by imports (EUMOFA, 2021). Given its commercial value, *G. morhua*
562 is reported among the most substituted species in the world (Feldmann, Ardura, Blanco-Fernandez,
563 & Garcia-Vazquez, 2021; Naaum et al., 2016). This aspect is certainly encouraged by the fact it is
564 mainly sold as frozen fillets worldwide (EUMOFA, 2020), as also observed in this study, where
565 morphological key features of the whole specimens lack.

566 Similarly, the other market forms observed for cods *bs* in this study may drive fraudulent
567 substitutions, such in the case of highly processed seafood preparations made of *G. chalcogrammus*
568 and “baccalà” (processed salted) made of *G. morhua* or *G. macrocephalus*. *Gadus chalcogrammus*
569 (Alaska pollock) is historically the main species used for surimi production worldwide but, due to its

570 overexploitation, numerous previously underutilized fish species have started to be used posing this
571 product to a high risk of species substitution (Galal-Khallaf, Osman, Carleos, Garcia-Vazquez, &
572 Borrell, 2016, Giusti et al. 2017; Keskin & Atar, 2012). Baccalà is instead one of the main heavy-
573 salted products consumed in Mediterranean countries (Smaldone, Marrone, Palma, Sarnelli, &
574 Anastasio, 2017). In Italy, it has been established that it can be obtained exclusively from *G.*
575 *macrocephalus* (Pacific cod) and *G. morhua* (Atlantic cod) (Ministerial decrees of January 31st, 2008;
576 Ministerial Decree n.19105 of September 22nd, 2017), but in other countries the legislation is
577 different. For instance, the term “*Bacalao*” refers to all the species included in the genus *Gadus* in
578 Spain, while “*Bacalada*” refers to *Micromesistius potessou*; in Portugal, also the species *Boreogadus*
579 *saida* can be used for the “*Bachalau*” manufacturing; in Romania, only the species *Merlangius*
580 *merlangus* is intended as “*Bacaliar*” ([https://fish-commercial-names.ec.europa.eu/fish-](https://fish-commercial-names.ec.europa.eu/fish-names/home_en)
581 [names/home_en](https://fish-commercial-names.ec.europa.eu/fish-names/home_en)). Given this legislation discrepancy, cases of intentional or unintentional species
582 substitution cannot be excluded, as also reported in literature (Di Pinto et al., 2013). The family
583 Merlucciidae is also highly investigated worldwide in terms of mislabeling rates (Blanco-Fernandez
584 et al., 2021; Luque & Donlan, 2019) and the species belonging to the genus *Merluccius* are of great
585 interest due to their commercial relevance, especially in EU (Blanco-Fernandez et al., 2021).
586 Currently, many of the *Merluccius* spp. have stocks under high fishing pressure and, since many
587 species overlap their range of distribution with at least another congeneric species (FAO, 2020b).
588 accidental mislabeling may occur due to the similar morphology of sympatric species, aggravating
589 the fishing pressure on the threatened ones. In this respect, the market form observed in this study for
590 *Merluccius* spp. (mainly processed breaded) may facilitate this event. The species *M. merluccius*,
591 which is one of the main target species of the Mediterranean fisheries (Sioni et al., 2019), is instead
592 mainly consumed in Italy as unprocessed fresh fillet (as confirmed by the observed *bs* sampling),
593 with higher commercial value respect to the other *Merluccius* spp. However, annual catches have
594 been halved from '90 to 2000-2013, indicating an overfishing status in several Mediterranean areas,
595 with several scientists who highlighted the risk of a stock collapse (Russo et al., 2017). The reduced

596 availability of this species, associated to its economic value, may encourage substitution practices
597 with less valuable species, possibly deceiving consumers even respect to the purchasing of frozen-
598 thawed instead of fresh products (Tinacci et al., 2018b).

599 Processed canned mackerels (family Scombridae) and herrings (Clupeidae) were also found as the
600 most sampled *bs*. Mackerels are among the most commercially relevant fish group worldwide. The
601 global market is primarily driven by the rising demand for canned tuna as consumers are shifting
602 toward ready-to-eat products. EU consumption of tuna is largely supported by imports, consisting
603 almost entirely of processed tuna, of which 30% is frozen and 70% includes prepared-preserved
604 products (mainly canned). In fact, canned tuna is the most consumed seafood product also in EU
605 (EUMOFA, 2021). Scombridae are among the families most investigated for m. r. also at global level
606 (Luque & Donlan, 2019). Respect to Clupeidae, they represent the 18% of the EU traded small pelagic
607 fish and processed products sold at retail level generally consist of whole, beheaded or filleted smoked
608 exemplars, ready-to-eat, marinated or pickled, and canned delicacies, all of them also available on
609 the Italian market. Semi-preserved anchovies (*E. encrasicolus*) are traditionally consumed within EU,
610 with Spain and Italy among the major consumers, covering alone the 71% of the total EU
611 consumption (EUMOFA, 2018). In Italy, anchovies are mainly consumed in form of ready-to-eat
612 products, i. e. salted, marinated or in oil.

613 Other highly investigated species were mainly found as unprocessed (fresh or frozen) not whole,
614 and they were *P. platessa* (MG flatfishes) and *X. gladius* (MG swordfish). Flatfishes are widely
615 sampled for mislabeling evaluation also at global level (Luque & Donlan, 2019; Pardo et al., 2016).
616 Italy is one of the main EU markets of *P. platessa*, and the supply is mainly based on imports, of
617 which 95% of the volumes are fillets (mainly frozen) for consumption on the national market
618 (EUMOFA, 2016). Also in the case of *X. gladius*, Italy is by far the main market in the EU
619 (EUMOFA, 2018); according to the Institute for Agricultural and Food Market Services (ISMEA), it
620 was the fifth most-consumed species in Italy in 2015, accounting for 3% and 5.5%, respectively, of

621 volume and value of seafood household purchases (fresh or thawed slices). Also in these latter two
622 cases, the market form (fillets and slices) highly poses the product at risk of fraudulent substitution.

623 Regarding the supply chain included in the studies, we found that sampling was mainly conducted
624 at retail level, while *bs* from mass caterers and official control were together just above 20% of the
625 overall *bs* number. Luque & Donlan (2019) reported that sampling was highly focused on restaurants
626 and grocery stores, while wholesale venues, ports, and markets were less sampled. However, the
627 different categorization proposed by the authors and the fact that retail level was fragmented in several
628 sub-categories does not allow us to make a comparison between Italian and global level in term of
629 distribution channels.

630 We especially believe necessary that surveys specifically focusing on seafood mislabeling in
631 Italian mass caterers are provided, as for other EU countries (Christiansen et al., 2018; Pardo et al.,
632 2018; Pardo & Jimenez, 2020), also considering that a great part of *bs* with no scientific name were
633 found as collected therein. In fact, EU restaurants and other mass caterers are not obliged to put the
634 mandatory information on their menus unless the Competent Authority requires so. They can do it
635 voluntarily to improve the image and credibility of their business, as they are just obliged to keep
636 such information and show the documents to the consumers if they require it (D'Amico, Armani,
637 Gianfaldoni, & Guidi, 2016a). For this reason, fraudulent substitution may be more easily performed.

638 Also, it is opportune to underline the need to detail the sampling geographical area (missing for
639 more than 30% of the *bs*), since this information may allow to better understand the mislabeling status
640 across the entire national territory. In fact, the more extensive sampling observed in Apulia and
641 Tuscany is essentially linked to the higher number of SPs performed in these regions, while for half
642 of the Italian regions no data on mislabeling are currently available.

643 **4.3 Mislabeling rates: publication year, taxon, market form, distribution channel and** 644 **geographical area.**

645 *4.3.1. M. r. calculated overall and for year of publication.* In this review, we decide to normalize
646 the overall *m. r.* to the sample size, meaning that SPs with a greater number of samples were given a

647 higher weight. This approach was also used by Oceana, the international organization dedicated to
648 protecting and restore the oceans on a global scale, to calculate seafood mislabeling rates at global
649 level through literature reviews (Golden & Warner, 2014; Warner et al., 2016). The latest one,
650 examining global data on mislabeling until 2015, reported a global m. r. normalized to sample size of
651 19% (Warner et al., 2016). The data was not reported for countries, so that a comparison with m. r.
652 in Italy cannot be performed. However, since the report also considered popular media sources, and
653 public documents from governments and NGOs besides peer-reviewed journal articles, and not only
654 those assessing the m. r. by molecular tools, we think that this comparison might not have been
655 pertinent. Luque & Donlan (2019), who used a Bayesian meta-analyses approach, found a global m.
656 r. of 24%, with a 95% highest density interval (HDI) from 20% to 29%. In Italy, they found a m. r of
657 26%, with 95% HDI from 18% to 34% (Luque & Donlan, 2019). The m. r. observed in our review
658 (28.2% with a 95% CI from 26% to 30%) falls within the HDI reported by Luque & Donlan (2019),
659 despite the different approaches used to calculate it. To remark that, also according to the diverse
660 inclusion criteria that were adopted, an accurate m. r. comparison cannot be made. We also do not
661 considered data from reviews reporting naïve m. r. since, in line with the observation by Luque &
662 Donlan (2019), we think that they have limited utility for characterizing mislabeling.

663 Respect to the m. r per years, the lower values observed since 2016 might suggest that the
664 increasing use of molecular tools to detect seafood frauds since 2015 has mitigated the mislabeling
665 occurrence (section 4.2). However, it is appropriate to underline that the type of sampling across the
666 years was essentially random; thus, considering that this aspect (especially the information related to
667 species and market form) largely influences the m. r. for each year, a proper cause-effect link cannot
668 be established. For instance, the higher m. r. observed in 2020 is probably related to the fact that, of
669 the 111 *bs* found as mislabeled in that year, more than half (n=59; 53.2%) belonged to species
670 showing m. r. within A category, namely *S. acanthias*/*S. blainville*, *M. mustelus*/*M. asterias*/*M.*
671 *punctulatus* and *L. vulgaris*.

672 4.3.2 *Mislabeled rate calculated for taxon*. In the systematic review by Luque and Donlan (2019),
673 species belonging to Serranidae and Lutjanidae had the highest estimated m. r. We found completely
674 different outcomes, essentially related the characteristics of the Italian market, where most of these
675 species are less consumed or not consumed at all. We found that the cases with highest m. r. (category
676 A) can be typically considered as commercial frauds, since the substituent species generally have
677 lower market price respect to the declared ones. It should be specified that the high m. r., discussed
678 below cannot characterize alone the magnitude of the problem. For example, an extremely popular
679 product with a low rate of mislabeling could yield a larger total quantity of mislabeled product than
680 a frequently mislabeled product with limited consumer demand (Kroetz et al. 2018). In this respect,
681 the higher m. r. was observed in non-conventional seafood (limited consumer demand) purchased
682 within ethnic shops namely jellyfish-based products (Armani et al., 2013). The products, mainly
683 labelled as the valuable *R. esculentum* were mainly substituted with *N. nomurai*, a species that has
684 spread in the Chinese sea and that is reported to have an undesirable taste, which made it cheap and
685 unpopular (Dong, Liu, & Keesing 2010). To consider that the products were sometimes marketed
686 with a trade name referring to vegetables, highlighting that the labeling of the ethnic products often
687 presents incongruences and deficits, as also reported in Armani et al. (2015b) and Armani et al.
688 (2012b). The analyses on jellyfish-based products were performed with the aim to investigate a novel
689 food marketed within the national territory (D'Amico, Leone, Giusti, Armani, 2016b).

690 Products labeled as *S. acanthias*/*S. blainville* (“*spinarolo*”), species found on Italian coasts and
691 with prized meats, were found as often replaced with the cheaper *P. glauca*, (Filonzi, Chiesa, Vaghi,
692 & Nonnis Marzano, 2010; Marchetti et al. 2020). This can also be attributed to the decrease of *S.*
693 *acanthias* in the Mediterranean Sea, now classified as vulnerable in the IUCN Red List (Table SM5).
694 For this reason, the EU has recently prohibited the fishing, storage on board, trans-shipment and
695 landing of this species (Council Regulation EU No 124/2019). Cases of replacement with *P. glauca*
696 or other cheap shark species (e. g. *S. canicula*, *I. oxyrinchus*) were also observed for other valuable
697 shark products, such as *M. mustelus*/*M. asterias*/*M. punctulatus* (“*palombo*”) (Barbuto et al., 2010;

698 Marchetti et al., 2020). In contrast with how mentioned before, *bs* declared as “*palombo*” were
699 especially substituted with *S. acanthias* in the SP by Barbuto et al. (2010), since the market price of
700 this species were lower more than a decade ago and no fishing prohibition were imposed by EU
701 legislation.

702 *Perca fluviatilis* (European perch) a freshwater species of high commercial interest living in the
703 northern Italian rivers was found as often substituted with cheaper species that are farmed in highly
704 polluted waters in the river Mekong in Asia and in African countries, represented by *P.*
705 *hypophthalmus* (Striped catfish), and *L. niloticus* (Nile perch), respectively. Similar substitution
706 patterns were observed for *E. marginatus* (Dusky grouper), another expensive and appreciated fish
707 species. Factually, striped catfish was identified as the most substituted fish worldwide, and it is
708 frequently disguised as wild, higher-value fish (Luque & Donlan, 2019; Warner et al. 2016). In the
709 case of *Scomber scombrus*, it was hypothesized that the high m. r. is due to the fact that products
710 labels often reported generic umbrella terms which can be ambiguously interpreted (Mottola et al.,
711 2022).

712 The mislabeling cases of species belonging to cods generally concern the replacements with
713 species included in the same family or order of the declared species. For instance, the highly relevant
714 commercial species *G. morhua* and *G. macrocephalus*, the only species for which the name “*baccalà*”
715 can be used in Italy (Ministerial Decrees n.19105 of September 22nd, 2017), were substituted with
716 other less valuable species from the Gadidae and Lotidae families. Also, *M. merluccius* (European
717 hake) was found as substituted with other species from Merlucciidae or Gadidae. Similar incidents of
718 replacement of *Gadus* spp. or *Merluccius* spp. with congeners or species belonging to the family
719 Gadidae or Merlucciidae, have also been periodically described (Blanco-Fernandez et al., 2021;
720 Garcia-Vazquez et al., 2011; Munoz-Colmenero et al., 2015; Tinacci et al., 2018b, Helgoe, Oswald,
721 & Quattro, 2020).

722 We observed high m. r. also for *X. gladius* (swordfish), which in Luke & Donlan (2019) showed
723 instead a m. r. (4%) lower than the global m. r. This may be because this product is commercially

724 relevant at national level. To underline that m. r. referring to cods and jacks were obtained from data
725 collected during 14 years and 10 years, respectively, out of the 17-years considered period. Therefore,
726 they can be considered more representative of the market situation respect to data arising from
727 sporadic studies.

728 *4.3.3 Mislabeled rate calculated for market form.* We found no significative differences between
729 m. r. in unprocessed and process *bs*. Contrariwise, significative differences were found within each
730 category: within unprocessed significantly higher m. r. were observed in fresh (fillets and/or slices),
731 and within processed significantly higher m. r. were observed in highly processed seafood
732 preparations and processed salted. Luque & Donlan (2019), reported no statistical evidence that
733 overall m. r. differs across product form at the global level. However, as the authors classified the
734 market forms differently from our study, a proper comparison cannot be made.

735 Although the objective of mislabeling is mainly financial gain, the introduction of any substituted
736 species into the food chain may result in health implication for consumers. Health risks associated
737 with the consumption of mislabeled seafood may be defined based on the perspective on freshness,
738 seafood allergies, contaminants such as mercury and other heavy metals, toxins including
739 gempylotoxin, tetrodotoxin, ciguatera, and even the unintentional consumption of zoonotic parasites
740 (Kusche & Hanel, 2021; Triantafyllidis et al., 2010; Williams et al., 2020). We are incline to believe
741 that the real extent of health implication of the *bs* found to be mislabeled in the included SPs could
742 be underestimated, since other types of hazards could have been involved. For example, Kusche &
743 Hanel (2021) observed that the occurrence of ciguatera-prone species in the cohort of DNA-identified
744 substituted fish was dramatically higher compared to the correctly labeled and the import tropical
745 fishes especially poses an underestimated health risk for seafood consumers in Europe (Kusche &
746 Hanel, 2021). This is equally true for zoonotic seafood borne parasites, since the substitution with
747 species that are susceptible to specific parasites poses a clear human health (Williams, Hernandez-
748 Jover, & Shamsi, 2020). In this respect, if we analyze *P. hypophthalmus*, one of the species found as
749 substitute in this review and generally highly involved in substitution practices, it should be remark

750 that, as farmed freshwater fish, it is vulnerable to infection by zoonotic parasites generally not
751 associated with saltwater fish species. In particular, it has been identified infected with the fish born
752 zoonotic trematodes *Centrocestus formosanus*, *Haplorchis taichui*, *H. pumilio* and *Chlonorchis*
753 *sinensis* (Williams et al., 2020). The risk for consumers is particularly high if this species is
754 substituted with valuable white fish species consumed raw, such as in sushi and sashimi, since humans
755 become infected after consuming raw or undercooked fish containing viable meta-cercariae (Hung,
756 Madsen, & Fried, 2013).

757 Even less is known about seafood mislabeling ecological and societal impact (Kroetz et al., 2018).
758 It is relevant to highlight the importance of knowing the m. r. and the most frequent substitute species
759 because this practices also harms fisheries and fishermen, allowing the introduction of illegal catches
760 or not declared ones into the food markets (Feldmann et al.,2021). In this review, out of the 19 species
761 reported as “vulnerable”, “endangered” or “critically endangered” in the IUCN Red List of
762 Threatened species (section 3.3.2), 14 are found as factually threatened, while the other five are
763 mainly farmed and it is assumed that the mislabeling cases do not involved the wild threatened
764 counterpart. Of these 14, shark species (*Galeorhinus galeus*, *Isurus oxyrinchus*, *M. mustelus*, *M.*
765 *punctulatus* *Oxynotus centrina*, *Carcharodon carcharias*, *Carcharhinus brachyurus*, *Squalus*
766 *brevirostris*, *S. acanthias*, *Alopias superciliosus*) were the most represented. In fact, according to the
767 most recent systematic analysis performed by the International Union for the Conservation of Nature
768 (IUCN) Shark Specialist Group (SSG), 74 of the 465 (15.9%) shark species included in the IUCN
769 Red List are threatened (Dulvy et al., 2014). The presence of shark species that are threatened or are
770 subject to global commerce regulation were also observed in mislabeled shark products collected in
771 China (Zhang et al., 2021).

772 *4.3.4 Mislabeling rate calculated for distribution channel and geographical area.* In our study, m.
773 r. was fund as significantly higher at retail level respect to mass caterers and official control levels.
774 Contrary from our outcomes, global data analysed by Luque & Donlan (2019) showed no evidence
775 for differences in mislabeling rates along the supply chain, although the m. r. observed for restaurants

776 was higher. The higher incidence of mislabeling cases at mass caterers is instead reported in other
777 reviews conducted in other EU countries (Christiansen, Fournier, Hellemans, & Volckaert, 2018;
778 Pardo et al., 2018; Pardo & Jimenez, 2020). In our study, the m. r. observed at retail level are highly
779 influenced by the contribution of the m. r. from small distribution (especially represented by ethnic
780 retailers), since the large distribution alone, showed m. r. like that of mass caterers and official control
781 activities. Ethnic activities are included in the small distribution, and despite a very good business
782 organization, they are often characterized by deficiencies in traceability and labeling systems (Armani
783 et al., 2013; Armani et al. 2015b; D'Amico et al., 2014). For instance, besides the case of jellyfish-
784 based products labeled as vegetables (Armani et al., 2013), one *bs* collected at ethnic shop retail in
785 2015 (Armani et al., 2015b) was even labeled as *Carcharocles megalodon* (“Megalodon”), which is
786 a shark that went extinct around 2.6 million years ago (Pimiento & Clements, 2014). To confirm this,
787 in a study targeting ethnic food stores in UK to examine accuracy of traceability information available
788 to consumers it was observed that about 41% of the samples were mislabeled, with a diverse range
789 of poorly-known fish species, often sold without any label or with erroneous information (Di Muri et
790 al., 2018). Differently from our outcomes, Pardo et al. (2016) observed that mislabeling incidents in
791 mass caterers are significantly higher than retailers. However, only 10% of analyzed samples were
792 obtained from mass caterers so that the authors underlined that specific studies should be conducted
793 to confirm it (Pardo et al., 2016).

794 The low m. r. found for samples collected within official control are in line with overall m. r.
795 reported in the aforesaid control plan performed by the EU Commission among Member State. In the
796 aforesaid control plan performed an overall m. r. of 6%, but the rate at Member State level varied
797 quite a lot, from 0 – 27 % (EU Commission Recommendation C(2015) 1558). Variations was related
798 to many factors, e. g. which species of fish are more popular on their market, or the type of processing
799 commonly used.

800 A statistical difference was observed for the first time among m. r. in Southern Italy respect to
801 Central and Northern. In fact, it should be considered that the products found as highly mislabeled,

802 such as *X. gladius* (swordfish), *P. fluviatilis*, *E. marginatus*, and baccalà, were especially sampled in
803 this area.

804 **4.4. Final remarks: strengths and weaknesses**

805 **4.4.1 Strengths.** Considering the extent and severity of the food fraud impact on the economic,
806 health and ecological aspects, the EU Commission and the Member States agreed on concrete
807 measures and coordinated action to step up the fight against this practice. Besides strengthening the
808 official control activities aimed at detecting frauds within all the EU territory, a consistent information
809 exchange on food fraud notifications among Commission, Europol and the Competent Authorities
810 designated by the Member States must be guaranteed within the RASFF portal. To facilitate
811 information exchange and interpretation within this food fraud network, data standardization is
812 essential. This aspect also drives the appropriate and successful outcomes of the risk assessment, the
813 scientific process assumed as fundamental to establish the procedures for correct risk management at
814 EU level. While for other issues involving the agri-food chain the data analysis is substantially
815 defined and applied, for the food fraud field, and especially mislabeling practices, it still needs to be
816 improved. In fact, current understanding of seafood mislabeling is largely limited to idiosyncratic
817 studies without consistent methodologies or metrics (Kroetz et al., 2018; Luque & Donlan, 2019). It
818 was in fact observed that all the available literature (systematic and non-systematic reviews, scientific
819 papers, reports) categorized data differently, limiting the studies comparison and making those data
820 scarcely usable for performing a target risk assessment. Although Italy was already investigated in
821 previous surveys, detailed data divided for taxon, market form, distribution channel and geographical
822 area were not provided or not easily extrapolated as provided aggregated with other data. Therefore,
823 this is the first systematic review in which we tried to characterize seafood mislabeling at Italian level,
824 trying to adopt a rigorous and standardized analytical approach that can be successfully used to assess
825 mislabeling in other countries. Respect to the analysis of data related to sampling, we especially
826 rigorously categorized the *bs* according to their taxon, market form, distribution channel and
827 geographical area, to guarantee the synthesis, interpretation and reproducibility of information, as

828 also recommended by EFSA (2010). In particular, dispositions provided by legislation (EU
829 regulations and Italian Ministerial Decrees) and official reports were used for the categorization.

830 As regards the analysis of data related to mislabeling, we decided to calculate the overall m. r.
831 weighted on the sampling size. The benefit of using a weighted average is that it allows the final
832 average number to reflect the relative importance of each number that is being averaged. The
833 importance to use weighted mean values has been highlighted by EFSA for standardizing the analysis
834 of other parameters, such as the abundance of microplastics in food (EFSA, 2016), but no particular
835 advices was provided for the m. r. calculation. and, as also observed in this study, m. r. are differently
836 calculated in literature, so that outcomes from single studies are poorly informative for mislabeling
837 characterization. We also decided to to fix 30 as minimum *bs* number to consider significative a
838 mislabeling value

839 *4.4.2. Weakness.* Some bias of the included SPs inevitably affected the results of this review, and
840 may consequently mislead the interpretation of the national mislabeling situation:

841 i) There is a notable lack of adequate sampling plans involving prior statistical analysis. First,
842 sampling plan should include the prior statistical calculation of the “sample size” of the population
843 under consideration, together with the “confidence interval” and “confidence level” selected in each
844 specific study (Pardo et al., 2016). Overall, qualitative research has come under criticism for its lack
845 of rigor in terms of there being little or no justifications given for the sample sizes that are actually
846 used in research (Marshall, Cardon, Poddar, & Fontenot, 2013). Convenience sampling represent one
847 of the most popular sampling techniques because it aligns the best across nearly all qualitative
848 research designs. However, the sampling strategy reported in most of the included SPs did not
849 consider a convenience, non-probabilistic sampling, structured to include a proportional number of
850 products per type and brand. With a view to collect data that can be useful to evaluate mislabeling,
851 we consider that it would be more suitable to exclude mixed sampling having low sample number for
852 category and to opt for the analysis of a “representative” number of single product types (e. g. single
853 MG/family/species, or market form, or distribution channel, or geographical area, etc.). In general,

854 we think that specific and exhaustive guidelines on sampling strategy should be fixed, also by
855 legislation, for investigating mislabeling, as for other typologies of control on food.

856 ii) There are not enough SPs aimed at assessing mislabeling in important seafood categories,
857 namely taxa different from fish, and especially molluscs and crustaceans, which cover a substantial
858 market share at national level. Therefore, is essential that the scientific community take action to
859 investigate this taxon. In fact, data collected throughout most of the 17-years period only referred to
860 commercially relevant fish MG. Also, data on processed products, especially those different from
861 canned, are scarce. Considering their high predisposition to be mislabeled, complex multispecies
862 seafood matrices should be more investigated, also considering that they cover a growing market
863 segment.

864 ii) More efficient molecular techniques for species identification in the kind of products reported
865 before should be set up and validated. For instance, the lack of data on seafood categories different
866 from fish is probably because species identification by molecular tools is more challenging for some
867 seafood, such as bivalve molluscs or crustaceans, since the DNA Barcoding approach relying on the
868 sequencing of a standard region of the Cytochrome Oxidase I (COI) gene (Hebert, Cywinska, Ball,
869 & DeWaard, 2003), usually applied for most fish, is not effective (Armani et al., 2017; Tinacci et al.,
870 2018b; Giusti et al., 2022). Additionally, the analysis of processed *bs*, especially in the case of
871 complex multispecies matrices (e. g. surimi, burger, etc.), should be performed with the aid of more
872 sophisticated authentication techniques based on metagenomic approaches and involving the use of
873 Next Generation Sequencing Technologies (NGS). In fact, the standard molecular tools, such as DNA
874 barcoding, are ineffective for species identification in these products (Franco, Ambrosio, Cepeda, &
875 Anastasio , 2021; Haynes Haynes, Jimenez, Pardo, & Helyar, 2019). Despite of this, only 2 SPs
876 included in this review applied NGS for the authentication of complex seafood products (Giusti et
877 al., 2017; Piredda et al., 2022). However, this technique still presents high cost of analysis in term of
878 reagents, equipment and expert personnel for the data analysis and therefore is still rarely used for
879 research purposes related to food authentication. Since metagenomic approaches based on NGS

880 technologies currently represent the most suitable technique for the analysis of complex matrices, it
881 should become part of the routine activities of official and private laboratories operating in seafood
882 authentication.

883 **Conclusions**

884 This systematic review and meta-analysis provided for the first-time detailed information on
885 seafood mislabeling on the Italian territory. ~~according to seafood species, market form, distribution~~
886 ~~channels and geographical area. The inclusion of data only from peer-reviewed studies, the~~
887 ~~methodological rigor in the data extrapolation, and categorization based on dispositions provided by~~
888 ~~legislation (EU regulations and Italian Ministerial Decrees) and official reports represents an efficient~~
889 ~~analytical approach to support the obtained results.~~ Therefore, outcomes from this study, ~~could by~~
890 ~~providing~~ a risk assessment, ~~and~~ could serve for better implementing a risk management plan. In
891 particular, driving more targeted official control activities, it can allow sing the definition of specific
892 criteria to be considered in terms of seafood species, market form, distribution channels and
893 geographical area. In this respect, data may facilitate the identification of high-risk products,
894 permitting to drive more targeted official control activities and undertake timely food inspections.
895 ~~We think in fact that, the inclusion of data only from peer-reviewed studies, the methodological rigor~~
896 ~~in the data extrapolation, and categorization based on dispositions provided by legislation (EU~~
897 ~~regulations and Italian Ministerial Decrees) and official reports represents an efficient analytical~~
898 ~~approach to support the obtained the results.~~ This is especially important considering the recent
899 measures adopted by the EU Commission to fight against fraudulent practices.

900 **Figure captions**

901 **Figure 1:** Number of market blind samples (*bs*) analysed for each year of publication.

902 **Figure 2.** Number of blind samples (*bs*) belonging to the five most investigated generic market
903 groups (MG) (mackerels, cods, herrings, flatfishes and jacks) through the years.

904 **Figure 3.** Number of market blind samples (*bs*) collected from the Italian market associated to
905 each generic market group - MG (a), family (b) and species (c). MGs and relative families and species

906 have the same colour. Data in this figure only refer to MGs, families and species for which the *bs*
907 number covers percentages $\geq 0.5\%$ within each taxonomic level.

908 **Figure 4. Details on unprocessed (a) and processed (b) *bs*.** Both percentages and *bs* number are
909 reported. *The SPs did not specify if they were fresh or frozen. The percentages were calculated on
910 the overall number of a) unprocessed *bs* (n=2197), and b) processed *bs* (n=1379).

911 **Figure 5. Mislabeling rates (m. r.)** calculated for species (or higher taxonomic levels) with ≥ 30 *bs*.
912 Number of mislabeled and not mislabeled *bs* for each species is reported. The different m. r.
913 categories (A1, A2, B, C1, C2) are indicated in the right side.

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