A meta-review of DNA-based identification methods and mislabeling analysis of Eastern South Pacific seafood

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Abstract

The Eastern South Pacific Ocean is a nutrient-rich and highly diverse region that plays a pivotal role in the global seafood trade. Despite its importance, the seafood industry in this region is hindered by complex supply chains and insufficient regulation frameworks, which facilitate illegal practices, including mislabeling. DNA-based methods have emerged as essential tools for seafood authentication, helping to mitigate mislabeling and supporting conservation strategies. This study provides the first comprehensive review of DNA-based methods used globally to identify seafood species from the Eastern South Pacific Ocean. Historical and current techniques were systematically examined, with a focus on emerging technologies that offer promising applications in the field. Nearly three decades of research have enabled the successful identification of over 200 commercially valuable species using more than ten distinct DNA-based methods. Fish and mollusks constituted the most extensively studied seafood groups, with DNA sequencing emerging as the predominant technique. Furthermore, a global mislabeling meta-analysis, encompassing 1,806 seafood products from the Eastern South Pacific Ocean, revealed an estimated mislabeling rate of 24.8% (95% CI [22.9-26.9]). Notably, a substantial proportion of mislabeled and substituted products corresponds to highly threatened shark species. This raises serious conservation concerns, particularly given that nations bordering the Eastern South Pacific Ocean are major players in the global shark trade. Overall, the findings of this review underscore the urgent need to integrate advanced DNA-based techniques into existing regulatory frameworks. They also establish a solid foundation for developing targeted policies and encouraging collaborative efforts among nations in this region.

Keywords: Molecular identification, seafood fraud, meta-analysis, South America

1. Introduction

Fish and seafood products have become some of the most traded commodities around the world, with an estimated annual production value of US$ 472 billion (Hellberg, 2024; Lawrence et al., 2022; FAO, 2024). During 2022, seafood contributed an estimated 20.7 kg per capita and provided about 15% of the world´s animal protein supply (FAO, 2024). A significant portion of this production comes from the coastal and oceanic fisheries of the eastern South Pacific Ocean (hereafter referred to as ESPO). In 2021, landings from the ESPO reached 10 million tons, accounting for 12.5% of global landings (FAO, 2024). Marine ecosystems in the ESPO are characterized by nutrient-rich waters and highly productive coastal upwelling zones. These factors make the ESPO one of the most productive marine systems in the world, exhibiting extremely high primary productivity that supports a rich and diverse array of marine life (Gonzalez et al., 2019; Serratosa et al., 2020).

Despite management efforts, several fisheries in developing countries, including those bordering the ESPO region, suffer from weak regulatory systems, wildlife trafficking, and high levels of illegal, unreported, and unregulated (IUU) fishing (Marín et al., 2018; De la Puente et al., 2020; Gozzer-Wuest et al., 2023). These issues create opportunities for deceptive practices such as mislabeling and species substitution throughout the supply chain (Lawrence et al., 2022). Seafood mislabeling not only undermines conservation and sustainability initiatives, but it also poses risks to consumers' health, economic well-being, trust, and even religious beliefs (Marín et al., 2013; Silva and Hellberg, 2021; Neo et al., 2022).

In this context, accurate species identification of commercially important marine resources is a crucial step toward effective management and prevention of dishonest practices. Although some seafood species are easily recognized, many marine organisms undergo various adaptive evolutionary processes that complicate their morphological differentiation. These processes include convergent phenotypic evolution, interspecific conservatism, phenotypic plasticity,

98 hybridization, and morphological variation within species (Pérez-Jiménez et al., 2005; Hanner
99 et al., 2011; Mynhardt et al., 2014; Pliego-Cárdenas et al., 2016; Neves et al., 2021; Marín et
100 al., 2022). Furthermore, most processed and cooked seafood products lack distinctive
101 morphological features, making them unsuitable for identification through conventional
102 taxonomic methods. To address this issue, several alternative molecular identification methods
103 have been developed, which are independent of morphological characters and have proven to
104 be effective for identifying both fresh and processed seafood species (Ali et al., 2012; Lago et
105 al., 2014).
106 Recent advances in molecular biology have led to the development of various accurate and
107 sensitive methods that can of identify organisms at the species level, even from highly
108 processed samples or minuscule amounts of tissue. Consequently, a range of analytical
109 techniques based on proteins and DNA have been employed to authenticate seafood products
110 (Ali et al., 2012; Lago et al., 2014; Silva and Hellberg, 2021). However, the heat-labile nature
111 of most proteins limits the applicability of protein-based techniques to fresh or lightly
112 processed seafood samples (Teletchea, 2009; Silva and Hellberg, 2021; Aditi et al., 2024). In
113 contrast, DNA is more resistant to heat degradation, making it suitable for analyzing highly
114 processed seafood products, such as canned or cooked items. This advantage allows DNA
115 techniques to overcome the limitations associated with protein-based methods (Teletchea,
116 2009). Furthermore, DNA can be PCR-amplified from very small amounts of starting material,
117 which can be collected from virtually any organic substrate, including fins, blood, mucus, and
118 bones (Teletchea, 2009; Silva and Hellberg, 2021; Aditi et al., 2024).
119 Although some comprehensive reviews have discussed DNA-based techniques for global
120 seafood authentication and mislabeling (Teletchea, 2009; Ali et al., 2012; Lago et al., 2014;
121 Pardo et al., 2016; Luque and Donlan, 2019; Silva and Hellberg, 2021; Aditi et al., 2024), most
122 of the reviewed studies from South American countries are primarily focused on research

conducted in Brazil, which examines species from the western South Atlantic Ocean. In contrast, reviewed studies addressing seafood species from the ESPO region remain underrepresented. There is a noticeable lack of reviews on DNA detection of seafood diversity and mislabeling rates in articles from ESPO nations, despite the region´s rich marine biodiversity, significant wild-capture and mariculture production, and the wide variety of seafood products that these nations offer commercially around the globe.

This review provides a comprehensive overview of both past and present DNA-based methods used to identify commercially important species from the ESPO region. It offers a summary of the techniques, DNA markers, and oligonucleotide primers found in the reviewed literature. This review also intends to examine the ESPO's species diversity that has been identified using DNA methods, presenting the most current database of commercially significant species accompanied by molecular identification records. Furthermore, I performed an analysis of their current conservation status based on information from the International Union for Conservation of Nature (IUCN). Lastly, a systematic meta-review of seafood mislabeling was conducted based on data from the surveyed articles, which feature samples collected from both domestic and international markets where ESPO species are sold.

2. Materials and methods

2.1 Data collection and inclusion criteria

This study is based on an exhaustive analysis of peer-reviewed papers published between mid-December 1998 and early July 2025. The Level 1 screening focused on articles that report the development and application of DNA-based tools for identifying commercial marine samples from fisheries and mariculture within the ESPO region. Samples were collected throughout the seafood supply chain, including fish landings, farms, curing facilities, wholesale fish markets, manufacturers, fishmongers, local markets, supermarkets, ethnic markets, restaurants, and

148 exporters in ESPO's countries and international markets. Articles that originated outside the
149 ESPO's countries were included only if they analyzed products that contained declared species
150 from the ESPO region, specifically those identified as imported commodities. Relevant
151 research articles were sourced from multiple databases, including Google Scholar, Direct,
152 PubMed, ResearchScience, SciELO, and Scopus, using the following search terms (in both
153 English and Spanish): “canned” OR “crab” OR “crustaceans” OR “fish” OR “fish market” OR
154 “gastropods” OR “DNA barcoding” OR “DNA meta-barcoding” OR “DNA-based techniques”
155 OR “DNA-sequencing” OR “High-throughput sequencing” OR “mislabeling” OR “molecular
156 identification” OR “molecular markers” OR “mollusks” OR “polymerase chain reaction (PCR)”
157 OR “protected marine species” OR “qPCR” OR “seafood authentication” OR “seafood fraud”
158 OR “seafood supply chain” OR “sharks” OR “shellfish” OR “species identification” OR
159 “species-specific primers” OR “Eastern South Pacific” OR “South America” OR “Chile” OR
160 “Colombia” OR “Ecuador” OR “Peru”. Cited references from the identified articles were also
161 reviewed to find related papers not identified in the initial search.
162 The most targeted studies focused on developing molecular markers and applying DNA-based
163 identification tools for seafood authentication and detecting mislabeling. However, studies that
164 utilized DNA-based methods for identifying new range expansions, species occurrences,
165 phylogenetic relationships, or population genetics were considered only if the specimens
166 analyzed had commercial origins or were captured by fishermen, indicating the type of retail
167 venue and location where the samples were obtained. Studies based on self-collected samples
168 from wild populations and environmental DNA (eDNA) were excluded. However, articles
169 validating novel DNA-based methods (e.g. assessing the performance of novel primers) using
170 self-collected samples from natural populations were included if the target species had
171 economic significance. Unpublished studies, preprints, abstracts, or any research that had not
172 undergone a peer-review process were disregarded. Additionally, this review included studies

173 that analyzed samples from protected or endangered species of commercial value in local or
174 international markets (whether these samples were commercially obtained or seized by
175 authorities) whose trade is banned or regulated. Lastly, this review also examined articles that
176 reported on the molecular authentication of fish feed claimed to contain commercially valuable
177 species from the ESPO.
178

179 **2.2 DNA-based methods, molecular markers, and primers**

180 For practical purposes, DNA-based methods used for seafood authentication of ESPO's species
181 were categorized into three distinct groups. The first category consists of methods that rely on
182 the amplification of DNA by a polymerase enzyme using PCR or qPCR. The results from these
183 methods are based on the visualization of a specific size fragment or band pattern in a gel
184 matrix, a positive colorimetric reaction, or a fluorescence signal pattern displayed digitally.
185 This category includes the following methods: 1) PCR-RFLP (Restriction Fragment Length
186 Polymorphism), 2) PCR-RAPD (Random Amplified Polymorphic DNA), 3) PCR-SSCP
187 (Single Strand Conformation Polymorphism), 4) PCR-SSP (Species Specific Primers), 5)
188 qPCR-SSP, 6) Multiplex PCR and qPCR, 7) qPCR High-Resolution Melting (HRM), and 8)
189 PCR-Microarrays. The second category encompasses methods that depend on DNA
190 sequencing technologies. This category further divides into two subcategories: a) sequences
191 generated through a PCR step followed by the Sanger Sequencing technique, which includes:
192 9) FINS (Forensically Informative Nucleotide Sequencing) and DNA Barcoding; and b)
193 sequences generated by high-throughput NGS (Next Generation Sequencing) technologies,
194 specifically 10) HTS NGS-metabarcoding. The third category includes seafood species
195 identification based on 11) mass spectrometry analysis. The genetic markers discussed in the
196 reviewed articles were organized into three levels based on 1) genome origin: mitochondrial,
197 nuclear, and random markers (like those targeted by RAPD primers), 2) target organisms, and

198 3) DNA-based methods. Similarly, all oligonucleotide primers reported in the analyzed articles
199 were classified into two levels according to 1) target molecular marker (e.g., mitochondrial
200 COI gene, nuclear rhodopsin gene) and 2) targeted animal groups.
201
202 **2.3 Commercial species diversity and conservation statuses**
203 The species composition of commercially traded seafood from the ESPO region was assessed,
204 considering both domestic and international markets. This assessment was based on the species
205 identification results reported in the reviewed articles. This review focused exclusively on
206 seafood species from the ESPO region, which includes marine species (such as sharks and
207 tuna) and diadromous fish (like eel, herring, salmon, and trout). Strict freshwater species (such
208 as tilapia) were not included in the analysis. Only species that are native to the ESPO region
209 were considered; however, introduced or naturalized species of commercial value were also
210 taken into account. Species identified in reviewed studies collected from domestic ESPO
211 markets, which have a confirmed distribution range outside the ESPO (likely sourced from
212 imported commodities), were excluded from the assessment. Distribution ranges were verified
213 using several databases: The Ocean Biodiversity Information System OBIS (https://obis.org),
214 FishBase (https://fishbase.org), SeaLifeBase (https://www.sealifebase.org), The Barcode of
215 Life Data System -BOLD-(https://boldsystems.org), and the World Register of Marine Species
216 -WoRMS- (https://marinespecies.org). All identified species reported in the analyzed studies
217 were organized at the taxonomic resolution level based on the current accepted classification
218 and scientific names provided by the WoRMS database. Additionally, the current conservation
219 status of all species identified in the papers analyzed in this review were searched in the IUCN
220 Red List of Threatened Species website (https://www.iucnredlist.org).
221

222 **2.4 Mislabeling meta-analysis**

223 The mislabeling meta-analysis dataset was constructed using articles that met the Level 1
224 screening criteria. These articles underwent a second screening based on Level 2 criteria, which
225 required that all analyzed samples were of commercial origin. Following this, a third screening
226 was conducted using the Level 3 criteria, which mandated that detailed information for each
227 analyzed sample be provided either in the main text or as a supplementary file. This information
228 included the label (commercial name), type of product (e.g. fresh, cooked, cured, canned), and
229 sampling venue (e.g. fish landing site, market). Only samples identified at the species level
230 were considered, and classifications above the species level were not included. The samples
231 included in the mislabeling meta-analysis consisted of seafood products that were labeled as
232 containing an ESPO species, such as "Peruvian anchoveta" (*Engraulis ringens*). These
233 products were either identified as the correct species or were found to be substituted with
234 another ESPO species (e.g. *Sardinops sagax*), a non-ESPO species (e.g. "European anchovy",
235 *E. encrasicolus*), or a freshwater species. Additionally, the analysis included cases where ESPO
236 species were used to replace non-native ESPO species from international markets, for example,
237 the Peruvian scallop (*Argopecten purpuratus*) being sold as the European king scallop (*Pecten*
238 *maximus*).

239 In an attempt to recover samples that had been identified at a higher taxonomic level due to a
240 lack of reference sequences at the time of publication, a curation update step was implemented.
241 This involved using publicly available DNA sequences cited in the reviewed papers, which
242 were re-analyzed and compared against current reference sequences from the GenBank and
243 BOLD databases.

244 To prevent the inclusion of samples that might have been classified as mislabeled due to a strict
245 interpretation of expected common names, I carefully checked the label information
246 (commercial designation or common name) and the reported scientific name of each analyzed

247 sample. This information was compared against common names used in official landing reports,
248 governmental websites, relevant literature, the FAO ASFIS database, and listed common
249 names from the FishBase database. For instance, samples from domestic ESPO markets that
250 were originally reported as mislabeled because they used generic names such as squid
251 ("*calamar*"), flounder ("*lenguado*"), grouper ("*mero*"), shark ("*tiburón*" or "*tollo*") were not
252 considered mislabeled in this review if the identified species belonged to a seafood group
253 implied by the declared generic term. This criterion was adopted because generic or umbrella
254 market names are commonly used in seafood markets in the ESPO region, where no official
255 lists of commercial designations for seafood species have been established. In fact, several
256 acceptable market names included in the FDA´s The Seafood List (available at
257 https://www.hfpappexternal.fda.gov/scripts/fdcc/index.cfm?set=SeafoodList) are examples of
258 generic seafood names (e.g. abalone, anchovy, grouper, sea bass, shark). In contrast, for
259 samples purchased within European markets, which have stricter seafood labeling regulations,
260 products must be labeled with unique commercial designations and the scientific name,
261 according to Regulation (EU) Nº 1379/2013. Therefore, official market names were verified
262 using the commercial and scientific name of seafood species listed on the European Union
263 (EU) website (https://oceans-and-fisheries.ec.europa.eu/fisheries/markets-and-trade/seafood-
264 markets/commercial-and-scientific-name-species_en). For samples collected in Canada, the
265 Canadian Food Inspection Agency (CFIA) fish list was consulted from its official website
266 (https://inspection.canada.ca/en/food-labels/labelling/industry/fish/list).
267 Cured samples from selected articles were pooled across studies and organized into different
268 levels including label information, seafood type (e.g. finfish, sharks, bivalves), sampling venue,
269 and country. The mislabeling rate was calculated using the formula [mn/n*100], where "mn"
270 is the number of mislabeled samples and "n" is the total number of samples.
271

272 **2.4.1 Statistical analyses**

273 Confidence intervals of the mislabeling rates were calculated using the "binom.confint"
274 function from the "binom" package implemented in R (R for Mac OS X GUI version 4.2.3) (R
275 core Team, 2022) to generate upper and lower estimates of the predicted mislabeling rates. The
276 Agresti-Coull method was used for calculating 95% confidence intervals (CI) for large sample
277 sizes ($n > 40$), while the Wilson method was chosen for small sample sizes ($n \leq 40$) (Brown et
278 al., 2001). Since these values represent percentages, any negative confidence intervals were
279 reported as zero, and those exceeding 100% were reported as 100% (Bubernick and Faulstick,
280 1993). Exploratory analyses were conducted to assess the independence of the association
281 between mislabeling rates based on continent, country, distribution channel, and seafood type.
282 Categories with sample sizes of fewer than 25 ($n < 25$) were excluded from the analyses. The
283 analyses utilized the Chi-square test or Fisher's exact test, depending on whether any cell count
284 was below 5. This approach was taken because Chi-square test relies on approximations that
285 become unreliable with small expected cell counts (Kim, 2017). When a significant association
286 between variables was observed ($p < 0.05$), further pairwise tests were conducted in R to
287 determine which pairwise comparisons were significantly different. p values were adjusted for
288 multiple comparisons using the Bonferroni correction method, and the α-level was set at 0.05
289 for all analyses. All R scripts used in the analyses are provided in S1 File.

290

291 # 3. Results and discussion

292 **3.1 Data collection overview**

293 This review compiled all the DNA-based methods used globally to identify commercially
294 important species in the ESPO region. A total of 74 published articles (see Table 1) met the
295 Level 1 screening criteria outlined in section 2.1 and were selected for analysis. The 74
296 reviewed articles were published across 43 different peer-review journals, with publication

Table 1. List of articles reviewed in this study.

Nº	Authors	Publication year	Journal (Language)	Target species	Method	DNA markers	ESPO seafood species type (supply channel and country of origin)	Conducted in	Passed screening Levels	Samples (n) in meta-analysis	Reference
1	Toro	1998	Journal of Shellfish Research (English)	Mussels	PCR-RFLP	ITS, PAPM	Wild (Chile)	CANADA	1	—	Toro (1998)
2	Rego et al.	2002	Journal of Agricultural and Food Chemistry (English)	Mussels	PCR-RAPD	Random	Wild (Chile)	SPAIN	1	—	Rego et al. (2002)
3	Rehbein	2002	Journal of Aquatic Food Product Technology (English)	Fish	PCR-RFLP SSCP	CYTB	Commercial (IFOMA Germany, imported from Chile and Peru)	GERMANY	1 and 2	—	Rehbein (2002)
4	Jérôme et al.	2003a	Journal of Agricultural and Food Chemistry (English)	Sardines	PCR-RFLP	CYTB	Commercial (supermarket in France, canned in Peru)	FRANCE	1, 2, and 3	1	Jérôme et al. (2003a)
5	Jérôme et al.	2003b	Journal of Agricultural and Food Chemistry (English)	Sardines	FINS	CYTB	Commercial (supermarket in France, origin Chile and Peru)	FRANCE	1, 2, and 3	6	Jérôme et al. (2003b)
6	Perez and García-Vazquez	2004	Journal of Food Protection (English)	Hake	PCR-RFLP	5S rDNA, CYTB	Wild (Chile)	SPAIN	1	—	Perez and García-Vazquez (2004)
7	Toro et al.	2005	Journal of Shellfish Research (English)	Mussels	PCR-RFLP	ITS, PAPM	Wild (Chile)	CHILE	1	—	Toro et al. (2005)
8	Olivares-Paz et al.	2006	Investigaciones Marinas (Spanish)	Keyhole limpets	PCR-RFLP	CYTB	Wild (Chile)	SPAIN/CHILE	1	—	Olivares-Paz et al. (2006)
9	Marín et al.	2007	Journal of Shellfish Research (English)	Abalone	PCR-RAPD	RANDOM	Research facility (Chile)	CHILE	1	—	Marín et al. (2007)
10	Aguilera-Muñoz et al.	2008	Gayana (English)	Mollusks	PCR and band size polymorphism	ITS1, ITS2	Commercial (Chile, Mexico)	CHILE	1 and 2	—	Aguilera-Muñoz et al. (2008)
11	Hernández et al.	2008	Journal of Fish Biology (English)	Shark fins	Multiplex PCR-SSP	ITS2	Commercial (drying facility, commercial	CHILE	1, 2, and 3	200	Hernández et al. (2008)

							storage warehouse in Chile)				
12	Espiñeira et al.	2009a	Journal of Agricultural and Food Chemistry (English)	Bivalves	FINS	18S rDNA	Wild (Chile, Peru)	SPAIN	1	—	Espiñeira et al. (2009a)
13	Espiñeira et al.	2009b	European Food Research and Technology (English)	Salmon, trout, bream	PCR-RFLP	CYTB	Wild (Peru) and commercial (supermarket, Chile)	SPAIN	1 and 2	—	Espiñeira et al. (2009b)
14	Hernández et al.	2010	Hidrobiológica (English)	Shark fins	PCR-SSP	ITS2	Commercial (storage warehouse, Chile)	CHILE	1 and 2	—	Hernández et al. (2010)
15	Tzika et al.	2010	Conservation Genetics (English)	Cetaceans	DNA sequencing	CYTB	Commercial (markets, Peru)	SWITZERLAND/ PERU	1 and 2	—	Tzika et al. (2010)
16	Aranceta-Garza et al.	2011	Food Control (English)	Abalone	PCR-SSCP	18S rDNA	Commercial and wild (Retail market in Mexico, imported from Chile and Peru)	MEXICO	1, 2, and 3	2	Aranceta-Garza et al. (2011)
17	Fernández-Tajes et al.	2011	European Food Research and Technology (English)	Mussels	PCR-RFLP	PAPM, COI	Commercial and wild (Spanish supermarket, imported from Chile)	SPAIN	1, 2, and 3	80	Fernández-Tajes et al. (2011)
18	Ha et al.	2011	Journal of Agricultural and Food Chemistry (English)	Abalone	FINS	16S rRNA, (COI was used as auxiliary marker)	Commercial (wholesale and retail outlets in Hong Kong, imported from Chile)	HONG KONG/UK	1, 2, and 3	2	Ha et al. (2011)
19	Herrero et al.	2011	Food Chemistry (English)	Salmon	qPCR-SSP	ITS1	Commercial (supermarket in Chile)	SPAIN	1 and 2	—	Herrero et al. (2011)
20	Ardura et al.	2012	Fisheries Research (English)	Fish	DNA sequencing	16S rRNA	Commercial (Spanish producers, species origin: Peru)	SPAIN	1, 2, and 3	2	Ardura et al. (2012)

21	Caballero et al.	2012	Molecular Ecology Resources (English)	Sharks	Multiplex PCR-SSP, DNA sequencing	COI, ITS2	Commercial (landings in Colombia)	COLOMBIA	1 and 2	—	Caballero et al. (2012)
22	Haye et al.	2012	Food Control (English)	Crabs	DNA sequencing	COI	Commercial (seafood market and food store in Chile)	CHILE	1 and 2	—	Haye et al. (2012)
23	Näumann et al.	2012	Informationen aus der Fischereiforschung (German)	Scallops	DNA sequencing	16S rRNA	Commercial (Imported or local commerce in Germany, imported from Peru)	GERMANY	1, 2, and 3	1	Näumann et al. (2012)
24	Horreo et al.	2013	Journal of the Science of Food and Agriculture (English)	Several animal species	DNA sequencing	16S rRNA	Commercial (imported from Peru)	SPAIN	1, 2, and 3	1	Horreo et al. (2013)
25	Marín et al.	2013	Food Control (English)	Scallops	Multiplex PCR-SSP	16S rRNA	Commercial (landings and market in Peru)	JAPAN	1, 2, and 3	3	Marín et al. (2013)
26	Chairi and Rebordinos	2014	Journal of Agricultural and Food Chemistry (English)	Anchovies	Multiplex PCR-SSP	5S rDNA	Wild (Chile)	SPAIN	1	—	Chairi and Rebordinos (2014)
27	Santaclara et al.	2014	Food Chemistry (English)	Ling fish	FINS	COI	Wild (Chile)	SPAIN	1	—	Santaclara et al. (2014)
28	Marín et al.	2015	Fisheries Science (English)	Scallops	DNA sequencing	16S rRNA	Commercial (landings in Peru)	JAPAN	1, 2, and 3	8	Marín et al. (2015)
29	Velez-Zuazo et al.	2015	Fisheries Research (English)	Sharks	DNA sequencing	COI	Commercial (landings in Peru)	PERU	1 and 2	—	Velez-Zuazo et al. (2015)
30	Galal-Khallaf et al.	2016	Food Chemistry (English)	Shrimps/Cephalopods	DNA sequencing	COI, 16S rRNA	Commercial (supermarkets in Spain and Egypt, imported from Ecuador and Chile)	SPAIN/EGYPT	1, 2, and 3	18	Galal-Khallaf et al. (2016)
31	Pliego Cárdenas et al.	2016	American Malacological Bulletin (English)	Octopus	DNA sequencing	COI, COIII, 16S rRNA	Commercial (artisanal fishery in Ecuador)	MEXICO/ECUADOR	1, 2, and 3	7	Pliego Cárdenas et al. (2016)

32	Sanchez et al.	2016	Fisheries Science (English)	Cephalopods	DNA sequencing	16S rRNA	Wild (Peru)	JAPAN	1	—	Sanchez et al. (2016)
33	Velasco et al.	2016	Heliyon (English)	Anchovies	FINS	CYTB	Commercial (markets, supermarkets, and specialized stores in Spain, origin Chile and Peru)	SPAIN	1, 2, and 3	11	Velasco et al. (2016)
34	Abbadi et al.	2017	Journal of the Science of Food and Agriculture (English)	Bivalves	HTS Pyroseq	COI, 16S rRNA	Commercial (customs premises, market in Italy, imported from Chile)	ITALY	1, 2, and 3	44	Abbadi et al. (2017)
35	Jilberto et al.	2017	Food Chemistry (English)	Mussels	HRM, RFLP	PAPM	Wild (Chile)	SPAIN	1	—	Jilberto et al. (2017)
36	Marín et al.	2017	Aquaculture Research (English)	Scallops	Multiplex PCR-SSP	16S rRNA	Commercial (landings in Peru and supermarket in UK, imported from Peru)	JAPAN	1, 2, and 3	65	Marín et al. (2017)
37	Canales-Aguirre et al.	2018	Revista de Biología Marina y Oceanografía (English)	Fish	DNA sequencing	COI	Commercial (artisanal fishery in Chile)	CHILE	1 and 2	—	Canales-Aguirre et al. (2018)
38	Marín et al.	2018	Plos One (English)	Crustacean, fish, gastropods, mollusks	DNA sequencing	COI, 12S rRNA, 16S rRNA, Control Region	Commercial (landings, wholesales, markets, supermarkets, restaurants in Peru)	PERU	1, 2, and 3	120	Marín et al. (2018)
39	Mora et al.	2018	Salud y Tecnología Veterinaria (Spanish)	Fish	qPCR-SSP	ATP6, Control Region	Commercial (supermarkets in Peru)	PERU	1 and 2	—	Mora et al. (2018)
40	Shehata et al.	2018	Food Control (English)	Fish	DNA sequencing	COI	Commercial (Canadian Food and Inspection Agency surveillance)	CANADA	1, 2, and 3	9	Shehata et al. (2018)

							across Canada, imported from Chile and Peru)				
41	Giusti et al.	2019	Food Control (English)	Anchovies	DNA sequencing	CYTB	Commercial (large-scale retail distribution in Italy, imported from Chile)	CHILE	1, 2, and 3	9	Giusti et al. (2019)
42	Hu et al.	2019	Science and Technology of Food Industry (Chinese)	Sea cucumber	DNA sequencing	COI, 16S rRNA	Commercial (supermarket in China, species origin: Peru)	CHINA	1, 2, and 3	1	Hu et al. (2019)
43	Larraín et al.	2019	Scientific Reports (English)	Mussels	RFLP	COI, 16S rRNA, PAPM, ITS, MAC-1, 18S rDNA	Wild (Chile)	CHILE	1	—	Larraín et al. (2019)
44	Shehata et al.	2019	Food Research International (English)	Fish	DNA sequencing	COI	Commercial (Canadian Food and Inspection Agency surveillance across Canada, imported from Chile, Colombia, Ecuador and Peru)	CANADA	1, 2, and 3	12	Shehata et al. (2019)
45	Yu et al.	2019	Journal of Food Hygiene and Safety (Korean)	Cephalopods	DNA sequencing	COI, 16S rRNA	Commercial (market in South Korea, imported from Chile and Peru)	KOREA	1, 2, and 3	5	Yu et al. (2019)
46	Biffi et al.	2020	Scientific Reports (English)	Cephalopods , fish, cetacean	DNA sequencing	COI	Commercial (landings, wholesale, retail, supermarket, restaurants in Peru)	PERU	1, 2, and 3	413	Biffi et al. (2020)

47	Cabanillas-Torpoco et al.	2020	Zootaxa (English)	Sawfish	DNA sequencing	COI	Commercial (landings in Peru)	PERU	1 and 2	—	Cabanillas-Torpoco et al. (2020)
48	Colihueque et al.	2020	Recent Patents on Food, Nutrition & Agriculture (English)	Mussels	PCR-RFLP	18S rDNA	Commercial (supermarkets in Chile)	CHILE	1, 2, and 3	95	Colihueque et al. (2020)
49	Prida et al.	2020	Foods (English)	Salmon, trout	PCR-RFLP	CYTB	Commercial (restaurants in Chile)	CHILE	1, 2, and 3	84	Prida et al. (2020)
50	Cañedo-Apolaya et al.	2021	Diversity (English)	Angel shark	DNA sequencing	COI	Commercial (landings and wholesale in Peru)	PERU	1 and 2	—	Cañedo-Apolaya et al. (2021)
51	Costa et al.	2021	Molecular Phylogenetics and Evolution (English)	Squids	DNA sequencing	COI, 16S rRNA, Rhodopsin	Commercial (markets in Ecuador and Peru)	BRAZIL	1 and 2	—	Costa et al. (2021)
52	Gense et al.	2021	Foods (English)	Bivalves	NHT NGS-Metabar-coding	16S rRNA	Commercial (delicacy shop in Austria, imported from Peru)	AUSTRIA	1, 2, and 3	16	Gense et al. (2021)
53	Kappel et al.	2021	Analytical and Bioanalytical Chemistry (English)	*Penaeus* shrimps	Microarray, DNA sequencing	COI, 16S rRNA	Commercial (retailer in Germany, declared origin: Ecuador)	GERMANY	1, 2, and 3	1	Kappel et al. (2021)
54	Klapper and Schröder	2021	Food Control (English)	Scallops	Multiplex qPCR, DNA sequencing	16S rRNA	Commercial (artisanal fishery in Chile)	GERMANY	1, 2, and 3	2	Klapper and Schröder (2021)
55	Marín et al.	2021	Journal for Nature Conservation (English)	Fish	qPCR-SSP, DNA sequencing	COI, 16S rRNA	Commercial (landings, wholesale, and markets in Peru)	PERU	1, 2, and 3	61	Marín et al. (2021)
56	Parrondo et al.	2021	Food Control (English)	Scallops	DNA sequencing	16S rRNA	Commercial (fish shops, supermarkets, and restaurants in Spain imported	SPAIN	1, 2, and 3	77	Parrondo et al. (2021)

							from Chile or Peru)				
57	Quintrel et al.	2021	Foods (English)	Mussels	PCR-RFLP, qPCR-HRM	PAPM	Wild and commercial (Chile)	CHILE	1 and 2	—	Quintrel et al. (2021)
58	Velez-Zuazo et al.	2021	Food Control (English)	Fish	DNA sequencing	COI	Commercial (fish markets, restaurants, and supermarkets in Peru)	PERU	1 and 2	—	Velez-Zuazo et al. (2021)
59	Xing et al.	2021	Food Control (English)	Sea cucumber	DNA sequencing	COI, 16S rRNA	Commercial (supermarket in China, origin: Peru)	CHINA	1, 2, and 3	1	Xing et al. (2021)
60	Asorey et al.	2022	Food Chemistry: Molecular Sciences (English)	Mussels	HRM, FINS	PAPM, H1C	Commercial (growing center in Chile)	CHILE	1, 2, and 3	61	Asorey et al. (2022)
61	Dufflocq et al.	2022	Food Control (English)	Swordfish	DNA sequencing	COI	Commercial (fish market, open-air market, and Supermarkets in Chile)	CHILE	1, 2, and 3	47	Dufflocq et al. (2022)
62	Giusti et al.	2022	Food Control (English)	Mussels	PCR-RFLP	PAPM	Commercial (national large retailers, ethnic shop (Italy, imported from Chile)	ITALY	1, 2, and 3	23	Giusti et al. (2022)
63	Manzanillas-Castro and Acosta-López	2022	Biodiversity (English)	Sharks	Multiplex PCR-SSP	ITS2	Commercial (fish market in Ecuador)	ECUADOR	1 and 2	—	Manzanillas-Castro and Acosta-López (2022)
64	Marín et al.	2022	Marine and Fisheries Sciences (English)	Fish	DNA sequencing	COI, Control Region	Commercial (landings in Peru)	PERU	1, 2, and 3	96	Marín et al. (2022)
65	Villate-Moreno et al.	2022	PeerJ (English)	Sharks	DNA sequencing	NAD2	Commercial (landings in Colombia)	COLOMBIA	1 and 2	—	Villate-Moreno et al. (2022)

66	Wenne et al.	2022	Aquaculture (English)	Mussels	MassARRAY SNP Genotyping	M7	Commercial (market in Poland, imported from Chile)	POLAND	1 and 2	—	Wenne et al. (2022)
67	Alfaro-Cordova et al.	2023	Conservation Genetics Resources (English)	Devil rays	DNA sequencing	COI	Commercial (landings in Peru)	PERU	1 and 2	—	Alfaro-Cordova et al. (2023)
68	Cardeñosa et al.	2023	Animal Conservation (English)	Sharks fins	qPCR-SSP, DNA sequencing	ITS2, COI	Commercial (shark fin seizure at El Dorado International Airport-Colombia)	COLOMBIA	1, 2, and 3	194	Cardeñosa et al. (2023)
69	Vera et al.	2023	Revista Peruana de Biología (Spanish)	Jewelfish	DNA sequencing	COI	Commercial (landings in Peru)	PERU	1 and 2	—	Vera et al. (2023)
70	Ehemann et al.	2024a	Fish Biology (English)	*Urotrygon* rays	DNA sequencing	COI, NAD2	Commercial (landings in Ecuador and Peru)	MEXICO	1 and 2	—	Ehemann et al. (2024a)
71	Ehemann et al.	2024b	Taxonomy (English)	*Gymnura* rays	DNA sequencing	COI	Commercial (landings in Peru)	MEXICO/PERU	1 and 2	—	Ehemann et al. (2024b)
72	Gil et al.	2024	Journal of the Science of Food and Agriculture (English)	Shrimp/prawns	DNA sequencing	COI	Commercial (supermarket and fishmongers in Spain, imported from Ecuador)	SPAIN	1, 2, and 3	12	Gil et al. (2024)
73	Ortiz-Moriano et al.	2024	Food Control (English)	Shrimp/ prawns	DNA sequencing	COI, 16S rRNA	Commercial (supermarkets in Spain, imported from Ecuador)	SPAIN	1, 2, and 3	1	Ortiz-Moriano et al. (2024)
74	Marín et al.	2025	Plos One (English)	Shellfish/ fish	DNA sequencing, qPCR-SSP, PCR-SSP, multiplex PCR	COI, 16S rRNA, 12S rRNA	Commercial and wild (landings, wholesale, markets, supermarkets in Peru)	PERU	1, 2, and 3	15	Marín et al. (2025)

297

298 dates ranging from mid-December 1998 to early July 2025. Notably, there were no relevant
299 articles published between 1999 and 2001. The journals "*Food Control*" and "*Journal of*
300 *Agricultural and Food Chemistry*" were the most frequent publication venues, with 12 articles
301 (16.2%) and 6 articles (8.1%), respectively. English was predominant language, appearing in
302 68 articles (91.9%). Three articles were written in Spanish, and one article each was published
303 in Chinese, German, and Korean. Out of the 74 studies, 30 were conducted entirely in ESPO
304 countries: Chile (14 studies), Peru (12 studies), Colombia (3 studies), and Ecuador (1 study).
305 The remaining 44 studies analyzed seafood samples collected around the world, including
306 those from the ESPO region. These were conducted in Spain (17 studies), Germany (4), Japan
307 (4), Mexico (4), Canada (3), China (2), France (2), Italy (2), and one study was carried out in
308 each of the following countries: Austria, Brazil, Hong Kong, South Korea, Poland, and
309 Switzerland. A total of 62 articles reported the authentication of commercial products from the
310 ESPO. The remaining 12 articles validated their molecular assays using reference samples of
311 non-commercial origin, which were obtained from natural populations within the ESPO,
312 collected by researchers, donated by colleagues, or obtained from research facilities. Out of the
313 62 articles that reported the use of commercial ESPO products, 23 did not meet the Level 3
314 screening criteria, as they did not provide detailed information about each individual sample.
315 This lack of detail prevented me from using their results in further mislabeling meta-analysis.
316 As a result, only the findings from 39 papers were included in the mislabeling meta-analysis
317 review (section 3.7).
318

319 **3.2 DNA-based identification methods for seafood species from the ESPO region**

320 **3.2.1 PCR-RFLP**

321 This technique involves three main steps: 1) the PCR amplification of a specific DNA fragment
322 using universal or group-specific primer sets; 2) enzymatic digestion with one or more

323 restriction endonucleases that recognize specific sites; and 3) the separation of the digested
324 DNA fragments in a gel matrix. A successful RFLP assay will result in the amplicon being cut
325 into two or more fragments, generating species-specific band patterns (Lago et al., 2014). The
326 main advantage of this method relies on its simplicity and relatively low cost. However, one
327 potential drawback is that incomplete enzymatic digestion can lead to misleading diagnostic
328 results, which may necessitate longer incubation times to achieve more reliable outcomes,
329 thereby extending the overall duration of the identification procedure. Additionally, prior
330 knowledge of the target DNA sequence is essential to select the adequate enzyme capable of
331 producing distinct fragment patterns between two or more species (Bossier, 1999; Lago et al.,
332 2014).
333 PCR-RFLP has been widely utilized to authenticate seafood products globally since the early
334 90´s (Chow and Inoue, 1993; Chow et al., 1993). In the ESPO region, various commercial
335 species targeted for the development of RFLP assays have been documented in 13 studies.
336 These studies include Chilean mollusks like mussels focusing on various markers such as 18S
337 rDNA, ITS, PAPM, COI, and 16S rRNA (Toro, 1998; Toro et al., 2005; Fernández-Tajes et
338 al., 2011; Jilberto et al., 2017; Larraín et al., 2019; Colihueque et al., 2020; Quintrel et al.,
339 2021; Giusti et al., 2022) and keyhole limpets using the mitochondrial cytochrome b (CYTB)
340 gene (Olivares-Paz et al., 2006). Additionally, PCR-RFLP was used to identify different fish
341 species including canned sardines from Peru based on the CYTB gene (Jérôme et al., 2003a),
342 Chilean hake using the CYTB and 5S rDNA genes (Perez and Vazquez-García, 2004), as well
343 as bream, salmon, and trout from Chile (Espiñeira et al., 2009b) and salmon from Chilean
344 restaurants (Prida et al., 2020) using the CYTB gene.
345

346 **3.2.2 PCR-RAPD**

347 This approach utilizes short oligonucleotides of arbitrarily chosen sequence (10-12 nt) to
348 generate species-specific electrophoretic patterns, known as fingerprinting, based on the
349 random PCR amplification of several anonymous DNA fragments across the genome
350 (Yamashita et al., 2024). The primary advantage of this method is that it requires little prior
351 knowledge of the target DNA sequence. However, despite its speed and simplicity, the
352 reproducibility of PCR-RAPD can be affected by slight changes in the quality and quantity of
353 the target DNA (Bossier, 1999; Yamashita et al., 2024). As a result, the number of studies
354 reporting RAPD-based protocols has declined over time. Nevertheless, intra- and inter-
355 laboratory reproducible RAPD results can be achieved if reactions are performed under strictly
356 identical conditions (Atienzar et al., 2006).

357 PCR-RAPD has been applied to species of economic significance from the ESPO, such as
358 differentiating the Mediterranean mussel *Mytilus galloprovincialis* from other commercially
359 valuable mussel species, including the Chilean mussel *M. chilensis* collected from a harvested
360 natural population in Puerto Aguirre, Chile (Rego et al., 2002). In another study, Marín et al.
361 (2007) developed a RAPD-based method for identifying the Pacific abalone *Haliotis discus*
362 *hannai* and the red abalone *H. rufescens*, as well as their potential hybrids, obtained from a
363 Chilean research institute´s hatchery. Based on their RAPD results, the authors reported that
364 the supposed hybrids were actually phenotypic variants of *H. rufescens.*

365

366 **3.2.3 PCR-SSCP**

367 This method relies on the electrophoretic mobility of single-stranded DNA through a non-
368 denaturing gel. Specific nucleotide mutations present in a single-stranded PCR product alter
369 the molecule´s conformation, causing two DNA strands that differ by a single nucleotide to
370 migrate differently (Gasser et al., 2006; Lago et al., 2014). While this method is relatively

371 simple, cost-effective and time-efficient, it has some disadvantages, such as poor
372 reproducibility and the need for reference samples (Gasser et al., 2006; Silva and Hellberg,
373 2021).
374 Two studies have demonstrated the application of the PCR-SSCP method to identify fish and
375 abalone species of global commercial interest, including samples collected from the ESPO
376 region. Rehbein et al. (2002) evaluated the utility of PCR-SSCP and RFLP-SCCP assays using
377 a 464 bp fragment of the CYTB gene to identify various fish species in commercially produced
378 fishmeal samples. These samples included anchovy, mackerel, sardine, and hake from Peru
379 and Chile. In another study, Aranceta-Garza et al. (2011) developed a PCR-SSCP technique
380 based on two PCR products targeting partial fragments of the 18S rDNA and Lysin precursor
381 genes in three abalone (Haliotidae) species namely *H. corrugata*, *H. fulgens*, and *H. rufescens*,
382 as well as other gastropod species in raw, frozen, and canned presentations from different
383 origins (Chile, Mexico, and Peru). By utilizing the PCR-SSCP method for the 18S rDNA gene
384 fragment, the authors revealed that a canned abalone sample had been substituted with
385 *Concholepas concholepas* (Muricidae) from Peru.
386
387 **3.2.4 PCR-SSP**
388 Species identification using species-specific primers (SSPs) is a rapid, highly accurate, and
389 sensitive method. It relies on a perfect or near perfect complementarity between the SSP and
390 the target species' strand, along with the presence of punctual mutations within the primer
391 hybridization region of non-target species (Marín et al., 2025). Mismatches at the primer's 3'-
392 terminal of the primer can severely disrupt polymerase activity, leading to the most significant
393 detrimental effects (Stadhouders et al., 2010; So et al., 2020). Several techniques for species
394 identification utilize SSPs, including multiplex PCR, qPCR, eDNA monitoring, and more
395 recently, CRISPR-based methods (Goldberg et al., 2016; Williams et al., 2019; Silva and

396 Hellberg, 2021). The PCR-SSP technique for species identification can be conducted with basic
397 molecular laboratory equipment, and the final diagnostic is electrophoretically resolved based
398 on the presence or absence of a PCR product of a known size. This makes the method both
399 time-effective and easy-to-interpret. Additionally, modified SSPs can be combined with
400 isothermal amplification technologies, using nanoparticle-based colorimetric or lateral flow
401 strip approaches, to enable faster, *in-situ* identification of seafood (Maggioni et al., 2020;
402 Frigerio et al., 2023). The primary drawback of the SSPs approach is the need for prior DNA
403 sequence information from both target and non-target species.
404 In the ESPO region, the PCR-SSP method has been mentioned in four articles for identifying
405 shark species through fin samples collected in Chile (Hernández et al., 2008, 2010), as well as
406 from artisanal landings in Colombia (Caballero et al., 2012), and a market in Ecuador
407 (Manzanillas-Castro and Acosta-López et al., 2022). Additionally, the PCR-SSP method was
408 used to differentiate the Peruvian anchoveta, *E. ringens* (Chairi and Rebordinos, 2014), and the
409 Peruvian scallop, *A. purpuratus* (Marín et al., 2013, 2017, 2025). Furthermore, this method
410 was proven effective for the accurate identification of a squid and nine fish species of
411 commercial value in the Peruvian seafood sector (Marín et al., 2025).
412

413 **3.2.5 qPCR-SSP**

414 This method is a faster and more sensitive variant of endpoint PCR-SSP that relies on the real-
415 time detection of a fluorescent signal, which is proportional to the concentration of the DNA
416 product (Silva et al., 2021). Fluorescent chemistries can be derived from non-specific dsDNA-
417 binding dyes (e.g. SYBR Green I) or sequence-specific hydrolysis probes (e.g. TaqMan)
418 (Tajadini et al., 2014). The former technology is relatively inexpensive and easy to use, while
419 the latter offers better specificity because the fluorescent signal is emitted only from specific
420 amplifications (Tajadini et al., 2014). The qPCR-SSP method generally targets relatively short

421 DNA fragments (less than 300bp) and has proven highly effective in identifying seafood
422 species worldwide (Silva et al., 2021), including fish species of the ESPO region, as reported
423 in five articles compiled in this review.
424 Herrero et al. (2011) successfully developed and applied TaqMan qPCR-SSP assays targeting
425 commercial samples of Atlantic salmon (*Salmo salar*) collected from various countries,
426 including supermarkets in Chile. In another study, Mora et al. (2018) developed novel qPCR-
427 SSP assays for authenticating commercial Peruvian weakfish (*Cynoscion analis*) and hakes
428 (*Merluccius gayi* and *M. peruanus*) products based on partial fragments of the ATP6 gene and
429 the control region, respectively. Additionally, Marín et al. (2025) used a partial fragment of the
430 mitochondrial 16S rRNA gene to create a novel qPCR-SSP protocol aimed at authenticating
431 Peruvian scallop samples collected from markets, supermarkets, and restaurants in Peru. qPCR-
432 SSP protocols have also been developed to monitor the trade of ESPO species used in
433 traditional Chinese medicine. Marín et al. (2021) developed a qPCR-SSP assay designed to
434 target a 136 bp fragment of the mitochondrial 16S rRNA gene of the protected Peruvian
435 seahorse, *Hippocampus ingens*. They assessed its effectiveness using specimens confiscated
436 by Peruvian authorities, as well as dried and powdered presentations of seahorses. In a separate
437 study, Cardeñosa et al. (2023) applied a previously established qPCR-SSP protocol (Cardeñosa
438 et al., 2018) to identify CITES-listed sharks using fins that were seized by Colombian
439 authorities that were declared as "dried fish bladders".
440

441 **3.2.6 Multiplex-PCR and qPCR**

442 Multiplex-PCR involves the simultaneous amplification of two or more target loci by including
443 multiple primer sets in a single PCR reaction (Markoulatos et al., 2002). This method is both
444 time-saving and cost-effective, allowing for the identification of different species in one run.
445 The result is the generation of species-specific DNA fragments of varying sizes (Rasmussen

446 and Morrissey, 2008), which can be resolved on an agarose gel following endpoint PCR or
447 analyzed through melting curve analyses based on species-specific melt profiles after qPCR
448 (Winder et al., 2011). Some of the disadvantages of this method include the need for proper
449 primer design, which is crucial to avoid the formation of primer dimers and non-specific PCR
450 products, which can deplete the reaction components (Edwards and Gibbs, 1994) and
451 negatively affect efficiency. Additionally, all primers should be designed to have the same or
452 closely related annealing temperatures to ensure effective co-amplification of all target loci.
453 Achieving optimal co-amplification results also requires careful titration of component
454 concentrations, including primers, $MgCl_2$, and dNTPs (Marín et al., 2025), which can be a time-
455 demanding process during PCR reaction standardization.
456 A total of nine studies reviewed herein assessed the effectiveness of multiplex PCR or qPCR
457 methods for authenticating species from the ESPO region, specifically focusing on sharks
458 (Hernández et al., 2008, 2010; Caballero et al., 2012; Manzanillas-Castro and Acosta-López,
459 2022; Cardeñosa et al., 2023), and scallops (Marín et al., 2013, 2017). Additionally, five
460 commercially important finfish species from the ESPO region were targeted for species
461 identification using multiplex PCR-SSP assays. These species include the Peruvian anchoveta,
462 *E. ringens*, which was identified through a SSP assays based on the nuclear 5S rDNA gene
463 (Chairi and Rebordinos 2014). Also, fresh and cooked commercial samples of two congeneric
464 rock seabass, *Paralabrax callaensis* and *P. humeralis*, were successfully identified using a
465 PCR-SSP assay that targeted a partial fragment of the mitochondrial 16S rRNA gene (Marín
466 et al., 2025). In the same study, the authors reported a second multiplex PCR-SSP assay that
467 targeted a partial region of the mitochondrial COI gene for the simultaneous identification of
468 commercial cooked fish that share the same market name "*ojo de uva*" in Peruvian markets:
469 the mocosa ruff *Schedophilus haedrichi*, and the grape-eye seabass *Hemilutjanus*
470 *macrophthalmos* (Marín et al., 2025). Conversely, less attention has been given to developing

471 multiplex PCR assays for identifying commercial invertebrate species from the ESPO region.
472 Thus far, only the Peruvian scallop, *A. purpuratus*, has been included in two different multiplex
473 PCR-SSP assays targeting the mitochondrial 16S rRNA gene (Marín et al., 2013, 2017).
474

475 **3.2.7 qPCR-HRM**

476 High-resolution melting (HRM) is a qPCR-based technique primarily used for genotyping
477 single-nucleotide polymorphism (SNPs) and for species identification. This method monitors
478 the fluorescence signal shift that occurs during the dissociation of the qPCR product from
479 double-stranded to single-stranded DNA in the presence of a saturating dye as the temperature
480 increases (Kim et al., 2023). Specialized HRM software utilizes this fluorescence data to create
481 sequence-specific peak patterns based on the amplicon sequence and temperature of the
482 melting curves (Warnke et al., 2020). This single-tube reaction method is both time- and cost-
483 effective, and it has proven successful in authenticating fish and shellfish species globally
484 (Silva and Hellberg, 2021).
485 Nevertheless, within the ESPO region, the HRM approach has only been used for the
486 identification of native, introduced, and hybrid commercial mussel species from Chile,
487 specifically *M. chilensis*, *M. edulis*, and *M. galloprovincialis*. This identification is based on
488 the Polyphenolic Adhesive Protein of Mussels (PAPM) (Jilberto et al., 2007; Asorey et al.,
489 2022), and also on a multilocus approach using SNPs discovered through data mining from
490 ESTs and RADseq (Quintrel et al., 2021).
491

492 **3.2.8 PCR-Microarrays**

493 PCR-Microarrays, also known as DNA chips, traditionally consists of a glass microscopy slide
494 that has oligonucleotide probes attached. These probes are specifically designed to be
495 complementary to the DNA of target species (Teletchea, 2009). Typically, during the PCR

496 process, products are labeled with fluorophores. This labelling allows for the detection of target
497 DNA after hybridization with the species-specific oligonucleotide probes, following the
498 washing steps (Teletchea, 2009). This method enables the simultaneous identification of
499 hundreds, or even thousands, of species. Several studies from different countries across Asia,
500 Europe, and North America have demonstrated its effectiveness for fish identification
501 (Teletchea, 2009; Silva and Hellberg, 2021).
502 A recent proof-of-concept study (Kappel et al., 2021) assessed the utility of a DNA microarray
503 assay using 21 crustacean species-specific probes targeting a segment of the 16S rRNA gene.
504 This study focused on the giant tiger prawn, *Penaeus (Penaeus) monodon*, and the Pacific
505 whiteleg shrimp *P. (Litopenaeus) vannamei*. The assay proved successful in identifying
506 commercial samples of *P. (Litopenaeus) vannamei* from Ecuador. Importantly, all probes
507 designed to recognize *P. (Litopenaeus) vannamei* sequences displayed no cross-reactivity with
508 any other crustacean species examined, highlighting the high specificity of the reported
509 microarray assay.
510

511 **3.2.9 FINS and DNA Barcoding**

512 Although both strategies share a similar rationale, the FINS method for species authentication
513 was first introduced in 1992 by Bartlett and Davidson (1992) to identify tuna species using the
514 DNA sequence information from CYTB gene. Later, in 2003, Paul Hebert and colleagues
515 proposed the concept of DNA barcoding, which focuses on using a partial region of the
516 mitochondrial COI gene to identify species across all animal phyla, except for the Cnidaria
517 (Hebert et al., 2003). Both species identification methods consist of three main steps: 1) PCR
518 amplification of a specific partial DNA fragment from the target sample; 2) Sanger sequencing
519 of the PCR product; and 3) phylogenetic analysis based on genetic distance (Tamura and Nei,
520 1993) and Neighbor-Joining methods (Saitou and Nei, 1987), in which the query sequence is

521 compared to related reference sequences obtained from databases. The final results are
522 presented in a phylogenetic tree, where the unknown sample clusters with the reference
523 sequences that exhibit the fewest nucleotide substitutions or genetic distance (Bartlett and
524 Davidson, 1992; Rasmussen and Morrissey, 2008). A key difference between FINS and DNA
525 barcoding is that FINS relies on informative sites and phylogenetic relationships derived from
526 vouchered reference organisms (Li et al., 2011). In contrast, DNA barcoding follows a
527 standardized procedure that emphasizes the presence of a "barcode gap". This gap indicates
528 sufficient interspecific genetic distance to allow for species resolution (Bucklin et al., 2011;
529 Hellberg et al., 2016).
530 This review indicates that DNA sequencing methods, such as FINS or DNA barcoding, were
531 the most commonly used method for seafood species identification, appearing in 43 (58.1%)
532 out of the 74 papers compiled for this study. For instance, DNA barcoding was utilized to
533 examine mislabeling at different stages of the supply chain in Peru and Chile (Marín et al.,
534 2018; Biffi et al., 2020; Velez-Zuazo et al., 2021; Dufflocq et al., 2022). Additionally, it was
535 employed to uncover unreported fish species in landings from both Peru and Chile (Canales-
536 Aguirre et al., 2018; Marín et al., 2022). Other studies have utilized traditional taxonomic
537 methods combined with DNA barcoding to describe new distribution ranges, determine species
538 boundaries, and document rare occurrences in fish samples from Peruvian artisanal fisheries
539 (Cabanillas-Torpoco et al., 2020; Cañedo-Apolaya et al., 2021; Vera et al., 2023).
540 Additional economically significant marine species from the ESPO region identified through
541 DNA sequencing include sharks from landings in Peru (Velez-Zuazo et al., 2015) and
542 Colombia (Caballero et al., 2012; Villate-Moreno et al., 2022), mobulid rays (Myliobatiformes)
543 collected from artisanal fisheries in Peru and Ecuador (Alfaro-Cordova et al., 2023; Ehemann
544 et al., 2024a), and a variety of crustaceans (crabs and shrimps) and mollusks (clams, scallops,
545 snails, squids, and octopus) from the Peruvian fishery sector (Marín et al., 2018). Furthermore,

546 DNA analysis has been applied to crab meat products in Chilean markets (Haye et al., 2012),
547 cephalopod species from Ecuador (Pliego-Cárdenas et al., 2016), and non-traditional seafood
548 products such as cetacean meat sold in Peruvian markets (Tzika et al., 2010; Biffi et al., 2020).
549 A DNA mini-barcoding approach, which is a variation of the full DNA barcoding, utilizes short
550 DNA sequences (typically shorter than 200 bp) and has been effective in identifying seafood
551 species from highly degraded samples, such as processed seafood products (Fernandes et al.,
552 2021). Marín et al. (2018, 2025) successfully applied this mini-barcoding method, focusing on
553 short fragments of the mitochondrial COI and 12S rRNA genes, to authenticate various cooked
554 fish samples sourced from Peruvian restaurants. It is important to note that none of these
555 samples were amplifiable using different full DNA barcoding markers.
556 In the addition to the COI marker, numerous studies have reported the utility of DNA sequences
557 from other mitochondrial gene regions for seafood authentication, such as the 16S rRNA gene.
558 This genetic marker was utilized by Ardura et al. (2012) and Horreo et al. (2013) to authenticate
559 fish feed samples from various origins, including the Peruvian anchovy, *E. ringens*, which is
560 marketed in France, Germany, and Spain. Similar, the same marker was also employed to
561 authenticate scallop samples collected worldwide, including the Peruvian scallop, *A.*
562 *purpuratus*, sourced from seafood markets in Peru, Germany, and Spain (Näumann et al., 2012;
563 Marín et al., 2015, 2018; Klapper and Schröeder, 2021; Parrondo et al., 2021).
564 The performance of some nuclear genetic markers has also been assessed in FINS studies
565 aimed at identifying seafood species. For instance, Espiñeira et al. (2009a) highlighted the
566 effectiveness of the ribosomal 18S rDNA gene for identifying commercially important marine
567 bivalves collected from different regions worldwide, including Chile and Peru. Conversely, a
568 study by Asorey et al. (2022) showed that FINS based on the histone H1C gene were not
569 effective for distinguishing between the mussels *M. chilensis* and *M. galloprovincialis* sourced
570 from a growing center in Chile.

571 **3.2.10 HTS NGS-metabarcoding**

572 Next-generation sequencing (NGS) technologies enable the simultaneous sequencing of
573 hundreds of millions of DNA molecules from multiple samples within a relatively short
574 timeframe (Fernandes et al., 2021; Silva and Hellberg, 2021). The NGS approach focused on
575 species identification is known as "NGS metabarcoding". This method utilizes universal
576 primers to achieve massive amplification of barcode sequences from different species in a
577 single run (Fernandes et al., 2021). Numerous studies reported successful species identification
578 of seafood samples (e.g. tuna, cod, bivalves, clupeids, flatfish) using specific HTS techniques
579 based on Illumina, pyrosequencing, and Ion Torrent platforms (Silva and Hellberg, 2021; Silva
580 et al., 2021).

581 Among these NGS technologies, 454 pyrosequencing by Roche was the first commercially
582 available platform that used real-time detection of pyrophosphate (PPi) molecules released
583 during DNA sequencing. This process results in light emission from the firefly enzyme
584 luciferase, which is visualized as specific peaks corresponding to individual nucleotides
585 (Fernandes et al., 2021; Silva and Hellberg, 2021). This method has the advantage of providing
586 fast and high accurate performance, and the ability to produce longer reads (Fernandes et al.,
587 2021). Abbadi et al. (2017) utilized 454-pyrosequencing based on the mitochondrial COI and
588 16S rRNA genes to successfully identify 15 different bivalve species, including both fresh and
589 processed samples of the Chilean mussel, *M. chilensis*, sourced from markets in Italy.

590 Currently, the Illumina platform is the most widely used NGS technology. This method relies
591 on the PCR amplification and sequencing of DNA clusters that are immobilized on a disposable
592 flow cell, using reversible fluorescent dideoxy terminators (Fernandes et al., 2021; Silva and
593 Hellberg, 2021). One of the major advantage of this approach over traditional Sanger
594 sequencing is its higher throughput per run and lower cost per base (Silva and Hellberg, 2021).
595 Gense et al. (2021) reported the development of a DNA metabarcoding assay using the MiSeq

596 and Iseq Illumina platforms, which focused on a fragment of the mitochondrial 16S rRNA gene.
597 This assay was used to authenticate local and imported oyster, mussel, and scallop seafood
598 products purchased from different commerce in Austria. The authors accurately identified a
599 frozen Peruvian scallop (*A. purpuratus)* sample that was correctly labelled as "*purpur*
600 *kammmusc*hel" (German for "purple scallop), as well as 17 mussel products that claimed to
601 contain the Chilean mussel, *M. chilensis*. However, these products were identified as two
602 different mussel species: *M. edulis* and *M. galloprovincialis*.
603

604 **3.2.11 Mass spectrometry-based SNP genotyping**

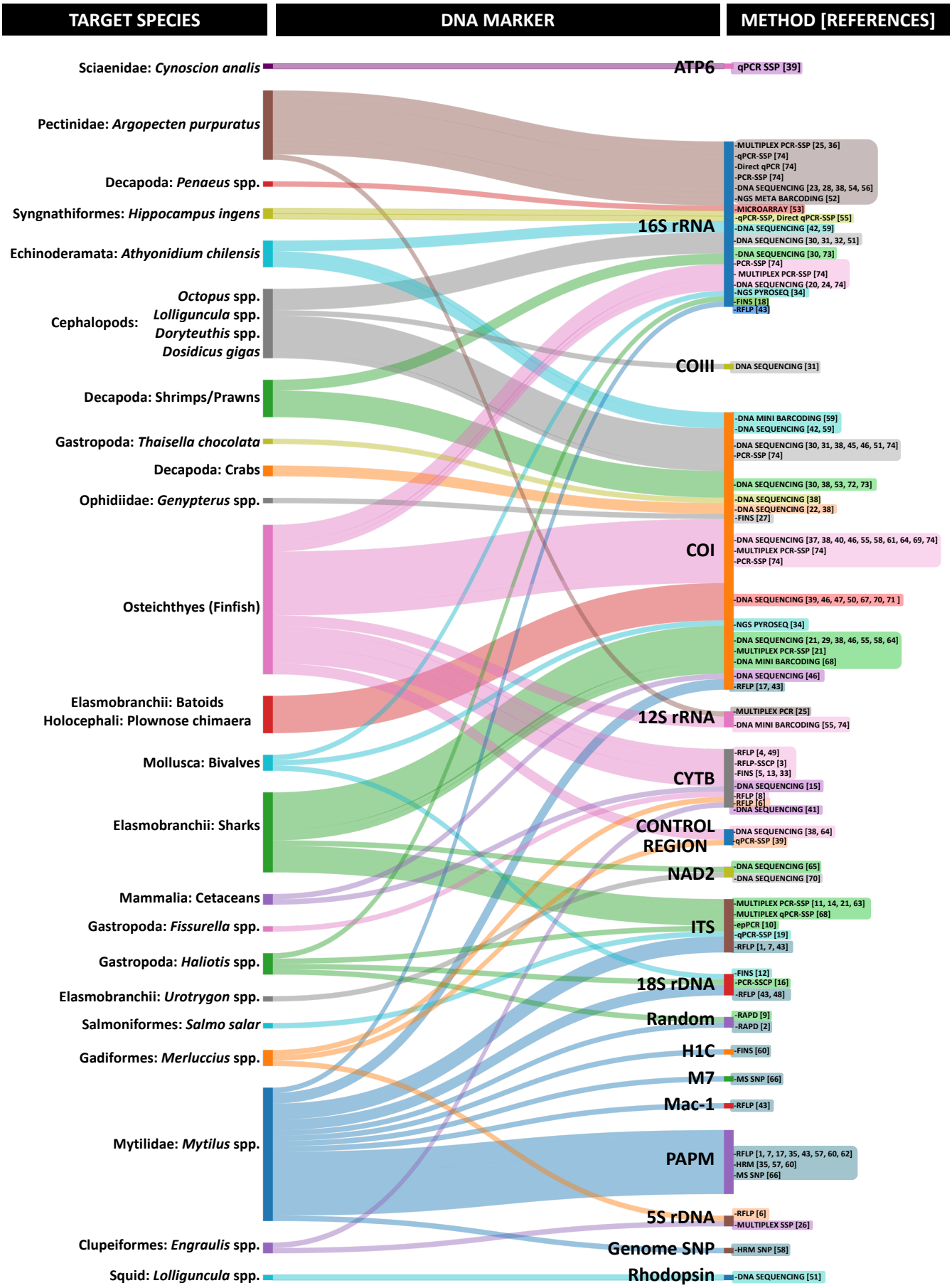
605 Mass spectrometry is one of the most commonly used method for protein identification and
606 quantification (Cerqueira et al., 2024). However, it can also be applied to the analysis of nucleic
607 acids, including the detection of SNPs and indels (Ellis and Ong, 2017). The process for SNP
608 detection using mass spectrometry involves coupling it with endpoint PCR. In this method,
609 targeted SNPs are amplified through standard PCR, followed by a "single base PCR extension"
610 reaction. This reaction employs mass-modified dideoxynucleotide (ddNTPs) terminators in an
611 oligonucleotide primer (called the extension primer) that anneals just upstream of the
612 polymorphic mutation site. Finally, the mass spectrometer detects the distinct mass of the
613 extended primer within the PCR product, thereby identifying the SNP allele (Gabriel et al.,
614 2009). Wenne et al. (2022) reported the development of a multi-locus SNP assay using mass
615 array spectrometry to authenticate mussel samples. This assay is based on a panel of 54 SNPs
616 from two mussel genes: Me15–16 (a nuclear adhesive protein gene marker) and M7 (an
617 acrosomal sperm protein called M7 lysin). The purpose of this assay was to assess the species
618 and geographical origin information declared in the label of mussel products sold in EU
619 markets. Reference samples from various *Mytilus* species, including farmed *M. chilensis*
620 collected in the province of Chiloe (Chile), were used in this analysis.

621 **3.3 Molecular markers and primers**

622 A total of 16 genetic markers were used to identify the ESPO species. Half of these markers
623 originated from the mitochondrial genome, including ATP6, COI, COIII, CYTB, NAD2, 12S
624 rRNA, 16S rRNA, and the Control Region. The other half came from the nuclear genome and
625 included M7, M1C, MAC-1, ITS, PAPM, Rhodopsin, 5S rDNA, and 18S rDNA. The
626 relationships among the molecular markers, target species, and detection methods discussed in
627 the surveyed articles are presented in the form of a Sankey diagram in Fig. 1.

628 The mitochondrial COI gene was the most frequently used marker, appearing in 34 articles
629 (46%). It was primary applied in DNA sequencing identification methods, including DNA
630 barcoding, mini barcoding, FINS, and pyrosequencing, to identify fish, mollusks, crustaceans,
631 cetaceans, and holothurians. The mitochondrial 16S rRNA gene was the second most
632 commonly utilized marker, featured in 24 articles (32.4%). This gene was employed in
633 sequencing and species-specific primers detection methods targeting crustaceans, fish,
634 holothurians, and mollusks. The mitochondrial CYTB gene and the nuclear ITS region were
635 the third and fourth most assessed marker, with 10 articles (13.5%) and 9 articles (12.2%)
636 respectively. The CYTB gene was used in DNA sequencing and RFLP methods focused on
637 fish and cetaceans. The nuclear ITS region was utilized in species-specific primer and RFLP
638 detection methods targeting gastropods, mussels, sharks, and salmon.

639 Most mitochondrial markers reviewed herein have been used to identify multiple animal groups,
640 including the COI, 16S rRNA, 12S rRNA, and CYTB genes. In contrast, four mitochondrial
641 markers were specifically employed to identify individual seafood types: ATP6, NAD2, and
642 the control region for fish, and the COIII for cephalopods. Among nuclear markers, ITS and18S
643 rDNA were used to target multiple seafood types, while the H1C, M7, Mac-1, and PAPM genes
644 were dedicated solely to authenticate mussels. The 5S rDNA was used for fish identification,
645 and Rhodopsin was designated for cephalopods.


TARGET SPECIES
DNA MARKER
METHOD [REFERENCES]
Sciaenidae: Cynoscion analis
Pectinidae: Argopecten purpuratus
Decapoda: Penaeus spp.
Syngnathiformes: Hippocampus ingens
Echinoderamata: Athyonidium chilensis
Cephalopods:
Octopus spp.
Lolliguncula spp.
Doryteuthis spp.
Dosidicus gigas
Decapoda: Shrimps/Prawns
Gastropoda: Thaisella chocolata
Decapoda: Crabs
Ophidiidae: Genypterus spp.
Osteichthyes (Finfish)
Elasmobranchii: Batoids
Holocephali: Plownose chimaera
Mollusca: Bivalves
Elasmobranchii: Sharks
Mammalia: Cetaceans
Gastropoda: Fissurella spp.
Gastropoda: Haliotis spp.
Elasmobranchii: Urotrygon spp.
Salmoniformes: Salmo salar
Gadiformes: Merluccius spp.
Mytilidae: Mytilus spp.
Clupeiformes: Engraulis spp.
Squid: Lolliguncula spp.
ATP6
qPCR SSP [39]
16S rRNA
-MULTIPLEX PCR-SSP [25, 36]
-qPCR-SSP [74]
-Direct qPCR [74]
-PCR-SSP [74]
-DNA SEQUENCING [23, 28, 38, 54, 56]
-NGS META BARCODING [52]
-MICROARRAY [53]
-qPCR-SSP, Direct qPCR-SSP [55]
-DNA SEQUENCING [42, 59]
-DNA SEQUENCING [30, 31, 32, 51]
-DNA SEQUENCING [30, 73]
-PCR-SSP [74]
- MULTIPLEX PCR-SSP [74]
-DNA SEQUENCING (20, 24, 74]
-NGS PYROSEQ [34]
-FINS [18]
-RFLP [43]
COIII
-DNA SEQUENCING [31]
COI
-DNA MINI BARCODING [59]
-DNA SEQUENCING [42, 59]
-DNA SEQUENCING [30, 31, 38, 45, 46, 51, 74]
-PCR-SSP [74]
-DNA SEQUENCING [30, 38, 53, 72, 73]
-DNA SEQUENCING [38]
-DNA SEQUENCING [22, 38]
-FINS [27]
-DNA SEQUENCING [37, 38, 40, 46, 55, 58, 61, 64, 69, 74]
-MULTIPLEX PCR-SSP [74]
-PCR-SSP [74]
-DNA SEQUENCING [39, 46, 47, 50, 67, 70, 71]
-NGS PYROSEQ [34]
-DNA SEQUENCING [21, 29, 38, 46, 55, 58, 64]
-MULTIPLEX PCR-SSP [21]
-DNA MINI BARCODING [68]
-DNA SEQUENCING [46]
-RFLP [17, 43]
12S rRNA
-MULTIPLEX PCR [25]
-DNA MINI BARCODING [55, 74]
CYTB
-RFLP [4, 49]
-RFLP-SSCP [3]
-FINS [5, 13, 33]
-DNA SEQUENCING [15]
-RFLP [8]
-RFLP [6]
-DNA SEQUENCING [41]
CONTROL REGION
-DNA SEQUENCING [38, 64]
-qPCR-SSP [39]
NAD2
-DNA SEQUENCING [65]
-DNA SEQUENCING [70]
ITS
-MULTIPLEX PCR-SSP [11, 14, 21, 63]
-MULTIPLEX qPCR-SSP [68]
-epPCR [10]
-qPCR-SSP [19]
-RFLP [1, 7, 43]
18S rDNA
-FINS [12]
-PCR-SSCP [16]
-RFLP [43, 48]
Random
-RAPD [9]
-RAPD [2]
H1C
-FINS [60]
M7
-MS SNP [66]
Mac-1
-RFLP [43]
PAPM
-RFLP [1, 7, 17, 35, 43, 57, 60, 62]
-HRM [35, 57, 60]
-MS SNP [66]
5S rDNA
-RFLP [6]
-MULTIPLEX SSP [26]
Genome SNP
-HRM SNP [58]
Rhodopsin
-DNA SEQUENCING [51]

647 **Fig. 1.** Sankey diagram illustrating the relationships between target seafood species and DNA
648 markers. The width of each connector is proportional to the number of articles reporting the
649 use of each DNA marker. The molecular methods associated with the DNA markers are shown,
650 along with their corresponding article reference numbers (in brackets), which can be found in
651 Table 1.
652
653
654 The DNA marker assessed using the highest number of detection methods corresponds to the
655 mitochondrial 16S rRNA gene. This marker was utilized in ten different methods including
656 multiplex PCR-SSP, PCR and qPCR-SSP, Direct qPCR-SSP, DNA sequencing (FINS and
657 barcoding), NGS meta-barcoding, microarray, NGS pyrosequencing, and RFLP. These
658 findings demonstrate the high utility and effectiveness of this mitochondrial marker for
659 identifying a wide range of seafood species. This effectiveness is supported by the broadly
660 targeted region spanned by the universal primers developed by Palumbi (1991), as well as by
661 the extensive number of available 16S rRNA gene sequences in public databases.
662 A descriptive analysis of the primers used in the reviewed articles is provided in Supplementary
663 Annex 1. This section includes a detailed list of all the primers identified in the articles, along
664 with their associated molecular markers, targeted species, and original reference sources.
665
666 **3.4 Species diversity**
667 A total of 202 species from the ESPO were identified by DNA-based methods reported in the
668 articles reviewed herein. These species were distributed among 142 genera, 82 families, and
669 44 orders (Table 2, Fig. 2). Fish accounted for the majority of the identified samples (150
670 species, 74.3%), followed by mollusks (40 species, 19.8%), crustaceans (7 species, 3.5%),
671 cetaceans (4 species, 2%), and holothurians (1 species, 0.5%). Out of the total species identified,

Table 2. Species diversity found in the articles reviewed by the present study.

Group	Order	Family	Scientific name	Common name	Identification method	Genetic marker	Product presentation	Retailer (city-country)	IUCN status	(GenBank)/[BOLD] accessions	References
Chondrichthyes											
Sharks	Carcharhiniformes	Carcharhinidae	*Carcharhinus brachyurus*	Copper shark	DNA sequencing	Control Region	—	Commercial fishery (Peru)	VU	—	Benavides et al. (2011)
						COI	Fin or muscle from landed specimen	Landing (La Libertad-Peru)		(KJ146027)	Velez-Zuazo et al. (2015)
			Carcharhinus cerdale	Pacific smalltail shark	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	CR	(OM165094 to OM165097)	Villate-Moreno et al. (2022)
			Carcharhinus falciformis	Silky shark	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)	VU	—	Biffi et al. (2020)
					Multiplex PCR-SSP	ITS2	Fresh meat	Fish Market (Santo Domingo-Ecuador)		—	Manzanillas-Castro and Acosta-López (2022)
					DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)		(OM165098 to OM165107)	Villate-Moreno et al. (2022)
					DNA sequencing, qPCR-SSP	COI	Dried fin	Shark fin seizure (El Dorado International Airport-Colombia)		—	Cardeñosa et al. (2023)
			Carcharhinus leucas	Bullshark	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	VU	(OM165108)	Villate-Moreno et al. (2022)
					DNA sequencing, qPCR-SSP	COI	Dried fin	Shark fin seizure (El Dorado International Airport-Colombia)		—	Cardeñosa et al. (2023)
			Carcharhinus limbatus	Blacktip shark	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	VU	(OM165109 to OM165111)	Villate-Moreno et al. (2022)
			Carcharhinus obscurus	Dusky shark	Multiplex PCR-SSP, DNA sequencing	COI, ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	EN	—	Hernández et al. (2008)
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (La Libertad-Peru)		(KJ406021)	Velez-Zuazo et al. (2015)
			Galeocerdo cuvier	Tiger shark	DNA sequencing	COI	Skin or muscle samples	Landing (Buenaventura-Colombia); seized from illegal fisheries (Malpelo Sanctuary-Colombia)	NT	(JN315435)	Caballero et al. (2012)
					DNA sequencing, qPCR-SSP	COI	Dried fin	Shark fin seizure (El Dorado International Airport-Colombia)		—	Cardeñosa et al. (2023)
			Prionace glauca	Blue shark	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	NT	—	Hernández et al. (2008)
					Multiplex PCR-SSP	ITS2	Fresh whole individual, dried fin	Commercial storage warehouse (Paico-Chile)		—	Hernández et al. (2010)
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (La Libertad and Moquegua-Peru)		(KJ146042, KJ146043, KJ146044)	Velez-Zuazo et al. (2015)
					DNA sequencing	COI	Frozen and refrigerated fillets, dried, fish fritters	Market (Lambayeque-Peru); Restaurant, Supermarket (La Libertad-Peru)		(MH194440, MH194441, MH194480, MH194481, MH194484)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Tumbes-Peru); Retail, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					Multiplex PCR-SSP	ITS2	Fresh meat	Fish Market (Santo Domingo-Ecuador)		—	Manzanillas-Castro and Acosta-López (2022)
			Rhizoprionodon longurio	Pacific sharpnose shark	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	VU	(OM165170 to OM165178)	Villate-Moreno et al. (2022)
		Sphyrnidae	*Sphyrna corona*	Scalloped bonnethead	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	CR	(OM165179)	Villate-Moreno et al. (2022)
			Sphyrna lewini	Scalloped hammerhead	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	CR	—	Hernández et al. (2008)
					Multiplex PCR-SSP, DNA sequencing	COI, ITS2	Skin or muscle samples	Landing (Buenaventura-Colombia); seized from illegal fisheries (Malpelo Sanctuary-Colombia)		(JN315436 to JN315443)	Caballero et al. (2012)
					Multiplex PCR-SSP	ITS2	Fresh meat	Fish Market (Santo Domingo-Ecuador)		—	Manzanillas-Castro and Acosta-López (2022)
					DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)		(OM165180 to OM165194)	Villate-Moreno et al. (2022)
					DNA sequencing, qPCR-SSP	COI	Dried fin	Shark fin seizure (El Dorado International Airport-Colombia)		—	Cardeñosa et al. (2023)
			Sphyrna media	Scoophead	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	CR	(OM165195)	Villate-Moreno et al. (2022)
			Sphyrna tiburo	Bonnethead	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	EN	(OM165196 to OM165197)	Villate-Moreno et al. (2022)
			Sphyrna zygaena	Smooth hammerhead	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Cooperative traders	VU	—	Hernández et al. (2008)
					DNA sequencing	COI	Skin or muscle samples	Landing (Buenaventura-Colombia); seized from illegal fisheries (Malpelo Sanctuary-Colombia)		(JN315444, JN315445)	Caballero et al. (2012)
					DNA sequencing	COI	Fin or muscle from landed specimens	Landing (La Libertad and Lambayeque-Peru)		(KJ146045)	Velez-Zuazo et al. (2015)
					DNA sequencing	COI	Fresh headless, fish fritters	Landing (Tumbes-Peru), Wholesale, Market, Restaurant (La Libertad-Peru)		(MH194422, MH194431, MH194471 to MH194475, MK070513)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Wholesale (Lima-Peru); Retail (Tumbes-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880591 to MN880593)	Marín et al. (2022)
					DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)		(OM165198 to OM165199)	Villate-Moreno et al. (2022)
		Triakidae	*Galeorhinus galeus*	Tope shark	DNA sequencing	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	CR	—	Hernández et al. (2008)
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (La Libertad and Moquegua-Peru)		(KJ146028, KJ146029)	Velez-Zuazo et al. (2015)
			Mustelus albipinnis	Whitemargin smoothhound	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	LC	(OM165112 to OM165117)	Villate-Moreno et al. (2022)
			Mustelus lunulatus	Sicklefin smooth-hound	DNA sequencing	COI	Refrigerated fillet	Supermarket (Lima-Peru)	LC	(MH194496)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru); Retail (Tumbes-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880526, MN880605)	Marín et al. (2022)
					DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)		(OM165136 to OM165166)	Villate-Moreno et al. (2022)
			Mustelus mento	Speckled smooth-hound	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	CR	—	Biffi et al. (2020)
			Mustelus henlei	Brown smooth-hound	DNA sequencing	NAD2	Fresh whole body	Landing (Colombia)	LC	(OM165118 to OM165135)	Villate-Moreno et al. (2022)
			Mustelus whitneyi	Humpback smooth-hound	DNA sequencing	COI	Fresh, refrigerated fillet	Wholesale, Supermarket (La Libertad-Peru); Multimarket (Callao-Peru)	CR	MH194477, MH194478, MH194506)	Marín et al. (2018)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880507 to MN880509, MN880531, MN880532, MN880606)	Marín et al. (2022)
	Lamniformes	Alopiidae	*Alopias pelagicus*	Pelagic thresher	Multiplex PCR-SSP, DNA sequencing	COI	Skin or muscle samples	Landing (Buenaventura-Colombia); seized from illegal fisheries (Malpelo Sanctuary-Colombia)	EN	(JN315423 to JN315434)	Caballero et al. (2012)
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (La Libertad-Peru)		(KJ406022 to KJ406026)	Velez-Zuazo et al. (2015)
					DNA sequencing	COI	Fresh fillet, headless	Retail (Lima and Tumbes-Peru)		(MH194433, MH194456, MH194476)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima and Tumbes-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Dried fillet	Market (Ancash-Peru)		(MN839531)	Marín et al. (2021)
					Multiplex PCR-SSP	ITS2	Fresh meat	Fish Market (Santo Domingo-Ecuador)		—	Manzanillas-Castro and Acosta-López (2022)
					DNA sequencing, qPCR-SSP	COI	Dried fin	Shark fin seizure at El Dorado International Airport (Bogotá-Colombia)		—	Cardeñosa et al. (2023)
			Alopias superciliosus	Bigeye thresher	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	VU	—	Hernández et al. (2008)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)		—	Biffi et al. (2020)
			Alopias vulpinus	Thresher	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	VU	—	Hernández et al. (2008)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)		—	Biffi et al. (2020)
		Lamnidae	*Isurus oxyrinchus*	Shortfin mako	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	EN	—	Hernández et al. (2008)
					Multiplex PCR-SSP	ITS2	Fresh whole individual, dried fin	Commercial storage warehouse (Paico-Chile)		—	Hernández et al., 2010
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (La Libertad and Moquegua-Peru)		(KJ146030 to KJ146038)	Velez-Zuazo et al. (2015)
					DNA sequencing	COI	Fresh fillet	Multimarket (Lima-Peru)		(MH194507)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Retail, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Meat slice	Fish market (Santiago-Chile)		—	Dufflocq et al. (2022)
					Multiplex PCR-SSP	ITS2	Fresh meat	Fish Market (Santo Domingo-Ecuador)		—	Manzanillas-Castro and Acosta-López (2022)
			Isurus paucus	Longfin mako	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	EN	—	Hernández et al. (2008)
			Lamna nasus	Porbeagle	Multiplex PCR-SSP	ITS2	Dried pectoral fin	Drying facility, Commercial storage warehouse (Caldera, Coquimbo, Paico-Chile)	VU	—	Hernández et al. (2008)
					Multiplex PCR-SSP	ITS2	Fresh whole individual, dried fin	Commercial storage warehouse (Paico-Chile)		—	Hernández et al. (2010)
					DNA sequencing	COI	Fin or muscle from landed specimen	Landing (Piura, La Libertad, Ancash, Lima, or Moquegua-Peru)		(KJ146039, KJ146040, KJ146041)	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Meat slice	Fish market, Open-air Market (Santiago-Chile)		—	Dufflocq et al. (2022)
	Orectolobiformes	Rhincodontidae	*Rhincodon typus*	Whale shark	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	EN	(MH194458)	Marín et al. (2018)
Batoids	Myliobatiformes	Dasyatidae	*Hypanus dipterurus*	Diamond stingray	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	VU	(MH194454)	Marín et al. (2018)
			Pteroplatytrygon violacea	Pelagic stingray	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MH194470)	Marín et al. (2018)
		Gymnuridae	*Gymnura afueroe*	Butterfly ray	DNA sequencing	COI	Fresh whole body, fresh fillet	Landing (Tumbes-Peru)	NT	(MH194463, MH194465)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Isla de Lobos (Peru)		(PP756688 to PP756691)	Ehemann et al. (2024b)
		Myliobatidae	*Aetobatus laticeps*	Pacific eagle ray	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	VU	(MH194470)	Marín et al. (2018)
			Mobular birostris	Giant manta	DNA sequencing	COI	Whole body or pectoral fins	Landing (Tumbes-Peru)	EN	[Project Code: DBPDC]	Alfaro-Cordova et al. (2023)
			Mobula mobular	Devil fish	DNA sequencing	COI	Fresh whole body and fillet, dried, tortilla	Landing, Market (Tumbes-Peru); Market (Lambayeque-Peru); Restaurant (La Libertad-Peru)	EN	(MH194439, MH194451 to MH194453, MH194455, MH194457, MH194461, MH194464, MH194469, MH194482, MK070514, MK070516)	Marín et al. (2018)
					DNA sequencing	COI	Whole body or pectoral fins	Landing (La Libertad and Tumbes-Peru)		[Project Code: DBPDC]	Alfaro-Cordova et al. (2023)
			Mobula munkiana	Munk's devil ray	DNA sequencing	COI	Whole body or pectoral fins	Landing (La Libertad and Tumbes-Peru)	VU	[Project Code: DBPDC]	Alfaro-Cordova et al. (2023)
			Mobula tarapacana	Chilean devil ray	DNA sequencing	COI	Whole body or pectoral fins	Landing (La Libertad-Peru)	EN	[Project Code: DBPDC]	Alfaro-Cordova et al. (2023)
			Mobula thurstoni	Smoothtail mobula	DNA sequencing	COI	Whole body or pectoral fins	Landing (La Libertad and Tumbes-Peru)	EN	[Project Code: DBPDC]	Alfaro-Cordova et al. (2023)
			Myliobatis chilensis	Chilean eagle ray	DNA sequencing	COI	Refrigerated and fresh fillets, dried	Market (Lambayeque-Peru); Market, Supermarket (La Libertad-Peru)	VU	(MH194450, MH194479, MH194483, MH194485)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)		—	Biffi et al. (2020)
			Myliobatis longirostris	Snouted eagle ray	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	VU	(MH194462)	Marín et al. (2018)
		Urotrygonidae	*Urotrygon chilensis*	Blotched stingray	DNA sequencing	COI, NAD2	Fresh whole body	Landing (Manta, Punta Blanca, Santa Rosa-Ecuador),	NT	(PP179040 to PP179043)	Ehemann et al. (2024a)
	Rajiformes	Arhynchobatidae	*Sympterygia brevicaudata*	Shorttail fanskate	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	NT	(MH194468)	Marín et al. (2018)
	Rhinopristiformes	Pristidae	*Pristis pristis*	Common sawfish	DNA sequencing	COI	Fresh whole body	Landing (Máncora-Peru)	CR	[PMFSH636-20]	Cabanillas-Torpoco et al. (2020)
		Rhinobatidae	*Pseudobatos planiceps*	Pacific guitarfish	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	VU	(MH194460)	Marín et al. (2018)
	Squatiniformes	Squatinidae	*Squatina armata*	Angel shark	DNA sequencing	COI	Fresh whole body	Wholesale (Lambayeque-Peru), Bayovar Port (Piura-Peru)	CR	[PMVTB046-20, PMVTB047-20, PMVTB067-20, PMVTB068-20]	Cañedo-Apolaya et al. (2021)
			Squatina californica	Pacific angelshark	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Tumbes-Peru)	NT	—	Biffi et al. (2020)
					DNA sequencing	COI	Wholy body	Punta Pico coast (Tumbes-Peru)		[FMCT1223-19]	Cañedo-Apolaya et al. (2021)
	Torpediniformes	Narcinidae	*Narcine entemedor*	Giant electric ray	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	VU	(MH194459, MH194488, MK070517)	Marín et al. (2018)
Holocephali	Chimaeriformes	Callorhinchidae	*Callorhinchus callorynchus*	Plownose chimaera	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	VU	—	Biffi et al. (2020)

Osteichthyes											
Finfish	Acanthuriformes	Lobotidae	*Lobotes pacifica*	Pacific tripletail	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Piura-Peru)		(MN839527)	Marín et al. (2021)
		Luvaridae	*Luvarus imperialis*	Luvar	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
	Acropomatiformes	Malakichthyidae	*Hemilutjanus macrophthalmos*	Grape-eye seabass	DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)	DD	(MN839520)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880513, MN880589)	Marín et al. (2022)
					DNA sequencing, Multiplex PCR-SSP	COI	Fresh whole body, cooked	Landing and Wholesale (Piura-Peru), Restaurant (Tumbes-Peru)		(PP092953)	Marín et al. (2025)
	Atheriniformes	Atherinopsidae	*Odontesthes regia*	Chilean silverside	DNA sequencing	COI	Fried and fresh fillets	Restaurant (Lima-Peru)	LC	(MH194518, MH194550)	Marín et al. (2018)
					DNA sequencing	COI	Whole or fillet	(Canada, imported from Peru)		—	Shehata et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(MN839513)	Marín et al. (2021)
	Blenniiformes	Labrisomidae	*Labrisomus philippii*	Chalapo clinid	DNA sequencing	COI	Cooked whole body	Restaurant (Lima-Peru)	LC	(MH194519)	Marín et al. (2018)
	Carangaria *incertae sedis*	Centropomidae	*Centropomus unionensis*	Yellowfin snook	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880528)	Marín et al. (2022)
		Sphyraenidae	*Sphyraena ensis*	Mexican barracuda	DNA sequencing	COI	Fresh whole body	Multimarket (Lima-Peru)	LC	(MH194547)	Marín et al. (2018)
	Carangiformes	Carangidae	*Selene peruviana*	Peruvian moonfish	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
			Seriola lalandi	Yellowtail amberjack	DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)	LC	—	Velez-Zuazo et al. (2021)
			Seriola peruana	Fortune jack	DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)	LC	—	Velez-Zuazo et al. (2021)
			Seriola rivoliana	Longfin yellowtail	DNA sequencing	COI	Marinated ceviche	Restaurant (Lima-Peru)	LC	(MH194546)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880603)	Marín et al. (2022)
			Trachinotus paitensis	Paloma pompano	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880583 to MN880587)	Marín et al. (2022)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(PP092957)	Marín et al. (2025)
			Trachurus murphyi	Chilean jack mackerel	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Chile)	DD	—	Rehbein (2002)
					DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)		—	Biffi et al. (2020)
		Coryphaenidae	*Coryphaena hippurus*	Common dolphinfish	DNA sequencing	COI	Steamed fillet, marinated ceviche, fresh whole body, stir-fried, deep fried fillet, fish roe, fish burger	Landing (Tumbes-Peru); Restaurant (La Libertad-Peru); Supermarket (Ancash-Peru); Multimarket, Restaurant, Supermarket (Lima-Peru)	LC	(MH194438, MH194444, MH194449, MH194511, MH194512, MH194520, MH194521, MH194535, MH194542, MK070511)	Marín et al. (2018)
					DNA sequencing	COI	Whole, frozen	Retailer, Importer (Canada, imported from Peru)		—	Shehata et al. (2019)
					DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
		Istiophoridae	*Istiompax indica*	Black marlin	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima and Tumbes-Peru)	LC	—	Biffi et al. (2020)
			Istiophorus platypterus	Indo-Pacific sailfish	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Tumbes-Peru)	VU	—	Biffi et al. (2020)
			Kajikia audax	Striped marlin	DNA sequencing	COI, Control Region	Fresh whole body	Landing (Tumbes-Peru)	LC	(MH194486, MK070523)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Landing (Tumbes-Peru)			Biffi et al. (2020)
			Makaira nigricans	Blue marlin	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)	VU	—	Biffi et al. (2020)
		Rachycentridae	*Rachycentron canadum**	Cobia	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN839528)	Marín et al. (2021)
		Xiphiidae	*Xiphias gladius*	Swordfish	DNA sequencing	COI	Fish fritters, fresh headless	Landing (Tumbes-Peru); Maket, Restaurant (La Libertad-Peru)	NT	(MH194430, MH194432, MH194466, MK070512)	Marín et al. (2018)
					DNA sequencing	COI	Whole, refrigerated	Importer (Canada, imported from Ecuador)		—	Shehata et al. (2019)
					DNA sequencing	COI	—	Restaurant, Retail, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Meat slice	Fish market, Open-air Market, Supermaket (Santiago-Chile)		—	Dufflocq et al. (2022)
	Centrarchiformes	Aplodactylidae	*Aplodactylus punctatus*	Zamba marblefish	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	NE	—	Biffi et al. (2020)
		Kyphosidae	*Girella freminvillii*	Black sea chub	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
	Clupeiformes	Alossidae	*Sardinops sagax*	South American pilchard	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Chile)	LC		Rehbein (2002)
					PCR-RFLP	Cytb	Canned	Supermarket (France, canned in Peru)		—	Jérôme et al. (2003a)
					FINS	Cytb	Canned	Supermarket (France, origin Chile and Peru)		(AY394046, AY394047)	Jérôme et al. (2003b)
		Clupeidae	*Strangomera bentincki*	Araucanian herring	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Chile)	LC		Rehbein (2002)
					FINS	Cytb	Canned	Supermarket (France, origin Chile and Peru)		(AY394050)	Jérôme et al. (2003b)
		Dorosomatidae	*Opisthonema medirastre*	Middling thread herring	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN839514)	Marín et al. (2021)
		Engraulidae	*Engraulis ringens*	Anchoveta	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Chile and Peru)	LC		Rehbein (2002)
					DNA sequencing	16S rRNA	Fish feed: Canned (whole fish), salty (without bones)	Spanish producers and pet shop (species origin: Peru)		—	Ardura et al. (2012)
					DNA sequencing	16S rRNA	Fish feed: Canned in oil	Imported (species origin: Peru)		(HQ623641)	Horreo et al. (2013)
					FINS	Cytb	Fresh, canned	Markets, Supermarkets, and specialized stores (Spain, origin Chile and Peru)		—	Velasco et al. (2016)
					PCR-SSP	SS rDNA	Fresh	(Valparaiso-Chile)		(JX070024-JX070033)	Chairi and Rebordinos (2014)
					DNA sequencing	COI	Canned, frozen burger	Supermarket (Ancash and La Libertad-Peru)		(MH194490, MH194491, MK070518, MK070519, MH194537)	Marín et al. (2018)
					DNA sequencing	Cytb	In oil	Large-scale retail distribution (Tuscany-Italy, imported from Chile)		—	Giusti et al. (2019)
			Ethmidium maculatum	Pacific menhaden	DNA sequencing	COI	Fresh whole body	Market (Lima-Peru)	DD	(MH194494, MH194495)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)			Biffi et al. (2020)
	Eupercaria *incertae sedis*	Haemulidae	*Anisotremus interruptus*	Burrito grunt	DNA sequencing	COI	Fresh whole body	Market (La Libertad-Peru)	LC	(MH194448, MK070515)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)		(MN839517)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880558)	Marín et al. (2022)
					DNA sequencing, PCR-SSP	COI	Fresh whole body, cooked	Restaurant and Wholesale (Piura-Peru)		(PP092956, PV562156)	Marín et al. (2025)
			Anisotremus scapularis	Peruvian grunt	DNA sequencing	COI	Fried, fresh, steamed whole body	Market, Restaurant (Ancash-Peru); Restaurant (La Libertad and Piura-Peru)	LC	(MH194443, MH194500, MH194522, MH194526)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(MN839516)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880542)	Marín et al. (2022)
			Haemulon scudderii	Grey grunt	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN839518)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)		(PQ459803 to PQ459804)	Marín et al. (2025)
			Isacia conceptionis	Cabinza grunt	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
		Labridae	*Decodon melasma*	Blackspot wrasse	DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)	LC	(MN880543)	Marín et al. (2022)
		Lutjanidae	*Lutjanus argentiventris*	Yellow snapper	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880525, MN880602)	Marín et al. (2022)
		Malacanthidae	*Caulolatilus affinis*	Bighead tilefish	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	LC	—	Biffi et al. (2020)
			Caulolatilus princeps	Ocean whitefish	DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)	LC	(MN880554)	Marín et al. (2022)
		Sciaenidae	*Cilus gilberti*	Corvina drum	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket (Lima-Peru)	DD	—	Biffi et al. (2020)
			Cynoscion albus	Whitefin weakfish	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	DD	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)			Velez-Zuazo et al. (2021)
			Cynoscion analis	Peruvian weakfish	qPCR-SSP	ATPase6	Fresh whole body	Wholesale and supermarket (Ancash, Lambayeque, Lima-Peru)	LC	—	Mora et al. (2018)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880521)	Marín et al. (2022)
			Cynoscion phoxocephalus	Cachema weakfish	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880604)	Marín et al. (2022)
			Cynoscion praedatorius	Boccone weakfish	DNA sequencing	COI	Fried	Restaurant (La Libertad-Peru)	DD	(MH194447)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
			Cynoscion stolzmanni	Stolzmann's weakfish	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880529)	Marín et al. (2022)
			Cheilotrema fasciatum	Arrillo drum	DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)	LC	(MH194527)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(MN839519)	Marín et al. (2021)
			Larimus acclivis	Steeplined drum	DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)	LC	(MN880556)	Marín et al. (2022)
			Paralonchurus peruanus	Peruvian banded croaker	DNA sequencing	COI	Steamed whole body	Restaurant (La Libertad-Peru)	LC	(MH194442)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(PP092959)	Marín et al. (2025)
			Pareques lanfeari	Royal highhat	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880527)	Marín et al. (2022)
			Umbrina xanti	Polla drum	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880599)	Marín et al. (2022)
		Sparidae	*Calamus brachysomus*	Pacific porgy	DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)	LC	(MN880544)	Marín et al. (2022)
					DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)		(PP092958)	Marín et al. (2025)
	Gadiformes	Merlucciidae	*Macruronus magellanicus*	Patagonian grenadier	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Chile)	NE	—	Rehbein (2002)
			Merluccius gayi	South Pacific hake	PCR-RFLP	Cytb, SS rDNA	Fresh whole body	(Chile)	DD	—	Perez and Garcia-Vazquez (2004)
					qPCR-SSP	Control Region	Whole body	Wholesale and supermarket (Ancash, Lambayeque, Lima-Peru)		—	Mora et al. (2018)
					DNA sequencing	COI	Marinated ceviche	Restaurant (La Libertad-Peru)		(MH194428)	Marín et al. (2018)
					DNA sequencing	COI	Whole, refrigerated	Retailer (Canada, imported from Peru)		—	Shehata et al. (2019)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(PP092962)	Marín et al. (2025)
			Merluccius peruanus	Peruvian hake	qPCR-SSP	Control Region	Whole fillet or chopped fillet	Wholesale and supermarket (Ancash, Lambayeque, Lima-Peru)	NE	—	Mora et al. (2018)
	Lampriformes	Lampridae	*Lampris guttatus*	Opah	DNA sequencing	COI	Fresh fillet	Multimarket (Lima-Peru)	LC	(MH194505)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Wholesale (Lima-Peru)			Biffi et al. (2020)
	Mugiliformes	Mugilidae	*Mugil cephalus*	Flathead grey mullet	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Retail, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(PP092963)	Marín et al. (2025)
	Ophidiiformes	Ophidiidae	*Brotula clarkae*	Pacific bearded brotula	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket (Lima-Peru)	DD	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880510, MN880535, MN880573, MN880574, MN880577, MN880578, MN880579, MN880607)	Marín et al. (2022)
			Brotula ordwayi	Ordway's brotula	DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)	LC	(MN880511, MN880568)	Marín et al. (2022)
			Genypterus chilensis	Red cusk-eel	FINS	COI	Fresh	(Chile)	NE	—	Santaclara et al. (2014)
			Genypterus maculatus	Black cusk-eel	FINS	COI	Fresh	(Chile)	NE	—	Santaclara et al. (2014)
			Lepophidium negropinna	Specklefin cusk eel	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880512, MN880569, MN880570 to MN880572)	Marín et al. (2022)

	Perciformes	Anthiadidae	*Acanthistius pictus*	Brick seabass	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Wholesale (Lambayeque-Peru)		(MN839525)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880541)	Marín et al. (2022)
			Anthias noeli	Rosy jewelfish	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	NE	[FMCT1282N21, FMCT1283N21, FMCT1284N21, FMCT1285N21, FMCT1237N19]	Vera et al. (2023)
			Hemanthias peruanus	Splittail bass	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880600)	Marín et al. (2022)
			Hemanthias signifer	Damsel bass	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru)	LC	—	Biffi et al. (2020)
			Pronotogrammus multifasciatus	Threadfin bass	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Tumbes-Peru)	LC	—	Biffi et al. (2020)
		Epinephelidae	*Alphestes immaculatus*	Pacific mutton hamlet	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880524)	Marín et al. (2022)
					DNA Sequencing, PCR-SSP	COI, 16S rRNA	Fresh whole body	Wholesale (Lambayeque-Peru)		(PQ459846 to PQ459848, PP092955)	Marín et al. (2025)
			Cephalopholis colonus	Pacific creole-fish	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket (Lima-Peru), Landing (Tumbes-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880594 to MN880596)	Marín et al. (2022)
			Epinephelus analogus	Spotted grouper	DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)	LC	(PP092961)	Marín et al. (2025)
			Epinephelus quinquefasciatus	Pacific goliath grouper	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	DD	(MN880588)	Marín et al. (2022)
			Hyporthodus acanthistius	Rooster hind	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)	VU	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Market (Tumbes-Peru)		(MN839521)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880575)	Marín et al. (2022)
			*Hyporthodus cifuentesi***	Olive grouper	DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)	LC	(MN839523)	Marín et al. (2021)
			Hyporthodus niphobles	Star-studded grouper	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880506, MN880520, MN880536, MN880537, MN880566, MN880567, MN880576, MN880590, MN880608)	Marín et al. (2022)
					DNA sequencing	COI	Fresh whole body	Market (Tumbes-Peru)		(PP092960)	Marín et al. (2025)
			Mycteroperca xenarcha	Broomtail grouper	DNA sequencing	COI	Cooked fish meat	Restaurant (Lima-Peru)	DD	(MH194543)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)		(MN839523)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880516, MN880557, MN880561 to MN880565)	Marín et al. (2022)
		Nototheniidae	*Dissostichus eleginoides*	Patagonian toothfish	DNA sequencing	COI	Whole or fillet	(Canada, imported from Chile)	NE	—	Shehata et al. (2018)
					DNA sequencing	COI	Whole, refrigerated	Retailer (Canada, imported from Chile)	NE	—	Shehata et al. (2019)
			Dissostichus mawsoni	Antartic toothfish	DNA sequencing	COI	Whole, frozen	Retailer (Canada, imported from Chile)		—	Shehata et al. (2019)
		Sebastidae	*Sebastes oculatus*	Patagonian redfish	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
		Serranidae	*Diplectrum conceptione*	Sand-perch	DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
			Diplectrum pacificum	Inshore sand perch	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(MN880597)	Marín et al. (2022)
			Paralabrax callaensis	Southern rock bass	DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)	DD	(MN880538, MN880539, MN880559)	Marín et al. (2018)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(MN839525)	Marín et al. (2021)
					DNA Sequencing, Multiplex PCR-SSP	COI, 16S rRNA	Fresh, cooked	Landing and Market (Tumbes-Peru), Market (Ancash-Peru), Restaurant (Piura)		(PP092943 to PP092947, PP087227 and PP087228)	Marín et al. (2025)
			Paralabrax humeralis	Peruvian rock seabass	DNA sequencing	COI	Marinated ceviche, fish fritters	Restaurant (Ancash and Piura-Peru)	DD	(MH194499, MH194524, MH194541)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)		(MN839526)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880503 to MN880505, MN880514, MN880517, MN880533, MN880534, MN880540)	Marín et al. (2022)
					DNA Sequencing, Multiplex PCR-SSP	COI, 16S rRNA	Fresh, cooked	Market (Tumbes, Piura, La Libertad, Ancash-Peru), Restaurant (Ancash-Peru)		(PQ459836 to PQ459845, PP092948 to PP092952, PP087229 and PV491563)	Marín et al. (2025)
		Triglidae	*Prionotus stephanophrys*	Lumptail searobin	DNA sequencing	COI	Fish fritters, fresh pieces	Market, Restaurant (Ancash-Peru)	LC	(MH194492, MH194531)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Tumbes-Peru)		(MN839515)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (Tumbes-Peru)		(PQ459813 to PQ459814)	Marín et al. (2025)
	Pleuronectiformes	Cynoglossidae	*Symphurus chabanaudi*	Chabanaud's tonguefish	DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)	LC	(PP092966)	Marín et al. (2025)
		Paralichthyidae	*Ancylopsetta dendritica*	Three-spot flounder	DNA sequencing	COI	Fresh whole body	Wholesale (Piura-Peru)	LC	(PP092964)	Marín et al. (2025)
			Cyclopsetta querna	Toothed flounder	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI, 12S rRNA	Fresh whole body, cooked	Landing (Tumbes-Peru), Restaurant (Tumbes-Peru)		(PP092965, PV505011, PV562161)	Marín et al. (2025)
			Etropus ectenes	Sole flounder	DNA sequencing	COI	Marinated ceviche	Restaurant (La Libertad-Peru)	LC	(MH194424, MH194425)	Marín et al. (2018)
					DNA Sequencing, PCR-SSP	COI	Fresh whole body	Landing (Tumbes-Peru)		(PP092942)	Marín et al. (2025)
			Hippoglossina tetrophthalma	Fourspot flounder	DNA sequencing	COI	Fresh whole body	Wholesale (Lambayeque-Peru)	LC	(MN839530)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Tumbes-Peru)		(MN880530)	Marín et al. (2022)
			Paralichthys adspersus	Fine flounder	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA Sequencing, PCR-SSP	COI	Fresh whole body	Market and Aquaculture facility (Ancash-Peru)		(PP092941, PQ459815 to PQ459825)	Marín et al. (2025)
			Paralichthys woolmani	Speckled flounder	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Supermarket (Lima-Peru)	DD	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Piura and Tumbes-Peru)		(MN880555, MN880580 to MN880582)	Marín et al. (2022)
					DNA sequencing	12S rRNA	Cooked	Retail (Tumbes-Peru)		(PV505012)	Marín et al. (2025)
	Salmoniformes	Salmonidae	*Oncorhynchus kisutch**	Coho salmon	PCR-RFLP	Cytb	Uncooked muscled	Sushi roll restaurant (Osorno, Puerto Montt-Chile)	NE	—	Prida et al. (2020)
			*Oncorhynchus mykiss**	Rainbow trout	DNA sequencing	COI	Whole, frozen	Importer, Retailer (Canada, imported from Chile and Peru)	NE	—	Shehata et al. (2019)
					PCR-RFLP	Cytb	Uncooked muscled	Sushi roll restaurant (Iquique, Osorno, Puerto Montt, Quellón, Viña del Mar, Temuco, Valparaíso-Chile)		—	Prida et al. (2020)
			*Oncorhynchus tshawytscha**	Chinook salmon	PCR-RFLP	Cytb	Uncooked muscled	Sushi roll restaurant (Osorno, Temuco-Chile)	NE	—	Prida et al. (2020)
			*Salmo salar**	Atlantic salmon	qPCR-SSP	ITS1		Supermarket (Chile)	NT	—	Herrero et al. (2011)
					DNA sequencing	COI	Fillet vacuum packaged	Multimarket (Lima-Peru)		(MH194516)	Marín et al. (2018)
					DNA sequencing	COI	Whole or fillet	(Canada, imported from Chile)		—	Shehata et al. (2018)
						COI	Whole frozen, refrigerated	Importer, Registered plant, (Canada, imported from Chile)		—	Shehata et al. (2019)
					PCR-RFLP	Cytb	Uncooked muscle	Sushi roll restaurant (Antofagasta, Concepción, Iquique, Osorno, Puerto Montt, Quellón,Temuco, Validivia, Valparaíso, Viña del Mar-Chile)		—	Prida et al. (2020)
			*Salmo trutta**	Sea trout	PCR-RFLP, FINS	Cytb	—	(Peru)	LC	—	Espiñeira et al. (2009b)
	Scombriformes	Bramidae	*Brama australis*	Southern rays bream	PCR-RFLP, FINS	Cytb	Fresh, processed	Supermarket (Chile)	NE	—	Espiñeira et al. (2009b)
			Xenobrama microlepis	Golden pomfret	DNA sequencing	COI	Fresh	Artisanal fishery (Calbuco-Chile)	NE	(KX497160, KX497161)	Canales-Aguirre et al. (2018)
		Centrolophidae	*Schedophilus haedrichi*	Mocosa ruff	DNA sequencing	COI	Fresh whole body, steamed fillet	Market, Restaurant (La Libertad-Peru)	LC	(MH194423, MH194446)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI	Fresh whole body	Market (La Libertad-Peru)		(MN839529)	Marín et al. (2021)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880515)	Marín et al. (2022)
					DNA sequencing, Multiplex PCR-SSP	COI	Fresh, cooked	Market and Restaurant (La Libertad-Peru), Landing (Tumbes-Peru), Wholesale (Piura and Lambayeque-Peru)		(PP092954, PV562157, PQ459805 to PQ459809)	Marín et al. (2025)
			Seriolella violacea	Palm ruff	DNA sequencing	COI	Whole fillet or chopped fillet	Supermarket, Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880601)	Marín et al. (2022)
		Gempylidae	*Lepidocybium flavobrunneum*	Escolar	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant (Lima-Peru)	LC	—	Biffi et al. (2020)
			Thyrsites atun	Snoek	DNA sequencing	COI	Whole or fillet	(Canada, imported from Chile)	NE		Shehata et al. (2018)
		Scombridae	*Acanthocybium solandri*	Wahoo	DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)	LC	—	Biffi et al. (2020)
			Katsuwonus pelamis	Skipjack tuna	DNA sequencing	COI	Whole fillet or chopped fillet	Landing (Tumbes-Peru)	LC	—	Biffi et al. (2020)
			Sarda chiliensis	Eastern Pacific bonito	DNA sequencing	COI	Fried fillet	Restaurant (La Libertad-Peru)	LC	(MH194515)	Marín et al. (2018)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail, Restaurant, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
			Scomber japonicus	Chub mackerel	RFLP-SSCP	Cytb	Fishmeal	International Fishmeal and Oil Manufacturers' Association, IFOMA (Germany, imported from Peru)	LC	—	Rehbein (2002)
					DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)		—	Biffi et al. (2020)
			Scomberomorus sierra	Pacific sierra	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh whole body	Landing (Piura-Peru)		(MN880519)	Marín et al. (2022)
			Thunnus albacares	Yellowfin tuna	DNA sequencing	COI	Whole fillet or chopped fillet	Restaurant, Retail, Supermarket, Wholesale (Lima-Peru); Landing, Retail (Tumbes-Peru)	LC	—	Biffi et al. (2020)
					DNA sequencing	COI	Fresh, refrigerated, or frozen	Fish market, Restaurant, or Supermarket (Lima-Peru)		—	Velez-Zuazo et al. (2021)
					DNA sequencing	COI, Control Region	Fresh whole body	Landing (Tumbes-Peru)		(MN880518, MN880522, MN880616, MN880618)	Marín et al. (2022)
	Syngnathiformes	Syngnathidae	*Hippocampus ingens*	Pacific seahorse	PCR-SSP	16S rRNA	Fresh whole body (seized by Peruvian authorities)	Seizure from Landing (Ancash-Peru)	VU	—	Marín et al. (2021)
					qPCR-SSP, direct qPCR-SSP, DNA Sequencing	16S rRNA	Dried	Donations (Ancash, Lima, and Piura-Peru)		(MN839505 to MN839510)	Marín et al. (2021)
	Tetraodontiformes	Tetraodontidae	*Sphoeroides annulatus*	Bullseye puffer	DNA sequencing	COI	Whole fillet or chopped fillet	Wholesale (Lima-Peru)	LC	—	Biffi et al. (2020)

Mollusca											
Bivalvia	Adapedonta	Pharidae	*Ensis macha*	Razor clam	FINS	18S rDNA	Frozen or preserved	(Chile, Peru)	NE	—	Espiñeira et al. (2009a)
	Arcida	Arcidae	*Anadara tuberculosa*	Pustulose ark	DNA sequencing	COI	Marinated ceviche	Restaurant (La Libertad-Peru)	NE	(MH194436)	Marín et al. (2018)
	Cardiida	Donacidae	*Donax obesulus*	Wedge clam	DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)	NE	(MH194540)	Marín et al. (2018)
		Semelidae	*Semele corrugata*	Clam	DNA sequencing	COI	Fresh whole body	Market (Ancash-Peru)	NE	(MH194538)	Marín et al. (2018)
		Solecurtidae	*Tagelus dombeii*	Hard razor clam	FINS	18S rDNA	Frozen or preserved	(Chile, Peru)	NE	—	Espiñeira et al. (2009a)
					DNA sequencing	COI	Boiled, fresh cut in pieces, marina	Market, Restaurant (Ancash-Peru); Multimarket (Lima-Peru)		(MH194523, MH194539, MH194548)	Marín et al. (2018)
			Tagelus peruanus	Razor clam	FINS	18S rDNA	Frozen or preserved	(Peru)	NE	(EU660762)	Espiñeira et al. (2009a)
	Mytilida	Mytilidae	*Aulacomya atra*	Chilean ribbed mussel	PCR-RFLP	ITS	Fresh	Corral Bay (Chile)	NE	—	Toro (1998)
					PCR-RFLP	18S rDNA	Fresh whole body	Supermarket (Osorno-Chile)		—	Colihueque et al. (2020)
					PCR-RFLP	PAPM	Raw	(Chile)		—	Quintrel et al. (2021)
			Choromytilus chorus	Choro mussel	PCR-RFLP	ITS	Fresh	Corral Bay (Chile)	NE	(EU636218)	Toro (1998)
					PCR and band size polimorphism	ITS1, ITS2	Fresh	(Concepción-Chile)		—	Aguilera-Muñoz et al. (2008)
					PCR-RFLP	PAPM	Raw	(Chile)		—	Quintrel et al. (2021)
			Mytilus chilensis	Chilean mussel	PCR-RFLP	ITS	Fresh	Corral Bay (Chile)	NE	—	Toro (1998)
					RAPD	RANDOM	Fresh	Puerto Aguirre (Chile)		—	Rego et al. (2002)
					PCR-RFLP	ITS, PAPM	Fresh	8 natural populations (from Arauco to Punta Arenas-Chile)		—	Toro et al. (2005)
					PCR-RFLP	COI, PAPM	Frozen	Supermarket (Chile)		—	Fernández-Tajes et al. (2011)
					HTS-Pyroseq	COI, 16S rRNA	Fresh, frozen	Customs premises (Italy, imported from Chile)		(KR078006)	Abbadi et al. (2016)
					HRM	PAPM	Fresh	Wild (Chile)		—	Jilberto et al. (2017)
					PCR-RFLP	COI, 16S rRNA, PAPM, ITS, MAC-1, 18S rDNA	Fresh	Wild populations (Chile)		—	Larrain et al. (2019)
					PCR-RFLP	18S rDNA	Frozen whole body	Supermaket (Osorno-Chile)		—	Colihueque et al. (2020)
					HRM	PAPM	Canned, frozen pre-cooked	(Chile and Germany imported from Chile)		—	Quintrel et al. (2021)
					HRM, FINS	PAPM, H1C	Fresh	Growing center (Relonca vi Sound and Dichato-Chile)		(MT949777 to MT949820, MT949830 to MT949837)	Asorey et al. (2022)
					PCR-RFLP	PAPM	Pre-cooked, frozen	National large retailers, Ethnic shop (Italy, imported from Chile)		—	Giusti et al. (2022)
					PCR and SNPs genotyping	PAPM	Whole body	Market (Poland, imported from Chile)		—	Wenne et al. (2022)
			*Mytilus edulis**	Blue mussel	HRM	PAPM	Fresh	Wild (Chile)	NE	—	Jilberto et al. (2017)
			*Mytilus galloprovincialis**	Mediterranean mussel	PCR-RFLP	ITS, PAPM	Fresh	8 natural populations (from Arauco to Punta Arenas-Chile)	NE	—	Toro et al. (2005)
					HRM	PAPM	Fresh	(Chile)		—	Jilberto et al. (2017)
			Perumytilus purpuratus	Purple mussel	PCR-RFLP	ITS	Fresh	Corral Bay (Chile)	NE	—	Toro (1998)
					PCR-RFLP	PAPM	Fresh	(Chile)		—	Quintrel et al. (2021)
	Ostreida	Ostreidae	*Ostrea chilensis*	Chilean flat oyster	FINS	18S rDNA	Frozen or preserved	(Chile)	NE	—	Espiñeira et al. (2009a)
	Pectinida	Pectinidae	*Argopecten purpuratus*	Peruvian scallop	FINS	18S rDNA	Frozen or preserved	(Peru)	NE	(EU660808, EU660809)	Espiñeira et al. (2009a)
					DNA sequencing	16S rRNA	Frozen	Imported or local commerce (Hamburg, Germany, imported from Peru)		—	Naumann et al. (2012)
					Multiplex PCR-SSP	16S rRNA	Fresh, processed	Landed by commercial diver (Pisco and Piura-Peru), market (Peru)		—	Marín et al. (2013)
					DNA sequencing	16S rRNA	Fresh	Landed by commercial diver (Ancash, Lima, Pisco, and Piura-Peru)		(KJ000134 to KJ000141)	Marín et al. (2015)
					Multiplex PCR-SSP	16S rRNA	Fresh, processed	Landed by commercial diver (Pisco and Piura-Peru); Supermarket (London-UK)		—	Marín et al. (2017)
					Multiplex PCR-SSP	16S rRNA	Fresh, ceviche, seafood rice	Restaurant (Lima-Peru)		(MH194434, MH194544)	Marín et al. (2018)
					NGS Metabarcoding	16S rRNA	Frozen	Delicacy shop (Austria, imported from Peru)		—	Gense et al. (2021)
					DNA sequencing	16S rRNA	Frozen, cooked	Supermarket, Restaurant (Germany, origen not declared, probably Chile or Peru)		—	Klapper and Schröder (2021)
					DNA sequencing	16S rRNA	Frozen, cooked	Supermarket, Fish shops (Cantabrian Coast-Spain), Restaurants (Asturias, Galicia, Segovia-Spain), (imported from Chile or Peru)		(MT126344 to MT126356)	Parrondo et al. (2021)
					DNA Sequencing, PCR-SSP, qPCR-SSP, direct qPCR-SSP	16S rRNA	Fresh, cooked, frozen	Market and Supermarket (Ancash-Peru), Landing (Piura and Pisco-Peru), Restaurant (Ancash and Piura-Peru)		(PP087160 to PP087193, PV4	Marín et al. (2025)
	Venerida	Mesodesmatidae	*Mesodesma donacium*	Macha clam	FINS	18S rDNA	Frozen or preserved	(Chile)	NE	(EU660756, EU0757)	Espiñeira et al. (2009a)
		Veneridae	*Ameghinomya antiqua*	Cancellated clam	FINS	18S rDNA	Frozen or preserved	(Chile)	NE	(EU660742, EU660743)	Espiñeira et al. (2009a)
			Leukoma thaca	Taca clam	FINS	18S rDNA	Frozen or preserved	(Chile)	NE	(EU660752, EU660753)	Espiñeira et al. (2009a)
Cephalopoda	Myopsida	Loliginidae	*Doryteuthis gahi*	Patagonian squid	DNA sequencing	COI	Steamed rings	Restaurant (Piura-Peru)	LC	(MH194501)	Marín et al. (2018)
					DNA Sequencing, PCR-SSP	COI, 16S rRNA	Fresh, cooked	Restaurant (Ancash and Piura-Peru), Market (Ancash and Tumbes-Peru)		(PQ459851 to PQ459852, PV562158)	Marín et al. (2025)
			Lolliguncula argus	Argus brief squid	DNA sequencing	COI, 16S rRNA, Rhodopsin	Whole individual	Market (Machalilla-Ecuador)	DD	(MN787690, MN787710, MN787730)	Costa et al. (2021)
			Lolliguncula diomedeae	Dart squid	DNA sequencing	COI, 16S rRNA, Rhodopsin	Whole individual	Market (Isla Santa Clara, Marta-Ecuador, Talara-Peru)	DD	(MN787672 to MN787677, MN787692 to MN787697, MN787712 to MN787717)	Costa et al. (2021)
					DNA sequencing	16S rRNA	Fresh tentacles	Landing (Tumbes-Peru)		(PQ459849 to PQ459850)	Marín et al. (2025)
			Lolliguncula panamensis	Panama brief squid	DNA sequencing	COI, 16S rRNA, RH	Whole individual	Market (Posorja, Río Verde-Ecuador, Talara-Peru)	DD	(MN787678 to MN787682, MN787698 to MN787702, MN787718 to MN787722)	Costa et al. (2021)
	Octopoda	Octopodidae	*Octopus mimus*	Changos octopus	DNA sequencing	COI	Boiled, grilled, seafood rice	Restaurant (Ancash and Lima-Peru)	LC	(MH194493, MH194502, MH194545)	Marín et al. (2018)
					DNA sequencing	COI, COIII, 16S rRNA	Arm tissue	Las Palmeras zone at the Salinas seaside (Santa Elena-Ecuador)		—	Pliego Cárdenas et al. (2016)
	Oegopsida	Ommastrephidae	*Dosidicus gigas*	Jumbo flying squid	DNA sequencing	COI, 16S rRNA	Frozen	Supermarkets (Cairo, Menoufia, and Qalyubia-Egypt, imported from Chile)	DD	(KJ879299 to KJ879303)	Galal-Khallaf et al. (2016)
					DNA sequencing	16S rRNA	—	(Peru)		(LC063230 to LC063237)	Sánchez et al. (2016)
					DNA sequencing	COI, 16S rRNA	Chopped, Sliced, Seasoned	Market (South Korea, imported from Chile and Peru)		—	Yu et al. (2018)
					DNA sequencing	COI	Marinated ceviche, frozen seafood mix	Restaurant (La Libertad-Peru); Supermarket (Ancash-Peru)		(MH194426, MH194427, MH194533)	Marín et al. (2018)
					DNA sequencing	COI	—	Retail, Supermarket, Wholesale (Lima-Peru)		—	Biffi et al. (2020)
					DNA sequencing	COI	Cooked tentacles	Restaurant (Lambayeque-Peru)		(PV562159 and PV562160)	Marín et al. (2025)
Gastropoda	Lepetellida	Fissurellidae	*Fissurella bridgesii*	Lapa chequhe	PCR-RFLP	Cytb	Fresh	(Chile)	NE		Olivares-Paz et al. (2006)
			Fissurella crassa	Thick keyhole limpet	PCR-RFLP	Cytb	Fresh	(Chile)	NE	—	Olivares-Paz et al. (2006)
					PCR and band size polimorphism	ITS1, ITS2	Fresh	(Concepción-Chile)		(EU636216)	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Concepción-Chile)		(EU636211, EU636216)	Aguilera-Muñoz et al. (2008)
			Fissurella cumingi	Lapa rosada	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella latimarginata	Lapa negra	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella limbata	Lapa ploma	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella maxima	Lapa criolla	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella nigra	Key-hole limpet	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella oriens	Small banded keyhole limpet	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fisurella picta	Large banded keyhole limpet	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fissurella pulchra	Lapa rosada	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
			Fisurella radiosa	Lapa	PCR-RFLP	Cytb	Fresh	Wild population (Chile)	NE	—	Olivares-Paz et al. (2006)
		Haliotidae	*Haliotis discus hannai**	Pacific abalone	RAPD	RANDOM	Fresh	Reseach facility (Chile)	EN	—	Marín et al. (2007)
					PCR and band size polimorphism	ITS1, ITS2	Fresh, canned	(Coquimbo-Chile; Baja California-Mexico)		(EU636215)	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Coquimbo-Chile)		(EU636202, EU636208, EU636215)	Aguilera-Muñoz et al. (2008)
			*Haliotis rufescens**	Red abalone	RAPD	RANDOM	Fresh	Reseach facility (Chile)	CR	—	Marín et al. (2007)
					PCR and band size polimorphism	ITS1, ITS2	Fresh, canned	(Coquimbo-Chile), (Baja California-Mexico, imported from Chile)		(EU636214)	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Coquimbo-Chile)		(EU636201, EU636207, EU636214)	Aguilera-Muñoz et al. (2008)
	Neogastropoda	Muricidae	*Chorus giganteus*	Top shell whelk	PCR and band size polimorphism	ITS1, ITS2	Fresh, processed	(Concepción-Chile)	NE	—	Aguilera-Muñoz et al. (2008)
			Concholepas concholepas	Chilean abalone	PCR and band size polimorphism	ITS1, ITS2	Fresh, canned	(Concepción-Chile), (Baja California-Mexico, imported from Chile)	NE	—	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Concepción-Chile)		—	Aguilera-Muñoz et al. (2008)
					PCR-SSCP	18S	Fresh, Canned	Retail market (Mexico)		(HM775291)	Aranceta-Garza et al (2011)
					FINS	COI, 16S rRNA	Dried	Wholesale and retail outlets (Hong Kong, imported from Chile)		—	Ha et al. (2011)
			Thaisella chocolata	Chocolate rock shell	PCR and band size polimorphism	ITS1, ITS2	Fresh, processed	(Antofagasta-Chile)	NE	—	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Antofagasta-Chile)		(EU636204, 636210)	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI	Marinated ceviche, fresh cut in pieces	Market, Restaurant (Ancash-Peru)		(MH194525, MH194530)	Marín et al. (2018)
	Trochida	Tegulidae	*Tegula atra*	Smooth black trochid	PCR and band size polimorphism	ITS1, ITS2	Fresh, processed	(Concepción-Chile)	NE	(EU636217)	Aguilera-Muñoz et al. (2008)
					DNA sequencing	COI, 16S rRNA, ITS	Fresh	(Concepción-Chile)		(EU636206, EU636212, EU636217)	Aguilera-Muñoz et al. (2008)
Crustacea											
Crabs	Decapoda	Cancridae	*Cancer plebejus*	Chilean crab	DNA sequencing	COI	Raw crab chelipeds	Seafood market (Coquimbo-Chile, 29° 57' S)	NE	—	Haye et al. (2012)
			Cancer porteri	Boco	DNA sequencing	COI	Raw crab chelipeds, Canned chelipeds	Food store, Seafood market (Coquimbo-Chile, 29° 57' S)	NE	—	Haye et al. (2012)
			Metacarcinus edwardsii	Mola rock crab	DNA sequencing	COI	Frozen chelipeds, Frozen minced meat, Frozen chelipeds	Food store, Seafood market (Coquimbo-Chile, 29° 57' S)	NE	—	Haye et al. (2012)
			Romalean setosum	Rock-crab	DNA sequencing	COI	Raw crab chelipeds, Canned chelipeds, and frozen crab meat, Frozen minced meat	Food store, Seafood market (Coquimbo-Chile, 29° 57' S)	NE	—	Haye et al. (2012)
					DNA sequencing	COI	Crab meat	Supermarket (Ancash-Peru)		(MH194536)	Marín et al. (2018)
		Platyxanthidae	*Homalaspis plana*	Blackberry crab	DNA sequencing	COI	Crab claws, Canned chelipeds, Frozen minced meat	Food store, Seafood market (Coquimbo-Chile, 29° 57' S)	NE	—	Haye et al. (2012)
			Platyxanthus orbignyi	Purple crab	DNA sequencing	COI	Marinated ceviche, fresh	Restaurant (La Libertad-Peru)	NE	(MH194445)	Marín et al. (2018)
Shrimps		Penaeidae	*Penaeus (Litopenaeus) vannamei*	Whiteleg shrimp	DNA sequencing	COI, 16S rRNA	Frozen	Supermarkets (Oviedo, Principality of Asturias-Spain, imported from Ecuador)	NE	(KJ879313-KJ879314)	Galal-Khallaf et al. (2016)
					DNA sequencing	COI	Marinated ceviche, fresh	Restaurant (La Libertad-Peru); Supermarket (Ancash-Peru)		(MH194437, MH194528)	Marín et al. (2018)
					DNA sequencing, PCR-MICROARRAY	COI, 16S rRNA	—	Retailer (Germany, declared origin: Ecuador)		—	Kappel et al. (2021)
					DNA sequencing	COI	Fresh, frozen, boiled	Supermarket, Fishmongers (Madrid-Spain, imported from Ecuador)		—	Gil et al. (2024)
					DNA sequencing	COI	Peeled	Supermarket (Asturias-Spain, imported from Ecuador)		—	Ortiz-Moriano et al. (2024)
Echinodermata											
Sea cucumber	Dendrochirotida	Cucumariidae	*Athyonidium chilensis*	Burrowing shaggy sea cucumber	DNA sequencing	COI, 16S rRNA	Dried	Supermarket (China, origin: Peru)	NE	—	Hu et al. (2019)
					Mini barcoding	COI	Dried	Supermarket (China, origin: Peru)		—	Xing et al. (2022)
Cetaceans											
Dolphins	Cetartiodactyla	Delphinidae	*Delphinus delphis*	Common dolphin	DNA sequencing	tRNA-Glu to Cytb	Meat pieces or whole body	Fish market (Ancash and La Libertad-Peru)	LC	(HM572302) (HM572297 to HM572301)	Tzika et al. (2010)
					DNA sequencing	COI	Whole fillet or chopped fillet	Retail (Lima-Peru)		—	Biffi et al. (2020)
			Lagenorhynchus obscurus	Dusky dolphin	DNA sequencing	tRNA-Glu to Cytb	Meat pieces or whole body	Fish market (Ancash and La Libertad-Peru)	LC	(HM572303 to HM572305)	Tzika et al. (2010)
			Tursiops truncatus	Bottlenose dolphin	DNA sequencing	tRNA-Glu to Cytb	Meat pieces or whole body	Fish market (Ancash and La Libertad-Peru)	LC	(HM572307 to HM572320)	Tzika et al. (2010)
Porpoises		Phocoenidae	*Phocoena spinipinnis*	Burmeister's porpoise	DNA sequencing	tRNA-Glu to Cytb	Meat pieces or whole body	Fish market (Ancash and La Libertad-Peru)	NT	(HM572306)	Tzika et al. (2010)

*Introduced species for commercial purposes.

**This species is not found in Peruvian waters; it likely represents an imported item from Ecuador, where it occurs naturally.

192 were native to the ESPO, whereas 10 were introduced species. The introduced organisms included 6 fish species (*Oncorhynchus kisutch*, *O. mykiss*, *O. tshawytscha*, *Salmo salar, S. trutta*, and *Rachycentron canadum*), two mussel species (*Mytilus edulis* and *M. galloprovincialis*), and two abalone species (*Haliotis discus hannai* and *Haliotis rufescens*).

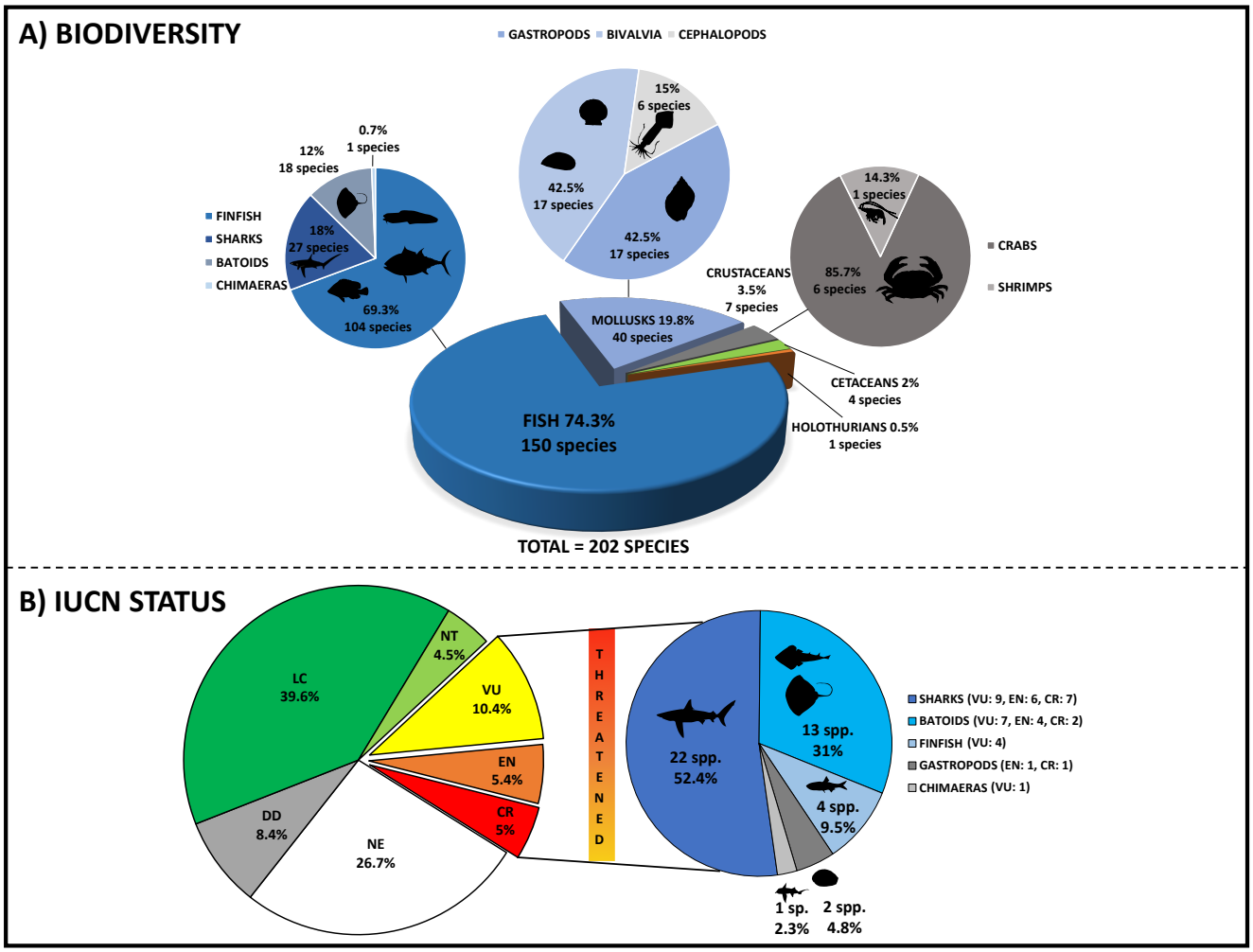


Fig. 2. Pie charts in Panel A show the taxonomic diversity of the seafood species identified using DNA-based methods. Species detected were grouped into five major taxonomic categories: fish (blue), mollusks (pale blue), crustaceans (dark grey), cetaceans (green), and holothurians (orange). Wedge sizes represent the proportion of identified species assigned to each category, based on the number of species identified across all reviewed studies. Panel B

shows a pie chart illustrating the proportion of total species, which are categorized by their conservation statuses, according to data from the IUCN. The satellite pie chart shows the proportions and taxonomic diversity of threatened species (Vulnerable: VU, Endangered: EN, and Critically Endangered: CR). These include sharks (blue), batoids (deep sky blue), finfish (pale blue), gastropods (dark grey), and chimaeras (light grey).

3.4.1 Fish

Fish were the most extensively studied seafood group, with samples analyzed in 36 studies. A total of 150 species were identified, distributed within 59 families and 28 orders. This group accounting for 74.3% of all identified species. The diversity within the fish group was primarily dominated by finsfish, which included 104 species (69.3%). This was followed by sharks with 27 species (18%), batoids with 18 species (12%), and chimaeras with just 1 species (0.7%). The fish group with the highest number of identified species belongs to the shark *Carcharhinus*, which has 6 species. This was followed by the finfish genus *Cynoscion*, which has 5 species.

3.4.2 Mollusks

The mollusk group comprised 40 species identified in 32 studies, distributed across 17 families and 13 orders. This group was evenly represented by gastropods and bivalves, with each group containing 17 species (42.5% each). Cephalopods were represented by 6 species, accounting for 15% of the mollusk group. The commercially important Chilean keyhole limpet species belonging to the genus *Fissurella* accounted for most of the gastropod species (12 out of 17 species).

3.4.3 Crustaceans

This shellfish group was analyzed in seven studies, including seven species from three families within one order. Six crab species, accounting for 85.7% of the findings, and one shrimp species, making up 14.3%, were identified in the studies reviewed herein.

3.4.4 Cetaceans

Cetaceans were represented by only four species (2%) in two studies conducted in Peru. The first study, reported by Tzika et al. (2010), analyzed DNA sequences of the mitochondrial CYTB gene from meat samples purchased in local markets across various coastal cities in Peru. This study identified four cetacean species namely: *Delphinus delphis*, *Lagenorhynchus obscurus*, *Phocoena spinipinnis*, and *Tursiops truncatus*. I should mention that *D. capensis* was also reported but it was later synonymized with *D. delphis* in 2015 (see Cunha et al., 2015). The second article, published by Biffi et al. (2020), provided molecular evidence of dolphin meat sold in a market in Lima, the capital of Peru. Their findings, based on COI sequences, revealed the illegal trade of a *D. delphis* meat sample labeled as "*muchame*", which is the market term used in Peru for fresh or cured cetacean meat. These results indicate that illegal catches and trade of small cetaceans continue to occur in Peru, despite conservation efforts and a ban against on the capture and commercialization of these species established by the Peruvian government in Law Nº 26585 on April 9, 1996 (El Peruano, 1996). This situation aligns with previous findings reported by Campbell et al. (2020).

3.4.5 Holothurians

This animal group included a single species, the burrowing shaggy sea cucumber (*Athyonidium chilensis*), which accounted for the smallest proportion (0.5%) of the total number of species analyzed in this review. Only two studies conducted in China (Hu et al., 2019; Xing et al.,

732 2021) have focused on this commercially valuable group, underscoring the need for more
733 research from ESPO countries to enhance our understanding of local holothurian diversity.
734

735 **3.5 Limitations of DNA-based methods in identifying ESPO species**

736 While most DNA-based methods for identifying seafood species are highly sensitive, efficient,
737 and accurate, several factors can complicate the identification process. These include:

738 • **Degraded DNA**: highly degraded DNA, often found in canned and cooked seafood due to
739 physical and chemical alterations, can hinder DNA extraction and further PCR amplification.
740 DNA mini-barcoding may help analyze degraded DNA, but it can struggle to distinguish
741 closely related species due to low coverage in gene regions with minimal or no variation.
742 This limitation often restricts identification to the genus level or higher taxonomic
743 categories.

744 • **Non-target DNA amplification**: Universal primers, which are frequently used for seafood
745 species identification, can mistakenly bind to non-target DNA, including that of parasites
746 and bacteria associated with the target organism.

747 • **Lack of a comprehensive database with reference sequences**: a database containing low-
748 coverage of reference sequences for species diversity can negatively impact seafood
749 identification. The success of DNA sequencing methods for species identification relies
750 heavily on a comprehensive DNA sequence database for accurate sequence comparison.

751 • **Incorrect marker selection**: choosing the right DNA marker is crucial for successful
752 seafood species identification. For example, slow-evolving markers may fail to distinguish
753 between closely related or recently diverged species. Additionally, low copy number
754 markers, such as those from the nuclear genome, can complicate the identification of highly
755 processed seafood products or when only a small amount of tissue is available.

- **Poor primer design:** effective primer design is essential for successful PCR amplification, and this requires the use of appropriate bioinformatics tools and experienced researchers. Primers that are designed based on highly variable regions or on a limited number of sequences may inadvertently miss detecting crucial mutations within the template strand that correspond to the complementary region of the primer's 3' end. This oversight can inhibit PCR amplification in organisms that contains these mutations.
- **Intrinsic biological nature of target seafood species**: the biological complexity of target seafood species can also complicate identification. Factors such as species complexes, cryptic taxa, recently diverged species, hybridization, and interspecific conservatism can hinder accurate interpretation of seafood species identification results.
- **Human error**: another important factor to consider during the identification process is the human error factor. These errors can occur at any stage, including seafood sampling, molecular identification analysis (such as DNA extraction, PCR amplification, and sequencing), and interpretation of the results.

Reviewed papers have highlighted some challenges in the successful identification of certain seafood species from the ESPO. These challenges primarily stem from a lack of comprehensive reference sequences and low levels of genetic differentiation among closely related species. Reviewed studies reported several instances of identifications at the genus level for smooth-hound sharks (*Mustelus* sp.), rays (*Gymnura* sp. and *Myliobatis* sp.), silversides (*Odontesthes* sp.), and clams (*Semele* sp.) (Marín et al., 2018; Biffi et al., 2020; Velez-Zuazo et al., 2021). Furthermore, species complexes have complicated the identification of octopuses (*Octopus* sp., Marín et al., 2018) and keyhole limpets (*Fissurella* sp., Olivares-Paz et al., 2006). These findings underscore the urgent need for developing an extensive database of DNA sequences for seafood species in the ESPO. To address these issues, researchers should consider exploring

781 alternative and more robust molecular techniques, like multilocus approaches (Feitosa et al.,
782 2018), phylomitogenomics (Alfaro et al., 2025), and whole genome sequencing (WGS)
783 combined with RAD-Seq targeting species-specific SNPs (Jiang et al., 2020).
784

785 **3.6 IUCN conservation status**

786 According to the International Union for Conservation of Nature´s Red List of Threatened
787 Species, out of the 202 species analyzed in the studies reviewed, 10 are listed as Critically
788 Endangered (CR) (5%), 11 as Endangered (EN) (5.4%), 21 as Vulnerable (VU) (10.4%), 9 as
789 Near Threatened (NT) (4.5%), 80 as Least Concern (LC) (39.6%), 17 as Data Deficient (DD)
790 (8.4%), and 54 as Not Evaluated (NE) (26.7%) (see Fig. 2). Threatened categories (CR, EN, or
791 VU) include a total of 42 species (21%), with sharks accounting for the majority at 22 species
792 (52.4%), followed by 13 batoids (31%), 4 finfish (9.5%), 2 gastropods (4.8%), and 1
793 chimaeroid fish (2.3%) (Fig. 2).
794 These findings highlight the rapid depletion of several commercial elasmobranch species,
795 primarily due to intense fishing pressure, overexploitation, and high bycatch rates. Additionally,
796 the K-strategist nature of these species (low fecundity, long gestation periods, slow growth,
797 and late sexual maturity) makes them particularly vulnerable to even moderate levels of fishing
798 pressure (Wheeler et al., 2020). All these characteristics contribute to their sensitivity to
799 environmental changes and human activities (Marín et al., 2018).
800 On the other hand, the LC category primarily consist of finfish species, with 71 out of a total
801 of 80 LC species. This category includes various small to medium-sized fish species, such as
802 anchovies, herring, mullets, pilchards, and sardines. These species exhibit r-strategist
803 characteristics, which include high fecundity, early age at first reproduction, and short life
804 spans, enabling them to withstand high levels of fishing pressure (Crosetti, 2016; Patti et al.,
805 2020; Owatari et al., 2024).

806 Of particular concern is that a considerable proportion of the species compiled are categorized
807 as NE with 54 species (26.7%) falling into this group. This category mainly comprises shellfish
808 species, including 40 species in total: 17 bivalves, 15 gastropods, 7 crustaceans, and 1
809 holothurian, along with 13 fish species. These findings indicate an urgent need for population
810 and demographic studies of commercially important shellfish species from the ESPO region.
811 The results from such studies would contribute to better assessments and determinations of the
812 current conservation statuses and population trends, ultimately leading to improved
813 management and sustainable exploitation of those resources.
814

815 **3.7 Mislabeling meta-analysis in ESPO seafood species**

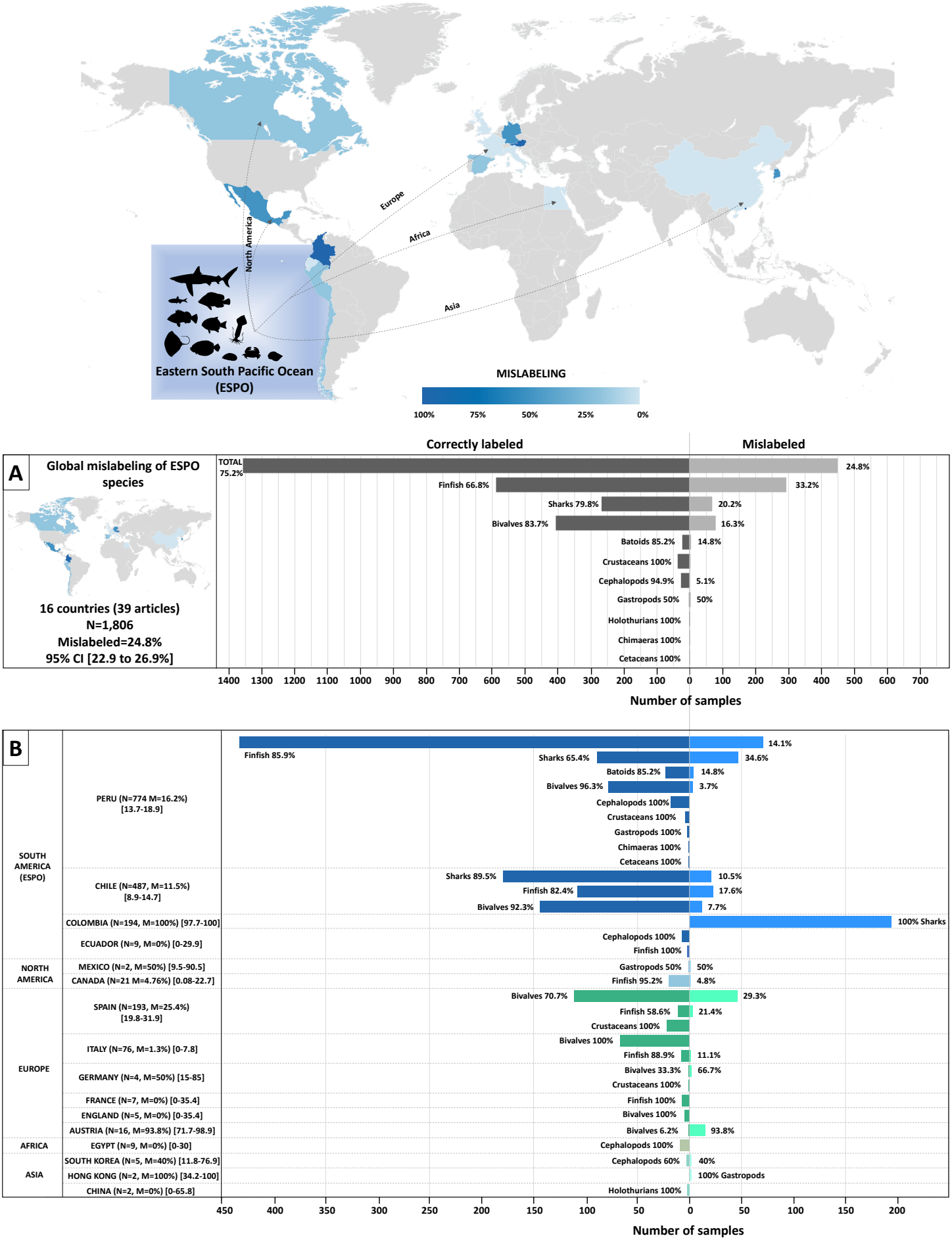
816 This study presents the first quantitative meta-analysis focused on seafood mislabeling of
817 ESPO species sold globally. Based on the Level 3 screening criteria, 39 articles were selected,
818 which included a total of 1,806 samples purchased throughout the entire supply chain, from
819 harvesting and processing to distribution and retail, across 16 countries. The number of samples
820 for each taxonomic group were: 882 finfish (48.8%), 485 bivalves (26.9%), 336 sharks (18.6%),
821 39 cephalopods (2.2%), 27 batoids (1.5%), 27 crustaceans (1.5%), 6 gastropods (0.3%), 2
822 holothurians (0.1%), 1 chimaera fish (0.05%), and 1 cetacean (0.05%).
823 A re-analysis of seafood samples with publicly available sequences allowed me to upgrade
824 eight seafood samples that were previously identified only to the genus level due to a lack of
825 reference sequences at the time of their publication. Among these upgrades was a canned
826 sardine identified by Jérôme et al. (2003b), which was reclassified from *Sardinops* sp. to *S.*
827 *sagax* (GenBank AY394046). Furthermore, four samples originally identified as *Mustelus* sp.
828 were upgraded to *Mustelus whitneyi* (Genbank MH194477, MH194478, MH194497, and
829 MH194506). Additionally, two samples identified as *Gymnura* sp. were upgraded to *Gymnura*
830 *afuerae* (Genbank MH194463 and MH194465), and one sample initially identified as *Semele*

831 sp. was reclassified as *Semele corrugata* (Genbank MH194538) (Marín et al., 2018). This
832 finding highlights the importance of sharing DNA records, which aligns with the data
833 availability policies of several relevant journals. Sharing DNA records not only supports the
834 conclusions of studies but also benefit the research community by allowing re-analysis of
835 published results, facilitating meta-analyses, and reducing costs of further research (Sielemann
836 et al., 2020). In this review, it was noted that out of the 39 articles selected for the meta-analysis,
837 27 studies focused on DNA sequencing, of which only 11 made their DNA records publicly
838 accessible.
839 The results of the global mislabeling analysis are shown in Fig. 3. These results indicated that
840 out of the 1,806 seafood products, 448 were mislabeled. This represents a global mislabeling
841 rate of 24.8% (95% CI [22.9-26.9]). The mislabeling rate found in this review, which focused
842 specifically on ESPO seafood species, falls within the range of previous global mislabeling
843 meta-analyses, which reported rates between 19% and 30% (Pardo et al., 2016; Warner et al.,
844 2016; Luque and Donlan, 2019). The complete meta-dataset can be found in S1 Table. While
845 the findings of the mislabeling meta-analysis are informative, they should be interpreted with
846 caution due to varying sampling strategies and efforts used across the different studies
847 reviewed.
848

849 **3.7.1 Mislabeling per geographic region**

850 Overall, the reviewed samples were collected from five continents, encompassing 16 countries.
851 The mislabeling results, categorized by continent, indicated that Asia had the highest rate of
852 mislabeling at 44.4% (4/9, CI [18.9-73.3]), followed by South America at 25.6% (375/1464,
853 95% CI [23.7-28.2]), Europe at 22.3%, (67/301, 95% CI [17.9-27.3]), and North America at
854 8.7%, (2/23, 95% CI [2.4-26.8]).
855

GLOBAL MISLABELING ANALYSIS OF SEAFOOD SPECIES FROM THE EASTERN SOUTH PACIFIC OCEAN



857 **Fig. 3.** Results of the global meta-analysis for seafood from the Eastern South Pacific Ocean
858 (ESPO). The heat map illustrates the countries from which seafood samples were collected and
859 analyzed. Color intensity indicates the mislabeling rate calculated for each country, as
860 displayed in the mislabeling rate color scale. The back-to-back bar graph in Panel A presents
861 the overall global rates of mislabeled and correctly labeled samples, along with rates specific
862 to each seafood category. The back-to-back bar graph in Panel B depicts the proportions of
863 mislabeled and correctly labeled samples observed in individual countries, categorized by
864 seafood type. Confidence intervals (95% CI) for the mislabeling rates in each country are
865 provided in brackets. "N" indicates sample size, and "M" denotes the mislabeling rate.
866
867
868 No mislabeling was detected in samples from Africa (0/9, 95% CI [0-30]), although the sample
869 size for this continent was small and not representative (see S1Table). Only South America
870 and Europe had sampling sizes exceeding the threshold of n > 25, consequently only both
871 continents were included in the statistical test of significant association. The mislabeling rates
872 observed in these two continents did not show a statistically significant relationship (Chi-
873 square, $p = 0.25$) (Fig. 4).
874 When mislabeling analyses were organized by country, the highest mislabeling rates of 100%
875 were found in Colombia (194/194, CI [97.7-100]) and Hong Kong (2/2, 95% CI [34.2-100]).
876 It should be noted that samples analyzed from Colombia involved 194 shark fins that were
877 incorrectly labeled as fish bladders. All of these selected fins were confiscated during an
878 official inspection at an airport, therefore mislabeling rates in these samples were expected to
879 be high. On the other hand, the sample size from Hong Kong consisted of only two ESPO
880 samples, which is not representative. Other estimates from countries with small sample sizes

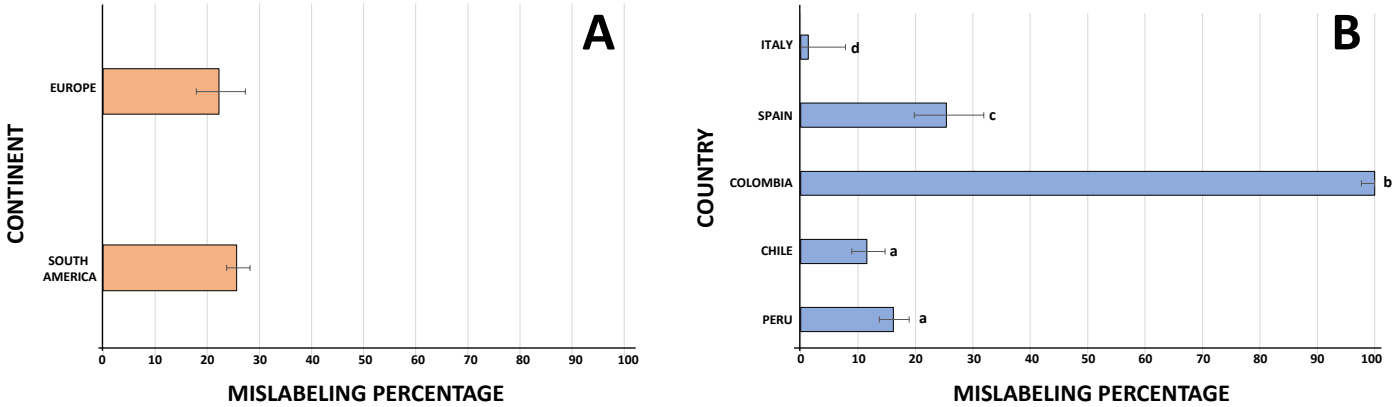


Fig. 4. Mislabeling rates by A) continent and B) country. Bars represent the mislabeling rate, error bars indicate the 95% confidence intervals. The relationship between the mislabeling rates in Europe and South America showed no significant deviation. Bars labeled with different lowercase letters are significantly different at $p < 0.05$. Statistical significance was determined using either the Chi-square test or Fisher's exact test, depending on the sample size.

(n < 10) reported mislabeling rates of 0% for China, Ecuador, Egypt, England, and France, while Mexico, Germany, and South Korea reported mislabeling between 40% and 50%. Countries with more representative sample sizes include Peru with a mislabeling rate at 16.5% (125/774, 95% CI [13.7-18.9.3]), Chile at 11.50% (56/487, 95% CI [8.9-14.7]), Spain at: 25.4% (49/193, 95% CI [19.8-31.9]), and Italy at 1.3% (1/76, 95% CI [0-7.8]). A statistical test of significant association between the mislabeling rates detected in five countries (Chile, Colombia, Italy, Spain, and Peru) showed non-significant similar relationship only between Chile and Peru (Chi-square, $p = 0.27$). All other relationships showed signs of significant deviation (Fig. 4). This finding was mainly driven by the strong contrast in mislabeling rates observed across the countries analyzed. Colombia exhibited an extremely high misleading rate,

while Spain, Peru, and Chile had moderate to high levels, and Italy had a very low mislabeling rate. Detailed mislabeling results for each country are shown in S1 Table.

3.7.2 Mislabeling per distribution channel

The analysis revealed that mislabeling rates varied significantly among the different distribution channels. The highest overall mislabeling rate was found in the inspection category at 64% (195/303, 95% CI [58.8-69.5]). This was followed by restaurants at 36% (76/210, 95% CI [30-42.9]), wholesale markets at 27.34% (38/139, 95% CI [20.6-35.3]), markets at 22.8% (52/228, 95% CI [17.8-28.7]), supermarkets at 12.2% (53/434, 95% CI [9.4-15.6]), warehouse at 10.5% (21/200, 95% CI [6.9-15.6]), fish landings at 5.9% (12/203, 95% CI [3.3-10.1]), and large scale retailers at 3.57% (1/28, CI [0.63-17.7]) (Fig. 5). The "market" category encompassed samples collected from the following subsectors: ethnic shops, delicacy shops, fishmongers, open air markets, retail markets, handicraft markets, fish markets, retailers, and local commerce.

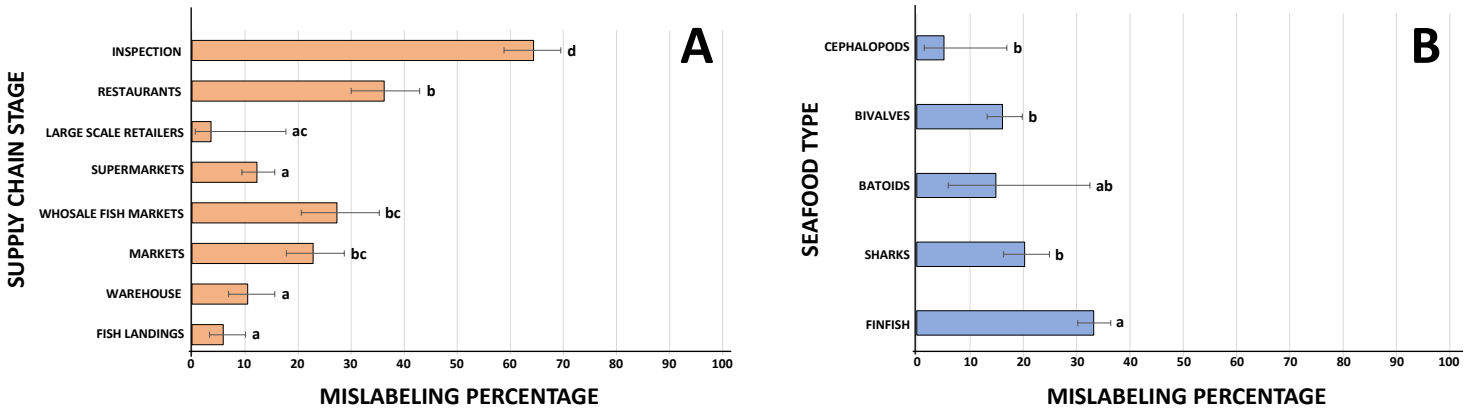


Fig. 5. Mislabeling rates by A) supply chain stage and B) seafood type. Bars represent the mislabeling rate, error bars indicate the 95% confidence intervals. Bars labeled with different lowercase letters are significantly different at $p < 0.05$. Statistical significance was determined using either the Chi-square test or Fisher's exact test, depending on the sample size.

917 The mislabeling rate observed at the inspection category was significantly higher than in all
918 other categories (Chi-square, $p < 0.05$). This discrepancy can be attributed to the elevated
919 mislabeling rate within this category compared to others. It is important to note that most
920 samples from this category were obtained through seizures at official control points, which
921 tend to contain a higher percentage of fraudulent items. Out of the 303 samples analyzed in
922 this category, 194 (64%) were processed shark fins that were falsely declared as fish bladders
923 at an airport in Colombia (Cardeñosa et al., 2023).
924 The mislabeling rate at restaurants was significantly higher (Chi-square, $p < 0.05$) compared
925 to other categories, except for wholesale and markets, where the rates were statistically similar
926 ($p > 0.05$). Excluding the inspection category, restaurants exhibited the highest mislabeling
927 rate, while the lowest rate was found at fish landings. This outcome was anticipated, as the
928 initial stages of the supply chain have fewer opportunities for mislabeling. This result aligns
929 with several studies that have shown that mislabeling tends to increase further along the supply
930 chain (Pardo et al., 2016; Marín et al., 2018).
931

932 **3.7.3 Mislabeling per seafood type**

933 The estimated overall mislabeling rates for the different types of seafood analyzed were highest
934 for gastropods at 50% (3/6, 95% CI [18.8-81.2]), followed by finfish at 33.2% (293/882, 95%
935 CI [30.2-36.4]), sharks at 20.2% (68/336, 95% CI [16.3-24.9], bivalves at 16.1% (78/485, 95%
936 CI [13.2-19.8]), batoids at 14.8% (4/27, 95% CI [5.9-32.5]), and cephalopods at 5.1% (2/39,
937 95% CI [1.4-16.9]) (Fig. 5). A global Chi-square test indicated a strong significant difference
938 ($p < 0.05$) in the mislabeling rates among the assessed groups (batoids, bivalves, cepahlopods,
939 finfish, and sharks). Subsequent multiple comparison analyses identified significant
940 differences among three groups: finfish vs. cephalopods (Fisher's exact test, $p < 0.05$), finfish
941 vs. bivalves (Chi-square, $p < 0.05$), and finfish vs. sharks (Chi-square, $p < 0.05$) (Fig. 5). The

finfish group exhibited the highest significant mislabeling rate. This is likely due to its high species diversity, the variety of commercial forms, and economic incentives, all of which make this category more susceptible to mislabeling or substitution. In contrast, the smaller sample sizes in other categories, such as batoids and cephalopods, reduce the statistical power to detect meaningful differences. Additionally, the unequal group sizes may influence the robustness of comparisons across seafood categories.

The most frequently encountered substitute species were three threatened shark species. A total of 161 samples, initially labeled as fish bladders (typically sourced from certain finfish species) were actually shark fins from two species: *Carcharhinus falciformis* (n=114, IUCN status: VU) and *Sphyrna lewini* (n=47, IUCN status: CR). The third species, *Prionace glauca* (n=38, IUCN status: NT), was found being used not only as a substitute for other sharks (i.e. hammerheads, shortfin makos, and smooth-hounds) but also for various finfish products (i.e. dolphinfish, rock seabass, and fish bladder). These findings highlight serious conservation concerns, particularly given the involvement of highly threatened species, demanding urgent policy actions and enforcement measurements.

The current review identified a total of 27 Peruvian seafood items labeled as "*tollo de leche*". Out of these samples, two were finfish, while the remaining 25 belonged to five different shark species. Notably, three of these shark species (*Alopias pelagicus*, *Isurus oxyrinchus*, and *S. zygaena*) are classified as threatened by the IUCN. In Peru, the term "*tollo de leche*" was originally designated for a single species: the Critically Endangered humpback smooth-hound shark, *M. whitneyi* (Elliot et al., 1996; Chirichigno and Cornejo, 2001). However, a recent study revealed that this term is now being used to refer to small-sized specimens of various shark species (Núñez and Gozzer-Wuest, 2019). The use of conflicting market names, which constitutes a form of mislabeling (Ahles et al., 2025), can result in overfishing of vulnerable species, hinder the enforcement of regulations, and limit consumers' ability to make informed

967 choices (Almerón-Souza et al., 2018). To address these issues, efforts should focus on
968 improving labeling accuracy and eliminating conflicting names by creating a standardized list
969 of unique market names (Marín et al., 2018).
970 Among the invertebrate seafood samples analyzed, the most commonly mislabeled species was
971 the Chilean blue mussel *M. chilensis*. This bivalve was substituted with three different species:
972 *Aulacomya atra*, which was detected in 12 samples collected from a supermarket in Chile
973 (Colihueque et al., 2020), and *M. galloprovincialis* or *M. edulis*, which were found in 15
974 products from European commerce (Gense et al., 2021). Another bivalve, the Peruvian scallop
975 (*A. purpuratus*), was the most commonly used substitute species. This scallop species was used
976 to replace two types of European scallops: the variegated scallop (*Mimachlamys varia*) in Spain,
977 with 45 substituted samples, and two samples of king scallops labeled as *Pecten maximus* and
978 *Pecten* sp. in Germany. The year-round availability of farmed Peruvian scallop positions this
979 species as a potential substitute for wild, seasonally available local European scallops
980 (Parrondo et al., 2021).
981

982 ## 4. Conclusions and future perspectives

983 This research presents the first comprehensive global survey of DNA-based methods used to
984 identify seafood species from the ESPO, with particular focus on species diversity,
985 conservation status, and issues related to mislabeling. The findings from this review contribute
986 significantly to our understanding of past, present, and future trends in molecular methods that
987 support traceability, regulation, and effective management of ESPO species. Among the
988 identification methods, Sanger sequencing technology stands out as the most frequently
989 utilized due to its high efficiency and accuracy. However, faster and more cost-effective
990 techniques, such as species-specific primers and multiplex PCR, were also identified in the
991 reviewed studies, mostly targeting vulnerable species like sharks and seahorses. Despite the

992 great potential of HTS-based methods for authenticating seafood species, few studies have
993 explored their utility in ESPO products. Notably, no research has yet explored the application
994 of emergent molecular species identification technologies, such as CRISPR-based platforms,
995 for seafood authentication in the ESPO. This relatively new technology has the potential to
996 revolutionize seafood authentication, as indicated by recent studies reporting higher specificity
997 and sensitivity levels, as well as shorter processing times compared to traditional DNA
998 identification methods (Ying et al., 2022; Moorthy et al., 2025).
999 This study also conducted the first meta-analysis on the mislabeling of ESPO seafood products
1000 sold globally, revealing an overall mislabeling rate of 24.8%. As expected, the highest rates of
1001 mislabeling were detected in the final stages of the supply chain. A significant finding from
1002 this review is that threatened shark species were not only the most frequently mislabeled but
1003 also the most commonly encountered substitute species. This raises important concerns about
1004 conservation, fishery management, trade, and regulation of vulnerable resources. In light of
1005 this, laudable shark conservation initiatives, like the "Shark Free Ceviche" seal (Díaz-Ferguson
1006 et al., 2024), which has already been implemented in Colombia, should be replicated or adopted
1007 in more ESPO nations like Ecuador and Peru, which are major players in global shark fishing,
1008 trade, and consumption.
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