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Short Communication

Meta-analyses of molecular seafood studies identify the global distribution of legal and illegal trade in CITES-regulated European eels

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ABSTRACT

Authentication of seafood products by means of molecular techniques has relevance for food sustainability and security, as well as international trade regulation, linked to transparency in food manufacturing. We focus on the molecular detection of the depleted European eel *Anguilla anguilla*, a species for which strict international trade regulations are in place since 2010, in studies conducted outside Europe. We found thirteen studies from nine countries (Canada, China, Japan, Malaysia, Peru, Singapore, South Korea, Taiwan, and USA) for which, on average, $59 \pm 28\%$ of the 330 sequenced eel samples comprised European eel. Only China, Japan, South Korea, and USA reported the import of European eel in the years prior to sampling. The authentication of eel products demonstrates a global, in part illegal, trade in European eel, covered up by incomplete or fraudulent labelling. This calls into question the compliance with existing national and international trade regulations and its implications for food safety and sustainability.

1. Introduction

The European eel *Anguilla anguilla* stock has declined by about 90% since the 1950s (Dekker, 2019); since 2011, however, recruitment of juvenile eels has levelled off (ICES, 2020). The life cycle of European eel includes different life stages, often related to the long migrations between the Atlantic spawning area in the Sargasso Sea and the coastal and freshwater habitats ranging from North Africa to the Barents Sea (Tesch, 2003). Due to the complex life cycle, artificial reproduction of European eel is challenging, and artificially bred eel larvae survive for not more than a month (Okamura et al., 2014). Therefore, global aquaculture of eel is based on raising wild-caught glass eels (Tesch, 2003). Capturing of European glass eel to be used in aquaculture occurs mostly in western Europe around the Bay of Biscay and Great Britain and to lesser extents in the Mediterranean and North Africa (Tesch, 2003).

The trade in European eels from the European Union (EU) is banned since 2010 (EU, 2010), and from the end of the transition period in 2013 (Musing et al., 2018), no European eel product originating from the EU should be available outside the EU. This also applied to the United Kingdom from January 2021 after withdrawal from the EU, including

Northern Ireland where Europe's largest wild eel fishery in Lough Neagh depends on restocking with juvenile eels (Stein and Nijman, 2021). In May 2021, the UK Government decided to allow trade of glass eels to Northern Ireland, based on its own interpretation of the UK advice in relation to CITES (Stein and Bunt, 2021). Due to the species listing in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (CITES, 20074), international trade outside the EU is only permitted with CITES trade certificates. All Parties to the Convention (18 in January 2022) are obliged to report all trade of listed species to the CITES Secretariat (this data then becomes available in the CITES trade database). Eels have a global distribution, and the European eel is one of 19 species of eel (Tsukamoto et al., 2020), at least four of which are traded internationally in substantial numbers (i.e., European eel, Japanese eel *A. japonica*, American eel *A. rostrata* and Pacific bicolor eel *A. bicolor pacifica*) (Kaifu et al., 2019; Nijman 2015). Once prepared, as fillets, smoked or jellied, it is near impossible to identify what species is involved, and mislabeling, incomplete labelling or fraudulent labelling has been reported from the United Kingdom (Vandamme et al., 2016; Stein et al., 2021), Italy (Pappalardo et al., 2021), mainland Europe (Stein et al., 2021) and Taiwan (Chang et al.,

; CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora; *cox1*, cytochrome c oxidase subunit 1 mitochondrial gene; *cytb*, cytochrome b gene; PRISMA, Preferred Reporting Items for Systematic review and Meta Analysis; EU, European Union; WCO, World Customs Organization.

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2021).

Food fraud including the lack of sufficient traceability is of high concern (e.g., [Butler et al., 2021](#)). Absence of food traceability increases the likelihood of the misuse of substances of human health concern such as antibiotics and potentially poses multiple risks on global food security (e.g., [Holmström et al., 2003](#); [Davis et al., 2021](#)). Authentication of seafood products by means of molecular techniques, including DNA barcoding and mini-barcoding ([Filonzi et al., 2021](#)), can help to provide transparency in food manufacturing and traceability in trade and is hence relevant to ensure food sustainability and security ([Wong and Hanner, 2008](#); [Nagalakshmi et al., 2016](#); [Shehata et al., 2018](#)). Since trade of European eel is banned across the EUs outer border (in and out), simple DNA-based species identification can help to identify illegal trade, if results are analyzed in combination with trade statistics.

We here take the opportunity to review DNA barcoding authentication studies of seafood that detected European eel in countries outside their natural range, most of which was incompletely labeled or mislabeled. For each study we assess if the detection of European eel was in line with current trade regulations and we discuss the relevance for food sustainability and security.

2. Methods

2.1. Data acquisition

Following the Preferred Reporting Items for Systematic review and Meta Analysis (PRISMA) statement and procedures outlined in [Moher](#)

[et al. \(2009\)](#), in July 2021 we conducted a systematic search to identify relevant publications that conducted molecular seafood or fish authentication and identified eel. Two databases (Google Scholar and Clarivate Web of Science) were searched using the keywords “seafood” AND “*Anguilla*” or “DNA” AND “*Anguilla* *anguilla*” and all review and research studies published between 2014 and 2021 were extracted (n = 476). We collated all records and duplicate publications were removed (n = 281), resulting in a set of 195 unique publications. We reviewed all publication study titles and abstracts (when available) and applied exclusion criteria to remove publications limited in scope to the following: the sampling had taken place in 2014 or later in countries outside the range of the European eel (thus excluding Europe, North Africa, and parts of western Asia) and at least one sample comprised European eel. This left us with eleven publications. Finally, we searched for references of the publications to find any additional relevant publications we had missed, resulting in the addition of one more report, and we were permitted to take into account an eel shop survey that was carried out by Canadian authorities during 2018 (Wildlife Enforcement Directorate, Environment and Climate Change Canada, personal communication, December 21, 2021). For the latter study, 101 shops in 21 cities across eight Canadian provinces ([Table 1](#)) were visited and product assortments were checked for vacuum packed eels. Investigators found and purchased target products in 80 shops and took samples for DNA species identification applying *16S* in a first step and *cox1* and *cytb* for verification. We contacted the lead authors of two studies to obtain missing data.

Table 1

Studies conducted outside Europe or North Africa, post 2013, that detected European eel that were mislabeled, with details on sampling regime, molecular marker used (bp = base pairs; *cox1* = cytochrome oxidase subunit I; *cytb* = cytochrome b), and the mass of eels imported (from the CITES trade database; in tonnes). Fish markets include wholesale traders; shops include supermarkets. Note that [Greenpeace \(2014\)](#), [Richards et al. \(2020\)](#), [Chan \(2021\)](#) and Environment and Climate Change Canada (ECCC, 2021, pers. comm.) specifically targeted eels, whereas the other studies included a wide range of seafood species.

Cities, country	Where	When	Eel samples (total seafood samples)	European eel (rate)	Imported up to 2 years prior (reported by importer)	Gene	Reference
Penang, Malaysia	shop, restaurant	2014	1 (62)	1 (100%)	0	150 or 700 bp <i>cox1</i>	Chin Chin et al. (2016)
Hiroshima, Futabanosato, Shinmatsudo, Toyonari, Higashiokoshi, Takasu, Japan	shop	May–June 2014	17 (17)	7 (41%)	16,261.0	n/a	Greenpeace (2014)
Calgary, Canada	shop, restaurant, fish market	September 2014–September 2019	10 (295)	2 (20%)	0	562 bp <i>cox1</i>	Morris (2020)
New York City, Austin, San Francisco, USA	restaurant, fish market	June–September 2014	1 (228)	1 (100%)	5.8	417–618 bp <i>cox1</i>	Khakshar et al. (2015)
Honolulu, USA	shop, restaurant	September–April 2016	3 (75)	2 (67%)	7.8	unknown <i>cox1</i>	Wallstrom (2020)
Lima, Peru	shop, restaurant, fish market	September 2017–February 2018	2 (400)	2 (100%)	0	650–695 bp <i>cox1</i>	Velez-Zuazo et al. (2021)
Hong Kong, China	shop	November 2017–February 2018	49 (49)	22 (45%)	14.6	655 bp <i>cox1</i>	Richards et al. (2020)
Johor, Penang, Malaysia	shop, restaurant	2018	3 (50)	2 (67%)	0	295 bp <i>cox1</i> /287 bp <i>cytb</i>	Ooi (2019) , Ooi et al., (2021)
Vancouver, Richmond, Burnaby, Calgary, Lethbridge, Edmonton, Regina, Saskatoon, Winnipeg, Markham, Unionville, Scarborough, Willowdale, North York, Toronto, Thornhill, Richmond Hill, Ottawa, Montreal, Moncton, Halifax, Canada	shop	2018	121 (121)	43 (36%)	0	655 bp <i>cox1</i> /307 bp <i>cytb</i>	ECCC 2021, pers. comm.
Seoul, South Korea	shop, restaurant, fish market	January–December 2018	31 (302)	2–19 (13–61%)	665.9	unknown <i>cytb</i>	EJF (2019)
Singapore, Singapore	shop, restaurant	May 2018	2 (105)	1 or 2 (50 or 100%)	0	650 bp <i>cox1</i>	Ho et al. (2020)
Hong Kong, China	restaurant	May–June 2020	80 (80)	36 (45%)	9.5	655 bp <i>cox1</i>	Chan (2021)
Taipei, Taoyuan, Taichung, Kaohsiung, Taiwan	restaurant	June–August 2020	10 (122)	3 (30%)	0	471–618 bp, <i>cox1</i>	Chang et al. (2021)

2.2. Analysis

For each country included in this study, we obtained data from the CITES trade database on the import and export of European eel, if any, for the year in which the products were purchased and the two years prior to that. Eel products included in the studies were purchased in sushi/seafood restaurants and shops, implying that the eel meat was prepared unagi kabayaki fillets which are sold as butterfly fillets or sliced sushi toppings. Unagi kabayaki products have a shelf life of up to two years (Stein et al., 2021). Therefore, we concluded that none of the eel products tested was older than that. Trade data were obtained from the CITES trade database, using both data as reported by the importing country (e.g., Singapore, Malaysia, the USA) and the exporting range country (e.g., Tunisia) or re-exporting country (e.g., China) (CITES, 2021). Data was log-transformed prior to analysis to approach a normal distribution more closely; we calculated Pearson's correlation coefficients to explore relationships between import and export figures as included in the CITES trade database, as well as the relationship between sampling and eel imports. We used unpaired t-tests to compare between countries that did report the import of European eel in the relevant time period and the ones that did not. Throughout we report means \pm SD, and we accept significance when $P < 0.05$ in a two-tailed test.

3. Results

We found thirteen studies that reported the presence of European eel in their samples (Table 1). Four studies, two from Hong Kong and one from Japan and Canada each, specifically focused on eel, whereas the other nine focused on a wide range of species. The total number of seafood samples (mean 147 ± 120) and number of eel samples (25 ± 37) used in each study were not correlated ($R = -0.145$, $R^2 = 0.021$, $N = 13$, $P = 0.637$). Excluding two studies that only sampled one eel product, larger studies had a significant lower percentage of eel that was European eel ($R = -0.605$, $R^2 = 0.367$, $N = 11$, $P = 0.048$) (Fig. 1). There was no significant correlation between the percentage of eel that was European eel and the reported import volumes of European eel ($R = -0.222$, $R^2 = 0.049$, $N = 13$, $P = 0.4675$).

There was a high correlation between mass reported to CITES by importing and exporting countries (Pearson's correlation coefficient on log-transformed data, $R = 0.706$, $R^2 = 0.498$, $N = 11$, $P = 0.015$) and here we focus on data from importing countries only as this has the most relevance when it comes to food quality compliance. For seven of the studies, involving five countries (Malaysia, Peru, Canada, Singapore and Taiwan) no European eel was reported to CITES during year of sampling or two previous years. Four countries (China, Japan, South Korea and the USA) did report the import of European eel (mean $1,305 \pm 4,498$ tonnes for a three-year period). There was no significant difference between countries that did report the import European eel and ones that did not in terms of the number of eels sampled (30 ± 30 vs 21 ± 44 eel samples: $t = 1.017$, $P = 0.331$) or the percentage of eel that was European eel ($56 \pm 24\%$ vs $61 \pm 33\%$: $t = 0.404$, $P = 0.694$).

4. Discussion

Due to the export ban of European eel across Europe's outer border (EU, 2010) and national restrictions prohibiting the exports of live glass eels from North African countries and Turkey (UNEP-WCMC, 2018), no European eel aquaculture should be legally possible outside the species distribution range. This includes countries such as Malaysia, Singapore, Taiwan, Hong Kong, Peru, and the USA. European eel has been legally farmed in some Asian countries prior to the EU trade ban in 2010 but trade in all European eel products without CITES permission has stopped with the end of the transition period in 2013 (Musing et al., 2018). Consequently, European eel products found outside the EU after 2013, that cannot be traced back to records in the CITES trade database, are the result of errors in reporting, indicate fraudulent labelling, or are the

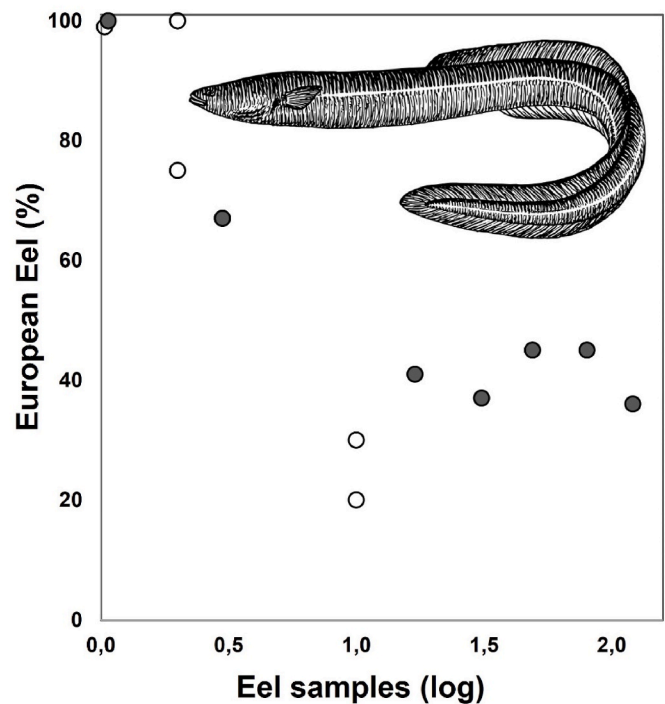


Fig. 1. Relationship between sampled eel products and percentage of identified European eel. Relationship between the total number of eel products that were sampled and the percentage of these that comprised European eel, showing that larger studies recorded proportionally fewer European eel. Filled circles are studies in countries that did report the import of European eel up to two years prior to sampling and open circles are studies in countries that did not report any imports.

results of illegal trade. The absence of any trade records of European eels to countries such as Singapore, Peru and Taiwan is strongly suggestive of illicit trade. Previous studies suggest that eel aquaculture in China, accounting for more than 80% of the global eel aquaculture production (mean for period 2008 to 2018) according to FAO (2020), depends on illegal glass eel supply (Stein et al., 2016; Kaifu et al., 2019; UNODC, 2020).

There are challenges with interpreting data from the CITES trade database specifically when dealing with East Asian Parties, as for instance Taiwan does not report its trade (but importing or exporting countries do report transaction to and from Taiwan), and Hong Kong does not report its imports from China (but China does report its exports to Hong Kong). For instance, for 2019 China reports European eel (meat and live) exports to Hong Kong, originating from Morocco and Egypt. There are however, no records of either the importer (China) or exporters (Morocco, Egypt) for at least four years prior to 2019. Likewise, South Korea and Japan report the import of eels (live, meat and bodies) from Morocco, Tunisia and Turkey, and South Korea additionally from Egypt, and Japan additionally from Chile but concerns over the origin have previously been raised since. For example, Turkey seems not to have a glass eel fishery to supply eel aquaculture (ICES, 2017) and trafficking of glass eels from Spain to Morocco has been reported (Europol, 2018). Chile does not report the import nor the export of European eel.

The presence of two or three European eel products in places like Peru, Malaysia, Taiwan, or Singapore in itself does not support the general conclusion of a global illegal trade in the species. It is, however, important to note that nine of the thirteen studies we refer to were not designed specifically to authenticate eel products, and in some studies only one or two eel products were tested. As such it is more the high proportion of eel products that were European eel ($59 \pm 28\%$) that is reason for concern rather than the absolute number of European eels

detected. Likewise, it is near impossible based on thirteen seafood authentication studies to establish with certainty that any laws were broken. But it is clear from our analysis using official CITES trade statistics that there is a misalignment with what was observed and what was reportedly imported.

The mis-declared, underreported, and non-declared presence of European eel in a wide range of countries has implications for food sustainability and security. To assess the sustainability of a certain seafood product in accordance with the requirement of the legal agreements e.g., international law (UN, 1982), fisheries science (e.g., Hilborn et al., 2020), ecosystem approaches to fisheries management (e.g., FAO, 1995; FAO, 2010) and multilateral initiatives (e.g., CBD, 2004; UN, 2016) there are sustainability requirements related to (1) sourcing in the wild, (2) global trade, and (3) consumption. Considering that China, the globally largest producer of eel in aquaculture (FAO, 2020) relies on illegally fished, trafficked and unreported glass eels from Europe (UNODC, 2020; Stein et al., 2021), and that the true global trade is not reflected in the CITES trade data base (CITES, 2021), it seems questionable to consider the current majority of global eel products, sustainable.

During the course of Interpol Operation *Eel-Licit Trade II*, Canadian authorities determined not only that 36% of the eel meat in Canadian markets was European eel, but US and Hong Kong authorities further determined eel products, imported from mainland China, to be contaminated with the prohibited substance malachite green (CFS, 2018; Interpol, 2020; US Fish and Wildlife Service, 2020). The US Food and Drug Administration classifies this compound as an unapproved aquaculture drug that has been recognized as of human health concern (FDA, 2021). Furthermore, the frequent mislabeling or creative labeling when it comes to European eel products, are indicative of problems with responsible manufacturing practices, traceability and is deceptive towards consumers (Velez-Zuazo et al., 2021).

We demonstrate that meta-analyses of already existing studies have the potential to effectively supplement new, often cost-intensive (Butler et al., 2021), analytical studies, amplifying their explanatory power or even reveal new insights into the global distribution of seafood products that would remain hidden otherwise.

5. Conclusion

We conclude that the increasing number of available seafood studies, applying novel molecular identification methods, provide new opportunities for meta-analysis, helping to understand the global distribution of specific seafood products. Molecular identifications of European eel in markets outside the species distribution range, reveal the global distribution of eel products which hitherto was not evident from the CITES trade database, and has previously been revealed by comparative analyses of Customs data and CITES trade data (Musing et al., 2018; Pavitt et al., 2021). Enforcing coherent use of CITES term codes and units for the trade in European eel as recommended by Pavitt et al. (2021) as well as a further improvement of the harmonized system (HS) administered by the World Customs Organization (WCO) (Chan et al., 2015) seem promising solutions to record and reveal the true dimensions of global eel trade.

Observed availability of European eel in gastronomy and food markets around the globe demonstrates that existing national and international trade regulations are not sufficiently enforced, and this has direct implications for food sustainability and security.

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CRedit authorship contribution statement

Vincent Nijman: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing.
Florian Stein: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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