



From ocean to screen: Data gaps, conservation concerns, and sustainability challenges in Germany's online marine ornamental fish trade

Nora Leonie Rust^{a,b,c,d,e,*} , Jacqueline Jürgens^{c,d,e,f}, Rikke Oegelund Nielsen^{c,d,e,g}, Johanna Staerk^{e,h}, Morgane Tidière^{c,d,e}, Dalia A. Conde^{c,e}

^a University of Oldenburg, Carl-von-Ossietzky-Straße 9-11, 26129 Oldenburg, Germany

^b Institutional and Behavioural Economics Working Group, Programme Area 1, Leibniz Centre for Tropical Marine Research (ZMT), Fahrenheitstraße 6, 28359 Bremen, Germany

^c Species360 Conservation Science Alliance, 7900 International Drive, Suite 300, Bloomington, MN 55425, USA

^d Science Team, Conservation Department, Species360, 7900 International Drive, Suite 300, Bloomington, MN 55425, USA

^e Population Biology Team, Department of Biology, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark

^f Department of Mathematics and Computer Science, University of Southern Denmark, 5230 Odense M, Denmark

^g Terrariet Vissenbjerg - Reptile Zoo, Kirkehelle 5, 5492 Vissenbjerg, Denmark

^h Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, 04103 Leipzig, Germany

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ABSTRACT

Traditional pet stores have moved online to reach a wider customer base, expanding access to exotic pets, including marine ornamental fish. Germany, the third-largest global importer of marine ornamental fish, mandates that retailers comply with the German Animal Welfare Act, particularly regarding the provision of species-specific information. Despite these regulations, concerns remain about the trade's transparency, animal welfare, and overall sustainability. To investigate these concerns, we collected data from eight major German online aquarium shops using web scraping tools to analyze species diversity and trade volumes of marine ornamental fish sold, as well as the legally required species-specific information provided by those retailers. Our analysis revealed that 767 species from 59 families were available, with only 12% of the 2,467 ornamental fish products declared as captive-bred, while the majority (88%) were from unknown-source. Prices ranged from 8.90€ to 4,899.00€, with captive-bred products being, on average, 29.3% more expensive than from unknown-source. Additionally, our study revealed that globally threatened fish species (13 spp.), are openly sold in the German aquarium industry, potentially harming their wild populations. Despite legal obligations, most retailers provided minimal or no species-specific information, lacking key details on care, conservation status, or trade documentation. We underscore the urgent need for stricter enforcement of the German Animal Welfare Act for marine ornamental fish, and highlight the importance of comprehensive monitoring and research into the marine ornamental fish trade, along with increased consumer awareness, as crucial tools for sustainable international trade, among other policy recommendations.

1. Introduction

Aquarium keeping is one of the world's most popular hobbies, driving the global trade of an estimated 1.3 billion ornamental fish annually and contributing between \$15 – \$20 billion to the global economy (King, 2019). Europe plays a significant role in this industry, with Germany ranking as the third-largest importer of ornamental fish after the USA and China, accounting for \$21.9 million in imports in 2021 (Novák, Kalous, & Patoka, 2020; The Observatory of Economic

Complexity (OEC), 2021). Despite this prominent position, little is known about the scope and composition of Germany's marine ornamental fish trade, particularly in the context of online retail, where concerns about transparency, sustainability, and compliance with animal welfare laws are increasingly raised. This study addresses that gap by analyzing species diversity, sourcing practices, and transparency across leading German online retailers of marine ornamental fish.

Despite growing sustainability concerns about the ornamental fish trade globally, the collection and trade of marine ornamental fish

* Corresponding author at: Leibniz Centre for Tropical Marine Research (ZMT), Fahrenheitstraße 6, 28359 Bremen, Germany.

E-mail address: noraleonierust@gmail.com (N.L. Rust).

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remain poorly monitored and understudied (Biondo & Burki, 2019; Pinnegar & Murray, 2019). Most marine species in this trade are still sourced from the wild, a practice that can threaten wild populations through overexploitation, destructive fishing methods, and insufficient welfare standards (Cohen, Valenti, & Calado, 2013; Kolm & Berglund, 2003; Rhyne, Tlusty, Szczebak, & Holmberg, 2017). These risks are compounded by limited oversight and regulation, particularly as the industry becomes more globalized and fragmented. Other concerns include the introduction of non-native species or invasive hitchhikers, and the lack of traceability across trade chains (Patoka, Magalhães, & Kouba, 2018).

As the ornamental fish trade increasingly shifts online, it introduces new challenges for regulation, oversight, and biosecurity. One of the major concerns raised in the literature is the risk of invasive species entering non-native ecosystems through online sales (Borgelt, Dorber, & Høiberg, 2022; Chucholl, 2013; Magalhães, Azevedo, Maceda-Veiga, & Patoka, 2023; Mazza et al., 2015; Olden, Whattam, & Wood, 2021). Despite this, much of the current focus on invasive species remains on freshwater fish, including the risks of the transboundary spread of infectious diseases, leaving marine ornamental fish underexamined in this context (Whittington & Chong, 2007).

At the same time, the online retail sector for marine ornamental fish has grown significantly. Both large companies and small pet stores are establishing digital platforms to meet rising consumer demand, driven by changing habits and the convenience of e-commerce (Hall, 2019; Hill et al., 2024; Siriwat & Nijman, 2020). These platforms frequently offer structured catalogs and overnight delivery with “100 % live arrival” guarantees, making access to exotic marine species easier than ever (Hernant & Rosengren, 2017; Masterfisch, 2022).

While online retail offers opportunities to improve traceability and consumer education, such as alerting buyers to a species’ invasive potential or conservation status, many current platforms still lack adequate transparency. This raises concerns not only about the risk of biological invasions but also about compliance with animal welfare and trade laws, both internationally and at the national level. Strengthening traceability systems and regulatory oversight is therefore essential to mitigate these emerging risks in the digital trade of marine ornamental fish.

At the international level, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) remains the primary legal instrument for regulating the global wildlife trade. While CITES has listed a few marine ornamental fish species, including seahorses (*Hippocampus* spp.), the humphead wrasse (*Cheilinus undulatus*), and the clarion angelfish (*Holocanthus clarionensis*), the majority of traded species remain unregulated under the Convention (Biondo, 2017; Foster, Justason, Magera, & Vincent, 2022). Recognizing the sector’s rapid growth and limited oversight, CITES adopted decisions 18.296 and 18.298 at the 18th Conference of the Parties (CoP) in 2019 (CITES, 2019, 2022). These decisions called for gathering and reviewing information on the trade in marine ornamental fishes to assess the need for improved sustainability and regulation. In 2024, this effort was followed by a workshop that addressed conservation and management challenges and emphasized the need for further research and data collection (Biondo, Burki, Aguayo, & Calado, 2024; CITES, 2024; The Observatory of Economic Complexity (OEC), 2021). The workshop recommendations were further discussed at the CITES Animals Committee meeting in July 2024 and will be presented at the 20th CITES CoP conference in 2025 (Biondo et al., 2024; CITES, 2024). However, not all species perceived as threatened by trade are listed. For example, the Banggai cardinalfish, endemic to parts of Indonesia, has been repeatedly proposed for CITES listing but remains unlisted due to Indonesia’s existing national management measures being considered sufficient to ensure sustainable trade (Soehartono et al., 2020).

At the regional level, the European Union (EU) has implemented several policy tools relevant to the ornamental fish trade, though these remain limited in scope. Regulation (EU) No 1143/2014 aims to prevent and manage the introduction and spread of invasive alien species, a

known risk in the ornamental pet sector (European Parliament, Council of the European Union, 2014). However, no marine fish species are currently listed under this regulation, despite evidence that some have the potential to become invasive and disrupt local ecosystems (Patoka et al., 2018). In parallel, the EU’s Trade Control and Expert System (TRACES) is designed to monitor the movement of live animals across borders, primarily to control disease and ensure traceability (TRACES, European Trade Control and Expert System, 2023). Although not designed for this purpose, TRACES has been proposed as a potential monitoring tool for marine ornamental fish imports (Biondo & Burki, 2019).

Germany, as one of the world’s largest importers of marine ornamental fish, offers a relevant case study for examining regulatory gaps in the online trade. Its central role in the European market combined with well-established animal welfare legislation, makes it a useful context for understanding how national regulation interacts with the growing digital pet trade. In particular, Germany’s legal obligations for retailers, especially regarding species-specific care information, raise important questions about enforcement and consumer transparency in the online marketplace.

Under § 21 of the German Animal Welfare Act (section 5, paragraph 2), retailers are legally required to provide customers with written information on the species-specific husbandry needs of any animal offered for sale (Federal Republic of Germany, 2014, § 21 Abs. 5 Ziffer 2 TschG). This includes guidance on essential factors such as water quality, diet, and tank conditions-critical for ensuring the health and welfare of marine fish (Braithwaite & Boulcott, 2008). However, in practice, many online retailers fail to disclose even basic care information or details about species origin and collection methods, limiting consumers’ ability to make informed and sustainable choices (Cohen et al., 2013; McCollum, 2007). A 2015 study commissioned by Germany’s Federal Ministry of Agriculture emphasized the need for stricter oversight of the exotic pet trade, recommending minimum care standards and licensing requirements for species with high maintenance needs (Krautwald-Junghanns & Erhard, 2018). More recently, the German government has begun drafting updates to its animal protection law-including identity verification for online sellers as part of its 2021 coalition agreement to strengthen regulation of the pet trade (Federal Government of Germany, 2021). Despite this momentum, no study to date has evaluated whether online marine ornamental fish retailers are meeting their legal obligations under this law.

To assess the current state of the German online marine ornamental fish trade, we collected and analyzed product data from eight leading online retailers using web scraping tools. Our analysis focused on species diversity, sourcing (captive-bred vs. unknown-source), geographic origin and conservation status based on the IUCN Red List. We also evaluated retailer compliance with national legislation by assessing the amount of available species-specific care information as required by the German Animal Welfare Act. To set Germany in the context of the European market we compared our findings with the study by Biondo & Burki, 2019 on the marine ornamental fish trade to the EU. By providing a snapshot of trade patterns and information practices in one of the world’s largest markets, this study contributes to ongoing discussions on sustainable sourcing, regulatory enforcement, and consumer responsibility in the marine ornamental fish trade.

2. Methods

We considered all bony coral reef fish and sharks traded for the aquarium hobby market as marine ornamental fish. To identify German online retailers, we used various keywords in Google searches (2023), related to terms translating to “marine aquarium fish for sale” (Table S3, column “Website”). Between April and May 2023, we selected ten online shops based on their Google rankings and extensive marine fish inventory. These criteria were chosen to capture high-traffic websites likely responsible for a substantial portion of online sales of marine

ornamental fish in Germany, and to reflect the typical online shopping experience of marine aquarium hobbyists. We assumed that most users rely primarily on the top search results when searching for marine ornamental fish (Pan et al., 2007). Due to complex website structure, only eight retailers were included in the web scraping. For confidentiality, we anonymized the retailers by assigning them numbers from 1 to 8. While these data are preliminary and do not capture the full scope of the German marine ornamental fish trade, we believe that our selection provides a representative sample of the species available through commercial retailers in Germany.

Data collection was conducted using the web scraping R-package “rvest” v.1.0.3. (Wickham, 2022) with R version 4.2.2 (R Core Team, 2022). To avoid potential website blocking measures against automated processes or bots, we created a user agent that mimicked human browsing behavior (Pham, Santos, & Freire, 2016). Furthermore, link, name, price, and origin were scraped for all marine fish products (see supplementary material ‘R-Script S1’). All retailers sell various products for each species as separate items, such as different sizes, sexes, or quantities. We scraped all products presented on the websites, including those listed as “sold out” or “currently not available”, because retailers indicated that these could still be purchased upon request.

We standardized species names across datasets according to the *Global Biodiversity Information Facility* (GBIF) backbone taxonomy (GBIF Secretariat, 2022) using the R package *taxize v.0.9.100* (Chamberlain & Szocs, 2013). There remains a possibility that some species names were misidentified due to potential mislabeling on retailers’ websites. However, we assumed such cases to be infrequent and unlikely to affect the overall results of this study.

To collect data about the source of advertised species, we searched for various terms used to label products as captive-bred in German and English (Table S3, column “Source”). In Germany, some aquarium stores breed marine ornamental species themselves and explicitly advertise these as such, often highlighting their in-house breeding facilities, which are typically located in back rooms or basements of the shops. These stores commonly use terms like “ENZ” (“Eigene Nachzucht,” meaning own breeding) to indicate fish bred on-site, and “DNZ” (“Deutsche Nachzucht,” meaning German captive bred) for fish sourced from other domestic breeders. The more general label “captive-bred,” without further specification, may also refer to individuals imported from breeding facilities in other countries. For consistency in analysis, we grouped all such labels under the category “captive-bred”. Given that retailers labeled products sourced from captive breeding as a selling point and have an incentive to provide this information, we assumed that unlabeled products were likely sourced from the wild. This assumption is further supported by cases where retailers offered the same species in two forms: one clearly labeled as “captive-bred” and the other unlabeled. Furthermore, commercial captive breeding of marine ornamental fish is currently limited to a relatively small number of species. Consequently, less common species are unlikely to be bred in captivity at scale and are therefore more plausibly wild-caught. However, to avoid erroneous assumptions, we refer to unlabeled products as products of unknown-source. For our analysis, we split products into “captive-bred” and “unknown-source”. To compare prices between captive-bred and products from unknown-sources, we conducted a Mann-Whitney *U* test (Mann & Whitney, 1947). All data visualizations were done using the R-packages *ggplot* (Wickham, 2016), *treemapify* (Wilkins, 2021), *rworldmap* (South, 2011) and *zipcodeR* (Rozzi, 2021).

Nearly all websites (7 out of 8) provided information on the geographic origin of species. However, it was often unclear whether this information referred to the exact geographic origin of the product (i.e., the exporting country) or to more general information about the distribution area of the species. To address this problem, we compared the stated origins on the websites with the species distribution data from the IUCN Red List for each species (IUCN, 2023; Fig. S6). To determine the number of species threatened with extinction sold by the German retailers, we collated data on species’ IUCN Red List status and population

trend, downloaded from the IUCN Red List website using the advanced search function (IUCN, 2023).

To evaluate retailer transparency, we classified the information provided on each product page regarding product origin and species-specific needs into three categories: low, medium, and high (see Fig. S8). Products that included only a brief table with 1–3 rows or a short text of 2–3 sentences were categorized as low. Those featuring a more detailed table with 4–6 rows or a text covering 5–7 species-specific needs were categorized as medium. Lastly, products with a comprehensive table combined with an extensive text were categorized as high (Fig. S8). Due to time constraints, 10 product pages on each website were randomly selected (as suggested by Rahman, Tabash, Salamzadeh, Abdul, & Rahaman, 2022). We also assessed whether websites provided information on conservation status (e.g., IUCN Red List status) and/or a reference with proof of origin (e.g., CITES permits) in a separate analysis. Our analysis was limited to the presence or absence of specific information types. We did not assess the clarity, accuracy, or completeness of the content. A more detailed, quality-based evaluation was beyond the scope of this study but is identified as an important direction for future research.

Finally, to place our findings on the German trade in the broader context within the European trade of marine ornamental fish, we compared the data from a 2019 study by Biondo and Burki with this study’s findings. Their research utilized the European Trade Control and Expert System (TRACES) to examine the marine ornamental fish trade across Europe from 2014 to 2017 (Biondo & Burki, 2019).

3. Results

3.1. Supply per Website

Overall, the eight selected websites contained a total of 2,467 products across 767 species, representing a vast taxonomic diversity, including 16 different orders, 59 families, and 251 different genera (see supplementary material ‘Data S2’). Considering individual retailers, we found that retailers sold on average 3.2 products (5.2 +/-SD) per species (couples, different sizes or sexes, etc.). Especially, the ocellaris clownfish (*Amphiprion ocellaris*, Pomacentridae) was represented by different so-called design types, such as “frostbite” or “moscha storm”, which are selectively bred color morphs (124 products). Retailer 7 alone sold 50 product types of ocellaris clownfish. Moreover, taxonomic variety was on average 30.5 families (9.33 +/- SD) and 255.9 (156.3 +/-SD) species and ranging 12 to 42 families, and 19 to over 500 species sold per retailer website. In total, 11 families were present on all studied websites, while 17 families occurred on only one of the websites (Fig. 1). Labridae was the family with the highest number of species represented (112 spp., 14.4 %), closely followed by Gobiidae (83 spp., 10.7 %).

3.2. Captive-bred vs unknown-source

Of a total of 2,467 products identified on the eight retailer websites, only 12 % of them representing 285 species were marked as captive-bred. The remaining 2,182 products (88 %, representing 482 species) were of unknown-source. The families of Pomacentridae (17 products) and Pomacanthidae (21 products) had the highest numbers of captive-bred products, while most products of unknown-source were of the families Labridae (111 products) and Pomacentridae (74 products) (Table S4). The high number of captive-bred products observed for the family Pomacentridae was mainly due to the variety of color morphs proposed for one of the species belonging to this family, the clownfish (*A. ocellaris*). Among the 285 captive-bred species, only 12 species (4.2 %) were advertised as “DNZ” (Deutsche Nachzucht – German captive-bred).

Overall, product prices range from 8.90 € to up to 4,899.00 € (median: 40.00 €), depending on species, sex, size, color morph, rarity and availability. Captive-bred fish were sold from 15.27 € to 1,999.90 €

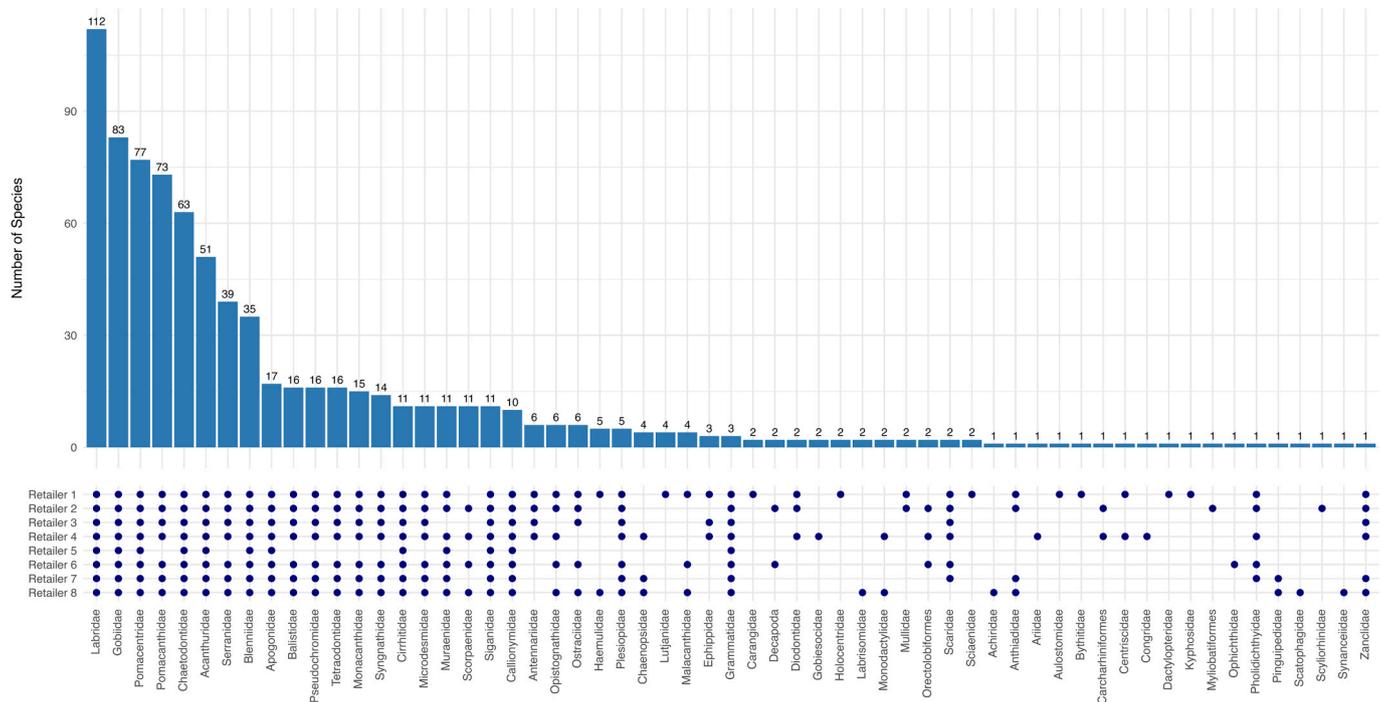


Fig. 1. Number of species per family offered for sale by at least one of the eight largest German online retailers identified in this study. The upper blue bars represent the number of species in each family listed below that were traded. The blue dots below indicate the presence of each family on the respective retailer’s website based on the data collected. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(median: 83.40 €), while fish of unknown-source were sold from 8.90 € to 4,899.00 € (median: 59.00 €). Captive-bred products were, on average, 29.3 % more expensive than species of unknown-source, indicating a significant price difference (Mann–Whitney *U*/Wilcoxon: *W* = 785245, *p*-value < 0.001) (Fig. 2).

3.3. Species geographic origin

To clarify whether the origins listed on the websites refers to the geographic origin of the product (i.e., the exporting country), we compared the stated origins with the native distribution range of each species extracted from the IUCN Red List data. We found a clear difference between species distribution and the origins stated on the websites (Fig. S6). Most species have a wide distribution range and occur in the waters of several countries. However, most retailers stated specific countries as the origin. Consequently, this suggests that the stated origin predominantly represents the exporting country. Based on this assumption, most traded species were exported from Indonesia (102 spp.) and the Philippines (65 spp.), followed by Sri Lanka (30 spp.) and Kenya (31. spp.). The USA and Hawaii (retailers listed Hawaii and the USA as two different origins), Polynesia, Fiji, Micronesia, the Maldives and Belize each exported less than 10 species (Fig. 3).

3.4. Conservation status

A total of 680 species (88.6 % out of 767 spp.) presented on the studied websites are assessed by the IUCN Red List, while the other 44 spp. (6.5 %) are not yet evaluated (NE) (Fig. S7). We found 668 species (98.2 %) listed as “Least Concern” (LC), nine species (1.3 %) as “Near Threatened” (NT), 12 (1.8 %) as “Vulnerable” (VU) and one (0.1 %) as “Endangered” (EN) (Table 1). Additionally, 32 species (4.7 %) are listed as “Data Deficient” (DD). Of the 12 VU listed species advertised, four (33.3 %) belong to the genus *Hippocampus*. The only EN species presented on the websites was the Banggai cardinalfish (*P. kauderni*).

Concerning population trends reported by the IUCN Red List, most assessed species offered on the websites had a stable population trend

(32.9 %, 224 spp.), while for 35 species, the IUCN Red List reports a decreasing trend. The only two species with an increasing population trend are the bluespotted ribbontail ray (*Taeniura lymna*) and the red lionfish (*Pterois volitans*).

3.5. Retailer transparency

Product information on the websites ranged from low to high, with considerable variation in content available for each product (Table 2). Some retailers provided detailed information for certain species, like the Banggai cardinalfish (*P. kauderni*), while completely lacking information for others, such as the twospot surgeonfish (*Ctenochaetus binotatus*, Acanthuridae). Half of the retailers (4 out of 8) lacked basic husbandry information legally mandated by § 21 of the German Animal Welfare Act, section 5 (2). Notably, the retailer offering the largest number of products provided only minimal information on species origin or species-specific needs, while others offered extensive information, particularly on breeding methods for some species. Regarding CITES-listed species, only two retailers mentioned that proof of legal origin and acquisition is necessary when acquiring *Hippocampus* species. The largest retailer merely included “inclusive proof of breeding,” while only one retailer provided more comprehensive information, mentioning that all *Hippocampus* species are listed under CITES.

3.6. Germany’s role in the European trade

Our results show that, of the 766 traded species within Germany, 645 (84.20 %) are also reported as traded within Europe. The remaining 121 species were identified exclusively in the German online trade (Table S5, Fig. S9). According to Biondo and Burki (2019), *Amphiprion ocellaris* was among the most imported marine ornamental species in Europe between 2014 and 2017. Consistent with these findings, *A. ocellaris* also emerged as the most frequently listed species across the eight German websites analyzed in our study.

In terms of taxonomic representation, 59 fish families were recorded in the German online trade, with Labridae and Gobiidae being the most

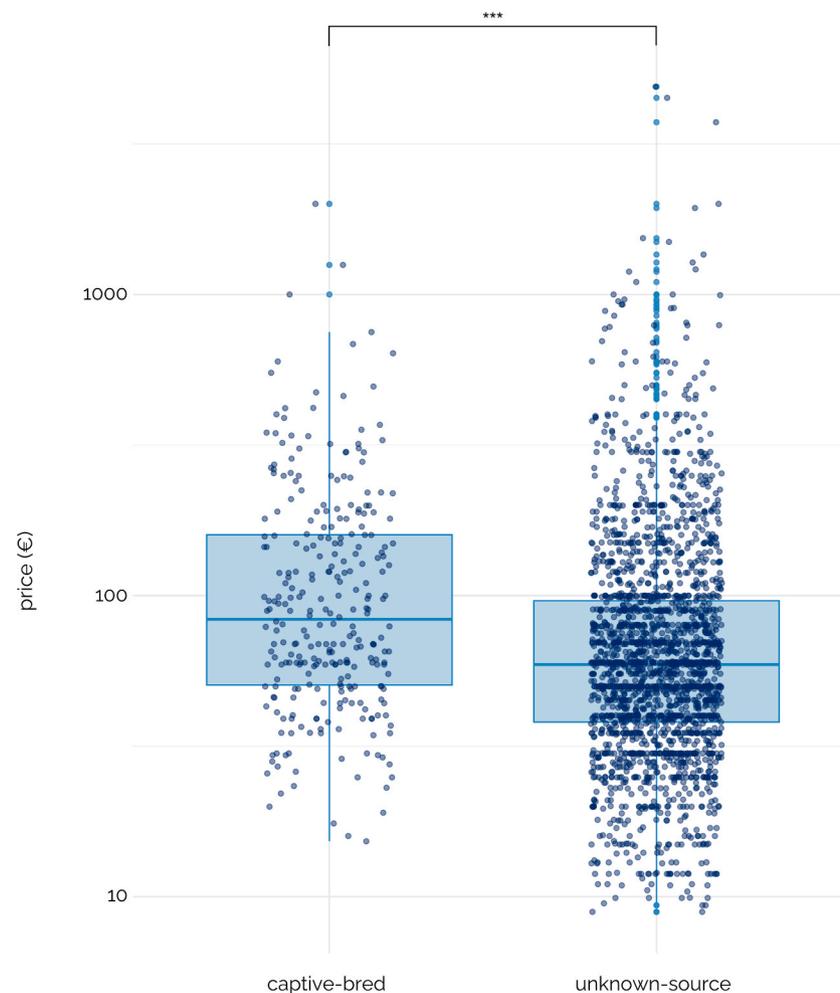


Fig. 2. Boxplot showing the prices (in €) of captive-bred versus unknown-source products on a logarithmic scale. Each dark blue dot represents an individual product. Statistical significance is indicated as three asterisks (***, i.e., p -value < 0.001). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

diverse. In comparison, the European import data from [Biondo and Burki \(2019\)](#) included 86 families. Of the 59 families found in the German trade, 51 (86.4 %) overlapped with those reported at the European level. Eight families were unique to the German trade, including Achiridae and Monodactylidae, while others such as Narcinidae and Priacanthidae appeared only in the European dataset.

4. Discussion

Germany is a leading player in the global marine ornamental fish trade ([The Observatory of Economic Complexity \(OEC\), 2021](#)). However, limited research exists on the scope of the trade, underscoring the importance of gaining a better understanding of the online trade of marine ornamental fish within the country. Our results reveal a high diversity of taxonomic families and genera traded across German online retailers. Although the majority of traded species were listed as Least Concern (LC) with stable population trends (229 spp.), we identified 13 threatened species in the trade warranting additional monitoring. We also observed that captive-bred species were, on average, more expensive than their wild-caught counterparts, likely driving higher consumer demand for wild-caught individuals. This increased demand could potentially place additional pressure on wild populations, exacerbating conservation concerns. Additionally, our findings highlight an extensive lack of information and transparency regarding species origin, husbandry needs, and the ethical and legal obligations when acquiring exotic pets, with most studied retailers not complying with current

German Animal Welfare law. This study stresses the need for better information provision by retailers to ensure consumers can make informed choices.

4.1. German online retailers lack transparency

Despite the legal requirement under § 21 of the German Animal Welfare Act (Tierschutzgesetz), [section 5 \(2\)](#), mandating that anyone commercially trading vertebrates provide written information about the animal's essential needs, and the availability of over 6,000 animal profiles from the Association of German Aquarium and Terrarium Associations (VDA) via "Petdata" ([Verband Deutscher Vereine für Aquarien- und Terrarienkunde \(VDA\) e.V., 2021](#)), most retailers in our study failed to provide species-specific information for the animals they sell. Additionally, in rare cases, species may have been listed under incorrect scientific or common names and these misidentifications may mislead consumers and further complicate traceability. This can potentially hinder enforcement of trade regulations, including CITES listings and national protection laws. Supplying this basic information is the minimum requirement to ensure good animal health and welfare, particularly for marine ornamental fish sold online. Retailers, failing to provide information on relevant animal diseases, biosecurity principles, and important details like body size - despite being obligated to do so - contribute to biodiversity risks and biosecurity threats. This lack of information may lead to aquarium fish being released into the wild, potentially resulting in the establishment of invasive species and



Fig. 3. Number of traded species per export country, based on the provided origin information by each retailer. Numbers presented in each box show the number of species reported as originating from the country. We assumed those origins as the export countries. Species which had ocean regions such as “Indo-Pacific” (449 spp.), “Atlantic” (22 spp.), “Red Sea” (7 spp.) and “Caribbean” (37 spp.) as origin are not represented. The plot was created with the R package ggmap (Kahle & Wickham, 2013). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ecological disruption (Gertzen, Familiar, & Leung, 2008; Tlusty et al., 2017). It is therefore concerning that 50 % of the studied retailers (4 out of 8) were missing information regarding basic husbandry needs. The inconsistency of information across different products, the misidentification of species, and the absence of customer advisory services during the online purchase of ornamental fish can lead to mishandling and poor animal welfare (Borges et al., 2021; Braithwaite & Boulcott, 2008; Mazza et al., 2015; McCollum, 2007).

The scarcity of information on species origin or conservation-related information is not only alarming from a conservation perspective, but can also lead to legal consequences for customers, particularly for CITES-listed species. Crucially, details about the origin and source (i.e., wild-caught or captive-bred), especially for threatened species like the clarion angelfish (*H. clarionensis*), would aid customers in making better-informed and more sustainable purchasing decisions (McCollum, 2007).

Another concerning case in our dataset involves wild-caught products originating from Hawaii. In 2018, Hawaii banned the use of fine mesh nets for commercial fishing, leading to a 80 % reduction in the catch of marine aquarium fishes in the state (Holcombe et al., 2022). This was followed by a broader ban on the collection of ornamental fish in 2021 (Anderson & Pomeroy, 2023), making wild-caught products from Hawaii increasingly rare. The retailer selling Hawaiian products even mentioned that the products are rarities due to the export ban in Hawaii, not providing any information on how the products were acquired and where they originated from. Moreover, another retailer lacked any details about the true source of all their traded species, by listing the majority of products with the generalized source as “Indo-Pacific”. These cases highlight the lack of transparency on species origins, making it challenging for consumers to make ethical and legal choices.

Customers are increasingly demanding product traceability

(Agrawal, Kumar, Pal, Wang, & Chen, 2021) as in the clothing and food industry, where awareness of sustainable sourcing and ethical practices is increasing (Agrawal et al., 2021; Lu, Wu, Wang, & Xu, 2016). Certifications such as the Marine Stewardship Council (MSC) for sustainable fisheries are intended to ensure that products meet environmental and social governance (ESG) criteria, although the robustness and transparency of such schemes are sometimes questioned (Christian et al., 2013; Foley, 2012). However, similar efforts have not yet been successfully implemented in the marine ornamental fish industry (Militz, Foale, Kinch, & Southgate, 2017). In fact, an attempt to implement a certificate for marine ornamentals failed in 2008 (Militz et al., 2017; Murray, Watson, Giangrande, Licciano, & Bentley, 2012) leaving customers without a clear option to identify sustainable and ethical purchasing options.

4.2. Specimen from unknown-sources dominate the German trade

The majority of marine ornamental fish continue to be collected from the wild (Pouil, Tlusty, Rhyne, & Metian, 2020), as supported by our results showing that 88 % of the products were from unknown-sources, likely indicating wild collection. Indeed, although none of the online retailers labeled their products as wild-sourced, they appeared to be transparent when a species was captive-bred. Many websites used the term “captive-bred” for promotional purposes, especially when the stores had their own breeding facilities, suggesting that customers may prefer captive-bred options. As German handcraft is associated with high quality worldwide (Thielmann, 2003), breeders in Germany use the term DNZ to advertise fish bred locally. The families with the highest numbers of captive-bred products identified here were the Pomacanthidae (21 products) and Pomacentridae (17 products). However, over 70 % of species in these two families had undeclared sources, suggesting

Table 1

Threatened and Near Threatened species offered on eight German online shops included in this study. The species are categorized according to their IUCN Red List status: Vulnerable (VU), Near Threatened (NT), and Endangered (EN). The population trend and the mean price and standard deviation (+/-SD) for each species are also specified. The lowest mean price is indicated in green, while the highest price is indicated in red.

Species	IUCN Red List Status	Population Trend	Mean Price (+/-SD)
<i>Acanthurus chronixis</i>	VU	Unknown	72.96 € (12.79€)
<i>Amphiprion mccullochi</i>	VU	Decreasing	209.27 € (10.82€)
<i>Atelomycterus marmoratus</i>	NT	Decreasing	211.75 € (108€)
<i>Balistes punctatus</i>	VU	Decreasing	230.75 € (-)
<i>Bryaninops natans</i>	NT	Unknown	37.60 € (-)
<i>Chaetodon rainfordi</i>	NT	Decreasing	149.99 € (-)
<i>Chaetodon trifascialis</i>	NT	Decreasing	63.70 € (-)
<i>Chiloscyllium plagiosum</i>	NT	Decreasing	210.00 € (-)
<i>Chiloscyllium punctatum</i>	NT	Decreasing	155.20 € (79.73€)
<i>Chrysiptera hemicyanea</i>	VU	Decreasing	13.86 € (1.68€)
<i>Coryphopterus personatus</i>	VU	Unknown	29.90 € (-)
<i>Elacatinus figaro</i>	VU	Decreasing	48.32 € (9.68€)
<i>Gobiodon acicularis</i>	NT	Unknown	15.49 € (0.57€)
<i>Hippocampus barbouri</i>	VU	Decreasing	156.65 € (26.96€)
<i>Hippocampus comes</i>	VU	Decreasing	91.35 € (2.71€)
<i>Hippocampus erectus</i>	VU	Decreasing	204.54 € (84€)
<i>Hippocampus kuda</i>	VU	Decreasing	193.38 € (83.49€)
<i>Hippocampus reidi</i>	NT	Decreasing	142.78 € (77.65€)
<i>Holacanthus clarionensis</i>	VU	Stable	99.90 € (-)
<i>Oxymonacanthus longirostris</i>	VU	Decreasing	41.17 € (1.47€)
<i>Pterapogon kauderni</i>	EN	Decreasing	34.75 € (5.65€)
<i>Siganus uspi</i>	NT	Unknown	100.77 € (18.57€)

that only a small proportion of marine ornamental fish species in the German trade are currently bred in captivity. Similarly, only 5 to 7 % of the species commonly available in the marine aquarium industry overall have been successfully bred in captivity so far (REEF to RAINFOREST MEDIA, 2023; Thornhill, 2012). Interestingly, to promote their captive-bred products, “Retailer 7” highlighted that *P. kauderni* is currently one of the most threatened fish species, partly because of its great popularity in marine aquariums.

We found evident price differences between captive-bred and wild-caught specimens and a high price range between the products, from 10 up to 4,899 €. Interestingly, captive-bred products were, on average, 29 % more expensive than wild-caught ones. This aligns with a previous study showing that captive-bred ornamental fish were at least 25 %

more expensive than wild-caught fish in the major markets (Fotedar & Phillips, 2011). Further research on this price gap could help identify cost drivers and support strategies to increase the attractiveness of captive-bred options to consumers. Catching marine ornamental fish from the wild is still more affordable than breeding them, especially as breeding is highly specialized or has not been sufficiently researched for many marine species yet. This potentially explains the higher presence of wild-caught species on the market (Thornhill, 2012). However, wild-caught rarities achieved the highest prices, such as the endemic tiger angelfish (*Apothemichthys kingi*, Pomacanthidae) which was the most expensive species found in our study with a price of 4,899 €. High prices of rare species in the aquarium trade could potentially lead to over-exploitation of wild populations, particularly those with limited

Table 2

Classification of provided information from the eight studied retailer websites concerning the animal's country of origin and/or source (captive-bred or unknown-source), species-specific needs, conservation status, and for CITES-listed *Hippocampus* species only, the mention of required CITES documentation. The quantity of information provided by the retailers are categorized as low, medium and high; as well as by "yes" = provided or "no" = not provided.

Retailer/ Website	Provided Information			Hippocampus: Reference to proof of origin/ CITES documents
	Origin/ Source	Species specific needs	Conservation status	
Retailer 1	low	low	No	Yes
Retailer 2	medium	medium	No	Yes
Retailer 3	low	low	No	No
Retailer 4	high	high	No	No
Retailer 5	low	high	No	No Hippocampus sold
Retailer 6	low	high	No	No
Retailer 7	medium	medium	No	No
Retailer 8	no	low	No	No

distributions or additional threats (Courchamp et al., 2006). Additionally, high mortality rates of marine ornamental fish in the supply chain can lead to increased harvest rates (Schmidt & Kunzmann, 2005; Yan, 2016). However, the adoption of improved technologies (such as tank systems that support the proper acclimation of fish) and sustainable handling practices, including the use of selective, non-destructive gear by trained fishers) could significantly reduce mortality (Chen, Liu, Huang, Chen, & Wang, 2022; Stevens, Croft, Paull, & Tyler, 2017; Rubec et al., 2001).

4.3. Potential conservation concerns

Of the 668 species listed as LC sold by retailers, 20 species have a decreasing population trend. Although this decline may not warrant uplisting the species to a more threatened Red List category yet, it could be a cause of concern. For example, experts advocate updating the LC threadfin butterflyfish (*Chaetodon auriga*, Chaetodontidae), a popular aquarium fish, due to its declining population (Myers & Pratchett, 2010). Moreover, our results show that of the 767 species identified within the German trade, 44 were not evaluated by the IUCN Red List, and 32 species were listed as Data Deficient (DD), indicating insufficient information for a proper threat assessment. This is concerning as studies on other animal groups found that species classified as DD are more likely to be threatened by extinction (Borgelt et al., 2022; Howard & Bickford, 2014; Parsons, 2016).

Our study also revealed that 13 threatened species are traded within Germany, potentially impacting their populations' survival in the wild. For example, populations of the azure demoiselle (*Chrysiptera hemicyanea*, Pomacentridae) and the harlequin filefish (*Oxymonacanthus longirostris*, Monacanthidae) are decreasing due to climate change (Allen, 2022; Matsuura & Motomura, 2016). However, the aquarium trade likely contributes to the decline of both species, especially for the heavily traded harlequin filefish (Allen, 2022; Matsuura & Motomura, 2016; Wilkinson, 2004). The only species listed as Endangered is *P. kauderni*, which is offered by each retailer sourced from both unknown-sources and captive breeding. While Indonesia has implemented a national management plan for this species, further research and data are needed to assess the sustainability of the trade (Serdiati, Gani, Wahyudi, Moore, & Ndobé, 2021; Ndobé, Serdiati, Gani, Walalangi, & Moore, 2023). Another particularly interesting species identified in this study is the vulnerable clarion angelfish (*H. clarionensis*), which is endemic to the Revillagigedo Islands "no-take" Marine Protected Area (Pyle et al., 2010) and listed in CITES Appendix II since 2017. Although traders and collectors claim that there has been no collection since 2015 and no evidence of illegal trade, the species was offered by one of the retailers in this study without being labeled as

captive-bred. This raises questions about its origin, as several other products by this retailer were clearly labeled as captive-bred. The international aquarium industry's demand for *H. clarionensis* is thought to be fully met by captive-bred specimens from Indonesia (FAO, 2016). Therefore, we assume that the retailer neglected to label it as captive-bred, which further highlights the need for better information provision and transparency by retailers.

Still the trade of species of conservation concern is not limited to Germany, for example Akmal et al. (2020) identified 501 species of bony fish (52 families) in Indonesian markets, including 21 species listed as Data Deficient, 311 as Least Concern (LC), 19 as Near Threatened (NT), 15 as Vulnerable (VU), and two as Endangered (EN). Similar to our findings, their dataset is dominated by LC species, with relatively few species falling into higher threat categories (NT, VU, EN). This highlights regional similarities and differences in species composition and threat status within the trade, underscoring the importance of context-specific assessments for effective conservation responses.

Seven out of eight retailers sell species of the genus *Hippocampus*, which are included in CITES Appendix II (Kuo & Vincent, 2018). Most *Hippocampus* species are threatened by habitat loss and heavy trade for medicine, souvenirs and aquariums, and are categorized as either NT or VU (Vincent, Foster, & Koldewey, 2011; Aylesworth, 2014; Oliveira & Pollom, 2017; Pollom, 2017). Despite the requirement for a proof of origin document for all *Hippocampus* products due to their CITES Appendix II listing, most retailers (6 out of 8) failed to provide this information. Only two mentioned the required permits, and just one explicitly guaranteed the inclusion of breeding documentation with each order. However, 18 *Hippocampus* products were identified as from unknown-source without any additional information, potentially leading to unintended consequences for unaware customers.

4.4. German trade policy and animal welfare legislation

Germany has taken several measures to improve legislation and animal welfare regarding (exotic) pet keeping. A 2015 study commissioned by the German government investigated the trade and welfare of exotic pets, including ornamental fish and requires retailers to provide husbandry information to new pet owners. Additionally, the German government created the online pet advisor platform "Haustier-Berater.de" (Federal Ministry of Food and Agriculture, 2020), which offers husbandry information for 120 animals, including some groups of marine ornamental fish, to provide future pet owners with comprehensive information before purchasing a pet.

Despite these measures, threatened marine ornamental fish species continue to be commonly traded without proof of origin, even as wild populations continue to decline. Researchers involved in the 2015 study proposed minimum requirements for pet keeping, a certificate of competence for acquiring wild animals protected by CITES, and mandatory licenses for keeping wild animals with complex husbandry needs (Krautwald-Junghanns & Erhard, 2018), such as seahorses and the clarion angelfish (*H. clarionensis*). This would ensure better animal welfare and support conservation efforts for these species. In addition, it has been suggested to restrict the sale of species such as the harlequin tuskfish and harlequin filefish, which are considered unsuitable for aquarium keeping, as well as for wild-caught species like the Banggai cardinalfish, which are particularly vulnerable to large-scale exploitation (Kolm & Berglund, 2003).

4.5. German trade in the European and global context

Our study identified 121 species not previously reported in the European trade in marine ornamental fish recorded in TRACES (Biondo & Burki, 2019), highlighting gaps in species-level trade monitoring on EU level. While we acknowledge that this discrepancy could be due to the different timeframes studied (2014–2017 for Biondo & Burki, 2019; 2023 in this study), it also supports the numerous studies that have

already highlighted the need for improved monitoring of marine ornamental fish throughout the supply chain (Biondo & Burki, 2019; Cohen et al., 2013; Rhyne, Tlustý, Schofield, Kaufman, & Morris, 2012; Rhyne et al., 2017). However, these differences may also reflect regional preferences or the specialization of certain retailers. Additionally, some species, particularly those from families found only in the European dataset, may be more commonly traded for public aquariums or institutional collections, and thus are less likely to appear in private online retail markets such as those surveyed in Germany. Nevertheless, our results highlight that improved monitoring and traceability of the aquarium trade on species and country level (not only in Europe) could support research, policy, and conservation efforts as well as assist the industry on its path toward sustainability (Cohen et al., 2013).

Although our results likely underrepresent actual trade in Germany, this study provides a preliminary exploration within a limited timeframe and number of retailers. Despite these constraints, we clearly show the prevalent lack of retailer transparency and the need for better data collection in the marine ornamental fish trade. Given Germany's role as one of the main importers of ornamental fish in Europe and globally, our results could be indicative of more general trends in other European countries, although additional studies are needed to confirm these results. Furthermore, while Germany leads as a major consumer, other countries such as the Czech Republic function as important transit hubs with potential influence on the lack of transparency of German retailers (Kalous et al., 2015). It is therefore critical to consider trade dynamics beyond just end-consumer markets.

In some rural coastal areas with limited resources and economic options, the collection of ornamental fish is the primary source of income (Akmal et al., 2020; Wabnitz et al., 2003). While collectors usually have minimal influence on global markets, German companies—with their substantial buying power—can significantly shape market dynamics (Dykman, 2012). Businesses like aquarium fish retailers therefore have a responsibility to ensure their operations do not negatively impact the local communities and biodiversity on which they depend. This is particularly the case in developing countries which may lack sufficient resources, tools and mechanisms for reef conservation, affecting the fragile coral reef ecosystems where they operate (Dykman, 2012; Moore & Best, 2001).

5. Conclusion

Our findings reveal that the German online trade in marine ornamental fish is taxonomically diverse (767 species across 59 families) and dominated by products of unknown-source (88 %), suggesting that many are likely wild-caught. Only 12 % of the products (representing 285 species) were identified as captive-bred, often at a higher price (median price of €83.40 compared to €59.00 for fish of unknown-source). Of particular concern are 13 species available on the market that are listed as globally threatened by the IUCN Red List, including one Endangered species (*Pterapogon kauderni*) and four vulnerable seahorse species. Moreover, only 2 out of 8 retailers provided clear information regarding CITES compliance.

Despite legal obligations under the German Animal Welfare Act, 50 % of the retailers studied failed to provide basic husbandry information required under §21 of the Act. This limits consumers' ability to make responsible choices and raises serious animal welfare concerns. Retailers also frequently omitted essential details such as species origin, conservation status, or sourcing methods, hindering both ethical consumer behavior and the enforcement of national and international legal frameworks.

Given Germany's status as the third-largest importer of ornamental fish globally and one of the largest within the EU, it is uniquely positioned to lead efforts toward a more sustainable and transparent trade. While our findings highlight significant gaps in information provision, sourcing transparency, and compliance with existing laws, they also reveal a clear opportunity.

To address these gaps, we recommend the following targeted actions

1. **Strict enforcement of existing legislation** — including the German Animal Welfare Act (§21) and CITES — through regular audits of online retailers and meaningful penalties for non-compliance, particularly regarding CITES-listed species such as seahorses.
2. **Mandatory disclosure requirements for online platforms**, including details on species origin (wild-caught vs. captive-bred), conservation status, CITES listing (where applicable), and invasive potential under EU regulations. This is especially critical for the 13 globally threatened species we identified, including the endangered Banggai Cardinalfish (*Pterapogon kauderni*).
3. **Improved traceability** by leveraging existing monitoring tools, such as TRACES, to enhance oversight of marine ornamental trade within the European Union.
4. **Development of national guidelines** for ethical marine ornamental trade and traceability, created in collaboration with scientific institutions, trade associations, and NGOs.
5. **Incentives for captive breeding and sustainable local sourcing**, such as certification schemes and tax benefits, to reduce pressure on wild populations.
6. **Public awareness campaigns** to educate consumers about responsible aquarium ownership and the ecological risks associated with poorly regulated trade and mismanagement of potentially invasive species.
7. **Active participation in EU-level and CITES coordination efforts** to harmonize trade standards and facilitate the sharing of best practices across countries.

By implementing these measures, Germany can set a benchmark for responsible marine ornamental trade in Europe and globally. This leadership could create opportunities for economic growth and conservation in source countries while ensuring the sustainable management of aquatic biodiversity. Strengthening traceability, improving consumer guidance, and fostering international cooperation will be essential to minimizing biodiversity loss and animal welfare risks, thus supporting the long-term viability of a responsible aquarium industry.

6. Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work the authors used Grammarly and ChatGPT (a language model developed by OpenAI (GPT-4)) to support the writing process: to correct grammar mistakes, avoid word repetition and select words to enhance linkage between paragraphs. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

7. Ethical considerations

Due to ethical considerations, we anonymised the retailer company names and numbered the retailers randomly. However, all websites selected for this study were publically accessible online. Ethics approval could not be obtained from the SDU Research Ethics Committee as there is no Danish law regarding this type of research.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jnc.2025.127032>.

Data availability

The data that support the findings of this study are openly available and can be found in the supplementary materials.

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