Journal of Coastal Conservation (2023) 27:57
https://doi.org/10.1007/s11852-023-00986-4

Marine aquarium trade: an open door for invasions in Iceland

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Received: 27 March 2023 / Revised: 27 September 2023 / Accepted: 28 September 2023

Abstract
Patterns of biological invasions are influenced and shaped by trends in human activities, including the trade of biota, which facilitates the spread of species and accelerates the rate of introduction of non-indigenous species into new environments. The aquarium trade moves thousands of species around the globe, and unwanted organisms may be released into aquatic systems, with adverse ecological and economic effects. A questionnaire delivered to the Icelandic aquarium stores identified a total of 1,275 marine species available to aquarium hobbyists, of which 134 have been introduced elsewhere, and seven of them being reported in the literature as invasive. While there may not be a strict climate match between the source and receptor environments of these species, this does not preclude the possibility of some of them proliferating along the coast of Iceland. Additionally, 73 species are considered Vulnerable, Near Threatened or Endangered on the *International Union for Conservation of Nature* (IUCN) Red List. Although Iceland has regulatory legislation on the importation of pets, including ornamental fish and aquatic animals, no information is currently collected by customs offices on aquarium species being traded. Management strategies, starting from gathering information on aquarium trade and educational campaigns aiming to avoid the release of unwanted live organisms into the environment, are urgent.

Keywords Endangered species · Non-indigenous marine species · Invasive species · Management strategies · Unwanted organisms

Introduction

The spread of marine non-indigenous species (NIS) around the world, which is being hastened by trade networks in an era of globalisation (Alves et al. 2021), is influencing and shaping the patterns of biological diversity, especially when their presence and behaviour impact the host ecosystem (Holmberg et al. 2015). The consequences include economic impairment, a decrease in global biodiversity, alterations in ecosystem functioning and structure of communities (Mantelatto et al. 2018).

The spectrum of NIS pathways is broad and dynamic over time, with different weights for each taxonomic group and geographic location (Mazza et al. 2015). Being an internet click away, the aquarium trade is a strongly growing economy that moves thousands of species around the globe (Mazza et al. 2015; Alves et al. 2021) and is particularly difficult to control and regulate (Geburzi and McCarthy 2018). Aquarium organisms might become an environmental and economic problem when released into the wild. The releases might occur accidentally, i.e., through drainage of water from domestic or public aquaria or disposal of water where specimens have been transported (Morrisey et al. 2011). They might also be intentional releases, as it is often considered a more humane alternative than euthanasia when dealing with unwanted organisms due to, e.g., large size, aggressiveness, and high reproductive rates (Holmberg et al. 2015).

The most traded marine aquarium species are usually characterised by intrinsic physiological plasticity that allows them to thrive in stressful conditions posed by collection and transport (Padilla and Williams 2004; Allen et al. 2017). This physiological plasticity is probably the key to successfully establishing these species in new geographical environments (Padilla and Williams 2004). Indeed, the marine aquarium trade has been responsible for introducing many algae, invertebrates, and fish species worldwide. For example, the Indo-Pacific soft corals of the genera *Sansibia* and *Clavularia*, which are typically found

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Published online: 17 October 2023

in the aquarium trade, are invading a tropical rocky reef in Ilha Grande Bay, southeast Brazil (Mantelatto et al. 2018). Additionally, the marine shrimp *Cinetorhynchus erythrostictus* Okuno, 1997, which is native to the Western Pacific Ocean, was introduced into the Western Atlantic Ocean and is presently invading the rocky bottoms of the Itapuã beach in Salvador, northeast of Brazil (Alves et al. 2021). The Indo-Pacific lionfish, *Pterois volitans* (Linnaeus, 1758), has been introduced to the east coast of North America and the Caribbean (Whitfield et al. 2002). This species is considered one of the worst invasive species due to its venomous spines, predation style, and lack of known predators (Mantelatto et al. 2018). In the Mediterranean Sea, the fish species *Acanthurus coeruleus*, *A. chirurgus*, *Zebrasoma flavescens* and *Z. xanthurum*, all of which are common aquarium trade species, have been sporadically spotted, indicating a high probability that their presence is related to aquaria releases (Guidetti et al. 2016).

The supplies of marine aquarium trade derive mainly from wild populations, which pose another type of threat related to the sustainability of the trade, with overexploitation of the resources, especially in the case of rare or vulnerable species (Morrisey et al. 2011; Rhyne et al. 2017; Patoka et al. 2020). Additionally, there are negative impacts on marine habitats due to damaging methods for capturing organisms, e.g., the use of sodium cyanide, which is a non-selective method to catch fish and that adversely affects the health and/or kills non-target species (Gopakumar and Ignatius 2006).

The growing demand and the current lack of information on the marine aquarium trade argue for a clear picture of the number of live marine species and individuals involved in this industry. In this paper, we focus on Iceland, a sub-polar region already being invaded by marine NIS able to proliferate under climate change (e.g., Gíslason et al. 2014; Micael et al. 2022, 2023). The present study aims to characterise the aquarium trade of marine animal species in Iceland by developing an overview of species available through the Icelandic aquarium/pet shops, supplier countries, species' native origin and conservation status, and to analyse the ornamental species import data and regulations. The present work highlights the aspects involved in the trade of marine aquarium species, including the diversity of animals involved in the trade, the release of potentially invasive species and the threat they might pose to biodiversity and maritime industries.

Methods

A survey questionnaire was created to collect information about the marine species available to customers by the aquarium stores in Iceland, along with the supplier countries and methods of disposing of dead or unwanted individuals. The questionnaire was distributed in the summer of 2021 (Supplementary material 1).

As not all the species are in stock, most of them are ordered from a catalogue, our species list is based on the label provided by the store. As the store label includes a scientific name for each species and the species identification cannot be checked prior to order, we rely on the species' scientific name provided by the supplier. When there was a disparity between the scientific name and common name on the store label, or if there was a misspelling, we used the scientific name provided in FishBase (http://www.fishbase.org/), in Coral Trait Database (https://coraltraits.org) and/or in the World Register of Marine Species (WoRMS - https://www.marinespecies.org). Once the species list was completed, we used the same databases to obtain the geographic distribution of each species. The International Union for Conservation of Nature (IUCN 2000) definition of ''native'' species was adopted, i.e., a species, subspecies or lower taxon occurring within its natural range and dispersal potential. In contrast, "non-indigenous species" (NIS) represent a species that lacks geographical contiguity with its native range and/or is associated with introduction vectors or pathways (Carlton 1985). Algae were not included in this study due to the lack of identification of algae species being traded.

The distribution was classified as part of the major oceans (Atlantic, Indian, and Pacific) or circumglobal. The Atlantic Ocean was subdivided into the western, eastern, and Mediterranean Sea.

The composite list was compared with NIS lists such as AquaNIS (http://www.corpi.ku.lt/databases/index.php/aquanis), DAISIE (http://www.europe-aliens.org/expertSearch.do), NOBANIS (http://www.nobanis.org/Search.asp) and GBIF (https://www.gbif.org) to determine whether each species has a demonstrated history of being introduced outside its native range. Data on NIS´s previous invasion history and impacts were compiled by examining scientific literature. A species was considered "invasive" if it is an agent of ecological change and thus threatens native biological diversity, as defined by The International Union for Conservation of Nature (IUCN 2002), triggering habitat changes (Occhipinti et al. 2011). Additionally, species that cause economic damage, namely on ecosystem services or have negative effects on human health, were also considered "invasive" (EPA 2001). Only impacts that have been reported as evidence of an effect were taken into consideration.

The global conservation status of each species was assessed using the IUCN Red List database of Threatened Species (https://www.iucnredlist.org). Six categories were considered: 1 – Endangered (ED); 2 – Near Threatened

(NT); 3 – Vulnerable (VU); 4 – Least Concern (LC); 5 – Data Deficient (DD); 6 – Not Evaluated (NE).

Import data on marine ornamental species were obtained from the Statistics Iceland (the National Statistical Institute of Iceland), as shipment declarations collected by the customs were sent to them. Import information was retrieved from the Statistics Iceland website (https://www.statice.is). The database comprises main categories, which include marine ornamental species. For each category, it is possible to obtain the total number of kilos, total price (ISK) and country of origin for each month since January 2020. Information is not differentiated by species.

Results

Questionnaire

There are only three marine aquarium suppliers in Iceland. No other companies related to the transaction of marine aquarium species are registered in Iceland. About the suppliers, Supplier 1: Does not have a list of species. Customers are therefore compelled to visit the store and see what species are currently in stock. The store supplies specimens every two months, and they usually import 200–300 species annually. Supplier 2: Has a list of over 1000 available species but only has a few in stock. Specimens are supplied upon order, but some are always available in the store. Supplier 3: Does not have any specimens in stock and currently supplies only the aquarium at the Children's Hospital.

The aquarium suppliers obtain their stock from Great Britain, the Netherlands, the Czech Republic, Indonesia, and Kenya. Parasitised specimens are treated by medication, UV light, lowering salinity, or other unspecified methods.

Dead stock is disposed of by salting the specimen and disposing it in municipal waste collection or by "flushing it down the toilet". Aquarium water is discharged into the sewer or toilet.

Aquarium fauna species available in Icelandic stores

The survey of Icelandic aquarium stores unveiled a total of 1,275 marine fauna organisms identified to species, available to aquarium hobbyists in Iceland; including 921 fish (Chordata Osteichthyes), 124 corals (Cnidaria Anthozoa), 72 crustaceans (Arthropoda Malacostraca), 56 gastropods (Mollusca Gastropoda), 21 sea stars (Echinodermata Asteroidea), 21 sea urchins (Echinodermata Echinodea), 15 sharks (Chondrichthyes Elasmobranchii), 11 bivalves (Mollusca Bivalvia) and seven cephalopods (Mollusca Cephalopoda) among other marine groups that sum to 27 species (Supplementary material 2).

Species native origin

The native origin of 87% of the species available in the aquarium trade in Iceland is from the Indian and/or Pacific Oceans. The remaining species originated from the Atlantic Ocean (Fig. 1). Most species are from tropical and subtropical areas. The same trend is observed for all species groups, except for sharks, which are all from the Indian and/or Pacific Oceans.

Non-indigenous species

Of the 1,275 marine species available in the Icelandic aquarium market, 134 have established and proliferated in new geographic regions around the globe, 116 of which are marine fish species. Seven have been associated with negative impacts outside of their native range (Table 1).

Negative impacts of each of the invasive species

Fish

1 - *Scarus ghobban* (H. Milne Edwards, 1853)
The increased abundance of the new parrotfish in the eastern Mediterranean is changing the trophic interactions in the rocky habitats. *S. ghobban* is a grazer that forms feeding schools in shallow waters and can reach a length of 90 cm (Goren and Aronov 2002).
2 - *Plotosus lineatus* (Thunberg, 1787)
The striped eel catfish is rapidly becoming a dominant component of the benthic biota of Israel (Gweta et al. 2008). It has venomous spines that have caused dozens of injuries to fishermen and beachgoers in Israel (Haddad et al. 2008). *Plotosus lineatus* is listed among the 100 worst invasive species in the Mediterranean (Streftaris and Zenetos 2006).
3 and 4 - *Pterois miles* (Bennett, 1828) and *Pterois volitans* (Linnaeus, 1758)
The red lionfish *Pterois volitans* and the devil firefish *P. miles* are more abundant in the western Atlantic than in their native region. They have been shown to decrease the abundance of over 40 prey species by 65%, on average, in 2 years (Kletou et al. 2016).

Corals

5 - *Tubastraea micranthus* (Ehrenberg, 1834)
Tubastraea micranthus is a successful competitor for space, having been observed growing over 90% of all

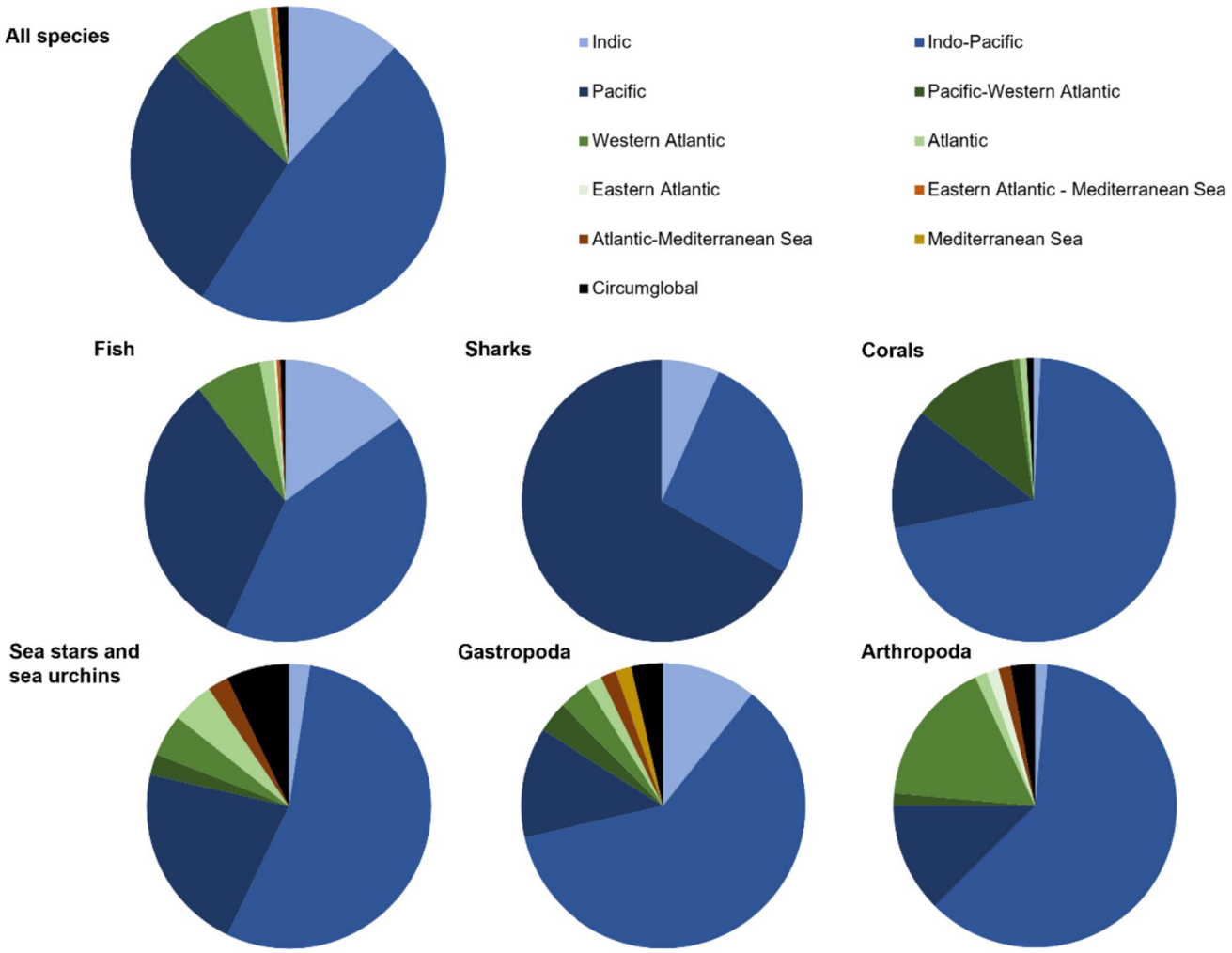

Fig. 1 The relative percentage of the native origin of the marine species available in the Icelandic aquarium market

Table 1 Native origin and invaded geographic areas of NIS with invasive potential available in the Icelandic aquarium market

Species	Native origin	Invaded geographical area
Scarus ghobban (H. Milne Edwards, 1853)	Indo-Pacific	Eastern Mediterranean [a]
Plotosus lineatus (Thunberg, 1787)	Indo-Pacific	Eastern Mediterranean [b]
Pterois miles (Bennett, 1828)	Indian Ocean	Western Atlantic [c]
Pterois volitans (Linnaeus, 1758)	Indo-Pacific	Western Atlantic [c]
Tubastraea micranthus (Ehrenberg, 1834)	Indo-Pacific	Gulf of Mexico [d]
Perna viridis (Linnaeus, 1758)	Indo-Pacific	Atlantic Ocean [e]
Percnon gibbesi (H. Milne Edwards, 1853)	Pacific-Western Atlantic	Mediterranean Sea [f]

[a] Goren and Aronov 2002; [b] Gweta et al. 2008; [c] Kletou et al. 2016; [d] Sammarco et al. 2015; [e] Gobin et al. 2013; [f] Sciberras and Schembri 2008

sessile epibenthic species in several sampling locations in the northern Gulf of Mexico (Sammarco et al. 2015).

Mollusca Bivalvia

6 - *Perna viridis* (Linnaeus, 1758)

The green mussel *P. viridis* has been recognised as an invasive species since its introduction from the Indo-Pacific to the Atlantic Ocean (Gobin et al. 2013). Green mussels have been found in densities of 1,000–4,000 individuals/ m^2 and as high as 35,000 individuals/ m^2 (Fajans and Baker 2005). Densities up to 211 kg/ m^2

have caused damage to equipment and clogging of pipes, causing reduced water flow for industrial cooling systems (Rajagopal et al. 1998).

In Venezuela, the population of brown mussel *Perna perna* has decreased due to substrate competition with the green mussel (Rylander et al. 1996), and in Florida, green mussel populations were found covering dead oyster shells (Baker et al. 2007).

Arthropoda Percnidae

7 - *Percnon gibbesi* (H. Milne Edwards, 1853)

Percnon gibbesi is an opportunistic feeder of the shallow infra-littoral rocky shores, feeding primarily on algae but also on pagurids, polychaetes, gastropods, crustaceans, and jellyfish (Katsanevakis et al. 2011). In Malta, its distribution pattern suggests a spatial resource partitioning and exclusion of two native crab species, the marbled crab *Pachygrapsus marmoratus* and the yellow crab *Eriphia verrucosa* (Sciberras and Schembri 2008).

IUCN status

From the 1,275 marine species available in the Icelandic aquarium market, three are listed as having an "Endangered" conservation status, i.e., the two fish species *Callogobius amikami* and *Pterapogon kauderni* native from the Indic and Pacific Oceans, respectively; and the shark *Triakis scyllium* native from the Pacific Ocean. Forty species are listed as Near Threatened, including 29 corals, eight fish and three sharks. Thirty species are Vulnerable, mainly corals but also six fish, three sharks and one Merostomata (Fig. 2, Supplementary material).

The conservation status has been poorly evaluated in many groups of species. Only three groups (Sharks, Cephalopoda and Merostomata) have been completely evaluated from the marine animals available in the Icelandic stores. For instance, although 50 coral species are classified as Near Threaten or Vulnerable, 50 others have yet to be evaluated by the IUCN (Fig. 2).

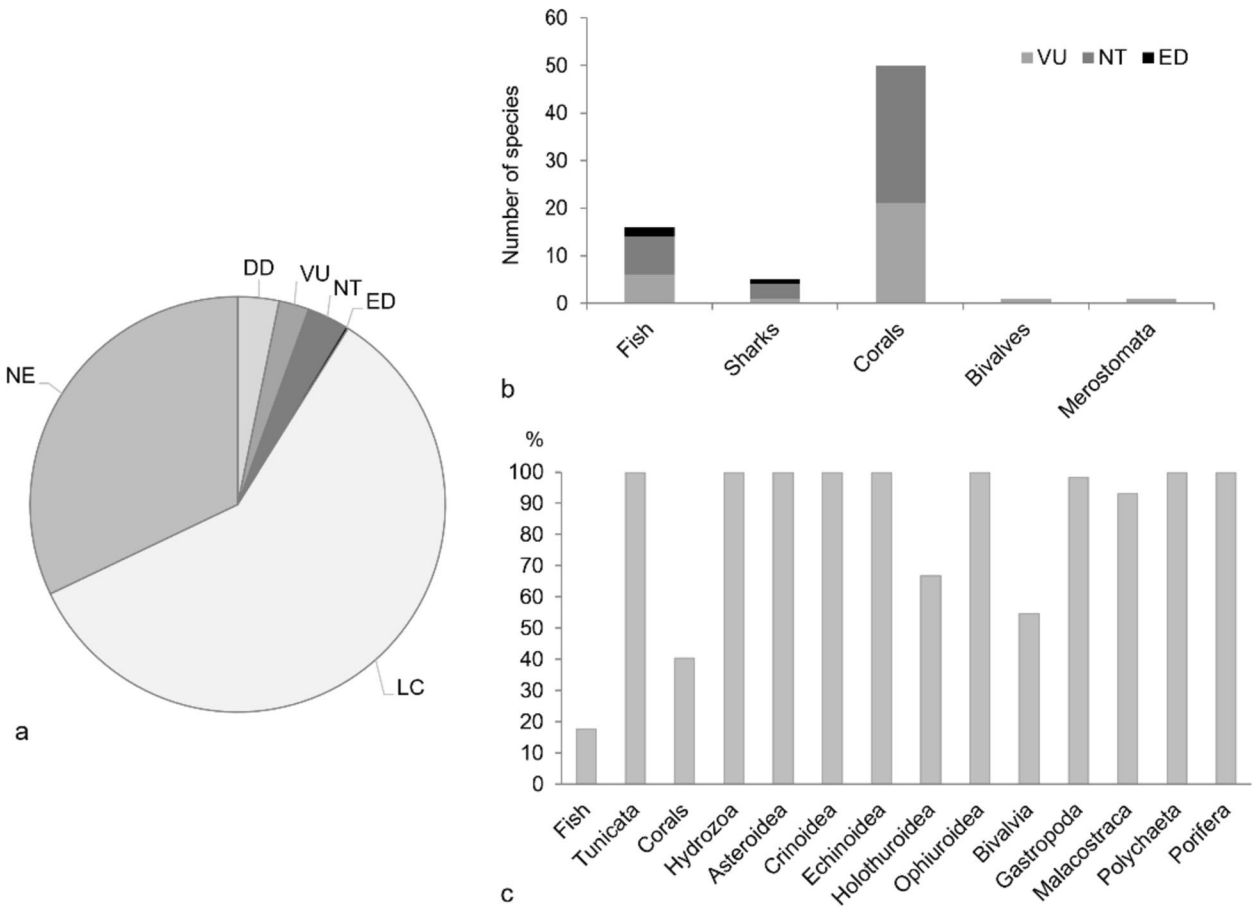

Fig. 2 The global conservation status of marine species available in the Icelandic aquarium stores. Six categories were considered: 1 – Endangered (ED); 2 – Near Threatened (NT); 3 – Vulnerable (VU); 4 – Least Concern (LC); 5 – Data Deficient (DD); 6 – Not Evaluated (NE). a – Percentage of species in each IUCN category; b – Number of species per group in VU, NT and ED categories; and c – Percentage of species per group that remain to be evaluated by the IUCN

Data on ornamental species imports in Iceland

Ornamental species that enter Iceland through the customs are from six main geographic regions (Fig. 3). This information is relative to suppliers and not to species origin.

Ornamental species have been imported for a value of about ISK 3,810,359 between January 2019 and October 2021 (custom value). The major contribution is by far from the coral group (Fig. 4). The actual number of species and individuals is not reported, nor are the species names, which have only been listed in vendor lists. These data do not differentiate between freshwater and marine species.

Import law

Under the Nature Conservation Act No. 60/2013, the import and distribution of living non-indigenous organisms are only permitted with the authorisation of the Environment Agency of Iceland. To import live animals or plants, a permit must also be obtained from MAST (Matvælastofnun, Icelandic Food and Veterinary Authority). According to regulation NO. 935/2004, which is based on law NO. 54/1990 on the import of animals, anyone wishing to import ornamental fish, invertebrates and plants for aquariums to Iceland is required to hand in a specific application form prepared by MAST that includes importer identification details, species name (which can be referred to by its common name), and the number of individuals being imported. Moreover, the importer must sign a declaration that the "species are accompanied by a health and origin certificate completed by a veterinarian in the exporting country" and that they are "kept in quarantine for the first four weeks after import, (Laws on Animal import 1990). The approval of MAST for quarantine facilities must be requested before the animals are brought to the country".

Discussion

The present survey allowed us to identify three stores in Iceland that offer marine species for aquariums. Although this number is small, the number of species currently available is extensive and diverse, with more than 177 families from seven phyla being targeted for this type of market. The majority of species available in Iceland are fish, followed by corals and crustaceans (mainly shrimps and crabs), which is following the global trend (Rhyne et al. 2017; Mantelatto et al. 2018). Most of the species are native to the Indo-Pacific region, and some have successfully established and proliferated in new geographic regions scattered around the globe (AquaNIS, DAISIE, NOBANIS, GBIF).

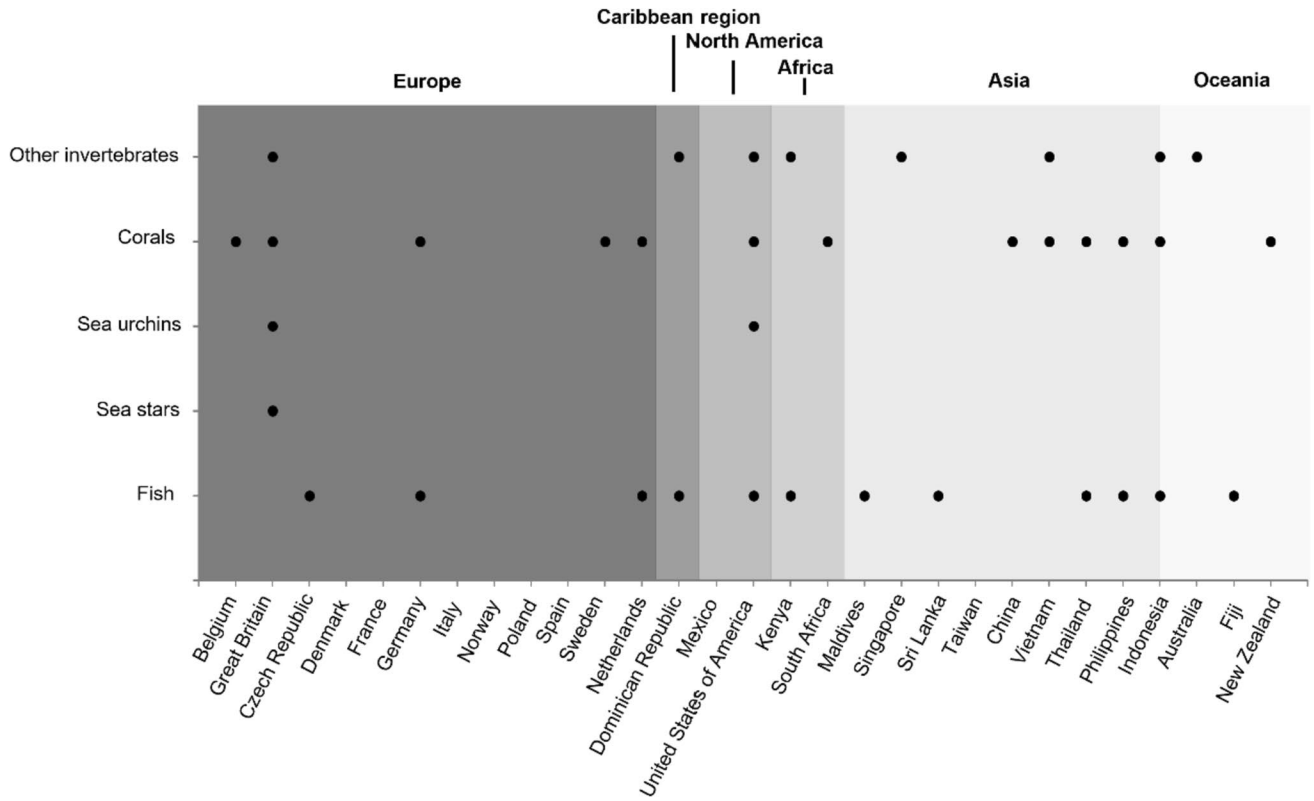

Fig. 3 Country origin of ornamental species that enter Iceland between January 2019 and October 2021 through the customs. Data from the Statistics Iceland

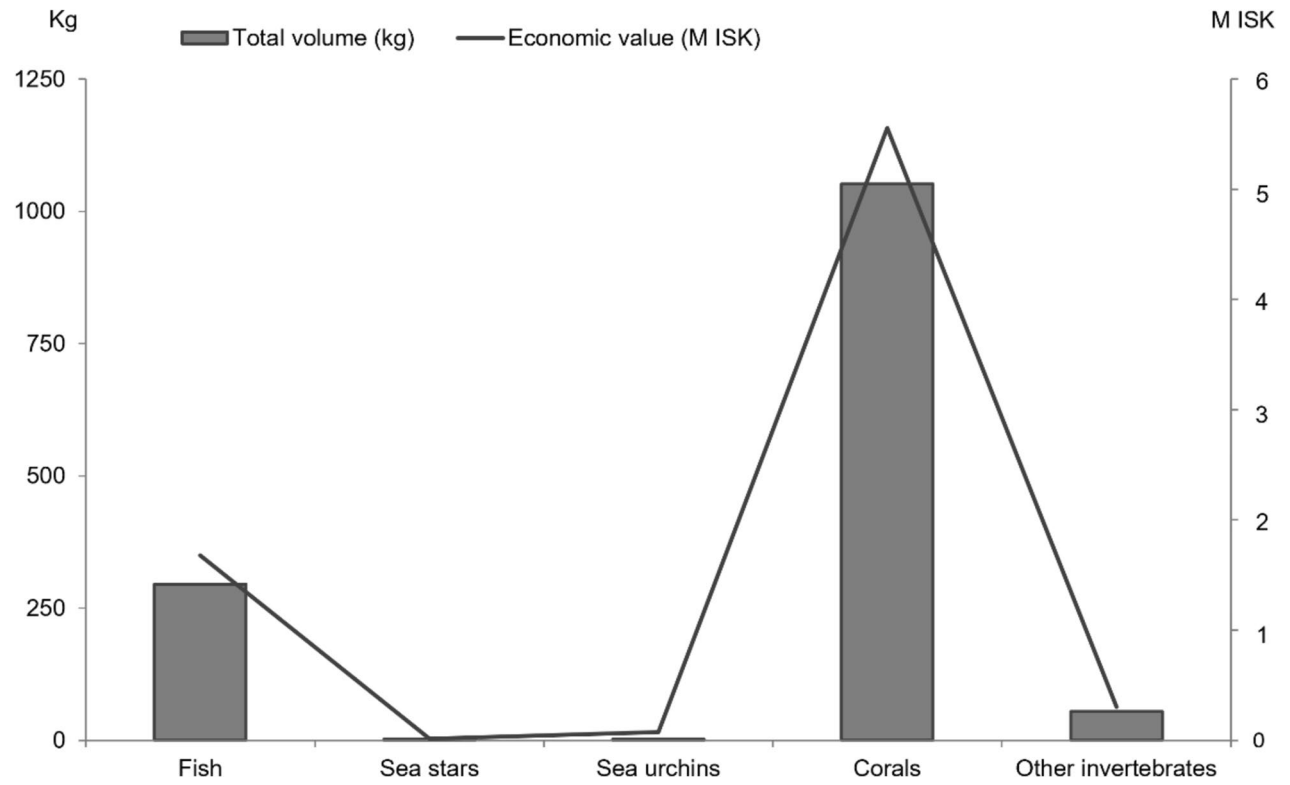

Fig. 4 Ornamental species' economic value (M ISK) and total volume (kg) were declared to Icelandic customs between January 2019 and October 2021

As it happens in the global aquarium trade, numerous species are of tropical origin and have a low tolerance for cold waters (Rixon et al. 2005; Gertzen et al. 2008). As such, one would expect that the survival probability of these species in high latitudes would be reduced. However, knowledge of lethal water temperatures for traded species is scant and uncertain (Maceda-Veiga et al. 2013), making it difficult to evaluate the probability of their successful establishment in new environments without experimental work. Additionally, although most of the species' distribution has been restricted to tropical and subtropical waters, some species are proliferating in temperate waters, such as *Perna viridis* and *Percnon gibbesi* (Gobin et al. 2013; Relini et al. 2000). Moreover, it has been demonstrated that several invertebrate species from temperate regions are thriving in Iceland. Although these species show a latitudinal pattern in their breeding activity by shortening the breeding season, this does not impede their establishment and proliferation (Micael et al. 2022). The invasion history from other countries of the eight traded species previously mentioned, available to Icelandic buyers, advocates for a realistic risk of possible new hazardous introductions (Vranken et al. 2018). One species is enough to jeopardise ecosystems, as has e.g. been demonstrated by species such as *Cinetorhynchus erythrostictus* and *Pterois volitans* (Mantelatto et al. 2018; Alves et al. 2021).

Additionally, when looking at the origin of the species, local depletion attributed to marine species collected for the aquarium trade has been reported in Indonesia, Hawaii and Australia (Gopakumar and Ignatius 2006). Currently, consumers have access to a broad range of species without any information about, for example, the species' IUCN status at the origin site. Efforts should be made to inform everyone involved in the trade about species' life history characteristics.

Iceland is not a European Union member, and as such, the obligation to comply with the EU regulations could be argued; nevertheless, as a member of the European Economic Area (EEA), regulations related to species trade are to be applied. Additionally, Iceland has signed the *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES), the *Convention on Biological Diversity* (CBD), and the *United Nations Convention on the Law of the Sea* (UNCLOS), which are related to aquarium species trade and go beyond the EU sphere. CITES, for example, emerges from a resolution adopted in 1963 at a meeting of World Conservation Union (IUCN) members. The Convention does not replace the national laws. Instead, it provides a framework to be respected by each Party, which should adopt its domestic legislation to ensure that CITES is implemented at the national level.

The declaration of Importation required by MAST does not oblige identifying the species by its scientific name,

which means that there is insufficient information on the live organisms imported through the aquarium trade. With the current procedure, it is, therefore, neither possible to know nor monitor which species and in what number are entering Iceland through the customs, i.e., which species are being traded. Our study is just an indication of the species availability in the market. Moreover, the difference between the countries' store suppliers and the statistical data on imports at the customs represent evidence of additional trade, probably from internet supplier(s) not registered in Iceland. Reliable records on the type and number of organisms being traded are lacking, both from stores and, more evidently from the customs. It is crucial to fill this information gap for biosecurity reasons and to develop risk assessments for the importation of aquarium species. Currently, consumers have access to potentially invasive species due to the lack of information about the species and the lack of enforced regulatory mechanisms.

With the increasing popularity of aquarium species, there is also the need to consider what to do with the unwanted organisms. Aquarium dumping (live release) has often been considered a convenient disposal method, and as a result, has been responsible for negative environmental impacts reported around the globe (Magalhães et al. 2017). Efforts are needed to inform everyone involved in the trade about adequate practices to deal with the issue. It is a biosecurity matter concerning species invasions (CBD 2010). It can be an attempt to reduce the propagule pressure, i.e., the rate at which a specific species is released in new environments. Public awareness can promote trade sustainability.

Conclusions

The marine aquarium trade in Iceland may represent a significant source of invasive species. Although the survival of tropical species in high latitudes might seem unlikely, climate change has already supported the establishment and proliferation of species from temperate regions. Additionally, the expected rise of sea surface temperature will probably assist in establishing a wider range of species. Furthermore, Endangered, Near Threatened and Vulnerable species are available on the market, which urges for the improvement of legislation and regulation of the aquarium industry. Management strategies are urgent and should include systematic gathering of information and educational campaigns aiming to reduce the potential release of unwanted live organisms to the environment.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11852-023-00986-4.

Acknowledgements We are thankful to Rakel Sigurveig Kristjansdottir for proofreading the manuscript.

Declarations

1 - All authors agree to the submitted version of the manuscript. The manuscript or parts of it have not been published elsewhere and are not under consideration elsewhere.
2 - All authors agree with the journal publication policy, including data publication policy and reviewing and publication decision procedure.
3 - There are no interests to declare.
4 - The manuscript has data included as Electronic Supplementary Material.

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