The marine ornamental fish trade in Switzerland and Europe

Inauguraldissertation
der Philosophisch-naturwissenschaftlichen Fakultät
der Universität Bern

vorgelegt von

Monica Virginia Biondo

von Oftringen, AG

Leiter der Arbeit:
Prof. Dr. W. Nentwig
Head of Division Community Ecology
Institute of Ecology and Evolution
Universität Bern

The marine ornamental fish trade in Switzerland and Europe

Inauguraldissertation
der Philosophisch-naturwissenschaftlichen Fakultät
der Universität Bern

vorgelegt von

Monica Virginia Biondo

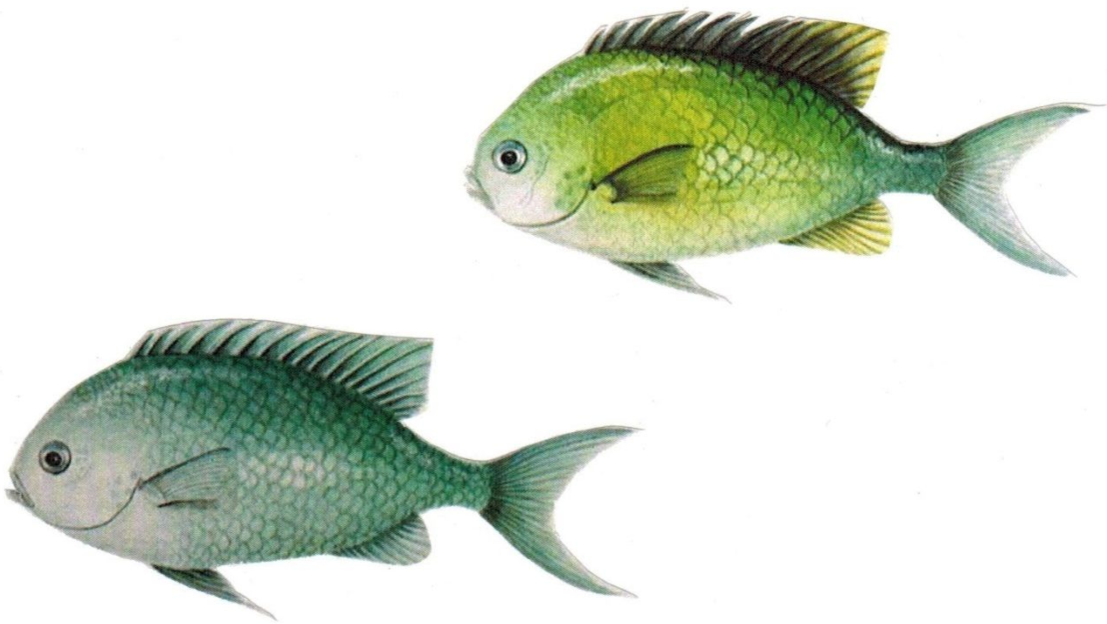
von Oftringen, AG

Leiter der Arbeit:
Prof. Dr. W. Nentwig
Head of Division Community Ecology
Institute of Ecology and Evolution
Universität Bern

Von der Philosophisch-naturwissenschaftliche Fakultät angenommen.

Bern, 12. März 2019 Der Dekan:

Prof. Dr. Z. Balogh



Chromis viridis: The most traded species of marine ornamental fish worldwide

Table of contents

General introduction

Coral reef ecosystems are one of the most biologically rich and diverse environments on the planet. Unfortunately, coral reefs are at risk from several threats such as global warming and ocean acidification (Hughes et al., 2017; Gattuso et al., 2014; Hoegh-Guldberg, 2007), and also from overexploitation, for example, by trade (Baillie et al., 2004). The trade in marine ornamental fishes originated in the 1930s with a few coral reef fishes being caught to be kept in aquariums. Today, about 40 million specimens are traded annually and the commerce expands over at least 50 exporting countries from (mainly) South East Asia, with most importing countries situated in the Western Hemisphere. This trade involves more than half the known 4,000 species of coral reef fishes (Rhyne et al., 2017), expands worldwide, and is worth billions of US$ each year (Leal et al., 2015; Dee et al., 2014; Monticini, 2010; Smith et al., 2008; Wabnitz et al., 2003). Historically, individual attempts have been conducted to monitor trade, although no global monitoring systems have emerged.

This dissertation focuses on the marine ornamental fish trade as well as aspects of its management in Switzerland, Europe and globally, along with impacts on species and the environment. The monitoring of this trade is challenging because so many species and specimens are involved, and the supply chain, from wild-capture to the aquarium holder, is also very extensive (Rhyne et al., 2017; Wabnitz et al., 2003). Almost no relevant fish species breeds in captivity (Sweet, 2017; Penning et al., 2009), and therefore supply originates from wild sources, which are coral reefs. Furthermore, there are concerns amongst scientists regarding the sustainability of this trade, due to the high mortality of specimens in the supply chain (Stevens et al., 2017; Vagelli, 2011; Wabnitz et al., 2003).

The purpose of this study was to review the existing data on the marine ornamental fish trade to Switzerland and Europe as well as its global implication. The first study examined Switzerland's role in the European and the global marine aquarium trade, and provided basic information on numbers of specimens traded and their diversity by using data from customs documents from 2009. The second and third studies used electronic data from the European Trade Control and Expert System (TRACES) for the years 2014 to 2017 for Switzerland and the European Union (EU). TRACES is in use for disease prevention where animal and plants or their products are imported to Europe. This data produced meaningful information for imports to Switzerland and the EU, although TRACES is not specifically created to monitor the marine ornamental fish trade. It was possible to yield useful information on the volumes, diversity and trends in number of fish specimens traded. These studies offered tangible ideas on how to adapt the TRACES to adequately collect species data.

References

Dee L.E., Horii S.S., Thornhill D.J., 2014. Conservation and management of ornamental reef wildlife: Success, shortcomings, and future directions. Biol Conserv. 169: 225-237. doi.org/10.1016/j.biocon.2013.11.025

Gattuso, J.-P., Hoegh-Guldberg O., Pörtner H.-O., 2014. Cross-chapter box on coral reefs. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R, Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 97-100. https://doi.org/10.1017/CBO9781107415379.005

Hoegh-Guldberg O., Mumby P.J., Hooten A.J., Steneck R.S., Greenfield P., Gomez E., Harvell C.D., Sale P.F., Edwards A.J., Caldeira K., Knowlton N., Eakin C.M., Iglesias-Prieto R., Muthiga N., Bradbury R.H., Dubi A., Hatziolos M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science. 318 (5857): 1737–1742. doi:10.1126/science.1152509

Hughes T.P., Barnes M.L., Bellwood D.R., Cinner J.E., Cumming G.S., Jackson J.B.C., Joanie Kleypas J., van de Leemput I.A, Lough J.M., Morrison T.H., Palumbi S.R., Egbert H. van Nes E.H., Scheffer M., 2017. Coral reefs in the Anthropocene. Nature 546: 82-90. doi:10.1038/nature22901

Leal M.C., Vaz M.C., Puga J., Rocha R.J., Brown C., Rosa R., Calado R., 2015. Marine ornamental fish imports in the European Union: an economic perspective. Fish Fish. 17: 459-468. https://doi.org/10.1111/faf.12120

Monticini P., 2010. The Ornamental Fish Trade. Production and commerce of ornamental fish. Technical-managerial and legislative aspects. FAO GLOBEFISH Research Programme; p. 102. Available: http://www.fao.org/3/a-bb206e.pdf (accessed 11.10.2018).

Penning M., Reid GMcG, Koldewey H., Dick G., Andrews B., Arai K., Garratt P., Gendron S., Lange S., Tanner K., Tonge S., Van den Sande P., Warmolts D., Gibson C., 2009. Turning the Tide: a Global Aquarium Strategy for Conservation and Sustainability. World Association of Zoos and Aquariums. Available: http://www.waza.org/files/webcontent/1.public_site/5.conservation/conservation_strategies/turning_the_tide/Aquarium%20strategy%20EN.pdf

Rhyne A.L., Tlusty M.F., Szczebak J., Holmberg R.J., 2017. Expanding our understanding of the trade in marine aquarium animals. PeerJ. 5:e2949. https://doi.org/10.7717/peerj.2949

Sweet T. 2017: The state of the marine Breeders' art, 2016. CORAL, 13(1). Available: http://www.reef2rainforest.com/2015/12/22/captive-bred-marine-fish-species-list-2016/

Vagelli A.A., 2011. The banggai cardinalfish. Natural history, conservation and culture of *Pterapogon kauderni*. Wiley-Blackwell

Wabnitz C., Taylor M., Green E., Razak T., 2003. From ocean to aquarium. UNEP-WCM, Cambridge, UK. http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf

Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union

Published in *Global Ecology and Conservation, 11 (2017) 95-10*

Global Ecology and Conservation 11 (2017) 95–105

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union

Monica V. Biondo

Institute of Ecology and Evolution, University of Bern, Baltzerstrasse 6, 3012 Bern, Switzerland

A R T I C L E I N F O

Article history:
Received 15 February 2017
Accepted 25 May 2017
Available online 3 June 2017

Keywords:
Marine ornamental fishes
International trade
Trade monitoring
Trade information system TRACES
IUCN red list
CITES convention on international trade of endangered species

A B S T R A C T

Millions of marine ornamental fishes are traded every year. Today, over half of the known nearly 4000 coral reef fish species are in trade with poor or no monitoring and demand is increasing. This study investigates their trade into and through Switzerland by analyzing import documents for live animals. In 2009, 151 import declarations with attached species lists for marine ornamental fishes from non-EU countries totaled 28 356 specimens. The 62% of the fishes remaining in Switzerland, comprised 440 marine species from 45 families, the rest transited to EU and non-EU countries. Despite the recognized large trade volume for the European region, due to bilateral agreements, no data is collected for imports from the EU. However, inferred data shows that more than 200 000 marine ornamental fishes could be imported into Switzerland every year and an unknown quantity re-exported. As biggest import region, it is therefore safe to assume, that the European region is importing at least as many marine ornamental fishes as the US. There is no adequate data-collecting system known to be in place in any country for monitoring this trade. The EU Trade Control and Expert System (TRACES) to monitor animal diseases could be adjusted to gather compulsory information for the EU and Switzerland. More than half of the species imported into Switzerland are not assessed by the IUCN and therefore marked as 'not evaluated' on the Red List. Overall, 70% of all known coral reef fish species have not been evaluated. If coral reef fishes are threatened or endangered due to large, possibly unsustainable numbers traded, it may be rational to monitor the trade in these species through the Convention on International Trade of Endangered Species (CITES).

1. Introduction

Coral reefs occupy less than 0.1% of the total expanse of the world's ocean areas (Spalding et al., 2001). However, coral reefs are considered to be amongst the most biologically rich and productive ecosystems on Earth, often referred to as the 'rainforest of the seas'. Coral reefs support approximately 4000 species of fish (Froese and Pauly, 2014) (or a third of the world's known marine fishes), about 800 species of reef-building corals (stony corals) (Veron, 2000), and a great number of other invertebrates (Spalding et al., 2001). Roughly 7.5% of the human population depends on coral reefs, for example, for food (Madin and Madin, 2015). However, over one third of the scleractinian corals are at elevated risk of extinction

E-mail address: monica.biondo@students.unibe.ch.

http://dx.doi.org/10.1016/j.gecco.2017.05.006
2351-9894/

(Carpenter et al., 2008). The world has effectively lost 19% of the original area of coral reefs, 15% are seriously threatened with loss within the next 10–20 years, and 20% are under threat of loss in 20–40 years (Wilkinson, 2008). Furthermore, overexploitation, coastal development (Wear, 2016) as well as land-based pollution (Lough, 2016) are identified as major threats.

Ornamental coral reef fishes and invertebrates are the most valuable product (Fotedar and Phillips, 2011; Wabnitz et al., 2003) that can be harvested from a coral reef, hence making it a profitable target for trade. In 2000, 1 kg of coral reef fish for the aquarium trade sold for US$500 whereas food fish sold for US$6 (Cato, 2003). Overcollection of coral organisms for the aquarium trade can have a significant impact on both population viability and the wider ecological system (Thornhill, 2012; Vagelli, 2011; Tissot et al., 2010; Bshary, 2003; Sadovy et al., 2001). According to a comprehensive study by the United Nations Environment Program (UNEP) and the World Conservation Management Centre (WCMC), the vast majority of fishes for marine aquariums come from the wild and only about 1% (approximately 15 species in 2003) are commercially produced and readily available (Wabnitz et al., 2003). The Food and Agriculture Organization of the United Nations (FAO) and the World Association of Zoos and Aquariums (WAZA) state that only 25 marine ornamental fish species are being captive bred in commercial numbers (Penning et al., 2009, Bartley, 2005). A list of captive bred marine ornamental fishes published by the Marine Breeders Association (MBA) lists 15 species in 2013 and 29 species of captive bred marine ornamental fishes in 2015 and 27 in 2016, which are readily availability in the US (Sweet, 2016a, b, 2014). There are reports of between 100 and 330 species of marine ornamental fish having been bred in captivity, largely on a hobbyist or research scale. Of these, approximately 30–35 species are currently in commercial production, albeit still on a relatively small scale (Sweet, 2016b; Fotedar and Phillips, 2011).

The United States (US) constitutes the largest importing country whereas all the countries of the European Union (EU) correspond to the largest market of marine ornamental fishes (Leal et al., 2015; Wabnitz et al., 2003). The diversity of species in trade has increased from 1000 marine ornamental fish species in 2001 and 1471 in 2005 (Rhyne et al., 2012; Wabnitz et al., 2003; Wood, 2001) to around 2300 species in international trade today (Rhyne et al., 2017) the volume being between 20 and 30 million a year (Wabnitz et al., 2003; Wood, 2001), 11 million alone to the US (Rhyne et al., 2017; 2012). Despite the volume and diversity of fishes traded few laws or regulations are in place to control this animal trade (Rhyne et al., 2017; 2012 and Wabnitz et al., 2003). Most exporting countries are reported to have either no specific management plans, or they have produced management plans that are rarely enforced and implemented based on weak scientific baseline studies or monitoring activities (Dee et al., 2014; Thornhill, 2012; Wabnitz et al., 2003).

Many fishes die during capture due to trauma, poor handling, stress and in transportation or as a result of poisoning from sodium cyanide, which, although illegal, is still widely used for the capture of reef fish throughout Southeast Asia and causes extensive fish mortality as well as damage to many more coral habitat animals (Dee et al., 2014; Cervino et al., 2003; Wabnitz et al., 2003). Therefore, the number of fishes extracted from the reefs must be higher than the estimated numbers (Militz et al., 2016). There are about two million private (Wabnitz et al., 2003) and about 1000 public (ConsultEcon, 2008) marine aquariums worldwide. Globally, many cities are planning to build new public aquariums (ConsultEcon, 2008) and also private demand is increasing (Santhanam et al., 2015; Fotedar and Phillips, 2011). Animation films such as Disney/Pixar's ‘Finding Nemo’, which first aired in 2003, seem to promote incentives to own marine aquariums in domestic environments, which may have a significant impact on trade and keeping (Frisch et al., 2016; Madduppa et al., 2014; Jones et al., 2008). Conservationists worry that the follow-up film ‘Finding Dory'could spike trade volumes as, in contrast to the main character in ‘Finding Nemo’, a clown fish, Dory, a surgeon fish, cannot be bred in captivity. So far, no increase in trade could be observed (Militz and Foale, 2017).

Data regarding numbers of marine ornamental fishes entering Switzerland is very limited. In 1995, the Swiss Animal Protection Organization (Schweizer Tierschutz STS) estimated that the most commonly kept pets in Switzerland constituted seven million ornamental fishes (Stumpf, 1995). The US is estimated to keep 160 million ornamental fishes (ASSALCO, 2015), around 10 millions of which are of marine origin (Rhyne et al., 2012). Very few marine ornamental fish are protected or monitored by the Convention on International Trade of Endangered Species (CITES), the exceptions are sea horses (*Hippocampus* spp.), the humphead wrasse (*Cheilinus undulates*) and since 2017 the clarion angelfish (*Holacanthus clarionesis*). Trade information on marine ornamental fishes in Europe is collected through the trans-European veterinary health agreement (Trade Control and Expert System TRACES).

Declarations pertaining to shipments from outside the EU are recorded on the Common Veterinary Entry Document (CVED) and it is optional to list species. The CVED is used in Switzerland as well as in the EU. A registered importer or private person has to declare imports to the appropriate border veterinary control body prior to importation. Border customs execute random checks by inspecting two boxes per shipment. Due to bilateral agreements, no import declarations are required to accompany a shipment when entering Switzerland through an EU country (European Trade Commission, 2016). In order to be able to monitor or restrict trade for a marine ornamental fish not only biological and ecological criteria are necessary (which are lacking for 70% of all known coral reef fishes) but also trade volumes are required. Both are necessary to convince the world community of the necessary of CITES-listing of species to monitor trade.

Except for very few studies on the marine ornamental fish trade (Rhyne et al., 2017, 2012; Smith et al., 2009, 2008), to date, no other study has tried to quantify the imports of marine ornamental fishes. The present study focuses on the import of marine ornamental fishes into Switzerland and their transit to EU and non-EU countries through Switzerland in 2009. This study is the first to analyze CVED information for the European region.

2. Materials and methods

The Swiss Federal Food Safety and Veterinary Office (FSVO) is responsible for the inspection of live wildlife shipments, but is not instructed to keep any species-specific data. Data on all imports of live animals, dead specimens, hunting trophies, medical animal materials, etc., which are not under the jurisdiction of the Convention on International Trade of Endangered Species (CITES) are collected through the Common Veterinary Entry Document (CVED) and transferred voluntarily to the electronic database Trade Control and Expert System (TRACES). This data is not intended for the supervision of wildlife trade, rather it serves to monitor animal diseases. Usually, these CVED documents are stored for three years, after which they are destroyed, and a retrospective analysis is no longer possible. All third countries (i. e. non-EU-countries) have to declare all exports of live animals at the border to an EU country or to Switzerland. However, due to bilateral agreements for fishes no border control is implemented between the EU and Switzerland and, therefore, no detailed information exists regarding coral reef fish species entering Switzerland through the EU.

Records of marine ornamental fishes are kept under the general data grouping of 'ornamental fishes', which comprises saltwater and freshwater fishes as well as invertebrates. To assess the volume of marine ornamental fishes imported into Switzerland, all declarations containing marine ornamental fishes were first identified from 2009 import declarations, which were made available to this study in 2013. To estimate the number of marine ornamental fishes entering Switzerland from imports without species lists, numbers of other pet animals in the US and European region were compared and two calculations were performed. Variant 1 assumes that the average specimens/shipment/destination (Switzerland or transit) is the same for the shipments without a species list as for the one with a species list. In variant 2, the number of specimens is calculated by expecting that the ratio of shipments of marine ornamental fishes to freshwater to invertebrates is the same for the shipments without a species list as for the one with species list. Both variants assume that 90% of ornamental fishes are freshwater species (Monticini, 2010; Bartley, 2005; Wabnitz et al., 2003).

All shipment declarations from the CVED documents and attached commercial invoices came through the airport of Zurich. Basel and Geneva airports had no discernible imports of marine ornamental fishes, and imports from online buyers and private persons importing by car could not be accounted for. Where a species list was included, the information was entered manually into a database at species level, citing the number of individuals, and, if available, body size and value were also recorded. The export country was listed as origin of the fishes. Not all importation documents included invoices and species lists, and documents that did not contain the required information were not considered for the calculation. In all cases, species names were verified using the World Register of Marine Species (WoRMS) (Appeltans et al., 2011) and FishBase (Froese and Pauly, 2014) and corrected when species names were misspelled, listed under a former synonym, or listed with common names (4% of cases). Forty-seven specimens (0.2%) were not identified to the species level and were removed from analyses where the species level was required. The information on the IUCN Red List status was gathered from FishBase (Froese and Pauly, 2014).

3. Results

3.1. Origin and destination

For 2009, 1478 import declarations labelled ornamental fishes for the aquarium industry from non-EU countries were counted. Of those imports, 55.9% contained only freshwater ornamental fishes, 28.6% did not have a species list, 5.3% contained only marine invertebrates, and 10.2% contained both marine and freshwater ornamental fishes. Of these, 45% stayed in Switzerland and 55% were transshipped to EU and non-EU countries. The marine fishes destined for Switzerland came from eight countries; Indonesia being the main exporter, followed by Sri Lanka, Singapore and the Philippines (Table 1). The size of shipment ($n = 68$) averaged 260 marine ornamental fishes with the smallest shipment containing 3, the largest 1070 fishes ($SD = 247$). Of the 422 import declarations without species lists 12% were destined for Switzerland. Of the 373 import (transshipped) declarations without a species list 55% were exported to Canada, followed by Israel with 13% and the US with 6%.

3.2. Number of imported ornamental fishes

Of the 1478 import declarations 1056 contained species lists. 68 declarations included marine fishes (17 673 specimens) whose final destination was Switzerland, 83 declarations (10 683 specimens) were transshipments of marine ornamental fishes, 826 declarations contained only freshwater fishes and 79 declarations were invertebrates. Import declarations with marine ornamental fishes consistently included freshwater fishes. In total, the import declarations contained 28 356 marine ornamental fishes (Table 2). 422 declarations did not enclose a species list, but 91% contained numbers of specimens of marine and freshwater fishes as well as invertebrates and totaled in 4 440 427 specimens. Of these, 96 268 remained in Switzerland and 4 344 159 were transshipped to EU and non-EU countries (Table 2).

Besides the counted 28 356 marine ornamental fishes that entered Switzerland in 2009, data for shipments without species lists inferred from known average marine ornamental fish specimens per shipment ($CH = 260$, $transit = 129$) resulted in a further 8627 specimens (variant 1). Inferring the ratio of shipments of marine to freshwater to invertebrates with species lists to the ones without species lists (average $CH + transit = 188$) resulted in 11 332 marine ornamental fishes (variant 2) that

Table 1
Origin and destination of shipments as well as number of shipments (= import declarations) containing species lists of marine ornamental fishes.

Origin	Final destination	Number of shipments	Number of fish specimens with final destination Switzerland
Singapore	Switzerland	21	1892
	Spain	32	
	Serbia	1	
	Russia	1	
	Romania	1	
	Portugal	11	
	Israel	1	
	Ireland	1	
	Germany	1	
	Czech Republic	3	
Sri Lanka	Switzerland	11	2179
	Russia	1	
	Romania	5	
	Portugal	5	
	Poland	2	
	Canada	1	
Indonesia	Switzerland	25	11 167
Thailand	France	11	
United States	Switzerland	5	522
	Russia	2	
Philippines	Switzerland	2	671
Vietnam	Switzerland	1	219
Kenya	Switzerland	2	659
Israel	Portugal	1	
Japan	Portugal	1	
Netherlands Antilles	Switzerland	1	364
Tanzania	Poland	1	
Total		151	17 673

were possibly additionally imported into Switzerland. Therefore, between 36 983 (variant 1) and 39 688 (variant 2) marine ornamental fishes could have entered the country in one year (Table 2). Due to bilateral agreements between Switzerland and the EU, no data is gathered for shipments entering Switzerland via the EU.

For 12 385 fishes (70% of 17 673), a value was specified on the import declarations, and the import prices ranged from US$0.20 to US$260 per fish. The average price for a fish was US$3.

3.3. Species

The 68 imports remaining in Switzerland and containing marine fishes totaled 17 673 specimens. These imports comprised 440 species from 45 families. The family with the most species was Labridae (70 species, 11.3% of specimens) followed by Pomacanthidae (47 species, 6.7% of specimens). The family with the most specimens was Pomacentridae at 27%. The six families with the most specimens represented 62% of species and 70.3% of individuals imported (Table 3). Four species from two families (Pomacentridae and Labridae) including the clown anemonefish (*Amphiprion ocellaris*) and the bluestreak cleaner wrasse (*Labroides dimidiatus*) represented 20.9% of the traded fishes. For 81% of the 17,673 fishes, there was no information on body size. From the 3343 fishes with body size information, 28% were labelled juvenile, 34% were medium sized (most probably sub-adults), and 38% were adults. Of the 940 juvenile fishes (from 84 genera), 902 fishes (from 55 genera) exhibited an ontogenetic dichromatism compared to the adult stage; specifically, angelfishes (Pomacenthidae). Of the 1273 adult fishes (from 110 genera), 425 were clown anemone fishes (*A. ocellaris*) followed by the longhorn cowfish (*Lactoria cornuta*) with 57 fishes and the bluestreak cleaner wrasse (*L. dimidiatus*) with 48 fishes.

3.4. Conservation status

Of all species entering Switzerland 51.8% were listed as 'not evaluated', 2.5% were 'data deficient', 43% 'least concern', 0.7% were 'near threatened', 0.5% were 'vulnerable', and 0.2% (one species, *Pterapogon kauderni*) was 'endangered'. Six species were not listed by FishBase. An analysis of the conservation status of all known coral reef fish species that are listed in FishBase (Froese and Pauly, 2014) showed that of all recorded 3711 coral reef fish species, 70% are not evaluated (Table 4).

Of the ten most imported fish species, seven are included on the IUCN Red List as 'not evaluated'. At import rank 1 is *Chromis viridis*, with 1600 specimens, followed by *Amphiprion occellaris* with 1008 specimens. Also, *Chrysiptera parasema* at rank 4, the *Pseudanthias squamipinnies* at rank 5 and *Valenciennea puellaris* at rank 7 as well as *Zoramia leptacanta* at rank 8 and *Synchiropus splendidus* at rank 10 are not evaluated by the IUCN Red List. *L. dimidiatus* (rank 3) with 597 specimens and *Paracanthurus hepathus* (rank 9) with 346 specimens are listed as warranting 'least concern'. *P. kauderni* (rank 6) with 413 specimens is listed as 'endangered' (Fig. 1).

Table 2
Number of import declarations with and without species lists of ornamental fishes staying in Switzerland (CH) or transshipped to EU and non-EU countries. Origin are non-EU countries. Variant 1: inferring data using the average specimens/shipment and assuming that 90% of ornamental fishes are freshwater. Variant 2: inferring amounts from the number of shipments with species lists and number of specimens. No information is available for shipments entering Switzerland via the EU. Inferred values in bold.

	Origin	Species list	Destination	Type	Counted shipments	Inferred shipments	Counted specimens	Inferred specimens	Counted specimens/ shipments	Total of counted and inferred specimens
Variant 1	**Non-EU**	With species list	CH	Marine	68		17 673		260	
				Freshwater		**364**		**159 057**	**437**	
				Invertebrates	34		60 805		1788	
			Transit	Marine	83		10 683		129	
				Freshwater	**462**			**96 147**	**208**	
				Invertebrates	45		467 212		10 382	
			Total CH + transit	Marine	151		28 356		**188**	
				Freshwater	826			**255 204**		
				Invertebrates	79		528 017		6684	
				Total	1056			**811 577**	**769**	
		Without species list	CH	Marine		**7**		**1860**	**260**	**19 533**
				Freshwater				**7774**	0.9	
				Invertebrates				**87 631**	**1788**	
			Total CH	MarFreInv	49		96 268			
			Transit	Marine		**52**		**6768**	**129**	
				Freshwater				**424 342**	0.9	
				Invertebrates				**3 872 668**	**10 382**	
			Total transit	MarFreInv	373		4 344 159			
			Total CH + transit	Marine				**8627**		**36 983**
				Total	422		4 440 427		10 522	
Variant 2		With species list	CH	Marine	151		28 356		**188**	
				Freshwater	826		255 204		**309**	
				Invertebrates	79		528 017		**6684**	
				Total	1056		811 577			
		Without species list	CH + transit	Marine		**60**		**11 332**	**188**	**39 688**
				Freshwater		**330**		**101 985**	**309**	
				Invertebrates		**32**		**211 007**	**6684**	
				Total	422			**324 323**		
			Total		1478					

Table 3
Family and number of species as well as specimens imported into and remaining in Switzerland in 2009. Top 20 families, ranked according to number of specimens; the first six families represent 70% of the total number of individuals imported.

Family	Species	Specimens
Pomacentridae	43	4763
Labridae	70	1991
Gobiidae	46	1958
Acanthuridae	38	1369
Pomacanthidae	47	1186
Serranidae	29	1157
Apogonidae	8	942
Chaetodontidae	42	738
Callionymidae	7	666
Blenniidae	18	617
Ptereleotridae	7	428
Pseudochromidae	10	263
Syngnathidae	8	194
Ostraciidae	3	184
Monacanthidae	11	144
Scorpaenidae	9	128
Grammatidae	1	124
Siganidae	4	123
Zanclidae	1	114
Tetraodontidae	9	94
Other	29	490

Table 4
IUCN Red List evaluation (%) of marine ornamental fish species imported into Switzerland. Switzerland, n = 440 (left) compared to worldwide known species, n = 3711 (right).

IUCN Red List Definition	Switzerland	Worldwide
Not evaluated NE	51.8	70.0
Data deficient DD	2.5	3.3
Least concern LC	43.0	23.2
Near threatened NT	0.7	1.1
Vulnerable VU	0.5	2.1
Endangered EN	0.2	0.2
Critically endangered CR	0.0	0.1
Not listed	1.4	0.0

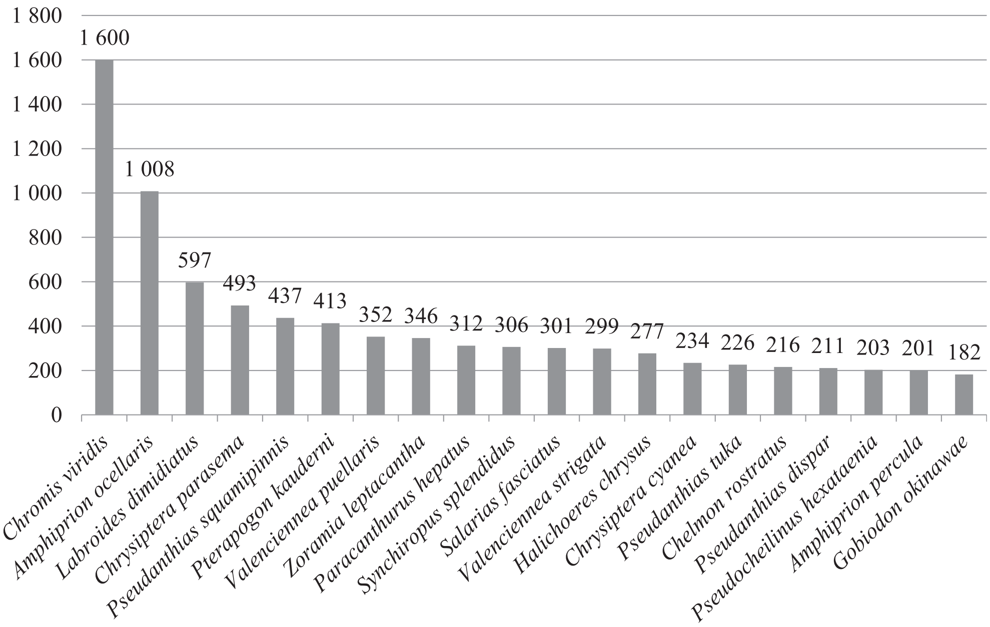


Fig. 1. Number of specimens of the top 20 marine ornamental fish species imported and remaining in Switzerland in 2009.

4. Discussion

4.1. Origin, destination and trade volume

In 2005, FAO estimated the entire freshwater and marine ornamental fish industry (non-exported products, wages, retail sales and associated materials) to be worth around US$15 billion. Considering that the marine ornamental fish trade amounts to 10% of the entire marine/freshwater ornamental fish industry (Monticini, 2010; Bartley, 2005; Wabnitz et al., 2003), this would translate to approximately US$1.5 billion a year. Collectively, European Union countries constitute the largest market (500 million consumers) for ornamental fishes (Leal et al., 2015), and Indonesia is the largest exporter, followed by the Philippines (Leal et al., 2015; Rhyne et al., 2012; Wabnitz et al., 2003).

Previously, no study has attempted to quantify the import volume of marine ornamental fishes into Switzerland through the available import documents. The only previous research on trade relied on oral or written information provided by Swiss importers and retailers (Weber, 2001).

The present analysis relies on the quantitative information contained on the shipping declarations (Common Veterinary Entry Document CVED) and the associated species lists. This study found that in one year, Switzerland imported 28 356 marine ornamental fishes, of which 17 673 specimens belonging to 45 families remained in Switzerland and came from eight countries. Switzerland imported most fishes from Indonesia followed by Sri Lanka (rather than the Philippines as is the case for the US, probably because Sri Lanka is geographically closer and Switzerland has a strong Sri Lankan community).

Almost a third of all imports lacked a species list, although 91% declared a total amount of ornamental fishes, which totaled 4 440 027 (marine, freshwater fishes and invertebrates). To overcome the uncertainties regarding the number of marine ornamental fishes entering Switzerland, two variants were used to calculate possible volume. Adding the inferred number of marine ornamental fishes to those formally counted, it is possible that almost 40 000 (between 36 983 and 39 688) marine ornamental fishes entered Switzerland in one year with one part being re-exported. However, it is very important to take into consideration that, due to bilateral agreements, no information at all is available for shipments entering Switzerland through the EU and therefore probably a substantial portion of this trade is not accounted for.

Comparing population, wealth and pets of the US, EU and Switzerland it seems peculiar that Swiss households should keep 10 times less marine ornamental fishes per capita than the US or the EU/UK (Table 5). Assuming that Switzerland imports (without re-exporting) the same volume of marine ornamental fishes per capita as the US, this would result in 240 000 marine ornamental fishes entering and staying in Switzerland every year (8 million citizen x 0.03 fishes). This would result in an estimated number of unreported cases of about 220 000 marine ornamental fishes (240 000 calculated - 17 673 counted - 1860 inferred fishes). As there are no declarations of this trade between the EU and Switzerland due to bilateral agreements, these specimens are likely to be coming from the EU.

Wabnitz et al. (2003) and Rhyne et al. (2017, 2012) state that the main destination countries are the US and the EU, which is reflected by the almost identical value of imported marine ornamental fishes in US$ for the two regions (Table 5). Although, the EU has about 60% more people than the US, but a 30% lower GDP, it is therefore possible that the EU imports a similar amount of marine ornamental fishes as the US. This supports an assumption that wealth is loosely coupled with fishes per capita.

4.2. Species

The diversity of species in trade has been increasing. Studies show that during approximately the last 20 years the species in trade worldwide rose from 1000 to about 2300 coral reef fish species (Rhyne et al., 2017, 2012; Wabnitz et al., 2003; Wood, 2001). Moreover, in one year (2004-5) the US, the main importing country, imported almost 10.5 million marine ornamental fishes, representing 125 families (Rhyne et al., 2012) re-exporting about 1 million marine ornamental fishes. The number of marine ornamental fish species in the aquarium trade will probably continue to increase, as demand for new species has been growing (Rhyne et al., 2017). Globally, the number of home aquariums (Rhyne et al., 2017; Santhanam et al., 2015; Fotedar and Phillips, 2011) is growing and new public and private aquariums are being built or planned (Google search, 2014). There is growth potential for the aquarium industry, as only half of the 100 major cities (more than three million habitants) have a public aquarium, in particular in China, the Middle East, North America, Southeast Asia, South America and Eastern Europe (ConsultEcon, 2008). As commercial fishing and storage equipment become more sophisticated, it will also be easier to acquire stock. This is underlined by the fact that within approximately 20 years, the marine aquarium hobby developed from ‘fishes-only’ aquariums to entire coral reef set-ups, with people spending up to US$20 000 for uncommon organisms (Ho, 2013; Courchamp et al., 2006). FAO calculated that between 1985 and 2005 the marine ornamental fish industry increased by 14% annually (Bartley, 2005). Most capital does not remain in the source country and is passed to importers and other traders, as well as to retailers in the importing nation. For example, fishermen receive approximately US$0.05 per Banggai cardinal (*P. kauderni*) caught (personal communication Vagelli, 2015) whereas the same fish is sold for up to US$65 in Switzerland (a 1300-fold increase) (Aqula, 2016). Furthermore, tank-bred marine ornamental fishes command at least 25% higher prices than wild-caught fishes (Fotedar and Phillips, 2011).

Table 5
Comparison of marine ornamental fishes (specimens), number of public aquariums and fishes per capita, as well as households with pets and per capita dog, cat and bird pets between the USA, the EU, the UK and Switzerland, N. d. = no data. Where available, data from 2009 was used.

	USA	EU-27[a]	UK	CH
Human population in millions (2009)[b]	307	503	62	8
GDP per capita in US$ (2009)[c]	47 000	34 000	37 000	70 000
Imported marine ornamental fish specimens in millions staying in country	10.5 (2005) (Rhyne et al., 2012)	n. d.	1.4 millions (2014)[d]	0.02 (this study)
Value of imported marine ornamental fishes (US$) in millions	11.2 (LEMIS, 2011)	11.3 (mean 2000–2011) (Leal et al., 2015)	4.6[d]	n. d
Number of public aquariums	118[e]	135[f]	28[f]	0
Imported marine fishes per capita	0.034	n. d.	0.02	0.003
Homes with pets in millions	80[g]	75 (2014)[h]	n. d	0.88[j]
Dogs per capita	0.3 (2015)[g]	0.2 (2014)[h]	n. d.	0.07[j]
Cats per capita	0.3 (2015)[g]	0.2 (2014)[h]	n. d.	0.2[j]
Birds per capita	0.05[g]	0.08[h]	0.02[i]	0.07[j]

[a] includes the UK.
[b] http://data.worldbank.org/indicator/SP.POP.TOTL?end=2009&start=1981.
[c] http://data.worldbank.org/indicator/NY.GDP.PCAP.CD?end=2009&page=1&start=1960.
[d] http://www.ornamentalfish.org/wp-content/uploads/Wild-caught-ornamental-fish-the-trade-the-benefits-the-facts.pdf.
[e] https://en.wikipedia.org/wiki/List_of_aquaria_in_the_United_States.
[f] https://en.wikipedia.org/wiki/List_of_aquaria#Europe.
[g] http://www.americanpetproducts.org/press_industrytrends.asp.
[h] http://www.fediaf.org/facts-figures/.
[i] http://www.pfma.org.uk/pet-population-2008-2012.
[j] https://www.hausinfo.ch/de/home/wohnen/haustiere/haustiere.html.

For over 80% of the imported fishes, information regarding size class was not included. However, over 60% (2070 specimens) of those fishes carrying size data were labelled as juveniles and sub-adults. Almost all juvenile fishes in the present study manifested ontogenetic dichromatism, i.e. juveniles and sub-adults showed different coloration compared with adults, and this is also the case for Pomacanthidae, which represents the second most traded family. These species seem to attract particular interest from the aquarium industry in Switzerland, as well as in the US and worldwide (Rhyne et al., 2012; Wabnitz et al., 2003). In addition, some coral reef fishes are sequential hermaphrodites (changing sex during their life cycle), and fishing may result in a sex drift, and ultimately in a reduction of size in natural populations (Coleman et al., 2000).

4.3. Conservation status

The natural habitat of coral reef fishes, the coral reefs, faces great threats such as climate change (Frieler et al., 2012; Hughes et al., 2007), ocean acidification and over collection for food and of key species (Hoegh-Guldberg, 2007). Moreover, there are no controlling entities in place for establishing sustainable trade. The Marine Aquarium Council (MAC) was established in 1998 in order to ensure responsible fishing, including the use of nets instead of illegal use of poison, and good husbandry, as well as managing fair prices - allowing consumers to choose more responsible operators and traders. Conforming companies were certified (MAC label) (UNEP, 2009). However, this certification has not been active since 2008 (GuideStar, 2014). Albeit this failing, Murray and Watson (2014) argue that a certification scheme which would be founded with governmental support could be a very efficient way to move towards a self-regulated commerce.

With few exceptions, for example *P. kauderni*, which has been thoroughly studied (CITES, 2016; Conant, 2015; Vagelli, 2011, 2008, 2002; Lunn and Moreau, 2004), very little information is available on the ecology, life cycle, and population dynamics for many known coral reef fish species. This dearth of information is arguably a major concern regarding the evaluation of potential threats to coral reef fishes.

4.4. Case studies

The Banggai cardinalfish (*P. kauderni*) endemic to Eastern Sulawesi, Indonesia, is a very popular marine ornamental fish in Switzerland (import rank 6) and the US (import rank 10) as well as worldwide (Rhyne et al., 2012; Wabnitz et al., 2003) and only caught for the aquarium trade. As of 2016 the US included *P. kauderni* in its Endangered Species Act ESA enabling protection through US laws (Conant, 2016). The species plays an important role in its environment by preying on larval stages of coral reef fish parasites, and as a prey item for several fishes and a sea snakes (CITES, 2016; Conant, 2015; Vagelli, 2011, 2008, 2002; Lunn and Moreau, 2004). Physical injury during capture, confinement in holding pens, and transportation stresses result in high mortality (Lilley, 2008). In addition, mortality can be approximately 80%–100% between post-import and consumer stages (Vagelli, 2011). It has been estimated that the abundance of *P. kauderni* within its natural range (~23 km^2) (CITES, 2016) has suffered an approximate 90% decline compared with its pre-harvest level (Vagelli, 2011; Allen and Donaldson, 2007). Some *P. kauderni* populations have already been overexploited and others extirpated (CITES, 2016; Conant, 2015; Vagelli, 2011, 2008, 2002; Lunn and Moreau, 2004). Although captive breeding *P. kauderni* is possible, wild caught fish are considerably cheaper and, therefore, widely traded (Vagelli, 2011). Attempts to restrict trade through CITES in 2007 and 2016 failed, although in 2016 the CITES member states decided that Indonesia will have to implement protection and management schemes by the mid 2018 (CITES, 2016). In 2007 the species was listed as 'endangered' by the IUCN. In light of the information available today, a listing of this species in CITES would be warranted and developing conservation approaches with the local communities could be beneficial to the species (Ferse et al., 2010).

The bluestreak cleaner wrasse (*L. dimidiatus*) was the third most imported marine ornamental fish in Switzerland and also one of the most imported species into the US and the EU (Rhyne et al., 2012; Wabnitz et al., 2003). *L. dimidiatus* fairs poorly in aquariums (Michael, 1999), but is essential to the health of coral reefs and drives diversity. The species removes ectoparasites from other animals and thus reduces parasite abundance (Grutter, 1999). Studies have shown that the species' absence is followed by a rapid decline of fish diversity (Waldie et al., 2011; Bshary, 2003).

The palette surgeonfish (*Paracanthurus hepatus*), at import rank 9 in Switzerland, is also one of the most traded and valuable marine ornamental fish traded in the US and worldwide (Rhyne et al., 2012; Wabnitz et al., 2003). The species requires a continuous intake of zooplankton (Thaler, 2015), reacts aggressively toward other surgeonfishes or coral reef fishes, is notably susceptible to disease (Corrales et al., 2009), and became well known as a result of the Disney/Pixar film 'Finding Nemo'. However, contrary to anemone fishes, it cannot be bred in captivity partly because very little is known of its very long larval cycle (Thaler, 2015, 2008). In 2016, the new Disney/Pixar film 'Finding Dory', which portrays a female *P. hepatus* as the primary character, and has led to concern that a surge in trade in this species may result, as occurred with anemone fishes when 'Finding Nemo' was screened (Frisch et al., 2016; Madduppa et al., 2014; Jones et al., 2008), but an increase does not seem to be happening (Militz and Foale, 2017) as *P. hepatus* grows to 30 cm, too big for home aquariums, and is much more difficult to keep (Thaler, 2015).

The mandarinfish (*S. splendidus*), at import rank 10 in Switzerland, manifests intricate fins and bright colors, and accordingly it is a highly prized fish in the marine aquarium trade in the US and worldwide (Rhyne et al., 2012; Wabnitz et al., 2003). Up to 70% of fish caught are male (Wabnitz et al., 2003). Female mandarin fishes may refuse to mate with smaller males (Sadovy et al., 2001). The species' leads a relatively secluded lifestyle, and this has led collectors to develop a spear fishing method for their capture, which can result in injury, paralysis, or even death (Thornhill, 2012). Furthermore, most individuals of these species do not acclimatize to the home aquarium, often refusing to feed, and consequently succumb to disease and death in captivity (Wabnitz et al., 2003; Michael, 1999). Captivity-related mortality increases demand, driving additional collection and results in further harm to mandarinfish populations (Sadovy et al., 2001).

5. Conclusion

This and other publications (Rhyne et al., 2017, 2012; Leal et al., 2015) show that collecting data via customs documents may lack precision due to data deficiency, although the method does provide a general overview of this trade. Regardless, more detailed information is warranted and important. The lack of trade controls and of an adequate information system for recording all imported and (re-) exported (transitory) marine ornamental fishes renders the monitoring of trade in marine ornamental fishes very difficult, if not impossible. Catch data at the species level is important when attempting to assess the effects of collection, development of management strategies, and assessment of their efficacy (Wabnitz et al., 2003). In addition, more detailed information should be collected in order to be able to quantify what effects trade is having on ecology, species conservation, and animal welfare. In Switzerland up to the year 2013 marine and freshwater ornamental fish as well as invertebrates where recorded as ornamental fish only. Since 2013, the electronic database TRACES (Trade control and Expert System) used by customs in Switzerland and the EU includes a list of approximately 2000 marine ornamental fishes, although TRACES is not suited to accurately monitor trade data. At present a trader can voluntarily state the number of specimens imported. Additional compulsory information such as volume, origin and size of specimens, and whether animals are wild-caught or captive-bred, should also be collected. Accordingly, and although not fully accurate (Rhyne et al., 2012; Smith et al., 2009, 2008; Jennings and Polunini, 1999), it has been suggested that the similar US database LEMIS (Law Enforcement Management Information System) could be adapted to incorporate more information on ornamental fishes, and hence be a useful tool to collect data concerning the coral reef fish trade (Rhyne et al., 2012; Tissot et al., 2010) but overall trade control have to improve (Foster et al., 2016; Chan et al., 2015). Also, these two databases could be made compatible to exchange information and support the data analysis.

To conserve and manage reef fishes properly, it is important to first identify those species that are susceptible to over-collection (Jennings and Polunini, 1999). However, in order to reliably assess the conservation status of relevant species, data regarding the ecology, population dynamics, and recruitment patterns are required, yet often poorly known. Because more than half of the specimens entering Switzerland, and 70% of all known marine ornamental fishes, are not evaluated using the IUCN Red List, it is recommended that all the known coral reef fish species listed in FishBase are urgently assessed by the IUCN. Potential impacts associated with the overall international trade remain unclear because data is only collected accurately for organisms listed in the CITES appendices (Bruckner, 2001), which therefore excludes very many species commonly in trade. Species, which are threatened by international trade should to be monitored by CITES (Murray et al., 2012). CITES listing requires that non-detriment findings will be conducted, and therefore, trade will not negatively impact species. Such a step was taken only three times. In 2002 all seahorses (*Hippocampus* spp.) as well as the humphead wrasse (*Cheilinus undulatus*) and in 2017 the clarion angelfish (*Holacanthus clarionensis*) were listed in CITES Appendix II to monitor their international trade (Foster et al., 2016; IUCN Red List, 2016). This situation indicates that it is important to have monitoring measures in place.

Conflict of interest

Author have been commissioned by the Swiss Federal Food Safety and Veterinary Office (FSVO) for data analysis and I am currently employed by the University of Basel and the Fondation Franz Weber.

Acknowledgments

I thank Mathias Lörtscher, Wolfgang Nentwig, Patricia Holm, Alejandro Vagelli and editor with four reviewers for valuable comments and discussions, Rainer Burki, Andy Rhyne and Michael Tlusty for helping with the database and Lisa Bradbury and Viktoria Kirchhoff for reading earlier versions and Clifford Warwick for reading and commenting on the manuscript.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.gecco.2017.05.006.

References

Allen, G., Donaldson, T., 2007. *Pterapogon Kauderni* Banggai Cardinalfish IUCN RedList. Available: www.iucnredlist.org/details/63572/0.
Appeltans, W., Bouchet, P., Boxshall, G., Fauchald, K., Gordon, D., et al., 2011. World Register of Marine Species. Available: www.marinespecies.org.
Aqula, 2016. Aquarium Retail Shop, Oetwil, Switzerland. Available: http://www.aqula.ch/stocklisten/meerwasser/meerwasser-fische.
ASSALCO, 2015. Zoomark 2015 Report on the Feeding and Care of Pets. Zoom Ark. Available: http://www.zoomark.it/media/zoomark/pressrelease/2015/Assalco_-_Zoomark_2015_Report_-_Summary_for_the_media.pdf.
Bartley, D., 2005. Fisheries and Aquaculture Topics. Ornamental Fish. Topics Fact Sheets. FAO fisheries and aquaculture department. Available: https://www.google.ch/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwj029W-0qzNAhULHxoKHSvWCyEQFggcMAA&url=http%3A%2F%2Fwww.

fao.org%2Ffigis%2Fpdf%2Ffishery%2Ftopic%2F13611%2Fen%3Ftitle%3DFAO%2520Fisheries%2520%2526amp%253B%2520Aquaculture%2520-%2520Topics&usg=AFQjCNHFtyNyaPclZ3FJb8LQTHcCC_xIcg&sig2=hPQXoB0M96p_S0cW0kw7FA&bvm=bv.124272578,d.d2s&cad=rja.

Bruckner, A.W., 2001. Tracking the trade in ornamental coral reef organisms: the importance of CITES and its limitations. Aqu. Sc. Cons. 3, 79–94. http://dx.doi.org/10.1023/A:1011369015080.

Bshary, R., 2003. The cleaner wrasse, *Labroides dimidiatus*, is a key organism for reef fish diversity at Ras Mohammed National Park. Egypt. J. Anim. Ecol. 72, 169–176. http://dx.doi.org/10.1046/j.1365-2656.2003.00683.x.

Carpenter, K.E., Abra, M., Aeby, G., Aronson, R.B., Banks, S., Bruckner, A., et al., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321, 560–563. http://dx.doi.org/10.1126/science.1159196.

Cato, J.C., 2003. Marine ornamental Species: Collection, Culture and Conservation. Blackwell Publishing.

Cervino, J.M., Hayes, R.L., Honovich, M., Goreau, T.J., Jones, S., Rubec, P.J., 2003. Changes in zooxanthellae density, morphology, and mitotic index in hermatypic corals and anemones exposed to cyanide. Mar. Pollut. Bull. 46, 573–586. http://dx.doi.org/10.1016/S0025-326X(03)00071-7.

Chan, H.-K., Zhang, H., Yang, F., Fischer, G., 2015. Improve customs systems to monitor global wildlife trade. Science 348 (6232), 291–292. http://dx.doi.org/10.1126/science.aaa3141.

CITES, 2016. Convention on international trade in endangered species of wild fauna and flora: consideration of proposals for amendment of appendices I and II. Johannesburg, South Africa. In: Fourteenth Meeting of the Conference of the Parties. September 30st – October 5th. Available: https://cites.org/sites/default/files/eng/cop/17/prop/060216/E-CoP17-Prop-46.pdf.

Coleman, F.C., Koenig, C.C., Huntsman, G.R., Musick, J.A., Eklund, A.M., McGovern, J.C., et al., 2000. Long-lived reef fishes: the grouper-snapper complex. Fisheries 25 (14–21). http://dx.doi.org/10.1577/1548-8446(2000)025<0014:LRF>2.0.CO;2.

Conant, T.A., 2015. Endangered Species Act Status Review Report: Banggai Cardinalfish, Pterapogon Kauderni. National Oceanic and Atmospheric Administration NOAA. Available: http://www.nmfs.noaa.gov/pr/species/Status%20Reviews/banggaii_cardinalfish_sr_2015.pdf.

Conant, T.A., 2016. Endangered and Threatened Wildlife and Plants; Final Listing Determinations on Proposal to List the Banggai Cardinalfish and Harrisson's Dogfish under the Endangered Species Act, 81. US Federal Registry, pp. 3023–3030. Available: https://www.federalregister.gov/documents/2016/01/20/2016-00943/endangered-and-threatened-wildlife-and-plants-final-listing-determinations-on-proposal-to-list-the.

ConsultEcon, 2008. Keys to economic sustainability of aquariums: examples from the worldwide aquarium 'industry'. In: Conference Presentation ConsultEcon, Inc.. Available: http://www.consultecon.com/insight/papers/presentations/CEI%20-%20CP%20Aq%20sustainability.pdf.

Corrales, J., Ullal, A., Noga, E.J., 2009. Lateral line depigmentation (LLD) in channel catfish, *Ictalurus punctatus* (Rafinesque). J. Fish. Dis. 32, 705–712. http://dx.doi.org/10.1111/j.1365-2761.2009.01069.x.

Courchamp, F., Angulo, E., Rivalan, P., Hall, R.J., Signoret, L., Bull, L., Meinard, Y., 2006. Rarity value and species extinction: the anthropogenic allee effect. PLoS Biol. 4, e415. http://dx.doi.org/10.1371/journal.pbio.0040415.

Dee, L., Hori, S.S., Thornhill, D.J., 2014. Conservation and management of ornamental coral reef wildlife: successes, shortcomings, and future directions. Biol. Conserv. 169, 225–237. http://dx.doi.org/10.1016/j.biocon.2013.11.025.

European Trade Commission, 2016. Countries and Regions. Available: http://ec.europa.eu/trade/policy/countries-and-regions/countries/switzerland/.

Ferse, S.C.A., Costa, M.M., Schwerdtner, M., Adhuri, D.S., Glaser, M., 2010. Allies, not aliens: increasing the role of local communities in marine protected area implementation. Environ. Conserv. 37, 23–34. http://dx.doi.org/10.1017/S0376892910000172.

Foster, S., Wisweder, S., Vincent, A., 2016. Opportunities and challenges for analysis of wildlife trade using CITES data – seahorses as a case study. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 154–172. http://dx.doi.org/10.1002/aqc.2493.

Fotedar, R.K., Phillips, B.F., 2011. Recent Advances and New Species in Aquaculture. Wiley-Blackwell.

Frieler, K., Meinshausen, M., Golly, A., Mengel, M., Lebek, K., Donner, S.D., et al., 2012. Limiting global warming to 2°C is unlikely to save most coral reefs. Nat. Clim. Chang. 3, 165–170. http://dx.doi.org/10.1038/nclimate1674.

Frisch, A.J., Justin, R., Rizzari, J.R., Munkres, K.P., Hobbs, J.-P.A., 2016. Anemonefish depletion reduces survival, growth, reproduction and fishery productivity of mutualistic anemone–anemonefish colonies. Coral Reefs 35, 375–386. http://dx.doi.org/10.1007/s00338-016-1401-8.

Froese, R., Pauly, D., 2014. FishBase. World Wide Web electronic publication. Available: http://www.fishbase.org.

Google. Search: 'New Public Aquariums Planned'. www.google.ch. Accessed 24 October 2014.

Grutter, A.S., 1999. Cleaner fish really do clean. Nature 398, 672–673. http://dx.doi.org/10.1038/19443.

GuideStar, 2014. Marine Aquarium Council Inc. Available: http://www.guidestar.org/organizations/52-2116916/marine-aquarium-council.aspx.

Ho, L., 2013. New video of peppermint angelfish at blue harbor. Available: http://www.advancedaquarist.com/blog/peppermint-angelfish-at-blue-harbor.

Hoegh-Guldberg, O., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318, 1737–1742. http://dx.doi.org/10.1126/science.1152509.

Hughes, R.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., et al., 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Curr. Biol. 17, 360–365. http://dx.doi.org/10.1016/j.cub.2006.12.049.

IUCN/Red List, 2016. Available: www.iucnredlist.org/details/10070/0.

Jennings, R.J., Polunini, N.V.C., 1999. Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. Conserv. Biol. 13, 1466–1475. http://dx.doi.org/10.1046/j.1523-1739.1999.98324.x.

Jones, A.M., Gardner, S., Sinclair, W., 2008. Losing 'Nemo': bleaching and collection appear to reduce inshore populations of anemonefishes. J. Fish. Biol. 73, 753–761. http://dx.doi.org/10.1111/j.1095-8649.2008.01969.x.

Leal, M.C., Vaz, M.C.M., Puga, J., Rocha, R.J.M., Brown, C., Rosa, R., et al., 2015. Marine ornamental fish imports in the European Union: an economic perspective. Fish. Fish. 17, 459–468. http://dx.doi.org/10.1111/faf.12120.

LEMIS, 2011. Law Enforcement Management Information System, 2009. Office of Law enforcement. Available: http://www.fws.gov/le/.

Lilley, R., 2008. The Banggai cardinalfish: an overview of conservation challenges. Secr. Pac. Community Live Reef Fish Inf. Bull. 18, 3–12. Available: https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/ef/ef5507d12baa4ff9b6895ddd0849f045.pdf?sv=2015-12-11&sr=b&sig=xuk9P%2Fjv8qEPQ36cMvBJBQtUG7ZalRMgWFR8K94ofII%3D&se=2017-08-05T14%3A08%3A02Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22LRF18.pdf%22.

Lough, J.M., 2016. Turning back time. Nature 531, 314. http://dx.doi.org/10.1038/nature17302.

Lunn, K.E., Moreau, Æ.M.-A., 2004. Unmonitored trade in marine ornamental fishes: the case of Indonesia's Banggai cardinalfish (*Pterapogon kauderni*). Coral Reefs 23, 344–351. http://dx.doi.org/10.1007/s00338-004-0393-y.

Madduppa, H.S., von Juterzenka, K., Syakir, M., 2014. KochziusM. Socio-economy of marine ornamental fishery and its impact on the population structure of the clown anemonefish *Amphiprion ocellaris* and its host anemones in Spermonde Archipelago, Indonesia. Ocean. Coast Manag. 100, 41e50. http://dx.doi.org/10.1016/j.ocecoaman.2014.07.013.

Madin, J.S., Madin, E.M.P., 2015. The full extent of the global coral reef crisis. Conserv. Biol. 29, 724–1726. http://dx.doi.org/10.1111/cobi.12564.

Michael, C., 1999. Marine Fishes. 500+ Essential-to-know Aquarium Species. Microcosm Ltd.

Militz, T.A., Kinch, J., Foale, S., Southgate, P.C., 2016. Fish rejections in the marine aquarium trade: an initial case study raises concern for village-based fisheries. PLoS One 11 (3), e0151624. http://dx.doi.org/10.1371/journal.pone.0151624.

Militz, T.A., Foale, S., 2017. The "Nemo Effect": perception and reality of Finding Nemo's impact on marine aquarium fisheries. Fish Fish. 18, 596–606. http://dx.doi.org/10.1111/faf.12202.

Monticini, P., 2010. The Ornamental Fish Trade. Production and Commerce of Ornamental Fish: Technical-managerial and Legislative Aspects. FAO GLOBEFISH Research Programme, p. 102. Available: http://www.fao.org/3/a-bb206e.pdf.

Murray, J.M., Watson, G.J., Giangrande, A., Licciano, M., Bentley, M.G., 2012. Managing the marine aquarium trade: revealing the data gaps using ornamental polychaetes. PLoS One 7, e29543. http://dx.doi.org/10.1371/journal.pone.0029543.

Murray, J.M., Watson, G.J., 2014. A critical assessment of marine aquarist biodiversity data and commercial aquaculture: identifying gaps in culture initiatives to inform local fisheries managers. PLoS One 9 (9), e105982. http://dx.doi.org/10.1371/journal.pone.0105982.
Penning, M., Reid, GMcG., Koldewey, H., Dick, G., Andrews, B., Arai, K., Garratt, P., Gendron, S., Lange, J., Tanner, K., Tonge, S., Van den Sande, P., Warmolts, D., Gibson, C., 2009. Turning the Tide: a Global Aquarium Strategy for Conservation and Sustainability. World Association of Zoos and Aquariums. Available: http://www.waza.org/files/webcontent/1.public_site/5.conservation/conservation_strategies/turning_the_tide/Aquarium%20strategy%20EN.pdf.
Rhyne, A.L., Tlusty, M.F., Schofield, P.J., Kaufman, L., Morris Jr., J.A., et al., 2012. Revealing the appetite of the marine aquarium fish trade: the volume and biodiversity of fish imported into the United States. PLoS One 7, e35808. http://dx.doi.org/10.1371/journal.pone.0035808.
Rhyne, A.L., Tlusty, M.F., Szczebak, J., Holmberg, R.J., 2017. Expanding our understanding of the trade in marine aquarium animals. PeerJ 5, e2949. http://dx.doi.org/10.7717/peerj.2949.
Sadovy, Y., Mitcheson, G., Rasotto, M., 2001. Early development of the mandarinfish *Synchiropus splendidus* (Callionymidae), with notes on its fishery and potential culture. Aqu. Sc. Cons. 3, 253–263. http://dx.doi.org/10.1023/A:1013168029479.
Santhanam, P., Thirunavukkarasu, A.R., Perumal, P., 2015. 2000. Advances in Marine and Brackishwater Aquaculture. Springer, New Delhi, India.
Smith, K.F., Behrens, M.D., Max, L.M., Daszak, P.U.S., 2008. Drowning in unidentified fishes: scope, implications, and regulation of live fish import. Conserv. Lett. 1, 103–109. http://dx.doi.org/10.1111/j.1755-263X.2008.00014.x.
Smith, K.F., Behrens, M., Schloegel, L.M., Marano, N., Burgiel, S., Daszak, P., 2009. Reducing the risks of the wildlife trade. Science 324, 594–595. http://dx.doi.org/10.1126/science.1174460.
Spalding, M.D., Ravilious, C., Green, E.P., 2001. World Atlas of Coral Reefs. Prepared at. the UNEP World Conservation Monitoring Centre. University of California Press, Berkley, USA.
Stumpf, S., 1995. Zierfischhaltung für Anfänger. Swiss Animal Protection Organization, (Schweizer Tierschutz) STS.
Sweet, T., 2014. Captive-breeding: state of the art 2014. CORAL 11 (1). Available: http://www.reef2rainforest.com/2013/12/17/coral-magazines-captive-bred-marine-fish-species-list-for-2014/.
Sweet, T., 2016a. The state of the marine Breeders' art, 2016. CORAL 13 (1). Available: http://www.reef2rainforest.com/2015/12/22/captive-bred-marine-fish-species-list-2016/.
Sweet, T., 2016b. The state of marien Breeders' art, 2017. CORAL 13 (6). Available: http://www.reef2rainforest.com/2016/11/17/coral-magazines-captive-bred-marine-fish-species-list-for-2017/.
Thaler, E., 2008. Doktorfische im Meerwasseraquarium. Natur und Tier Verlag, Münster.
Thaler, E., 2015. Denk ich an dory …. Available: http://www.saia-online.eu/images/downloads/de/Palettendr%20Ellen%20Thaler.pdf.
Thornhill, D., 2012. Ecological impacts and practices of the coral reef wildlife trade. Defenders Wildl. Available: https://www.defenders.org/sites/default/files/publications/ecological-impacts-and-practices-of-the-coral-reef-wildlife-trade.pdf.
Tissot, B.N., Best, B.A., Borneman, E.H., Bruckner, A.W., Cooper, C.H., D'Agnes, H., Fitzgerald, T.P., Leland, A., Lieberman, S., Amos, A.M., Sumaila, R., Telecky, T. M., McGilvray, F., Plankis, B.J., Rhyne, A.L., Roberts, G.G., Starkhouse, B., Stevenson, T.C., 2010. How US ocean policy and market power can reform the coral reef wildlife trade. Mar. Policy 34, 1385–1388. http://dx.doi.org/10.1016/j.marpol.2010.06.002.
UNEP, 2009. Certification and Sustainable Fisheries. United Nations Environment Programme, Geneva, Switzerland. Available: http://www.unep.ch/etb/publications/FS%20certification%20study%202009/UNEP%20Certification.pdf.
Vagelli, A.A., 2002. Notes on the biology, geographic distribution, and conservation status of the Banggai cardinalfish *Pterapogon kauderni* Koumans 1933, with comments on captive breeding techniques. Trop. Fish. Hobb 51, 84–88.
Vagelli, A.A., 2008. The unfortunate journey of *Pterapogon kauderni*: a remarkable apogonid endangered by the international ornamental fish trade, and its case in CITES. SPC Live Reef. Fish. Info. Bull. 18, 17–28. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.605.5915&rep=rep1&type=pdf.
Vagelli, A.A., 2011. The Banggai Cardinalfish. Natural History, Conservation and Culture of *Pterapogon Kauderni*. Wiley-Blackwell.
Veron, J.E.N., 2000. Corals of the World, vol. 1, 2, 3. Australian Institute of Marine Science.
Wabnitz, C., Taylor, M., Green, E., Razak, T., 2003. From Ocean to Aquarium. UNEP-WCM, Cambridge, UK. Available: http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf.
Waldie, P.A., Blomberg, S.P., Cheney, K.L., Goldizen, A.W., Grutter, A.S., 2011. Long-term effects of the cleaner fish *Labroides dimidiatus* on coral reef fish communities. PLoS One 6 (6), e21201. http://dx.doi.org/10.1371/journal.pone.0021201.
Wear, S., 2016. Missing the boat: critical threats to coral reefs are neglected at global scale. Mar. Policy 74, 153–157. http://dx.doi.org/10.1016/j.marpol.2016.09.009.
Weber, C., 2001. Zur Einfuhr von Zierfischen in die Schweiz. Bundesamt für Veterinärwesen, Switzerland. Available: http://www.tier-im-fokus.ch/wp-content/uploads/2009/10/weber_2001.pdf.
Wilkinson, C., 2008. Status of Coral Reefs of the World: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia. Available: http://www.icriforum.org/sites/default/files/GCRMN_Status_Coral_Reefs_2008.pdf.
Wood, E., 2001. Global advances in conservation and management of marine ornamental resources. Aquar. Sci. Conserv. 3, 65–77. http://dx.doi.org/10.1023/A:1011391700880.

Importation of marine ornamental fishes to Switzerland

Published in *Global Ecology and Conservation,15 (2018) e00418*

Global Ecology and Conservation 15 (2018) e00418

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

Importation of marine ornamental fishes to Switzerland

Monica V. Biondo

Institute of Ecology and Evolution, University of Bern, Baltzerstrasse 6, 3012, Bern, Switzerland

ARTICLE INFO

Article history:
Received 18 May 2018
Received in revised form 23 July 2018
Accepted 23 July 2018

Keywords:
Marine ornamental fishes
European and international trade
Trade monitoring
Trade information system TRACES
IUCN red list
CITES Convention on International Trade of Endangered Species

ABSTRACT

This study examines Switzerland's role in both the European and global marine aquarium trade providing basic information on trade data and offers tangible ideas on how to adapt the European Trade Control and Expert System (TRACES) to adequately collect species data. The trade in marine ornamental fishes comprises an increasingly important industry that handles millions of specimens annually. Although the potential for overexploitation of some marine ornamental fishes is great, only few mechanisms exist to control this financially strong trade. Analyses of data from 2014 to 2017 show that 19 countries exported over 193 850 fishes to Switzerland with over 70% of specimens remaining in Switzerland and the rest being trans-shipped to 11 European countries. Family diversity was between 54 and 60 taxa with most imported families being Pomacentridae, Labridae, Gobiidae, Acanthuridae and Pomacanthidae. Between 172 and 331 species where imported to Switzerland although as little as 16.9% of all imported specimens were discernible to species level in 2016. The two most traded species were *Amphiprion ocellaris* and *Chromis viridis*. The IUCN Red List labelled between 30.8% and 34.4% of species entering Switzerland as 'not evaluated' and 'data deficient'. The global number of reef fish species labelled 'not evaluated' and 'data deficient' decreased from 73.3% in 2014 to 44.8% in 2018, which means that more species have been assessed by the IUCN Red List. As very few species are protected under the Convention on International Trade in Endangered Species (CITES), very little specific trade data is collected. This study should extend the information on species regarding trade for the classification in IUCN and proposes some species to be protected through CITES.

1. Introduction

Global trade in marine ornamental fishes began already in the 1930s in Sri Lanka but is today a rapidly expanding industry that involves at least 45 exporting countries around the world (Rhyne et al., 2017; Schwerdtner Máñez et al., 2014; Shuman et al., 2005; Cohen et al., 2013; Wood, 2001). The few previous studies regarding the volume and diversity of the marine aquarium trade have mainly focused on the role of the United States (US) as the largest importing country for marine ornamental fishes (Rhyne et al., 2017, 2012; Wabnitz et al., 2003). With over 500 million inhabitants, the European Union (EU) plays at least as large a part as the US in this trade (Biondo, 2017; Leal et al., 2015; Wabnitz et al., 2003). With advances in marine aquarium technology in the 1990s, hobbyists started shifting their preferences from fish-only 'tanks' to displaying more complete coral reef ecosystems and since then, the popularity of marine aquariums has proliferated (Biondo, 2017; Rhyne et al., 2017, 2012; Cohen et al., 2013; Wabnitz et al., 2003).

E-mail address: monica.biondo@students.unibe.ch.

https://doi.org/10.1016/j.gecco.2018.e00418

The habitat of most marine ornamental fishes, coral reefs, are among the most diverse ecosystems in the world but are declining globally (Hughes et al., 2017; Triki et al., 2017). Today, 19% of the original area of coral reefs has been destroyed, 15% are seriously threatened with loss within the next 10–20 years, and 20% are under threat of loss in 20–40 years due to anthropogenic pressure (Hughes et al., 2017; Ferrari et al., 2011; Gattuso et al., 2014; Wilkinson, 2008; Hoegh-Guldberg et al., 2007).

The marine ornamental fish trade is estimated to be worth US$ 1.5 billion annually (Biondo, 2017; Rhyne et al., 2017, 2012; Leal et al., 2015; Dee et al., 2014; Monticini, 2010; Smith et al., 2008; Wabnitz et al., 2003). In 2000, 1 kg of coral reef fish for the aquarium trade fetched US$500 whereas food fish sold for US$6 (Cato, 2003). Compared to its market value, relatively little is known about the global volume and diversity of traded species because the industry lacks monitoring or systematic regulations in a number of places (Biondo, 2017; Rhyne et al., 2017, 2012; Stevens et al., 2017). Marine ornamental fishes are widely collected from coral reef habitats throughout the Indo-Pacific, as well as the Caribbean region. However, many supply systems are unorganized, multi-layered and patchy (Prakash et al., 2017; Cohen et al., 2013; Rhyne et al., 2012). In some places trade directly threatens ornamental species due to poor handling during capture and transportation or damages ecosystems due to unsustainable practices including the illegal use of cyanide in Southeast Asia (Cohen et al., 2013; Vagelli, 2011). Limited knowledge regarding the dynamics of exploitation has aroused increased concerns by stakeholders including fishermen, diving and other tourism operators, and environmentalists, that fishing is having negative impacts on targeted populations and associated coral reef habitats (Biondo, 2017; Rhyne et al., 2017; Okemwa et al., 2009).

Wildlife trade regulations such as the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) aim to ensure that the international trade of wild fauna and flora does not become a threat to their survival (CITES, 2018). However, very few species of marine ornamental fishes are regulated through CITES (CITES, 2018). Many of all marine ornamental fish species represented in the comprehensive FishBase database are not assessed by the IUCN Red List due to lack of information (Biondo, 2017). The IUCN Red List category is a starting point to warrant protection of a species.

The present study represents a continuation of a study published in 2017 (Biondo, 2017) concerning the trade in the European region with a focus on Switzerland. In 2009 the import data consisted of hard-copy shipment declarations (Biondo, 2017), whereas since 2011, electronic data is available via the Trade Control and Expert System (TRACES), which collects data for all imports of live animals or parts thereof from non-EU countries into the European region to monitor animal diseases. This data provides further information on volume, biodiversity and trade pathways and contributes to understanding the commerce of marine ornamental fishes. In addition, the larger dataset could aid in the collation of information for possible later evaluation of species through the IUCN Red List, and could also facilitate the listing on CITES of certain species or species groups, if deemed appropriate.

2. Material and methods

The European database Trade Control and Expert System (TRACES) stores data on the imports and exports of live animals and animal products within and across the borders of the European Union including Switzerland. TRACES is not intended to monitor wildlife trade, rather it is intended to monitor potential threats from animal diseases. However, TRACES is the only tool to evaluate the volume of marine ornamental fish trade in the European region. Traders are required to declare their exports at the border to an EU country or to Switzerland by entering the freight details in TRACES.

TRACES was introduced in 2004, although data on marine ornamental fishes only began to be collected in 2011. Between 2011 and 2013, data was insufficiently specific (at least family level) and many fishes were recorded under the name ‘otra pesca’ (other food fish) which is why these three years were excluded from the study. The information entered by traders in TRACES corresponds mainly to the information contained in the Common Veterinary Document (CVDE) accompanying the consignments on paper. Dealers must register in order to be able to enter the shipment data in TRACES. Government officials can request full access to the database through their local TRACES representative, but the data is not publicly accessible because it contains confidential company information. TRACES data for this study was provided on request by the Swiss Federal Food Safety and Veterinary Office (FSVO). The FSVO anonymized the data by removing the company information and provided it in Excel format. We then imported the data into our own Microsoft Access database.

A peculiarity of the TRACES database is the fact, that it records the species of fish in a field called ‘species’, which may either contain the proper scientific species name or just its family name. Spelling errors are not possible because TRACES offers a list of all possible families and species to choose from when entering shipment details. But the fact that the ‘species’ field can contain either a family or a species makes analysis of all species traded difficult. Our MS Access database separates the information of the TRACES species field into a real ‘species’ and a ‘family’ field on the condition that, if it contains two words, it must be a species, otherwise a family. All taxa in the MS Access database were checked manually. The records containing a species in the species field were then supplemented with the correct family name. The family name comes from FishBase, the most frequently accessed online database for fish species (Froese and Pauly, 2014). Information on origin and destination including trans-shipping (shipments entering into Switzerland and being transferred to another country), as well as volume and diversity of species were analysed. All species of marine ornamental fishes entering Switzerland were assigned the IUCN conservation status using the IUCN Red List database (IUCN, 2018). A list of all coral reef fishes worldwide was extracted from FishBase (Froese and Pauly, 2014) by filtering ‘reef-associated’ and ‘tropical’ species and also assigned a conservation status.

3. Results

3.1. Origin, destination and volume of imported marine ornamental fishes

From 2014 to 2017, 19 countries exported marine ornamental fishes to Switzerland and imports from 15 different countries remained in the country. In 2014, 2015, 2016 and 2017 shipments came from 7, 7, 10 and 12 countries respectively, that remained in Switzerland (Fig. 1). During these four years Switzerland trans-shipped to 11 EU countries. Most often trans-shipments went to France followed by Spain or Romania (e.g. in 2014). Micronesia, only trans-shipped through Switzerland. The shipment from land-locked Malawi comprised freshwater fishes from Lake Malawi that were mislabelled and therefore, data was excluded.

Most species reported on TRACES as entering Switzerland came from Indonesia followed by Sri Lanka except in 2017 when the Philippines overtook Sri Lanka by importing 1366 more specimens (Fig. 1). From the Indo-Pacific region, Australia, Fiji, French Polynesia, Maldives and Taiwan only commenced exporting to Switzerland in 2016 or 2017 (Fig. 1). Israel exported every year into Switzerland, although it was only in 2017 that specimens remained in the country (Fig. 1).

From 2014 to 2017, a total of 771 (SD 18) shipments containing marine ornamental fishes entered Switzerland. On average 193 shipments per year came from non-EU countries increasing steadily from 173 in 2014, 184 in 2015, 201 in 2016 and to 213 shipments in 2017. Four hundred and sixty four (SD 13) shipments remained in Switzerland.

During the four years, 2014 to 2017, 193 850 specimens were imported into Switzerland from non-EU countries with an average of 48 463 specimens per year (SD 6133) (Table 1). The 464 shipments remaining in Switzerland resulted in 144 000 specimens, which constituted 74.3% of specimens remaining in Switzerland and the rest being trans-shipped to EU countries (Fig. 1).

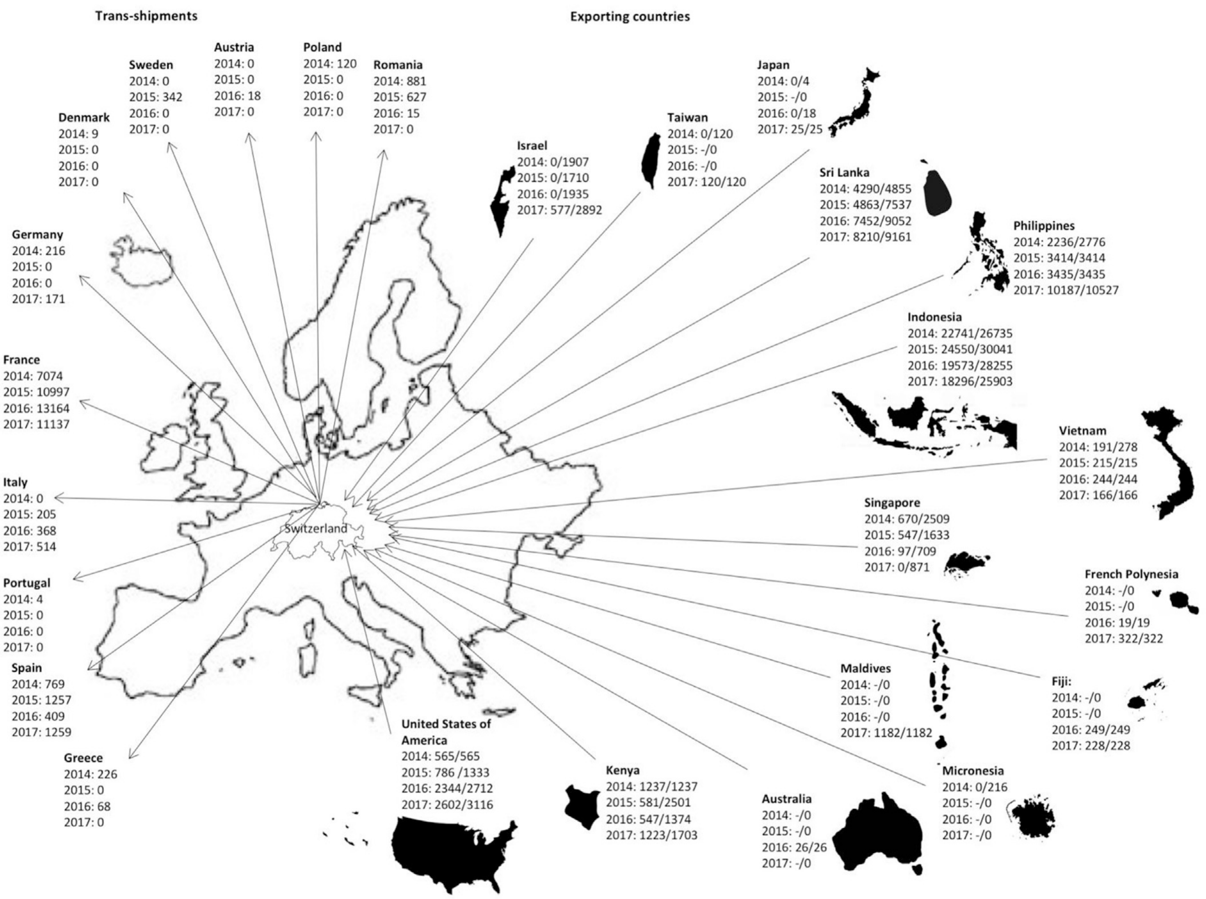


Fig. 1. Pathways of marine ornamental fishes imported to and trans-shipped from Switzerland from 2014 to 2017. Exporting countries = Number of specimens remaining in Switzerland/number of overall specimens. 0 = shipment without detailed data for specimen or species, - = no data discernible. Transshipping countries = Number of specimens transshipped.

Table 1
Comparative data from 2014 to 2017 for the ten families most commonly imported into Switzerland; total number of specimens; and number of species and specimens where species identified.

Family	# species where species identified	Total specimens	No. of specimens where species identified	# species where species identified	Total specimens	No. of specimens where species identified	# species where species identified	Total specimens	No. of specimens where species identified	# species where species identified	Total specimens	No. of specimens where species identified
	2014			2015			2016			2017		
Pomacentridae	29	10861	2449	32	15187	4731	18	12359	3237	21	22323	11056
Labridae	40	3679	614	48	4075	726	31	3988	300	35	4275	461
Gobiidae	27	6411	937	23	6584	922	13	8406	1220	11	6346	315
Acanthuridae	28	1989	462	25	3218	826	15	3362	735	23	3653	1184
Pomacanthidae	32	2133	640	35	3436	860	25	4639	1293	21	3251	773
Serranidae	14	2717	994	21	3149	1198	4	3244	238	11	3531	706
Apogonidae	4	2844	386	7	2801	428	2	2152	21	5	2354	143
Chaetodontidae	22	978	196	19	1241	206	9	1190	99	12	1537	71
Callionymidae	4	1637	476	5	1709	265	5	1843	40	3	1522	61
Blenniidae	9	1439	354	18	1558	311	4	1382	71	7	2604	137
Rest	76	6531	1063	88	5426	1199	46	5463	866	63	4823	621
Overall total	285	41219	8571	321	48384	11672	172	48028	8120	212	56219	15528
% known specimens			20.8			24.1			16.9			27.6

3.2. Family and species diversity

From 2014 to 2017 60, 57, 56 and 54 families and 285, 321, 172 and 212 species were imported respectively (Table 1). From 2014 to 2017 the accuracy of information to species level increased from 16.9% in 2016 to 27.6% in 2017 (Table 1). Every year the most traded family was Pomacentridae followed by Gobiidae or Labridae in 2014–2017. Labridae was always the family with the most discernible species as many as 48 species in 2015 (Table 1).

From 2014 to 2017, the two most traded species were *Amphiprion ocellaris* and *Chromis viridis* (Fig. 2). Over the four years *A. ocellaris* was the most frequently imported species into Switzerland with 60.2% of specimens being trans-shipped to the EU and the rest remaining in the country. Also, two other clownfish species, *Amphiprion polymnus* and *A. clarkii*, were trans-shipped to 56.8% and 61.0% respectively to the EU, albeit in lesser volume. The same is the case for *Zebrosoma flavescens* with 67.5% of specimens being trans-shipped to the EU (Fig. 2).

Imports of *C. viridis* peaked in 2017 and comprised 36.3% of all specimens entering and remaining in Switzerland in 2017 (Fig. 3), but only 1.5% were trans-shipped to the EU over the four-year study (Fig. 2). In 2016 C. *viridis* was not among the 20 most traded species, but *Cryptocentrus cinctus* was ranked 2 (Fig. 3).

3.3. Conservation status

All species that were imported to Switzerland from 2014 to 2017 were recorded on the IUCN Red List database. The Red List status of 'not evaluated' and 'data deficient' for lack of information, decreased from 33.7% in 2014, to 32.7% in 2015, to 30.8% in 2016 and increased to 34.4% in 2017 (Table 2). Conversely, the species listed as 'least concern' increased from 63.9% in 2015, to 65.1% in 2015, to 68% in 2016 and decreased to 63.2%. 'Near threatened' and 'vulnerable' occurred mostly in the range of less than 1%. Only one imported species, *P. kauderni*, was listed as 'endangered'. No species was listed as being 'critically endangered' (Table 2).

We analysed all known marine ornamental fish species in FishBase (Froese and Pauly, 2014) that are included on the IUCN Red List and found that 39.5% of species were listed as 'not evaluated' and 5.3% as 'data deficient', 'least concern' at 51.3% in 2018 with other categories between 0.5 and 2.3% (Table 2).

From the top 20 species imported by volume, the two most imported species, *A. ocellaris* and *C. viridis* (Fig. 2), were both listed as 'not evaluated' by the IUCN Red List, as were another 8 species (Fig. 2). The other half of the top 20 imported species were labelled 'least concern' (Fig. 2).

4. Discussion

The trade in marine ornamental fishes has increased over recent decades and the market for private (Rhyne et al., 2017; Leal et al., 2015; Dee et al., 2014; Wabnitz et al., 2003) and for public aquariums does not seem to be saturated (ConsultEcon,

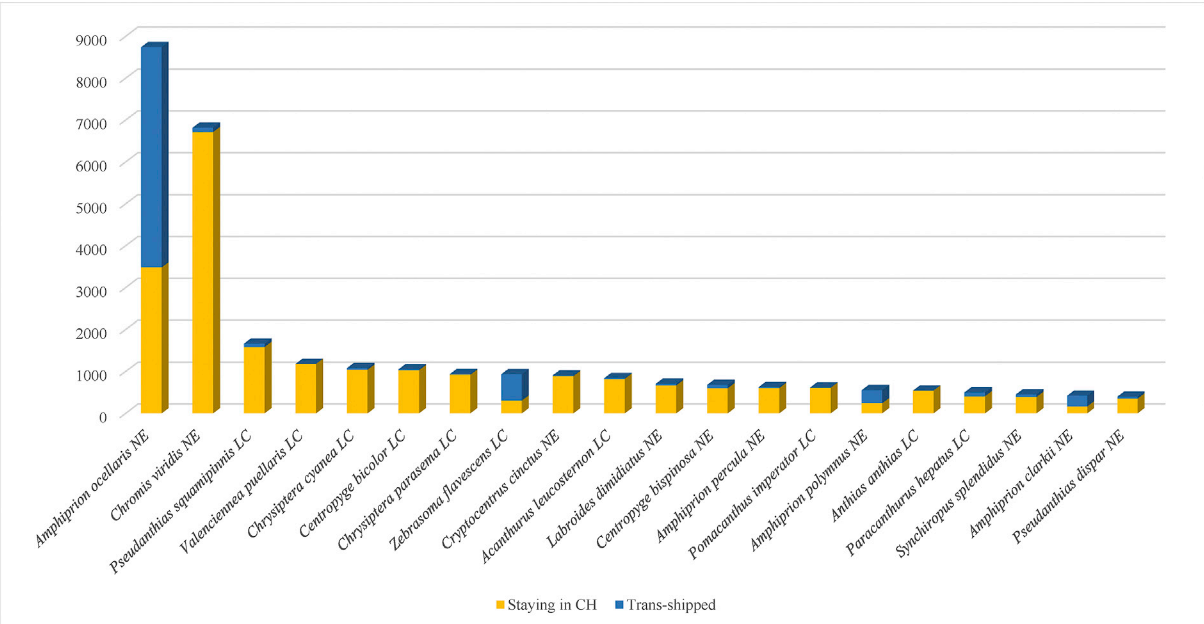


Fig. 2. Top 20 species imported to Switzerland from 2014 to 2017 and their IUCN Red List status. NE = not evaluated, LC = least concern. Yellow = remaining in Switzerland, blue = trans-shipped to the EU. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

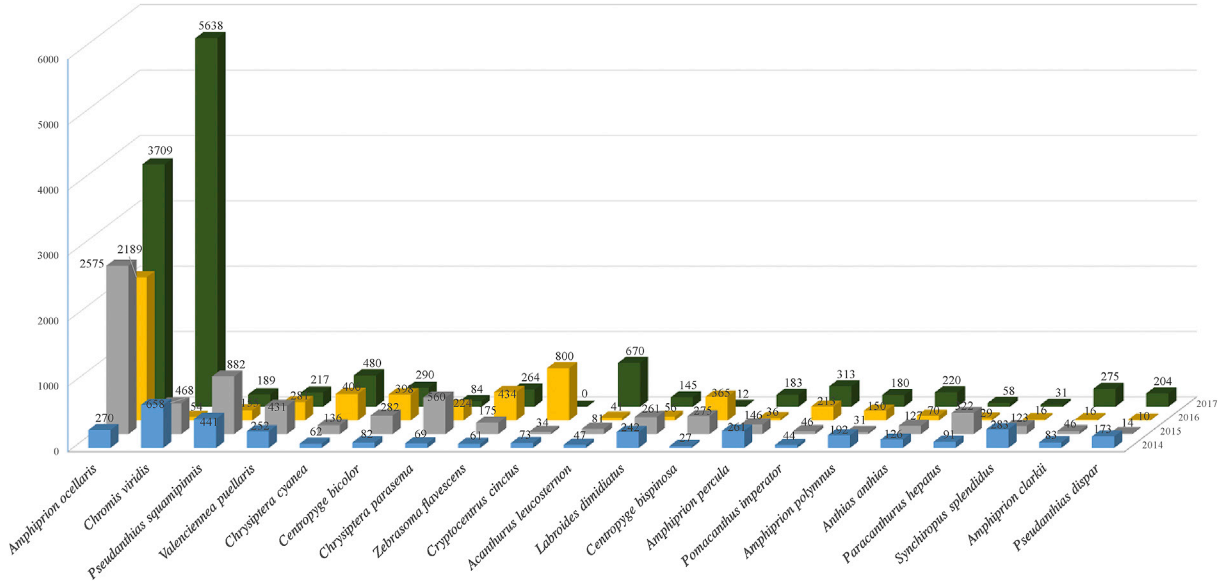


Fig. 3. Top 20 species imported to Switzerland from 2014 to 2017 with volume of specimens (numbers).

2008). The number of marine ornamental fish traded worldwide is unknown and estimates vary between 24 and 27 million (Townsend, 2011; Wabnitz et al., 2003). A review paper assessed that globally 1.5 billion ornamental fishes spanning the freshwater and marine realms are traded each year (Stevens et al., 2017). Considering that the marine ornamental fish trade amounts to 10% of the entire marine/freshwater ornamental fish industry (Biondo, 2017; Monticini, 2010; Wabnitz et al., 2003) this would result in 150 million marine ornamental fishes being traded annually. Mortality in the supply chain can represent a major concern (Stevens et al., 2017; Vagelli, 2011; Wabnitz et al., 2003), and the 150 million figure excludes mortalities among fishes caught prior to export where data is not recorded (Militz et al., 2016, 2018; Schmidt and Kunzmann, 2005).

4.1. Origin, destination and volume of imported marine ornamental fishes

Globally, the primary exporting countries are the Philippines, Indonesia and Sri Lanka, with the main consumer countries being the US followed by the EU and Japan (Leal et al., 2015; Rhyne et al., 2012; Wabnitz et al., 2003; Wood, 2001). Switzerland received most fishes from Indonesia during the observed periods, i. e. 2009 and from 2014 to 2017. The US, which is the best analysed country, imported most fishes from the Philippines (Rhyne et al., 2017, 2012) which is the third most important exporting country to Switzerland after Sri Lanka. Only in 2017 did the Philippines import more marine ornamental fishes than Sri Lanka. This situation may be due to the large Sri Lankan community in Switzerland (Biondo, 2017) and economic considerations. Unlike in 2009 where a lot of trans-shipments went to non-EU countries such as Canada, Israel, Serbia and the US, all shipments from 2014 to 2017 that trans-shipped through Switzerland went only to EU countries. It is possible that flight schedules through Switzerland have changed or that customs clearances have become stricter. It is unclear, why some countries such as Micronesia trans-shipped through Switzerland.

Table 2
IUCN Red List evaluation of marine ornamental fish species imported to Switzerland from 2014 to 2017 with status (%) per year and global IUCN Red List evaluation of coral reef fishes listed in FishBase in 2018 (accessed 23.05.2018).

Red List evaluation	Switzerland								Worldwide	
	# Species	%	# Species	%	# Species	%	# Species	%	# Species	%
	2014		2015		2016		2017		2018	
Not listed	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Not evaluated NE	86	30.2	95	29.6	46	26.7	63	29.7	1505	39.5
Data deficient DD	10	3.5	10	3.1	7	4.1	10	4.7	201	5.3
Least concern LC	182	63.9	209	65.1	117	68.0	134	63.2	1957	51.3
Near threatened NT	4	1.4	3	0.9	1	0.6	2	0.9	42	1.1
Vulnerable VU	2	0.7	3	0.9	1	0.6	2	0.9	88	2.3
Endangered EN	1	0.4	1	0.3	0	0.0	1	0.5	19	0.5
Critically endangered CR	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0

The number of countries exporting marine ornamental fishes to Switzerland increased from 12 to 19 countries from 2009 to the period from 2014 to 2017. The eight new countries being Australia, Malawi, the Maldives, Micronesia, Fiji, French Polynesia, Thailand and Taiwan. This increase may reflect an expansion of trade through the home ranges of relevant fish species. For example, in 2016 exportation of *Hippocampus abdominalis* commenced from Western Australia and the smaller Pacific islands. In 2017 the Maldives exported for the first time 1182 specimens to Switzerland. Many marine ornamental fishes exported from the US probably originate from states in the Pacific region, such as Hawaii. No fishes were exported from the Caribbean to Switzerland with the exception of the Netherlands Antilles in 2009.

The result of this study confirms the inferred estimate of between almost 37 000 and 40 000 specimens entering Switzerland in 2009 (Biondo, 2017). Assuming that Switzerland imports the same volume of marine ornamental fishes per capita as the US, the volume entering the country every year would result in over 200 000 specimens (Biondo, 2017) annually. Whereas in 2009 62% of specimens were trans-shipped, almost three quarters of all specimens entering Switzerland between 2014 and 2017 remained in the country, suggesting that more specimens were imported for the Swiss market from 2014 to 2017. Only clownfish species were trans-shipped in more than half of their volume to EU countries. Due to bilateral agreements with the EU, fishes are not recorded when trans-shipping within EU countries or Switzerland. Also, for fishes, there is no traceability required to their source. This is in contrast to other vertebrates, where information is collected through TRACES at each border crossing and traceability of animals is guaranteed to their origin. Therefore, it is possible that many more marine ornamental fishes enter Switzerland through an EU country but are not recorded (TRACES, 2004).

4.2. Family and species diversity

Since 2001, globally the diversity of traded species has increased rising from 1000 marine ornamental fish species to 1471 in 2005 and is at about 2300 species today (Rhyne et al., 2017, 2012; Wabnitz et al., 2003; Wood, 2001). During 2014 to 2017 the greatest number of species imported to Switzerland where species were identified, was in 2015 when 321 species were discernible. In contrast, in 2009 440 species were recorded, which would indicate a decrease in diversity. Overall the diversity of families entering Switzerland increased between 2014 and 2017 included up to 60 families suggesting a possible expansion in diversity compared to the 45 families imported in 2009. However, for TRACES specimens are often identified only by family and not by species. Therefore, it is unclear how many more species were imported than were recorded. For a trader it may be more convenient to just select a family instead of multiple species of the same family. It is though peculiar, that Switzerland should import only about 10% of all globally traded species. In 2009 the species listed on the hard-copy shipment declarations already contained 440 species which were about 25% of those globally traded at the time (Biondo, 2017).

The most imported family into Switzerland was Pomacentridiae, making up almost 40% of specimens in 2017. The following four families, Labridae, Gobiidae, Acanthuridae and Pomacanthidae, accounted for another third of the trade destined for Switzerland. These findings reflect the preferences of the Swiss market in 2009 as well as the US market (Rhyne et al., 2012). Among the most imported species were, and this was also true for the US (Rhyne et al., 2017), *Amphiprion ocellaris* and *Chromis viridis*, both from the Pomacentridae family, as was the case in 2009 (Biondo, 2017). Surprisingly, the species composition shifted considerably in one year, 2016, when *C. viridis* was not among the 20 most traded species, but *Cryptocentrus cinctus* was ranked 2, suggesting a slight shift in species composition, i. e. market preferences or availability or an error in the database collection. Both species, *C. viridis* and *A. ocellaris*, were not evaluated by the IUCN Red List. Not evaluated means that 'no assessment of extinction risk has been made' (IUCN, 2018).

Captive breeding may alleviate the impact of the aquarium trade on coral reefs (Foster, 2016; Olivotto et al., 2011). *A. ocellaris* is a favourite in the aquarium industry as it also reproduces in captivity with many colour variations being offered (Tan et al., 2018). However, due to high demands, many are still wild-caught and ecological consequences are unknown (Frisch et al., 2016; Jones et al., 2008). The film 'Finding Dory', which is the sequel to 'Finding Nemo', does not seem to have spiked trade volumes. In contrast to the clownfish character 'Nemo', 'Dory' portrays a surgeon fish, which so far has only bred in captivity in a research context (Militz et al., 2017).

Labroides dimidiatus, also among the top 20 traded and imported species, is also from one of the most traded families (Labridae), and this was the case for 2014 to 2017 as well as in 2009 for specimens remaining in Switzerland (Biondo, 2017). *L. dimidiatus* is also one of the most traded species in the EU and the US, where over 100 000 specimens were traded in 2008 (Rhyne et al., 2017; Wabnitz et al., 2003). *L. dimidiatus* is a key fish species in the coral reef, reducing parasite abundance (Grutter et al., 2018), and its complete removal has resulted in a rapid decline of fish diversity (Waldie et al., 2011; Bshary, 2003).

4.3. Conservation status

Encouragingly, the percentage of species imported to Switzerland and not evaluated by the IUCN Red List decreased to one third for 2014 to 2017 compared to over 50% for 2009 (Biondo, 2017). This suggests that more studies have been conducted on marine ornamental fishes and that the IUCN was able to review more species. Also, worldwide the species listed as 'not evaluated' or 'data deficient' decreased from over 70% of all known coral reef fish species (Biondo, 2017) to over 40% in 2018. Nonetheless, this means that, according to the IUCN Preamble: 'until such time as an assessment is made, taxa listed in these categories should not be treated as if they were non-threatened. It may be appropriate (especially for data deficient forms) to give those species the same degree of attention as threatened taxa, at least until their status can be assessed.' The fact that more species have been evaluated is promising, but by when all coral reef fish species will be assessed cannot be foreseen.

Also, a monitoring system such as TRACES, and a monitoring and control system such as CITES are crucial, because assigning a conservation status through the IUCN Red List alone does not ensure protection, although it does represent an important basis. Marine ornamental fishes that are threatened or endangered due to the large, and possibly unsustainable numbers that are traded, should warrant monitoring via CITES. For example, *C. viridis* is the most traded species worldwide and not assessed by the IUCN Red List and is already banned in the Maldives due to over-use as bait for tuna fishing (Dee et al., 2014; Saleem and Islam, 2008). Also, CITES should develop a precautionary list for certain key species, for example *L. dimidiatus* which is very challenging to keep in captivity and has a high mortality rate (Yan, 2016; Michael, 1999). Listing a species within CITES is an important, but cumbersome process that allows the collection of specific trade information to contribute to our understanding of the trade (Robinson and Sinovas, 2018; Foster, 2016; Foster et al., 2014; Murray et al., 2012; Christie et al., 2011).

4.4. Monitoring system

For the most part, global regulations or management schemes as well as monitoring mechanisms are lacking (Biondo, 2017; Calado et al., 2017; Rhyne et al., 2017, 2012; Stevens et al., 2017). The present study for Switzerland examined four years of available electronic information on marine ornamental fishes through the Trade Control and Expert System (TRACES) used in the EU and Switzerland, which collects data on the import and export of live animals and animal products for disease prevention. A previous study for Switzerland demonstrated that the paucity of data concerning the trade in marine ornamental fishes to and through Switzerland in 2009 (Biondo, 2017) obstructs progress in managing this industry (Rhyne et al., 2017). TRACES enables monitoring of only around 1800 species, whereas there are at least 2300 species in trade (Rhyne et al., 2017) and almost 4000 known coral reef fish species (Froese and Pauly, 2014). In addition, because it is also possible to enter the family name rather than the exact species name, TRACES produces imprecise results. Furthermore, TRACES also does not collect species specific information, for example, sex, size, source (i. e. wild, captive-bred) or value.

The data from 2009 was collected through hard-copy shipment declarations which, where they contained species lists, provided information such as size or sometimes source of the species. The analysis of hard-copy shipment declarations is much more time consuming because each document requires manual assessment given that freshwater and marine fish imports are not separately maintained, and relevant information has to be entered manually into a database and the names checked for accuracy (Biondo, 2017). TRACES data is easier to process but does not provide exhaustive, accurate species information or provide further in-depth information such as source (wild, captive-bred). This information is required for a thorough understanding of this trade.

A study conducted by the EU in 2008 regarding the monitoring of the ornamental fish trade, concluded that adapting TRACES would be the easiest and most adequate tool for overseeing this multi-facetted trade. Exporters and importers would be willing to copy the species information into such an electronic data collection system (UNEP-WCMC, 2008). It is assumed that the traders in the countries of origin and the wholesaler are most familiar with the species names hence making them the most adequate persons to correctly enter the species names into the electronic data base if this was compulsory. This could also lower the risk of mislabelling a taxon, or for example, merely assigning it a family name based on convenience or to circumvent export restrictions. According to a study (Rhyne et al., 2017) in the US, the Law Enforcement Management Information System (LEMIS) ((LEMIS, 2009), which is similar to TRACES, recorded different data compared to invoice information. For example, importers mislabelled shipments that contained freshwater fishes as containing marine species, or non-marine species, or non-aquarium fish augmenting the total number of fish reported in the LEMIS database. Also, there was an important divergence between the number of specimens on the declaration and the corresponding values on the invoices (Rhyne et al., 2017). Some data in LEMIS are possibly inaccurate because they were not entered by the first exporter but an intermediate trader who did not know the species. Other research from Costa Rica showed that about 20% of ornamental fishes' scientific or common name were misspelled or, for more than 40%, were absent (Allen et al., 2017). These anomalies provide another reason why species names are essential and need to be selected from a predetermined species list.

In previous decades, various endeavours have been made to monitor the international ornamental fish trade but these efforts have produced limited successes. The Marine Aquarium Council (MAC) label was established in 1998 to ensure traceability, good practices, and sustainable schemes of ecologically and socially responsible fishing, but has been inactive since 2008 (UNEP, 2009). The Global Marine Aquarium Database (GMAD) launched in 2002 was intended to collect accurate trade data, but voluntary data entry ceased after one year due to lack of funding (Murray et al., 2012; Townsend, 2011). Also, the EU commissioned consultancy study on improving trade statistics related to EU imports of tropical marine fishes (UNEP-WCMC, 2008) has not provided any outcome since the report's submission. Plans are underway in the US to improve their trade data (Townsend, 2011) and studies have suggested possible improvement schemes (Rhyne et al., 2017, 2012).

5. Conclusion

A TRACES-like monitoring system is important, and maybe essential, to ensure that trade in ornamental marine fish is sustainable. As a first step, TRACES should urgently correct some major monitoring shortcomings, not least given that these would not even significantly affect the trade practices. The system should include in the database the 500 missing species so that traders can indicate the species correctly. The possibility of choosing only the family instead of the species should also be removed. Additional fields should then be added to record whether the fishes come from the wild or from a breeding facility and enable recording of sex and size.

Another very important step, as with other traded vertebrates not protected by CITES, would be the traceability of fishes back to their origin. Every effort should be made to enter the information in TRACES as soon as possible because traders in the place of origin probably know what species they are shipping and where the fishes come from and purchase orders are always made according to species, and not by family. Other options are a common interface to LEMIS that would help merchants if it were not necessary to re-enter data along the supply chain.

Rapid steps should be taken to evaluate all coral reef fishes on the IUCN Red List, starting with the most traded species. Also, CITES should list certain species as a precautionary measure: key coral reef fish species such as *Labroides dimidiatus*, as well as species traded in high volumes but not assessed by the IUCN Red List. Although the inclusion of a species in CITES is a cumbersome process, it allows us to collect specific trade information that contributes to our understanding of trade in listed species.

Acknowledgments

I thank Wolfgang Nentwig for very appreciated discussions and comments, editor with four reviewers for their valuable comments, Mathias Lörtscher, Rolf Frischknecht, Sara Schärrer, Daniela Tanner and Frank Juschus for providing data and Rainer Burki for his valued inputs and for helping with the database. To Clifford Warwick I am grateful for proof reading and commenting on the manuscript.

References

Allen, P.E., Barquero, M.D., Bermúdez, E., Calderón, J.C., Hilje, B., Pineda, W., Saborío-Rodríguez, F., Arguedas, C., Chacón-Madrigal, E., 2017. Calling for more accurate information in aquarium trade: analysis of live-fish import permits in Costa Rica. Manag Biol. Inv 8 (4), 533–542. https://doi.org/10.3391/mbi.2017.8.4.08.

Biondo, M.V., 2017. Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union. Glob Ecol Conserv 11, 95–105. https://doi.org/10.1016/j.gecco.2017.05.006.

Bshary, R., 2003. The cleaner wrasse, *Labroides dimidiatus*, is a key organism for reef fish diversity at Ras Mohammed National Park Egypt. J. Anim. Ecol. 72, 169–176. https://doi.org/10.1046/j.1365-2656.2003.00683.x.

Calado, R., Olivotto, I., Oliver, M.P., Holt, G.J., 2017. Marine ornamental species aquaculture. Blackwell Publishing Company.

Cato, J.C., 2003. Marine ornamental Species: Collection, Culture and Conservation. Blackwell.

Christie, P., Oracio, E.G., Eisma-Osorio, L., 2011. Impacts of the CITES listing of seahorses on the status of the species and on human well-being in the Philippines: a case study. FAO Fisheries and Aquaculture Circular. No. 1058. Rome. http://www.fao.org/docrep/013/i2003e/i2003e00.pdf. (Accessed 7 July 2018).

CITES, 2018. Convention on international trade in endangered species of wild fauna and flora. http://www.cites.org. (Accessed 2 May 2018).

Cohen, F.P.A., Wagner, W.C., Calado, R., 2013. Traceability issues in the trade of marine ornamental species. Rev. Fish. Sci. 21 (2), 98–111. https://doi.org/10.1080/10641262.2012.760522.

ConsultEcon, 2008. Keys to economic sustainability of aquariums: examples from the worldwide aquarium ‘industry. In: Conference Presentation ConsultEcon, Inc. http://www.consultecon.com/insight/papers/presentations/CEI%20-%20CP%20Aq%20sustainability.pdf. (Accessed 3 May 2018).

Dee, L.E., Horii, S.S., Thornhill, D.J., 2014. Conservation and management of ornamental reef wildlife: success, shortcomings, and future directions. Biol. Conserv. 169, 225–237. https://doi.org/10.1016/j.biocon.2013.11.025.

Ferrari, M.C., Dixson, D.L., Munday, P.L., McCormick, M.I., Meekan, M.G., Sih, A., Chivers, D.P., 2011. Intrageneric variation in antipredator responses of coral reef fishes affected by ocean acidification: implications for climate change projections on marine communities. Global Change Biol. 17, 2980–2986. https://doi.org/10.1111/j.1365-2486.2011.02439.x.

Frisch, A.J., Justin, R., Rizzari, J.R., Munkres, K.P., Hobbs, J.-P.A., 2016. Anemonefish depletion reduces survival, growth, reproduction and fishery productivity of mutualistic anemone–anemonefish colonies. Coral Reefs 35, 375–386. https://doi.org/10.1007/s00338-016-1401-8.

Foster, S.J., 2016. Seahorses (*Hippocampus* spp.) and the CITES Review of Significant Trade. Fisheries Centre Research Reports. 24: 4. http://www.projectseahorse.org/research-publications/2016/10/13/seahorses-hippocampus-spp-and-the-cites-review-of-significant-trade. (Accessed 5 July 2018).

Foster, S., Wisweder, S., Vincent, A., 2014. Opportunities and challenges for analysis of wildlife trade using CITES data – seahorses as a case study. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 154–172. https://doi.org/10.1002/aqc.2493.

Froese, R., Pauly, D., 2014. FishBase. World wide web electronic publication. http://www.fishbase.org. (Accessed 3 May 2018).

Gattuso, J.-P., Hoegh-Guldberg, O., Pörtner, H.-O., 2014. Cross-chapter box on coral reefs. In: climate Change 2014. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Impacts, Adaptation, and Vulnerability. Part a: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 97–100. https://doi.org/10.1017/CBO9781107415379.005.

Grutter, A.S., De Brauwer, M., Bshary, R., Cheney, K.L., Cribb, T.H., Madin, E.M.P., McClure, E.C., Meekan, M.G., Sun, D., Warner, R.R., Werminghausen, J., Sikkel, P.C., 2018. Parasite infestation increases on coral reefs without cleaner fish. Coral Reefs 37, 15. https://doi.org/10.1007/s00338-017-1628-z.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C. M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatziolos, M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318 (5857), 1737–1742. https://doi.org/10.1126/science.1152509.

Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B.C., Kleypas, J., van de Leemput, I.A., Lough, J.M., Morrison, T.H., Palumbi, S.R., van Nes, E.H., Scheffer, M., 2017. Climate change promotes parasitism in a coral symbiosis. Nature 546, 82–90. https://doi.org/10.1038/nature22901.

IUCN Red List, 2018. http://www.iucnredlist.org (accessed 04.05.2018).

Jones, A.M., Gardner, S., Sinclair, W., 2008. Losing ‘Nemo’: bleaching and collection appear to reduce inshore populations of anemonefishes. J. Fish. Biol. 73, 753–761. https://doi.org/10.1111/j.1095-8649.2008.01969.x.

Leal, M.C., Vaz, M.C., Puga, J., Rocha, R.J., Brown, C., Rosa, R., Calado, R., 2015. Marine ornamental fish imports in the European Union: an economic perspective. Fish Fish. 17, 459–468. https://doi.org/10.1111/faf.12120.

LEMIS, 2009. Law Enforcement Management Information System, vol. 2011. Office of Law enforcement. http://www.fws.gov/le/. (Accessed 23 September 2017).

Michael, C., 1999. Marine Fishes. 500+ Essential-to-know Aquarium Species. Microcosm Ltd.

Militz, T.A., Kinch, J., Foale, S., Southgate, P.C., 2016. Fish rejections in the marine aquarium trade: an initial case study raises concern for village-based fisheries. PLoS One 11 (3). https://doi.org/10.1371/journal.pone.015162 e0151624.
Militz, T.A., Foale, S., Kinch, J., Southgate, P.C., 2017. Consumer perspectives on theoretical certification schemes for the marine aquarium trade. Fish. Res. 193, 33–42. https://doi.org/10.1016/j.fishres.2017.03.022.
Militz, T.A., Kinch, J., Southgate, P.C., 2018. Aquarium trade supply-chain losses of marine invertebrates originating from Papua New Guinea. Environ. Manag. 61849, 661. https://doi.org/10.1007/s00267-018-1006-9.
Monticini, P., 2010. The ornamental fish trade. Production and commerce of ornamental fish. Technical-managerial and legislative aspects. FAO GLOBEFISH research programme, p. 102. Available. http://www.fao.org/3/a-bb206e.pdf. (Accessed 11 July 2018).
Murray, J.M., Watson, G.J., Giangrande, A., Licciano, M., Bentley, M.G., 2012. Managing the marine aquarium trade: revealing the data gaps using ornamental polychaetes. PLoS One 7 (1), e29543. https://doi.org/10.1371/journal.pone.0029543.
Okemwa, G.M., Fulanda, B., Kimani, E.N., Ochiewo, J., 2009. Exploitation of marine aquarium reef fisheries at the Kenyan Coast. In: Advances in Coastal Ecology People, Processes and Ecosystems in Kenya. Afr. Stud. Centre Afr. Stud. Coll, vol. 20, pp. 29–42. https://www.oceandocs.org/bitstream/handle/1834/8323/ASC-1253933-07.pdf?sequence=2&isAllowed=y. (Accessed 3 May 2018).
Olivotto, I., Planas, M., Simões, N., Holt, G.J., Avella, M.A., Calado, R., 2011. Advances in breeding and rearing marine ornamentals. J. World Aquacult. Soc. 42, 135–166. https://doi.org/10.1111/j.1749-7345.2011.00453.x.
Prakash, S., Ajith Kuma, T.T.A., Raghavan, R., Rhyne, A., Tlusty, M.F., Subramoniam, T., 2017. Marine aquarium trade in India: challenges and opportunities for conservation and policy. Mar. Pol. 77, 120–129. https://doi.org/10.1016/j.marpol.2016.12.020.
Rhyne, A.L., Tlusty, M.F., Schofield, P.J., Kaufman, L., Morris Jr., J.A., Bruckner, A.W., 2012. Revealing the appetite of the marine aquarium fish trade: the volume and biodiversity of fish imported into the United States. PLoS One 7 (5), e35808. https://doi.org/10.1371/journal.pone.0035808.
Rhyne, A.L., Tlusty, M.F., Szczebak, J., Holmberg, R.J., 2017. Expanding our understanding of the trade in marine aquarium animals. PeerJ 5, e2949. https://doi.org/10.7717/peerj.2949.
Robinson, J.E., Sinovas, P., 2018. Challenges of analyzing the global trade in CITES-listed wildlife. Conserv. Biol. 0 (0) https://doi.org/10.1111/cobi.13095.
Saleem, M., Islam, F., 2008. Management of the aquarium fishery in the Republic of the Maldives. In: Proceedings of the 11th Intl Coral Reef Symp, Ft. Lauderdale, 7–11 July 2008. Session 22, 1038–1042.
Schmidt, C., Kunzmann, A., 2005. Post-harvest mortality in the marine aquarium trade: a case study of an Indonesian export facility. Spc Live Reef. Fish. Inf. Bull. 13, 3–12. https://www.researchgate.net/publication/232715398_Post-harvest_mortality_in_the_marine_aquarium_tradeA_case_study_of_an_Indonesian_export_facility. (Accessed 2 July 2018).
Schwerdtner Máñez, K., Dandavaac, L., Ekau, W., 2014. Fishing the last frontier: the introduction of the marine aquarium trade and its impact on local fishing communities in Papua New Guinea. Mar. Pol. 44, 279–286. https://doi.org/10.1016/j.marpol.2013.09.018.
Shuman, C.S., Gregor, Æ., Hodgson, R.F., 2005. Ambrose. Population impacts of collecting sea anemones and anemonefish for the marine aquarium trade in the Philippines. Coral Reefs 24, 564–573. https://doi.org/10.1007/s00338-005-0027-z.
Smith, K.F., Behrens, M.D., Max, L.M., Daszak, P., 2008. U.S. drowning in unidentified fishes: scope, implications, and regulation of live fish import. Conserv Lett. 1, 103–109. https://doi.org/10.1111/j.1755-263X.2008.00014.x.
Stevens, C.H., Croft, D.P., Paull, G.C., Tyler, C.R., 2017. Stress and welfare in ornamental fishes: what can be learned from aquaculture? J. Fish. Biol. 91, 409–428. https://doi.org/10.1111/jfb.13377.
Tan, M.H., Austin, C.M., Hammer, M.P., Lee, Y.P., Croft, L.J., Gan, H.M., 2018. Finding Nemo: hybrid assembly with Oxford Nanopore and Illumina reads greatly improves the clownfish (*Amphiprion ocellaris*) genome assembly. GigaScience 7 (3), 1–6. https://doi.org/10.1093/gigascience/gix137.
Townsend, D., 2011. Sustainability, equity and welfare: a review of the tropical marine ornamental fish trade. Spc Live Reef. Fish. Inf. Bull. 20, 2–12. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/d6/d674e0abd9fd9ddc9c43e86a793608b7.pdf?sv=2015-12-11&sr=b&sig=HtoPZyLFqyQNnuT%2Fpxs1v7qQtzKXO7Zdg3DmEaX1E0U%3D&se=2018-10-29T13%3A55%3A28Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22LRF20_02_Townsend.pdf%22. (Accessed 3 April 2018).
TRACES. TRade Control and Expert System, 2004. https://ec.europa.eu/food/animals/traces_en. (Accessed 1 February 2018).
Triki, Z., Wismer, S., Levorato, E., Bshary, R., 2017. A decrease in the abundance and strategic sophistication of cleaner fish after environmental perturbations. Global Change Biol. 24, 481–489. https://doi.org/10.1111/gcb.13943.
UNEP-WCMC, 2008. United nations environment programme – world conservation monitoring centre. In: Consultation Process on Monitoring of International Trade in Ornamental Fish. European Commission. https://www.scribd.com/document/122620918/2008-Monitoring-of-International-Trade-in-Ornamental-Fish-Consultation-Paper. (Accessed 6 March 2018).
UNEP Certification and Sustainable Fisheries, 2009. United Nations Environment Programme, Geneva, Switzerland. http://www.unep.ch/etb/publications/FS%20certification%20study%202009/UNEP%20Certification.pdf. (Accessed 23 January 2018).
Vagelli, A.A., 2011. The Banggai Cardinalfish. Natural History, Conservation and Culture of *Pterapogon Kauderni*. Wiley-Blackwell.
Wilkinson, C., 2008. Status of Coral Reefs of the World: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia. http://www.icriforum.org/sites/default/files/GCRMN_Status_Coral_Reefs_2008.pdf. (Accessed 13 November 2017).
Wabnitz, C., Taylor, M., Green, E., Razak, T., 2003. From Ocean to Aquarium. UNEP-WCM, Cambridge, UK. http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf. (Accessed 22 January 2018).
Waldie, P.A., Blomberg, S.P., Cheney, K.L., Goldizen, A.W., Grutter, A.S., 2011. Long-term effects of the cleaner fish Labroides dimidiatus on coral reef fish communities. PLoS One 6 (6), e21201. https://doi.org/10.1371/journal.pone.0021201.
Wood, E., 2001. Global advances in conservation and management of marine ornamental resources. Aquarium Sci. Conserv. 3, 65–77. https://doi.org/10.1023/A:1011391700880.
Yan, G., 2016. Saving Nemo. Reducing mortality rates of wild-caught ornamental fish. Live Reef Fish Inf Bull. 21. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/41/4137a5218f37dc28ae18759aec49b5d2.pdf?sv=2015-12-11&sr=b&sig=XY%2FD91lfwltJkE3geHqudQAXuBE0Muk3wNgam6N8nzM%3D&se=2018-11-12T09%3A54%3A26Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%22LRF21_03_Yan.pdf%22. (Accessed 12 September 2017).

Monitoring the trade in marine ornamental fishes through the European Trade Control and Expert System TRACES: challenges and possibilities

Submitted to *Marine Policy*

Monitoring the trade in marine ornamental fishes through the European Trade Control and Expert System TRACES: challenges and possibilities

Monica V. Biondo[1] and Rainer P. Burki[2]

[1]Institute of Ecology and Evolution, University of Bern, Baltzerstrasse 6, 3012 Bern, Switzerland, email: monica.biondo@students.unibe.ch

[2]asdfg IT, Fluh 86, 3204 Rosshäusern, Switzerland, email: rainer.burki@asdfg.it

Abstract

The trade in marine ornamental fishes is valued at over a billion dollars annually and comprises thousands of species. Historically, scientists have pointed out the importance of accurate trade statistics to monitor this trade. Today, there remains no global systems in place to monitor this trade. Europe is a major importer of coral reef fishes, and uses the Trade Control and Expert System (TRACES) to monitor trade in live animals for disease prevention. This database is not intended to record species-specific information on marine ornamental fishes, rather it records numbers of traded specimens and information on species to at least family level. Therefore, it is possible to estimate the volume of trade into Europe, which amounted to approximately 4 million marine ornamental fishes per year during 2014 and 2017. Susceptible species were identified using the number of traded specimens, trends in the trade volume, IUCN Red List conservation status, as well as vulnerability according to Fishbase. After normalization of this data a score was created to produce a watchlist that establishes susceptibility to overexploitation of the species traded considering all parameters combined. Unfortunately, almost one third of all species is listed as data deficient or not evaluated by the IUCN Red List and could not be included in this calculation. Species on the watchlist should be given priority for further monitoring through the Convention on International Trade of Endangered Species (CITES). This study suggests that TRACES, subject to several modifications, could be used as a tool to monitor trade in marine ornamental fishes.

Keywords

Coral reef fishes, European and international trade, trade monitoring, Convention on International Trade of Endangered Species CITES, IUCN, watchlist

1. Introduction

The international marine ornamental fish trade is a global, multi-billion-dollar industry targeting thousands of coral reef species [25,28,36], which are widely collected throughout the Indo-Pacific and Caribbean regions, mainly for the United States and the European market [4,5,10, 26,36]. The habitats of coral reef fishes are largely in decline and threatened due to several global problems, including climate change, ocean acidification and pollution [6,11,14,15,16,22]. To aid preservation of coral reefs and adjacent habitats, and to develop trade sustainability, it is first important to have data regarding the number of specimens traded and the diversity of species collected. Today, it is still unclear what effect trade may have on coral reef ecosystems and adjacent habitats [23]. However, it is known, that the ornamental fish industry has already impacted coral reefs and their biodiversity regionally due to unsustainable harvest [10,26,27,35,36,37].

Several studies have collected data on the number of specimens and species diversity traded. In the early 21st century, estimates ranged between 24 and 27 million individuals globally per year [36]. A more recent review estimated that 1.5 billion ornamental fishes (freshwater and marine) are currently traded globally per annum, and that about 73% die in transport [31]. Considering that the marine ornamental fish trade totals 10% of the entire ornamental fish industry [24,36], this would result in approximately 40 million marine ornamental fishes being handled per year. Also, the mortality rate in the supply chain is a major concern associated with this international trade [9,24,31,32,35,36]. Given that the number of fish species in the trade has also increased going from around 1,000 species in 2001 [37] to 1,471 in 2004/05 [26] to 2,300 species currently [28], it is important that this trade be monitored to scrutinize its sustainability.

With over 500 million inhabitants, the European Union (EU) is one of the largest consumer regions for marine ornamental fishes [4,19] after the United States (US) [26,28]. An economic assessment of the EU trade value accounted for € 135 million during the study period from 2000 to 2011 [19]. To date, the number of specimens traded and diversity of marine ornamental fish species entering the EU has only been estimated [4,5], but never quantified. Furthermore, the potential impact of trade on threatened species has not been analysed.

This study used data from the EU database Trade Control and Expert System (TRACES) to analyse the number of specimens traded and the diversity of species of marine ornamental fishes entering the European region between 2014 and 2017. Furthermore with this data, and using parameters such as number of specimens traded, trends of trade volume, vulnerability and the IUCN Red List conservation status from FishBase [13,], a watchlist was created that may help decision makers to conclude which species should be monitored through CITES. This study aims to emphasize the importance of species-specific trade data and to develop trade sustainability.

2. Material and methods

The Trade Control and Expert System (TRACES) is a management tool for tracking movements of animals, products of animal origin, and animal feed, but also plants and derivates from both outside and within the European Union [33]. TRACES aims to facilitate trade and prevent cross-border animal health issues. For TRACES, traders are required to be registered and complete customs documents titled Common Veterinary Document (CVDE), which physically accompany consignments. Traders also enter the same information into the TRACES database. The data is not publicly available, but may be accessed by government officials who can request full access from local TRACES representatives. For this study, the data was made available by the Directorate-General for Health and Food Safety of the European Commission.

TRACES is not meant to control wildlife trade or to collect species-specific information on wild animals. Nevertheless, TRACES collects data on trade in marine ornamental fishes for the EU. Importers are required to register their commodities at the border to a EU country [33]. TRACES was established in 2004, but collection of data on marine ornamental fishes only commenced in 2011. During the first three years until 2013, data lacked accuracy and was grouped into 'otra pesca' for other food fishes and was eliminated from the calculations. TRACES documents are web-based and can be completed online. TRACES records the species of fish in a predetermined pull-down list field called 'species', which may either contain the full scientific name or only a family name. This makes analysis of all species traded difficult. All records provided trade data at family level, but only a part thereof was discernible at species level. TRACES data from 2014 to 2017 was exported from TRACES into a local MS Access database to be analysed. This process separated the information of the TRACES species field into a real species field and a family field on the condition that, if it contains two words, it must be a species, otherwise it is recorded as a family [5]. All taxa in the MS Access database were checked manually using the World Register for Marine Species (WoRMS) [1] and FishBase [13], the most comprehensive database of the world's fishes. The records containing a species in the species field were then supplemented with the correct family name according to FishBase.

Fishes originating from land-locked countries were individually checked using the species name if available. Obvious freshwater ornamental fishes, e. g. from Malawi, were exempted from the study. Species identified originating from Turkey were retained although Turkey does not have a coral reef or tropical waters, but appears to act as a hub. Three shipments originating from Indonesia, Sri Lanka and the Philippines were identified as anonymous and eliminated from this study. Fishes that did not have a species name but were listed at genus level were manually checked using FishBase and WoRMS, and allocated a family name. Information on origin and destination, as well as number of specimens traded and diversity of species were analysed. The data was used to calculate trends in trade volume. Together with the IUCN Red List conservation status [17] and the vulnerability factors from FishBase [13], an attempt was made to ascertain the most impacted fishes. This was only possible for specimens where information was available at species level and which had a 'threatened' IUCN status.

A partial copy of the FishBase [13] database was replicated locally using fishbaseAPI provided by ropensci.org to filter marine species and assign an IUCN status as well as the vulnerability score. For each species a score was calculated using the following parameters: number of traded specimens, trends of trade volume, IUCN Red List conservation status, and vulnerability. The ranking of this score facilitated the creation of a species watchlist: the higher the score the more susceptible the species could be to overexploitation.

Number of traded specimens

The number of specimens traded per species was normalized by allocating a value of 100 to the species with the highest four-year trade volume. To flatten the data, for each species the median were taken instead of the sum of the four years and the result was scaled from 0 to 100. Data that sheered out was not eliminated because it might be correct and spikes are recorded by the trend.

Trends in trade volume

Trends for the number of specimens traded during the four years were derived by linear regression, which was named slope. The slope was normalized to values between 0 and 100. Positive numbers were divided by the maximum slope, negative numbers by the minimum slope, which again results in a positive number and was multiplied by 100.

IUCN Red List categories

The IUCN Red List categories were translated to a numerical value: least concern (LC) = 0, near threatened (NT) = 20, vulnerable (VU) = 40, endangered (EN) = 60, critically endangered (CR) = 80 and extinct in the wild (EW) = 100. Extinct (EX) did not receive a value because it is not possible to trade an extinct species. The status data deficient (DD) and not evaluated (NE) received no score due to a lack of information about the species. In the four years analysed, no species was ranked 80 or 100 because no traded species was listed as critically endangered or extinct in the wild. This way, the assigned values do not change for a species if further years will be analysed in the future.

Vulnerability

For each species, FishBase calculates a value for vulnerability, which expresses the ability of a species to withstand external influences and is calculated using selected life-history parameters of a fish species such as growth rate, fecundity, and gestation period. Vulnerability is calculated according to a Fuzzy Logic System [7] and is expressed as a figure between 0 and 100. In the four years analysed, no species had a vulnerability value higher than 90. FishBase also presents a categorical resilience status, which reflects the species susceptibility to overexploitation. As resilience was highly correlated to vulnerability (0.68 correlation coefficient), it was disregarded in the analysis. Also, the analysis of the five parameters, i. e. number of specimens, trends in trade volume, vulnerability, resilience, and IUCN Red List conservation status, by primary component analysis (PCA), shows that only four primary components are necessary to describe the situation. The proportions of variance for PC1 to PC5 are 0.36, 0.21, 0.19, 0.19 and 0.06.

Score for the watchlist

After normalizing the four parameters (Table 1), a score was calculated for each species by adding up the values of the normalized parameters: number of traded specimens, trends in trade volume, IUCN Red List conservation status, and vulnerability. The higher the value of the score for a species, the higher it is ranked and the more attention it needs, i. e. monitoring through CITES. A species should either be on the watchlist if it is ranked top in one of the parameters described above, or in a combination of multiple, medium or high parameter scores.

Table 1. (a) The statistical values of the not normalized parameters. Min. = minimum value, 1st Qu. = first quartile (lowest 25%), 3rd Qu. = third quartile (highest 25%), Max. = largest value. (b) The statistical values of the TRACES data using the normalized parameter scale.

a)

	Total 4 years	Trend	Vulnerability	IUCN category
Min.	1	-28025.90	10.00	EN: 5
1st Qu.	17	-21.95	14.00	VU: 18
Median	166	-0.50	23.00	NT: 19
Mean	7,320	-93.20	25.23	LC: 846
3rd Qu.	1,530	6.70	31.00	
Max.	962,220	27,879.00	90.00	

b)

	nTotal 4 years	nTrend	nIUCN category	nVulnerability
Min.	0.00000	0.00	0.00	10.00
1st Qu.	0.0000	0.26	0.00	13.79
Median	0.0100	0.47	0.00	22.77
Mean	0.6516	8.04	1.577	25.50
3rd Qu.	0.0700	1.22	0.00	32.30
Max.	100.000	100.00	60.00	90.00

3. Results

3.1 Country of origin and number of specimens traded

Between 2014 and 2017 50 countries exported marine ornamental fishes to Europe. The main exporting country was Indonesia, which made up 34.4% of all shipments with on average 1,727,940 specimens annually. Indonesia was followed by Sri Lanka with 15.1% of shipments and 599,072 specimens and the Philippines with 12% of shipments and 309,350 specimens. These three countries, together with the United States, Singapore and Kenya made up 82.8 % of all shipments and 84.7 % of all specimens from 2014 to 2017 (Table 2). In total, 25,556 shipments with 15,599,053 specimens were imported into Europe with an average of 3,899,768 specimens a year (Figure 1). The number of imported individuals has decreased from 100% (2014) to 68% in 2017 (Figure 1 and 2).

Table 2. Top six countries of export of marine ornamental fishes to Europe between 2014 and 2017. Average and standard deviation of shipments and number of specimens traded per year. AVG = average, SD = standard deviation.

Country of Export	% Shipments		Specimens	
	AVG	SD	AVG	SD
Indonesia	34.4	1.7	1,727,940	223,726.8
Sri Lanka	15.1	1.1	599,072	44,163.3
Philippines	12	0.4	309,350	49,431.9
Unites States	8.6	0.5	302,255	145,034.4
Singapore	6.9	0.1	195,000	26,231.1
Kenya	5.8	1	170,934	113,045.8
others	17.2		595,212	
Total	100		3,899,763	

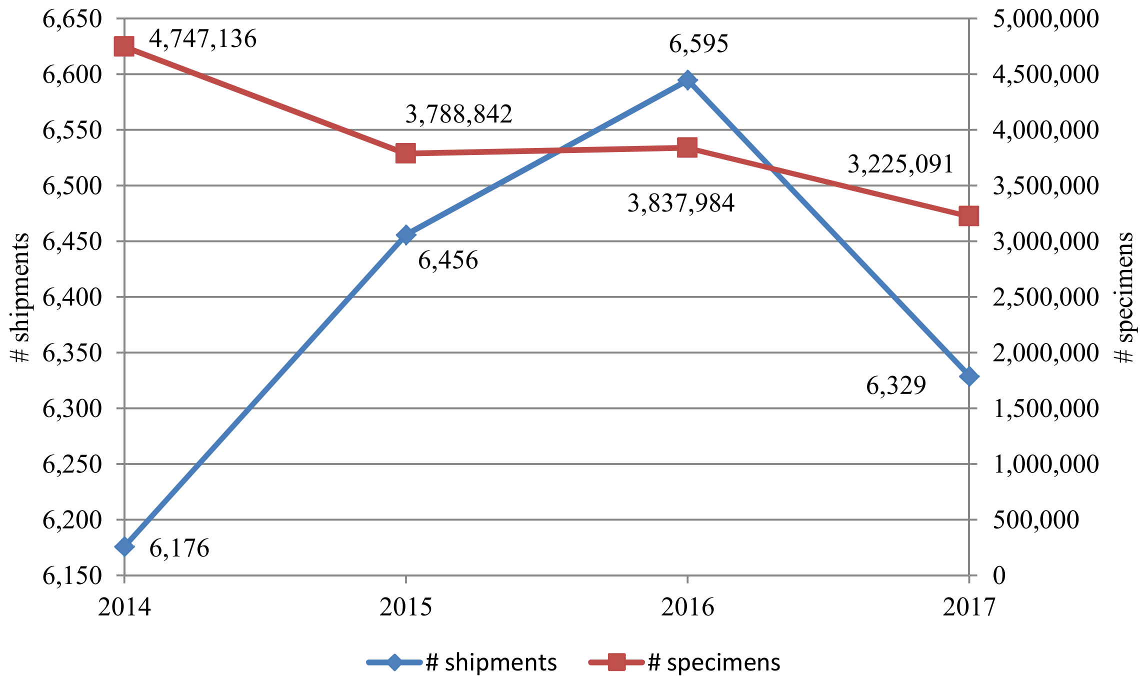


Figure 1. Overall shipments and number of traded specimens per year of marine ornamental fishes from 2014 to 2017 entering Europe.

Twenty-seven European countries imported marine ornamental fishes including Norway, San Marino and Switzerland, which are not members of the EU. The country importing most marine ornamental fishes was the United Kingdom followed by the Netherlands. These two countries made up 48.6 % of all imports between 2014 and 2017 (Table 3.). Germany, Italy and France made up another 33.4 % resulting in only five countries importing 82% of marine ornamental fishes (Figure 2, Table 3).

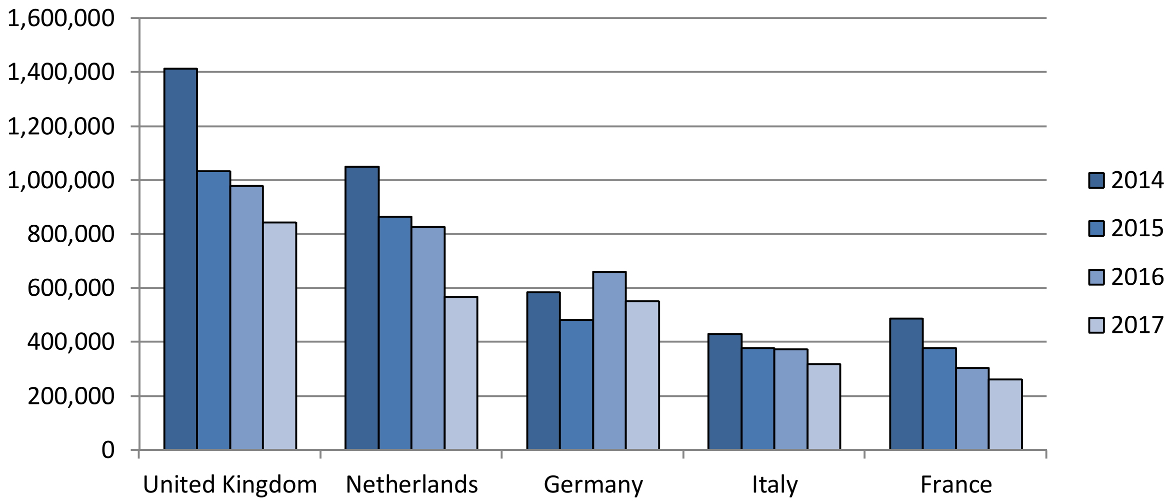


Figure 2. Number of specimens of marine ornamental fishes imported to the five top importing European countries by year from 2014 to 2017.

Table 3. Number of imported marine ornamental fishes per European country between 2014 and 2017 with total amount of specimens over four years and the slope of trade volume as the linear regression of the four years. Slope = negative or positive average number of specimens per year.

Import country	2014	2015	2016	2017	Total	Slope
United Kingdom	1,414,494	1,034,680	978,506	844,667	4,272,347	-176,566
Netherlands	1,049,798	864,511	828,314	567,534	3,310,157	-148,299
Germany	583,889	482,637	660,114	551,266	2,277,906	7,961
Italy	431,839	379,421	373,391	320,154	1,504,805	-34,109
France	487,863	377,900	305,278	261,525	1,432,566	-75,164
Spain	237,842	117,045	131,727	81,042	567,656	-45,572
Denmark	68,144	120,674	131,517	157,571	477,906	27,912
Poland	93,191	78,044	87,300	94,473	353,008	1,310
Belgium	99,186	62,984	76,810	70,276	309,256	-7,290
Sweden	30,922	48,561	42,061	81,367	202,911	14,484
Switzerland	38,407	37,217	42,152	43,138	160,914	1,913
Austria	33,803	34,032	35,225	34,999	138,059	478
Norway	48,171	26,843	33,440	20,321	128,775	-7,695
Greece	45,573	31,876	26,898	21,880	126,227	-7,606
Czech Republic	22,187	27,462	26,633	21,817	98,099	-194
Portugal	10,067	23,633	23,900	17,178	74,778	2,160
Hungary	20,442	7,065	6,834	9,797	44,138	-3,217
Luxembourg	13,311	12,248	10,319	6,683	42,561	-2,181
Malta	4,992	10,130	5,530	5,476	26,128	-315
Cyprus	6,576	6,068	4,735	5,566	22,945	-436
Romania	1,650	1,344	1,613	6,124	10,731	1,369
Bulgaria	2,517	766	909	1,681	5,873	-237
San Marino	0	1,801	2,392	0	4,193	59
Slovenia	953	770	1,041	182	2,946	-204
Croatia	481	879	519	199	2,078	-121
Ireland	838	190	826	175	2,029	-135
Slovakia	0	61	0	0	61	-6

3.2 Diversity of imported marine ornamental fishes for 2014 to 2017

Between 2014 and 2017, fish species from 86 families were imported to Europe. The top 10 families made up 90 % of traded marine ornamental fishes in number of specimens (Figure 3). Labridae was the family with the highest number of imported species followed by Pomacentridae, which were also most traded in number of specimens (Figure 3).

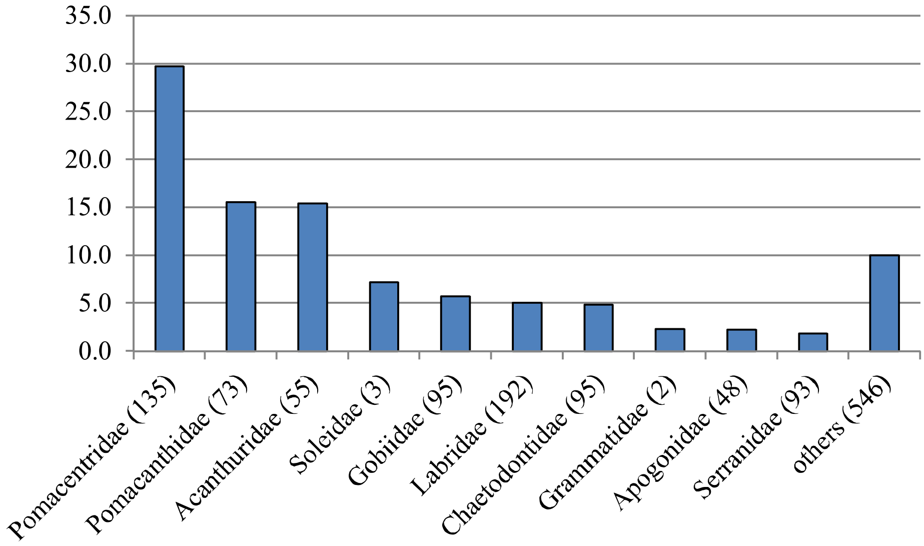


Figure 3. The volume (%) of the top ten families traded into Europe between 2014 and 2017. The number of imported species in the family are in parentheses.

Because TRACES allows declaration of specimens either at the species or family level, this resulted in 29.4% of all specimens between 2014 and 2017 being known only at the family level. The number of identified species increased from 2014 with 61.1% (4,747,136 specimens) to 78% (3,225,091 specimens) in 2017

In four years 1,334 species were recorded and imported to Europe with *Chromis viridis* being the most imported species comprising 13.1%, followed by *Amphiprion ocellaris* with 10.7% and *Centropyge bicolor* with 8.7% of the total volume (Table 4). The 20 most traded species constituted 63.8% of the overall volume for the four years (Table 4).

Table 4. Top 20 species of marine ornamental fishes imported to Europe between 2014 and 2017 and their IUCN Red List conservation status (NE= not evaluated, LC = least concern, EN = endangered). AVG = average, SD = standard deviation.

Spezies	IUCN Red List status	2014	2015	2016	2017	Total	AVG	SD	%
Chromis viridis	NE	334,458	377,022	385,430	348,661	1,445,571	361,393	23,872.2	13.1
Amphiprion ocellaris	NE	257,520	370,199	344,363	201,973	1,174,055	293,514	77,763.6	10.7
Centropyge bicolor	NE	187,298	258,010	265,842	251,070	962,220	240,555	36,013.8	8.7
Chelmon rostratus	NE	124,892	137,841	85,396	48,954	397,083	99,271	40,284.0	3.6
Acanthurus leucosternon	LC	105,389	96,610	99,005	86,144	387,148	96,787	8,004.6	3.5
Acanthurus achilles	LC	84,317	87,950	83,788	105,511	361,566	90,392	10,248.0	3.3
Gramma loreto	LC	130,850	75,770	55,206	80,675	342,501	85,625	32,105.2	3.1
Valenciennea sexguttata	NE	8,015	34,192	81,751	85,092	209,050	52,263	37,557.7	1.9
Zebrasoma flavescens	LC	40,959	54,527	54,535	45,846	195,867	48,967	6,727.7	1.8
Pterapogon kauderni	EN	43,982	38,169	56,494	56,649	195,294	48,824	9,256.2	1.8
Chrysiptera parasema	NE	68,649	60,702	33,348	32,110	194,809	48,702	18,734.3	1.8
Pomacanthus imperator	NE	64,740	53,493	27,088	26,183	171,504	42,876	19,310.4	1.6
Labroides dimidiatus	LC	28,988	46,030	22,903	60,396	158,317	39,579	16,982.6	1.4
Centropyge bispinosa	NE	37,520	32,310	23,273	65,186	158,289	39,572	18,061.8	1.4
Valenciennea puellaris	NE	22,715	33,845	23,828	39,997	120,385	30,096	8,283.6	1.1
Centropyge acanthops	NE	48,023	31,742	32,975	6,078	118,818	29,705	17,403.3	1.1
Chrysiptera cyanea	NE	25,785	37,679	28,166	20,473	112,103	28,026	7,194.2	1.0
Paracanthurus hepatus	NE	19,735	17,409	48,129	26,761	112,034	28,009	13,990.4	1.0
Centropyge loricula	NE	22,701	38,322	13,625	30,751	105,399	26,350	10,613.5	1.0
Pseudanthias squamipinnis	LC	20,229	19,840	28,918	28,896	97,883	24,471	5,125.0	0.9

The IUCN Red List conservation status of all 1,334 species traded between 2014 and 2017 showed 33.63% to be data deficient or not evaluated (Table 5), almost two thirds as being least concern and only 0.37% of species (5 species), as endangered (Table 5). There were no species assessed as critically endangered, extinct in the wild or extinct (Table 5).

Table 5. IUCN Red List conservation status of all species imported into Europe between 2014 and 2017 and percentage (%) of all species.

IUCN Red List status	# species	%
Not listed	0	0
Not evaluated NE	393	29.37
Data deficient DD	57	4.26
Least concern LC	846	63.23
Near threatened NT	19	1.42
Vulnerable VU	18	1.35
Endangered EN	5	0.37
Critically endangered CR	0	0
Extinct in the wild EW	0	0
Extinct EX	0	
Total	1,334	100

3. 3. The watchlist

Using all marine ornamental fishes imported into Europe between 2014 and 2017, a list was compiled where the ranking is given by the score. Thereof, 17 species that reached an overall score of 100 were put on a watchlist (Table 6). This list should help decision makers to conclude which species should be listed in CITES because they appear susceptible to overexploitation. Of these 17 species, 47.1% were Elasmobranchii with four families comprising five species of sharks and the family of the whiptail stingrays with three species. A total of 17.6% came from the tenth most traded family, Serranidae (Table 6), but no species came from the most traded family Pomacentridae. *Centropyge bicolor* had the highest overall score and comes from the second most traded family, Pomacanthidae (Table 6). Its IUCN Red List conservation status is of least concern, but the number of specimens traded is increasing. All four coral reef fishes listed as endangered in the IUCN Red List were included on the watchlist, although only *Cheilinus undulatus* and *Sphyrna lewini* are listed in Appendix II of CITES. The shark *Stegostoma fasciatum*, giant grouper *Epinephelus lanceolatus*, and banggai cardinalfish *Pterapogon kaudern*i are not listed in CITES (Table 6).

Table 6. Watchlist of the 17 species with an overall score of 100 ranked by the sum of four normalized parameters: the score of the median number of specimens traded over 4 years, the score of the trends of trade volume (slope), the score of the IUCN Red List conservation status and the score in vulnerability according to FishBase. Species that are data deficient or not evaluated by the IUCN Red List are not considered.

Rank	Species	Family	IUCN Red List status	Overall score	Median volume score	Slope score	IUCN score	Vulnerability score
1	*Centropyge bicolor*	Pomacanthidae	LC	223	100	100	0	23
2	*Chelmon rostratus*	Chaetodontidae	LC	156	41	100	0	15
3	*Sphyrna lewini*	Sphyrnidae	EN	141	0	0	60	81
4	*Stegostoma fasciatum*	Stegostomatidae	EN	137	0	0	60	77
5	*Cheilinus undulatus*	Labridae	EN	134	0	0	60	74
6	*Urogymnus asperrimus*	Dasyatidae	VU	130	0	0	40	90
7	*Pterapogon kauderni*	Apogonidae	EN	127	20	28	60	19
8	*Epinephelus lanceolatus*	Serranidae	VU	126	0	0	40	86
9	*Epinephelus striatus*	Serranidae	EN	123	0	0	60	63
10	*Taeniura meyeni*	Dasyatidae	VU	117	0	0	40	77
11	*Nebrius ferrugineus*	Ginglymostomatidae	VU	117	0	0	40	77
12	*Pomacanthus imperator*	Pomacanthidae	LC	116	16	51	0	50
13	*Taeniura lymma*	Dasyatidae	NT	112	1	1	20	90
14	*Mycteroperca interstitialis*	Serranidae	VU	108	0	0	40	68
15	*Carcharhinus amblyrhynchos*	Carcharhinidae	NT	105	0	0	20	85
16	*Triaenodon obesus*	Carcharhinidae	NT	103	0	0	20	83
17	*Gramma loreto*	Grammatidae	LC	102	31	61	0	10

4. Discussion

The European Trade Control and Expert System (TRACES) is the primary functioning tool to monitor the trade in marine ornamental fishes in large parts of the world, in particular, Europe. Although, TRACES is not specifically designed to monitor trade in wildlife, it produced very meaningful information on number of specimens traded as well as diversity of species over the four years study period (2014-2017). TRACES could be used to propose a scoring system to identify species that require monitoring because trade in these species could have detrimental effects. Furthermore, TRACES, with a few modifications, could be used as a tool to monitor trade in marine ornamental fishes.

4.1 Origin, destinations, number of specimens traded and trends

The marine ornamental fish trade is an international market with the most important source countries situated in Southeast Asia, and the main importing countries in the West [26,28,36]. Overall, during the period from 2014 to 2017, 50 countries exported marine ornamental fishes to Europe, which is an indication of the scale of this industry. In comparison to the US, the largest importing country, 45 other nations exported marine ornamental fishes [28]. More than two thirds of all European imported specimens originated from Indonesia, Sri Lanka and the Philippines, with the main importing countries located in Western Europe where GDP is higher than for the rest of the region. These same exporting countries shipped fish to the largest importing nation, the US [26,28] and a non-EU country, Switzerland [4,5]. It is unclear how big the trade in the Asian, South American or African markets are.

Today, approximately 40 million specimens of marine ornamental fishes are traded annually worldwide [31]. For Europe the number of specimens traded decreased approxinately one third over the study period 2014 and 2017 from almost 5 million to over 3 million specimens. Almost 45% came from Indonesia alone, and five importing countries imported over 80% of all specimens. With regard to potential number of consumers and comparison to the US volume and consumer capacity, the overall volume was expected to be higher.

Because the total value of coral reef fishes entering the EU was similar to the value of marine ornamental fishes entering the US [4,19,20], it was anticipated that the volume of specimens would also be similar. Furthermore, based on the fact that the EU has over 500 million inhabitants, an almost 60% larger population size than the US, it was also anticipated that even more specimens would have been imported to Europe. According to Leal et al. [19], the EU imports marine ornamental fishes worth about € 11.3 million (about US$ 12.8 million) per year. Interestingly, another study valued the EU imports of ornamental fishes at US$ 144,736 million in 2007 (Moniticini, 2010), and because the marine ornamental fish trade is estimated at 10% of the marine and freshwater ornamental fish trade combined [24,36], this would result in US$ 14.5 million for 2007, thus both studies give comparable figures. Also, some statistics are available for the UK, which has always been the biggest EU importer for marine ornamental fishes [36] followed by the Netherlands. Between 1997 and 2002 the UK imported about 875,000 specimens a year [36], which is the same as for 2017 whereas in 2014 the trade volume had reached 1.4 million specimens.

4.2 Diversity of marine ornamental fishes

Over the four years analysed, 1,334 species were recorded under TRACES at species level entering Europe whereas internationally there were at least 2,300 species of marine ornamental fishes in trade [28]. Conversely, there are at least 86 families entering Europe compared to 50 families entering the US [26,28]. It is possible that there are more species entering Europe because almost one third of specimens were not discernible at species level. Therefore, the overall accuracy of TRACES data needs to improve. Rhyne et al. [28] suggests that physical import documents record species more accurately, but one Swiss study that analysed physical import documents, showed that at least one third also did not contain species lists of ornamental fishes for that country [4]. In addition, exporting countries require closer examination, as implied by the examples of three declared 'Antarctican' fishes from the family Scorpaenidae - there are no Scorpaenidae in Antarctica.

Species traded are highly diverse, although the majority of specimens are confined to relatively few species. From the species identified, *Chromis viridis*, *Amphiprion ocellaris* and *Centropyge bicolor* comprised over a third of all imports and the top 20 species represented over 60% of all imports. A study for Switzerland between 2014 and 2017 showed that almost 40% of all imports were *C. viridis*. Interestingly, *A. ocellaris* was the most imported species over the same four years, although over 60% were transshipped to the EU [5]. In the US, *C. viridis* was also the most imported (>10%) and six other fish species represented one third of all imported specimens from 2008 to 2011. A total of 20 species represented over 50% of imports.

4.3 The significance of a watchlist

Of all threats facing the oceans, the evidence so far available suggests, that overexploitation, for example by trade, is the most serious threat to marine fish species [2]. Therefore, all traded species were allocated a score using information on number of specimens traded, trends of trade volume, IUCN Red List conservation status (IUCN Red List, 2018) and the vulnerability score [7,8,13]. The higher the score, the more susceptible the species could be to overexploitation. Seventeen species were put on a watchlist that recommends the species that should precautionarily be listed in the Appendix II of CITES. This would ensure the monitoring of these species. All species listed as endangered on the IUCN Red List were included on the watchlist, but only *Cheilinus undulates* and *Sphryna lewini* are listed on Appendix II of CITES. The banggai cardinalfish, *Pterapogon kauderni*, an endemic species that has been overfished [21,35] as well as the gian grouper, *Epinepelus striatus*, and *Stegostoma fasciatus*, are not listed in CITES.

Unfortunately, over one third of all species that were identified at species level were recorded as data deficient or not evaluated by the IUCN Red List and had therefore no conservation status. Consequently, these species did not qualify for the watchlist calculations. The fact that a species has not been assessed does not imply that it is not potentially threatened. As stated in the preamble of the IUCN Red List: '… until such time as an assessment is made, taxa listed in these categories should not be treated as if they were non-threatened. It may be appropriate (especially for data deficient forms) to give those species the same degree of attention as threatened taxa, at least until their status can be assessed' [17]. The species that were not included on the watchlist, such as *C. viridis* and *A. ocellaris,* are the most traded species in Europe and in the world [26,28,36], and could precautionarily be listed in CITES because the number of traded specimens shows an increasing trend. It is unclear how many specimens of *A. ocellaris* could derive from captive breeding facilities [28] as this information is not available.

Calculated positive trends support the assumption that some species could be traded in even larger numbers. Negative trends may indicate that species populations are decreasing or that interest from trade is diminishing. The collection of coral reef fishes on a large scale can have ecological consequences that are both direct - resulting from the selective and non-selective removal of the organisms concerned and indirect - resulting from the disruption of habitat [26,32,36,37]. Therefore, species that are either data deficient or not evaluated but are traded in large numbers, and species that have been identified as being sensitive to trade, such as *Synchirpus splendidus,* could be monitored as a precaution and listed in CITES [4,5,32].

4.4 Importance of monitoring the aquarium trade and effectiveness of TRACES

Concern has been expressed that where species are not regulated under CITES there is *de facto* neither a global reporting system for wildlife trade in general nor for the marine ornamental fish trade in particular [3,29]. Therefore, TRACES represents a good tool that could be easily modified to function as a monitoring system. Although at present TRACES is not intended to monitor the trade in marine ornamental fishes and therefore, the volume and diversity of traded species is rarely fully reported, it allows analysis of some data. TRACES has gradually been improved, and since 2014 data for ornamental fishes is clearly divided into freshwater and marine species. Also, a consultation process among industry operators focusing on the international trade in ornamental fishes entering the EU indicated that they are also interested in a sustainable trade and that they would be willing to work in partnership with regulatory bodies towards a monitoring mechanism, with TRACES to be further investigated as a tool to control this international trade [34]. To properly monitor the marine ornamental fish trade, several additional improvements would be needed: (1) All known species of coral fishes would need to be selectable in TRACES; (2) imports would need to be declared at species level and all taxa checked regularly for their accuracy using WoRMS [1] or synonyms and alternative names would need to be allowed; (3) TRACES should require specification whether a species is captive-bred or wild caught; (4) all fishes, as for other vertebrates [33], should be traceable to their source, for example, because fishes originating from Singapore, most likely did not birth in Singapore's coral reefs; and (5) TRACES includes important policies regarding non-native species and public health. TRACES does not allow importation of species that are recorded as invasive, and requires an electronic approval by the veterinary authority of the country of import [33]. In this study, sharks of the family Charcharidae from South Africa were allowed to be imported into Europe, although South African law prohibits the commercial sale of these species [30]. As is already the case for invasive species, TRACES could require the approval of the veterinary authority to import species that are protected in the source country.

5. Conclusion

The lack of a meaningful data collection system for the marine fish trade impedes effective management, which in turn limits the sustainability of the aquarium industry [12,26,29]. Government cooperation is urgently required to resolve monitoring and control issues [18]. The aquarium industry has clearly stated its interest in using a tool such as TRACES to monitor commerce, and to develop the sustainability of this trade. TRACES has gradually improved the information it collects on marine ornamental fishes but could supplement key parameters such as compulsory requirements to be able to select all known coral reef fish species at species-level and clarification of captive-bred or wild-caught status and sourcing country of origin. Where fishes are protected in the source country, this would elicit notification to the responsible authority, as is already the case for invasive species. Also, all species of coral reef fishes need to be evaluated by the IUCN Red List, whereas currently approximately 30% are not assessed. Additionally, using parameters from TRACES, FishBase and IUCN Red List the watchlist could determine whether a species requires monitoring via CITES.

Acknowledgements

I am thankful to Wolfgang Nentwig for his valued discussions and comments, Didier Carton and Frank Juschus for allowing me to use and for providing the raw data from TRACES. Andy Atkinson for his help on R and statistics, and Clifford Warwick for proof reading the manuscript.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Appeltans W., Bouchet P., Boxshall G., Fauchald K., Gordon D., et al., 2011. World register of marine species. Available: www.marinespecies.org. doi:10.14284/170
2. Baillie J.E.M., Hilton-Taylor C., Stuart S.N., 2004. 2004 IUCN Red List of threatened species. A global species assessment. IUCN, Gland, Switzerland and Cambridge, UK. xxiv + 191 (accessed 28.09.2018)
3. Baker S.E., Cain R., van Kesteren F., Zommers Z.A, D'Cruze N, Macdonald D.W., 2013. Rough trade: Animal welfare in the global wildlife trade. BioScience 63:12. doi:10.1525/bio.2013.63.12.6
4. Biondo M.V., 2017. Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union. Glob Ecol Conserv. 11:95–105. doi.org/10.1016/j.gecco.2017.05.006
5. Biondo M.V., 2018. Importation of marine ornamental fishes to Switzerland. Glob Ecol Conserv. 15:e00418. doi.org/10.1016/j.gecco.2018.e00418
6. Carpenter K.E., Abra M., Aeby G., Aronson R.B., Banks S., Bruckner A., et al. 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science. 321: 560-563. doi: 10.1126/science.1159196
7. Cheung W.W.L, Pitcher T.J., Pauly D., 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. Biol Conserv. 124: 97–111. doi:10.1016/j.biocon.2005.01.017
8. Cheung W.W.L., Watson R., Morato T., Pitcher T.J., Pauly D., 2006. Intrinsic vulnerability in the global fish catch. Mar Ecol Prog Ser. 333: 1–12. doi:10.3354/meps333001
9. Cohen F.P.A, Planas M.,Valenti W.C., Lillebø A., Calado R., 2018. Optimizing packing of live seahorses for shipping. Aquaculture. 482: 57-64. doi.org/10.1016/j.aquaculture.2017.09.024
10. Dee L.E., Horii S.S., Thornhill D.J., 2014. Conservation and management of ornamental reef wildlife: Success, shortcomings, and future directions. Biol Conserv. 169: 225-237. doi.org/10.1016/j.biocon.2013.11.025
11. Ferrari M.C., Dixson D.L., Munday P.L., McCormick M.I., Meekan M.G., Sih A., Chivers D.P., 2011. Intrageneric variation in antipredator responses of coral reef fishes affected by ocean acidification: implications for climate change projections on marine communities. Glob Change Biol. 17: 2980-2986. https://doi.org/10.1111/j.1365-2486.2011.02439.x
12. Foster, S. Wisweder, A. Vincent., 2014. Opportunities and challenges for analysis of wildlife trade using CITES data – seahorses as a case study. Aquat Conserv Mar. Freshw Ecosyst. 26: 154-172. doi:10.1002/aqc.2493
13. Froese R., Pauly D., 2014. FishBase. World Wide Web electronic publication. http://www.fishbase.org (accessed 06.09.2018)
14. Gattuso, J.-P., Hoegh-Guldberg O., Pörtner H.-O., 2014. Cross-chapter box on coral reefs. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A:

Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R, Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 97-100. https://doi.org/10.1017/CBO9781107415379.005
15. Hoegh-Guldberg O., Mumby P.J., Hooten A.J., Steneck R.S., Greenfield P., Gomez E., Harvell C.D., Sale P.F., Edwards A.J., Caldeira K., Knowlton N., Eakin C.M., Iglesias-Prieto R., Muthiga N., Bradbury R.H., Dubi A., Hatziolos M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science. 318 (5857): 1737–1742. doi:10.1126/science.1152509
16. Hughes T.P., Barnes M.L., Bellwood D.R., Cinner J.E., Cumming G.S., Jackson J.B.C., Joanie Kleypas J., van de Leemput I.A, Lough J.M., Morrison T.H., Palumbi S.R., Egbert H. van Nes E.H., Scheffer M., 2017. Coral reefs in the Anthropocene. Nature 546: 82-90. doi:10.1038/nature22901
17. IUCN Red List, 2018. http://www.iucnredlist.org (accessed 24.09.2018)
18. Kuo T.-C., Vincent A., 2018. Assessing the changes in international trade of marine fishes under CITES regulations – A case study of seahorses. Marine Policy, 88: 48-57. https://doi.org/10.1016/j.marpol.2017.10.031
19. Leal M.C., Vaz M.C., Puga J., Rocha R.J., Brown C., Rosa R., Calado R., 2015. Marine ornamental fish imports in the European Union: an economic perspective. Fish Fish. 17: 459-468. https://doi.org/10.1111/faf.12120
20. LEMIS. Law Enforcement Management Information System, 2011. Office of Law enforcement. 2011. http://www.fws.gov/le/ (accessed 23.09.2017)
21. Lunn K.E., Moreau Æ M.-A., 2004. Unmonitored trade in marine ornamental fishes: the case of Indonesia's banggai cardinalfish (*Pterapogon kauderni*). Coral Reefs 23: 344–351. doi:10.1007/s00338-004-0393-y
22. Madin J.S., Madin E.M.P., 2015. The full extent of the global coral reef crisis. Conserv Biol. 29: 724-1726. doi:10.1111/cobi.12564
23. Militz T.A., Kinch J., Southgate P.C., 2018. Aquarium trade supply-chain losses of marine invertebrates originating from Papua New Guinea. Environ Manage. 61849: 661. doi:10.1007/s00267-018-1006-9
24. Monticini P., 2010. The Ornamental Fish Trade. Production and commerce of ornamental fish. Technical-managerial and legislative aspects. FAO GLOBEFISH Research Programme; p. 102. Available: http://www.fao.org/3/a-bb206e.pdf (accessed 11.10.2018).
25. Prakash S., Kumar T.T.A., Raghavan R., Rhyne A., Tlusty M.F., Subramoniam T., 2017. Marine aquarium trade in India: Challenges and opportunities for conservation and policy. Marine Policy, 77: 120-129. doi.org/10.1016/j.marpol.2016.12.020
26. Rhyne A.L., Tlusty M.F., Schofield P.J., Kaufman L., Morris J.A. Jr., Bruckner A.W., 2012. Revealing the appetite of the marine aquarium fish trade: The volume and biodiversity of fish imported into the United States. PLoS ONE. 7(5): e35808. https://doi.org/10.1371/journal.pone.0035808
27. Rhyne A.L., Tlusty M.F., Kaufman L., 2014. Is sustainable exploitation of coral reefs possible? A view from the standpoint of the marine aquarium trade. Curr Opin Environ Sustain. 7:101–107. http://dx.doi.org/10.1016/j.cosust.2013.12.001
28. Rhyne A.L., Tlusty M.F., Szczebak J., Holmberg R.J., 2017. Expanding our understanding of the trade in marine aquarium animals. PeerJ. 5:e2949. https://doi.org/10.7717/peerj.2949

29. Smith K.F., Behrens M.D., Max L.M., Daszak P., 2008. U.S. drowning in unidentified fishes: Scope, implications, and regulation of live fish import. Conserv Lett. 1: 103-109. https://doi.org/10.1111/j.1755-263X.2008.00014.x
30. Staatskoerant, 2015: South African shark biodiversity management plan. South Africa. Available: https://www.environment.gov.za/sites/default/files/gazetted_notices/nemba10of2004_sharksbiodiversitymanagementplan_0.pdf (accessed 09.10.2018)
31. Stevens C.H., Croft D.P., Paull G.C., Tyler C.R., 2017. Stress and welfare in ornamental fishes: What can be learned from aquaculture? J Fish Biol. 91: 409-428. https://doi.org/10.1111/jfb.13377
32. Thornhill D., 2012. Ecological impacts and practices of the coral reef wildlife trade. Defenders of Wildlife. Available: https://www.defenders.org/sites/default/files/publications/ecological-impacts-and-practices-of-the-coral-reef-wildlife-trade.pdf (accessed 22.09.2018)
33. TRACES, 2018. European Trade Control and Expert System. https://ec.europa.eu/food/animals/traces_en (accesses, 14.09.2018)
34. UNEP-WCMC. United Nations Environment Programme – World Conservation Monitoring Centre, 2008. Consultation process on monitoring of international trade in ornamental fish. European Commission. https://www.scribd.com/document/122620918/2008-Monitoring-of-International-Trade-in-Ornamental-Fish-Consultation-Paper (accessed 06.03.2018)
35. Vagelli A.A., 2011. The banggai cardinalfish. Natural history, conservation and culture of *Pterapogon kauderni*. Wiley-Blackwell.
36. Wabnitz C., Taylor M., Green E., Razak T., 2003. From ocean to aquarium. UNEP-WCM, Cambridge, UK. http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf (accessed 22.01.2018)
37. Wood E., 2001. Global advances in conservation and management of marine ornamental resources. Aquarium Sci Conserv. 3:65-77. https://doi.org/10.1023/A:1011391700880

General discussion

The marine ornamental fish trade began in the 1930s, and has grown rapidly. Despite this, there has never been a proper monitoring system in place for this trade, and initiatives for control or overview have all failed (Biondo, 2018; Rhyne et al., 2017). For a long time, scientists have voiced concern stating that a confounding factor of the marine ornamental fish industry is the lack of species-specific trade data (Biondo, 2018, 2017; Prakash et al., 2017; Rhyne et al., 2017, 2012; Wabnitz et al., 2003). Today, more than half of the known 4,000 coral reef fish species are in trade (Rhyne et al., 2017), with approximately 40 million specimens traded annually worldwide (Stevens et al., 2017). The high mortality in the supply chain (Stevens et al., 2017; Vagelli, 2011; Wabnitz et al., 2003) is of great concern, and most species are wild-caught - because they rarely breed in captivity (Sweet, 2017; Penning et al., 2009) Accordingly, investigation into this trade is urgently required. The purpose of this work was to provide an overview of the marine ornamental fish trade in Europe, Switzerland and globally.

The first study evaluated data from almost 1,500 Swiss customs documents from 2009. Two thirds of these documents included species lists of freshwater and marine ornamental fishes as well as marine invertebrates. These data enabled almost 30,000 specimens of marine ornamental fishes to be identified to species level indicating 440 species and 45 families originating from 12 countries. Unfortunately, due to bilateral agreements, no data is collected for imports coming from the European Union (EU) and it was, therefore, not possible to determine how many individuals came from the EU. However, inferred data indicated that more than 200,000 marine ornamental fishes may be imported into Switzerland annually, and an unknown quantity re-exported (Biondo, 2017). The two most traded species were *Amphiprion ocellaris* and *Chromis viridis*.

The second study analysed fishes entering Switzerland from 2014 to 2017 using the European Trade Control and Expert System (TRACES) (TRACES, 2018) and showed that 19 countries exported yearly about 40,000 specimens of marine ornamental fishes, with over 70% of specimens remaining in Switzerland and the rest being transshipped to 11 European countries. Family diversity was between 54 and 60 taxa and between 172 and 331 species annually. As was the case for the customs documents analysed in 2009, only 16.9% to 27.6% of all imported specimens were identifiable at species level. The two most traded species were *Amphiprion ocellaris* and *Chromis viridis*.

The third study, also used data from TRACES for 2014 to 2017, and analysed all imports of marine ornamental fishes to the EU. This data indicated that approximately 4 million marine ornamental fishes entered the EU annually although volume decreased by approximately one third from 2014 to 2017. Over the four years only 29.4% of specimens were recorded at species level and totalled 1,334 species from 87 families. The United States, the largest importing country in the world, imports at least 2,300 species of marine ornamental fishes from 50 families (Rhyne et al., 2017). In the third study of all species with a threatened status, i. e. evaluated by the International Union for the Conservation of Nature (IUCN) Red List, a score of susceptibility to overexploitation by trade was calculated. To determine the score, the overall number of specimens traded, trends in trade volume, IUCN Red List conservation status and the vulnerability according to FishBase were used. A watchlist was produced with 17 species, which reached a score of 100.

It is recommended, as a precautionary measure, to include watchlist species in the Appendices to Convention on International Trade of Endangered Species (CITES), together with species traded in very large numbers and species identified as susceptible to trade (Biondo, 2017), in order to ensure that their trade is monitored. This precautionary measure is important because very few species are protected under CITES and therefore very little specific trade data is collected.

All three studies analysed the IUCN Red List conservation status of the imported species and found that approximately a third of all imported species were labelled ‘not evaluated’ or ‘data deficient’. Analysis of the IUCN Red List for all globally known coral reef fishes revealed that the number of species labelled ‘not evaluated’ and ‘data deficient’ decreased from 73.3% in 2014 to 44.8% in 2018 and to 33.7% in late 2018. This reduction is encouraging because it means that more species have been assessed by the IUCN Red List (IUCN, 2018). It is highly recommended, that all known coral reef fish species be evaluated by the IUCN Red List as soon as possible (Biondo, 2018).

These studies showed that TRACES may provide an adequate monitoring tool, subject to certain adaptations, such as a compulsory requirement for information at species-level and clarification of captive-bred or wild-caught status, as well as the sourcing country of origin. Furthermore, where fishes are protected in the source country, this should elicit notification to the responsible authority in the exporting country, as is already similarly the case for invasive species.

References

Biondo M.V., 2017. Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union. Glob Ecol Conserv. 11:95–105. doi.org/10.1016/j.gecco.2017.05.006

Biondo M.V., 2018. Importation of marine ornamental fishes to Switzerland. Glob Ecol Conserv. 15:e00418. doi.org/10.1016/j.gecco.2018.e00418

IUCN Red List, 2018. http://www.iucnredlist.org

Penning M., Reid GMcG, Koldewey H., Dick G., Andrews B., Arai K., Garratt P., Gendron S., Lange S., Tanner K., Tonge S., Van den Sande P., Warmolts D., Gibson C., 2009. Turning the Tide: a Global Aquarium Strategy for Conservation and Sustainability. World Association of Zoos and Aquariums. Available: http://www.waza.org/files/webcontent/1.public_site/5. conservation/conservation_strategies/turning_the_tide/Aquarium%20strategy%20EN.pdf

Prakash S., Kumar T.T.A., Raghavan R., Rhyne A., Tlusty M.F., Subramoniam T., 2017. Marine aquarium trade in India: Challenges and opportunities for conservation and policy. Marine Policy, 77: 120-129. doi.org/10.1016/j.marpol.2016.12.020

Rhyne A.L., Tlusty M.F., Schofield P.J., Kaufman L., Morris J.A. Jr., Bruckner A.W., 2012. Revealing the appetite of the marine aquarium fish trade: The volume and biodiversity of fish imported into the United States. PLoS ONE. 7(5): e35808. https://doi.org/10.1371/ journal.pone.0035808

Rhyne A.L., Tlusty M.F., Szczebak J., Holmberg R.J., 2017. Expanding our understanding of the trade in marine aquarium animals. PeerJ. 5:e2949. https://doi.org/10.7717/peerj.2949

Stevens C.H., Croft D.P., Paull G.C., Tyler C.R., 2017. Stress and welfare in ornamental fishes: What can be learned from aquaculture? J Fish Biol. 91: 409-428. https://doi.org/10.1111/jfb.13377

Sweet T. 2016. The state of marien Breeders' art, 2017.CORAL, 13(6). Available: http://www.reef2rainforest.com/2016/11/17/coral-magazines-captive-bred-marine-fish-species-list-for-2017/

TRACES, 2018. European Trade Control and Expert System. https://ec.europa.eu/food/animals/traces_en

Vagelli A.A., 2011. The banggai cardinalfish. Natural history, conservation and culture of Pterapogon kauderni. Wiley-Blackwell.

Wabnitz C., Taylor M., Green E., Razak T., 2003. From ocean to aquarium. UNEP-WCM, Cambridge, UK. http://www.unep.org/pdf/from_ocean_to_aquarium_report.pdf

Acknowledgements

I thank my supervisor Prof. Dr. Wolfgang Nentwig for all his valuable input and greatly appreciated discussions, as well as the support in providing me with the possibility for this PhD thesis. I thank Mathias Lörtscher from the Swiss Federal Food Safety and Veterinary Office, who gave me permission to use the import papers and electronic data, and who also provided financial support. My thanks also to Rolf Frischknecht, who introduced me to the Trade Control and Expert System (TRACES) and to Sara Schärrer and Daniela Tanner who provided the TRACES data for Switzerland. I would also like to thank Dr. Didier Carton and Frank Juschus from the Directorate-General for Health and Food Safety of the European Commission for providing the TRACES data for the EU.

To all my family members, I am very grateful. My brother, Marcello Biondo, has always motivated me in my work – work that I could not have done without my husband, Rainer Burki, who has always backed me up and encouraged me when I thought I would quit. And I also thank greatly my lovely son Gian, whose immense patience I admire deeply. Although he is still small, he always showed empathy and comprehension when things did not work out at once as I wished.

I would also like to thank Prof. Dr. Patricia Holm for initial discussions and her willingness to be my examiner for the PhD examination, as well as Prof. Dr. Raffaël Arlettaz as my chairman. I thank Dr. Andy Rhyne and Dr. Michael Tlusty for helping with the database in the beginning of my studies and Dr. Andy Atkinson for his much valued help regarding statistical matters. Also, I would like to thank Lisa Bradbury and Viktoria Kirchhoff for reading earlier versions of my first publication, and Clifford Warwick for taking time to proof read all my manuscripts.