Risks associated with the global demand for novel exotic pets: a new and emerging trade in snakeheads (*Channa* spp.) from India

ABSTRACT

Ornamental fish keeping is a popular hobby worldwide, supporting a significant global aquarium industry. Using export records of live snakeheads (*Channa* spp.) from India, we show a six-fold increase in the numbers of these (wild-sourced, freshwater) species exported worldwide between 2014 and 2019, driven by an increase in exports from West Bengal to China, Taiwan, and Hong Kong. We highlight issues associated with exploitation of a poorly-known taxonomic group (in this case, the genus Channa), species that have restricted ranges, are rare, recently described, and difficult for non-experts to distinguish from others, and the risks associated with global transport of a potentially invasive species. We outline knowledge gaps relevant to national-level management; more broadly, we suggest a fundamental change of approach whereby traders of 'luxury' wildlife products (e.g. exotic pets) are required to demonstrate that trade is sustainable and safe, rather than conservationists to demonstrate that it is not.

Keywords: aquarium trade, freshwater ornamental fish, invasion, overexploitation, wildlife trade

1 INTRODUCTION

People's increasing desire for exotic pets (e.g. Grant et al. 2017) drives a significant global commercial trade, both legal and illegal (UNODC 2016), that involves several hundreds of species whose trade is regulated under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (e.g. Can et al. 2019) and many more that are traded out with CITES

regulations (e.g. Auliya et al. 2016). Primarily, but not exclusively, to supply markets in the northern hemisphere, the exotic pet and aquarium trades source a wide taxonomic variety of animals from countries on all continents (e.g. Bush et al. 2014), with a proportion of them taken directly from the wild (e.g. Andrews 1990, Harrington 2015, Auliya et al. 2016, D'Cruze et al. 2020a, b). Species involved range from parrots and songbirds, turtles, lizards and snakes, to civets, slow lorises, flying squirrels, cheetahs, and tarantula spiders and beetles (Bush et al. 2014, Harrington et al. 2021). Amongst reptiles, one of the most highly traded is the ball python *Python regius*, c.100,000 of which are exported under CITES permit annually from range states in West Africa (Harrington et al. 2020), where they are 'ranched' via wild collection of eggs and gravid females (D'Cruze et al. 2020b), destined for the USA, Europe, and Asia. A similar number of wild-sourced blue tang fish *Paracanthurus hepatus* (a marine ornamental fish that featured as the character 'Dory' in the animated movie *Finding Dory*, that is not under CITES regulation) are imported into the USA alone, primarily from Indonesia and the Philippines (www.aquariumtradedata.org, cited in Verissimo et al. 2020). For wild-sourced animals, the most rudimentary international trade chain comprises capture and harvest from the wild, international shipping and, ultimately, private ownership (often in a country outside the species' native range, and often on a different continent). Where this process is not well managed, the exotic pet and aquarium trades potentially risk population-level conservation impacts at source due to over-collection (e.g. Berkunsky et al. 2017, Auliya et al. 2016), and at destination due to invasion (e.g. Lockwood et al. 2019) and disease (Travis et al. 2011, Can et al. 2019).

Assessing and potentially mitigating these risks depends on an understanding of the species: the status and distribution of their wild populations, their biological characteristics (reproduction, longevity, diseases and pathogens carried), and their physical and behavioural needs in the wild and in captivity. However, for biologists and managers keen to identify and manage for conservation risks, identifying potential target ('high-risk-associated') species is difficult, in part because consumer demand is changeable and influenced by ephemeral popularity and fashion 'fads' (e.g. Harrington et

al. 2019). Novel taxa (species not commonly kept as pets, e.g. otters or kinkajous, Harrington et al. 2019), and rare (Tournant et al. 2012) and 'newly described' species (Stuart 2006), are often highly sought after, or quickly become popular. Interest in both diversity and rarity is prevalent amongst aquarium collectors (Rhyne et al. 2012) and the aquarium ('ornamental fish') trade illustrates many of the complexities and multi-faceted issues involved in the supply of exotic pets (both terrestrial and aquatic) more generally (see, for example, discussion in Andrews 1990). Here, as a case study, we assess the evidence for a new and emerging trade in an ornamental fish group (snakeheads, belonging to the genus *Channa*; Teleostei: Channidae), and consider the conservation risks that might be associated with such a trade, and the potential impacts that would need to be considered to inform policy and other protective decision making.

Fish keeping is a hugely popular pastime (Marchio 2018), supporting a global industry reportedly worth an estimated USD 15-20 bn (in King 2019). The numbers involved are uncertain, but King (2019) suggests that over one billion ornamental fish may be exported worldwide every year. Among the freshwater species (which comprise an estimated 90% of all ornamental fish trade), King (2019) suggests that the majority of species are captive bred, with 5–10% wild-sourced. Freshwater fish are one of the most threatened group of vertebrates (Reid et al. 2013) and mortality rates suffered by ornamental species during capture and transport can exceed 70% (Stevens et al. 2017). Consequently, there is considerable debate in the literature and among practitioners regarding the relative benefits and disbenefits of the ornamental fish trade, particularly with respect to sustainability and local livelihoods (e.g. Maceda-Veiga et al. 2016, Evers et al. 2019).

India has the highest diversity of endemic freshwater fish in Continental Asia (De Silva et al. 2007, Allen et al. 2010). However, unlike marine species (11 of which, together with all syngnathidians [seahorses, pipefish, and seadragons] are listed on Schedule 1 of India's Wildlife (Protection) Act, 1972 [WPA] and thus protected from hunting and trade), none of the freshwater fish occurring in India (with the exception of the pipefish [Teleostei: Syngnathidae] that occur in freshwater) are

included under any of the wildlife schedules of the WPA (ENVIS Centre on Wildlife and Protected Areas, Wildlife Institute of India, http://www.wiienvis.nic.in). Formal protection of freshwater fish in India is limited to National Parks, and sanctuaries, where the 'removal of wildlife' (defined to include fish) is not permitted (under Indian's WPA, see www.indiacode.nic.in), and 'reserved forests' where fishing is prohibited under Section 26 of the Indian Forest Act, 1927. Consequently, the harvest of freshwater fish in India (whether for consumption or export) is largely unregulated at a national level (Allen et al. 2010; although local restrictions may apply under state legislation). Ornamental fish exporters must register with the Marine Products Export Development Authority (MPEDA, http://mpeda.gov.in). A Health Certificate can also be obtained under the Export (Quality Control and Inspection) Act, 1963, for wild caught and captive bred ornamental fish meant for export, but it is not required for export from India. Otherwise, there is little legislative control of this industry. Currently, ornamental fish export in India is reported to be relatively small-scale in terms of revenue, generating approximately one million USD per year (USD 1.43 million in 2017; factfish.com) - a small proportion of total fish and fishery product exports, valued at USD 5.9 billion in the same year (www.statista.com). However, revenue associated with the ornamental fish trade in India has increased over the last five years (2013–2018, MPEDA, http://mpeda.gov.in) suggesting on-going growth in this sector. Among India's ornamental freshwater fish species, snakeheads (*Channa* spp.) are a diverse group that occur across Asia (Conte-Grand et al. 2017, Rüber et al. 2020). In recent years, this group has been the subject of considerable taxonomic interest (Conte-Grand et al. 2017 and references therein), with fifteen or more 'new' species described since the year 2000 (Rüber et al. 2020 and references therein). Currently, c. 21 distinct species are thought to occur in India (Rüber et al. 2020), many of which are thought to be endemic to the Eastern Himalayan (EH) region or to have restricted ranges elsewhere in peninsular India. Snakeheads are unusual, in that these air-breathing predatory fish are able to migrate short distances over land (Bressman et al. 2019) and can potentially stay out of the water for 2 to 4 days (Courtney and Williams 2004, Li et al. 2017 and references therein). Snakeheads provide an important local food source (Laxmappa 2017), and the

large (>60 cm, cf. Rüber et al. 2020) species in particular may be cultured for food (in India and elsewhere, Courtenay and Williams 2004); both large and small species include brightly coloured forms popular among aquarium hobbyists (Courtenay and Williams 2004). Several snakeheads have been introduced outside their native range (Courtenay and Williams 2004, Herborg et al. 2007) and they (e.g. *C. argus*, northern snakehead) are known as damaging invasives in some places (notably the US, where strict regulations apply and import and interstate transport is prohibited; US Federal Register 02-25337). None of the snakeheads are currently CITES-listed.

Anecdotal observations of snakehead collection in the wild suggested a particular interest in this group for export as live aquarium fish. We used commercial export records, supplemented with field observations (Appendix 1), to describe and quantify the extent and nature of trade in this group. By considering the characteristics of the species involved, we assessed the conservation issues that might be encountered as a result of unregulated harvest and export of snakeheads. We asked specifically: 1) is there evidence of an emerging trade (i.e. is this a 'new' phenomenon?), 2) where (in what state of India) are they sourced, 3) what markets (country destinations) are supplied, and 4) what species are involved? In addition, to assess the relative commercial importance of snakehead trade in India, we quantified reported total annual revenue generated by snakehead exports as a proportion of all ornamental fish exports. We also summarised and compared reported species-specific per item value to explore possible variation in price among species. We discuss management needs for this genus in India, but, more generally, we use this case study to illustrate some of the risks and complexities of new and emerging unregulated wildlife trade to supply the continual demand for novelty in the global exotic pet and aquarium markets.

2 METHODS

2.1. Data collection

125 Commercial export records for all snakeheads exported live from India, January 2014 (the oldest
126 records available) to September 2019, were obtained from an export-import data information
127 service (www.seair.co.in). Seair.co.in collates export data from India's Ministry of Commerce and
128 Industry portal (https://commerce.gov.in/), which is supplemented with information from Customs
129 House Agents, Shipping Companies, and Shipping Line Clearing Agents, and cross-referenced with
130 import data from destination countries, where available. The database described the point (city) of
131 export from India, the name of the export company, the importing country, point (city) of import
132 and import company, together with the shipment contents ('product description', quantity, and
133 value), and the date of export.

134 Individual export records were tentatively assigned to species on the basis of scientific and common
135 names in the product description, in accordance with latin names for snakeheads as listed in the
136 IUCN Red List (IUCN 2019, version 3) and FishBase, a global database of fish species
137 (www.fishbase.de); newly described snakeheads were assigned to a species name in accordance
138 with a recent molecular species-level phylogeny presented in Rüber et al. (2020) and additional
139 species descriptions published in taxonomic journals (located via a google search for scientific names
140 not included in previous sources). Where only common names were given, scientific names were
141 inferred on the basis of matching common and scientific names in other records that gave both, as
142 well as listings on ornamental fish wholesaler websites (e.g. www.aquariumglaser.de) and other
143 online resources (e.g. www.seriouslyfish.com).

144 For each export record, we collated date of export, quantity, value (per item), city of export, and
145 destination country. In all cases, we assumed that quantity (listed as 'pieces' or 'numbers') was
146 equivalent to the number of individuals (as in Raghavan et al. 2013). Additional data on species
147 distribution and conservation status (IUCN Red list category and population trend) were obtained
148 from Rüber et al. (2020) and the IUCN Red List (IUCN 2019, version 3). Species size and known

149 invasion risk were obtained from Rüber et al. (2020) and the Invasive Species Compendium
150 (www.CABI.org/isc), respectively.

151

152 **2.2. Data analysis**

153 To test for trends over time in the numbers of snakeheads exported in recent years, we collated
154 export volume (total number of individuals exported) by month to create a time series (with a
155 frequency of one month), and used the tslm function (designed to fit linear regression models to
156 time series data) in the "forecast" package in R (Hyndman 2017) to quantify and test the significance
157 of any underlying trend whilst taking account of seasonal and random effects. Missing values in the
158 time series were imputed using the Kalman function in the "imputeTS" package (Moritz and Bartz-
159 Beielstein 2017). Seasonality in the time series was tested using the seasplot function in the "tsutils"
160 package (Kourentzes 2020). Chi-squared tests were used to test for an association between species
161 composition and importing region, and analysis of variance and t-tests used to compare reported
162 per item value among species. All statistical analyses were carried out in R (version 3.5.1, R Core
163 Team 2018).

164

165 **3 RESULTS**

166 **3.1. Database**

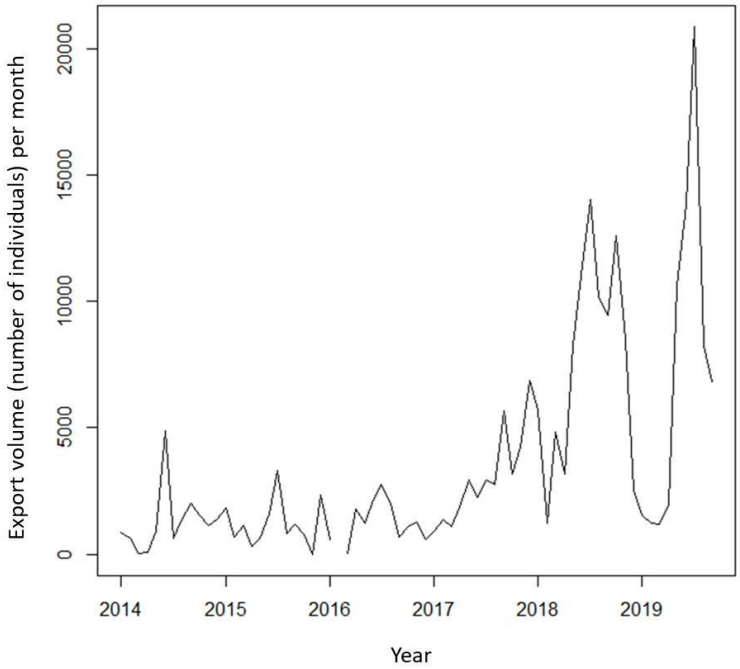
167 The export database included 2,370 records of live snakeheads, detailing shipment of a total of
168 238,356 individuals, January 2014-September 2019.

169

170 **3.2. Trends over time**

171 Monthly exports of snakeheads between January 2014 and September 2019 showed significant
172 seasonal variation (p=0.048) and an underlying positive trend (trend=129, $F_{1,67}$=43.6, p<0.001, 1
173 missing value in February 2016 imputed), with an overall increase in export volume from an average
174 of c.1,300 per month through 2014-2016 to c. 7,500 per month in 2018-2019 (Fig. 1). Seasonal
175 variation fluctuated between minima in the first quarter of the year and maxima in the third or
176 fourth quarter of the year, reaching an absolute monthly peak of 20,866 in July 2019 (Fig. 1). This
177 equates to an average of c.15,000 individual snakeheads exported per year in 2014-2016 increasing
178 to >90,000 in 2018.

179 Revenue generated by snakehead exports increased over time from c. 20,000 USD per year between
180 2014 and 2016 to >300,000 USD in 2018, comprising c.2% of total annual ornamental fish trade
181 revenue (annual mean=1.07 million USD, SD=160,000 USD) between 2014 and 2016, increasing to
182 24% in 2018. There was little variation in annual revenue generated by 'other' ornamental fish
183 species (estimated as total revenue minus revenue generated by snakeheads) over this time period
184 (annual mean=0.96 million USD, SD=45,536 USD).



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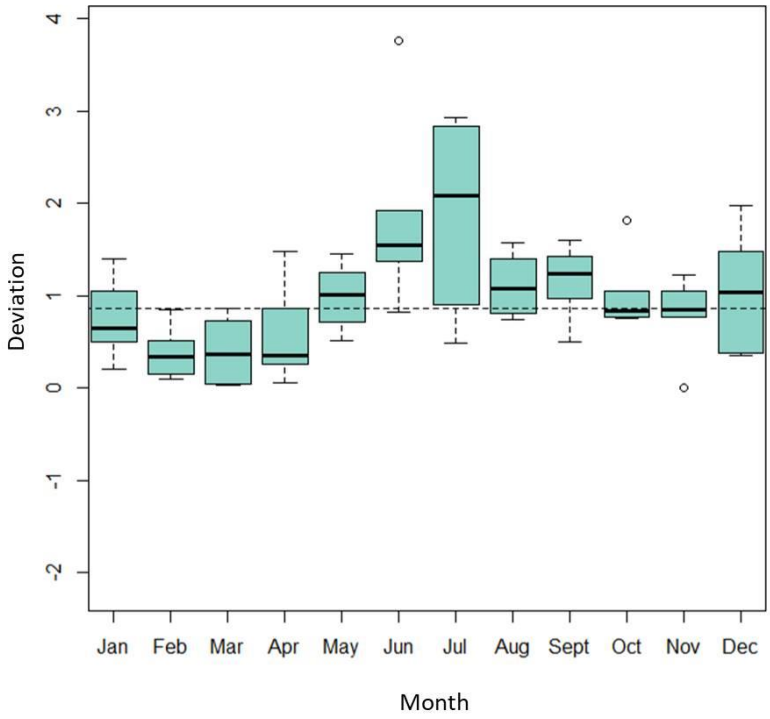

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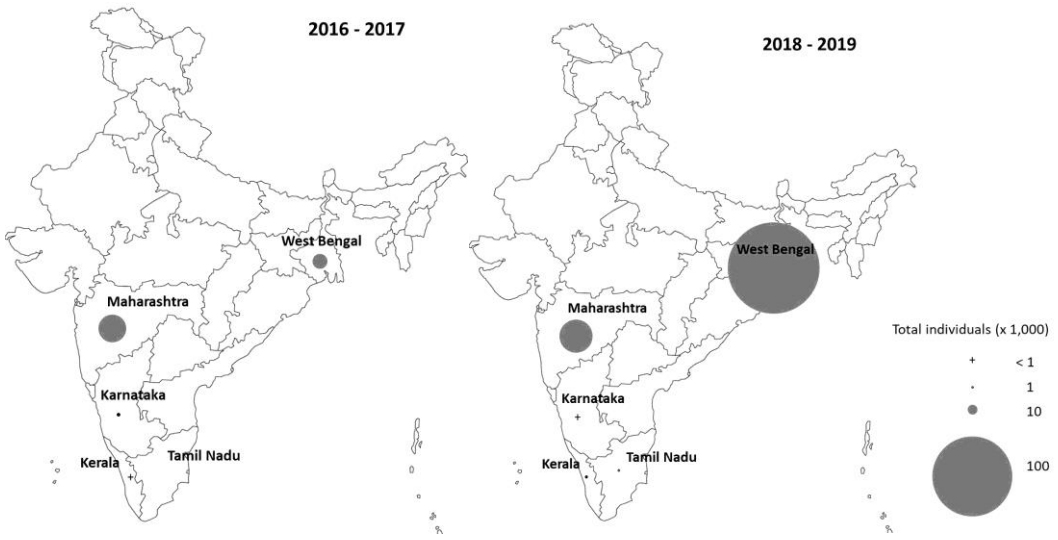
Fig 1. Snakeheads (*Channa* spp.) exported as ornamental fish from India, 2014 – 2018, showing (a) number of individuals exported per month (Feb 2016 missing), and (b) seasonal variation (shown as deviation in numbers exported from a centred average). Source: www.seair.co.in.

3.3. Source

Exports were recorded from five states (cities in brackets): Maharashtra (Mumbai), Karnataka (Bangalore) and Kerala (Ernakulam, Thrissur) on the south-western coast, Tamil Nadu (Chennai) on the south-eastern coast, and West Bengal (Kolkata, Sonarpur, Howrah) in the north-east (Fig. 2). Total exports over the period of study were highest from West Bengal and Maharashtra, responsible for 55.8% and 40.4% of total exports, respectively (exports from Kolkata alone were responsible for 50.3% of all exports, Fig. 2a). However, trends differed such that the overall increase in snakehead exports (Fig. 1) was largely due to an increase in exports from West Bengal (Fig. 2b).



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203 a) b)

204 Fig 2. Ornamental fish production in source states in India, showing snakeheads (*Channa* spp.) exported as
205 ornamental fish in (a) 2016 and 2017, and (b) 2018 and 2019. Circular markers depict proportional export
206 volumes among states, and between the two time periods (see key); note that there were no exports reported
207 from West Bengal in 2016. Source: www.seair.co.in.

208

209 **3.4. Destinations**

210 Most (87.4%) snakeheads were exported to Asia, 12.5% to Europe, and <1% to both North America
211 (the USA) and Africa (South Africa) (Fig. 3). In Asia, the main importing countries or states were
212 China (32.4%, n = 77,209) and Singapore (18.7%, n = 44,579); and, in Europe, Germany (5.4%, n =
213 12,755) and the UK (4.8%, n = 11,489) (Appendix 2), with average annual imports for these countries
214 ranging between 1,811 (Germany) and 7,603 (Singapore). The number of countries importing
215 snakeheads more than doubled (from 7 to 16) between 2016 and 2017, but the overall increase in
216 export volume (Fig. 1a) appeared to be largely due to an increase in Asian imports (see insert, Fig. 3).

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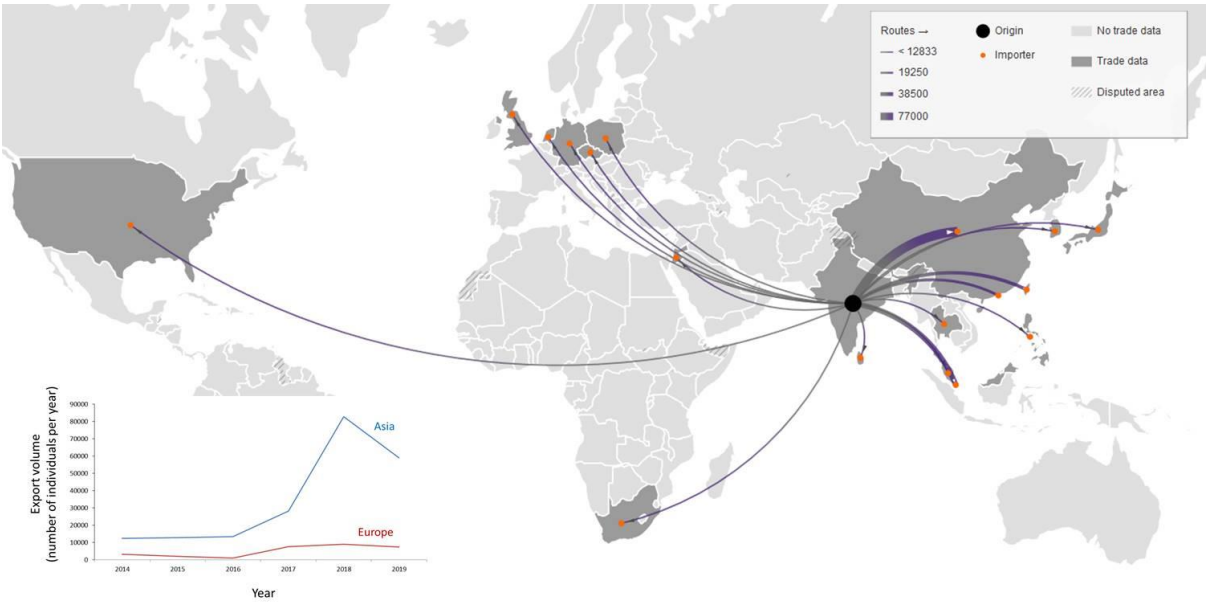

Fig 3. Global destinations for snakeheads (*Channa* spp.) exported as ornamental fish from India, 2014 – 2019 (line width proportional to total export volume, number of individuals), insert graph shows trends in annual export volume imported by Asian and European countries, the two main importing regions. Source: www.seair.co.in. Note that 2019 data includes only the months up to and including September. Map drawn using TradeMapper (TRAFFIC 2018).

3.5. Species

Exports of live fish involved at least 19 snakehead species (Appendix 3), but were dominated by four - *C. bleheri*, *C. aurantimaculata*, *C. andrao* and *C. stewartii* - that together comprised 90.6% of all individuals exported (Fig. 4a). Three of these frequently exported species were 'dwarf' species (10-25cm in length), one (*C. aurantimaculata*) was large (reaching over 60 cm); all are colourful, exhibit striking morphological patterns (e.g. Haniffa et al. 2013), and are considered endemic to the EH region. *Channa bleheri* has been recorded only from the Brahmaputra river basin in Arunachal Pradesh and upper Assam and is categorised on the IUCN Red List as Near Threatened. *Channa stewartti* has a much larger range and is categorised as Least Concern but with unknown population trends; *C. aurantimaculata* is categorised as Data Deficient due to insufficient information on the species' distribution. *Channa andrao* (described in 2013) has not yet been assessed for the IUCN Red List. None are known invasives.

238 The less frequently exported species comprised 'dwarf' (n=9), medium-sized (n=1), and large (n=5)
239 species (Fig. 4a). Eleven of these species are considered endemic to the EH region; *C. diplogramma*
240 and *C. pseudomarulius* (both large) are restricted to the Western Ghats. *Channa diplogramma* is
241 categorised on the IUCN Red List as Vulnerable; *C. barca* (a large species endemic to the EH region) is
242 categorised as Data Deficient. Nine of the 15 less frequently exported species were 'newly described'
243 species that had been named between 2011 and 2019, none of which were assessed for the IUCN
244 Red List at the time of writing; the remaining five species were categorised as Least Concern (Fig. 5).
245 Three of these species - *C. marulius*, *C. striata*, and *C. punctata* - are listed on the Invasive Species
246 Compendium (www.cabi.org/isc; the latter on a precautionary basis).

247 Limited information in the Product Descriptions of 159 export records, meant that c.4% of
248 individuals (n=8993) could not be assigned to species.

249 Species composition among Asian and European importers differed (χ^2=6632, df=4, p<0.001), with
250 exports of the larger *C. aurantimaculata* comprising almost one third of exports to Asia, compared
251 with less than one tenth of exports to Europe, whilst exports of *C. andrao* (one of the smallest of the
252 snakehead species) were relatively higher to European countries (Fig. 4b).

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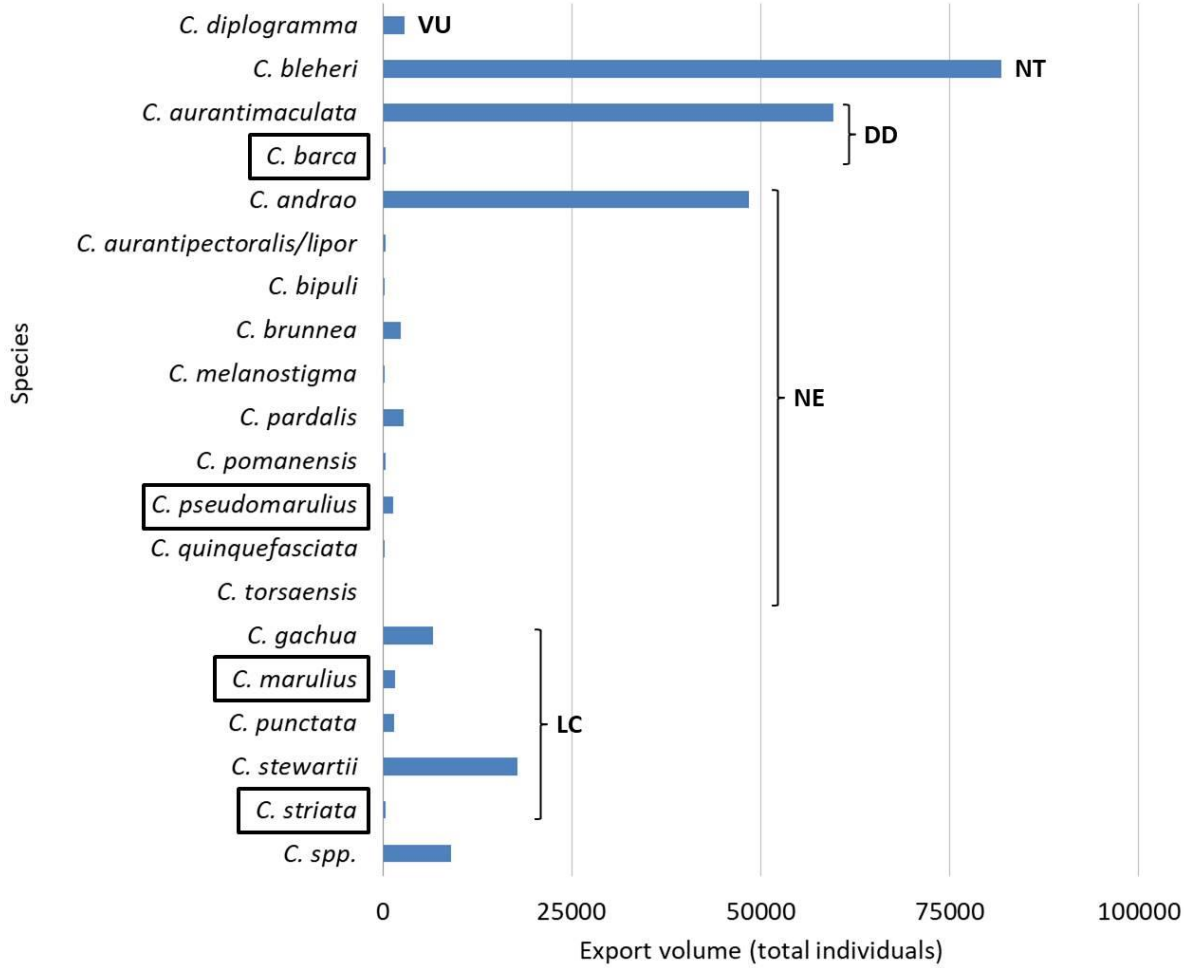

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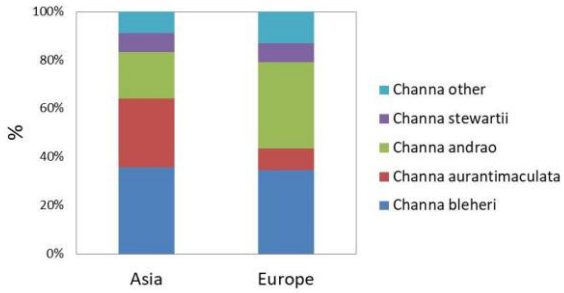

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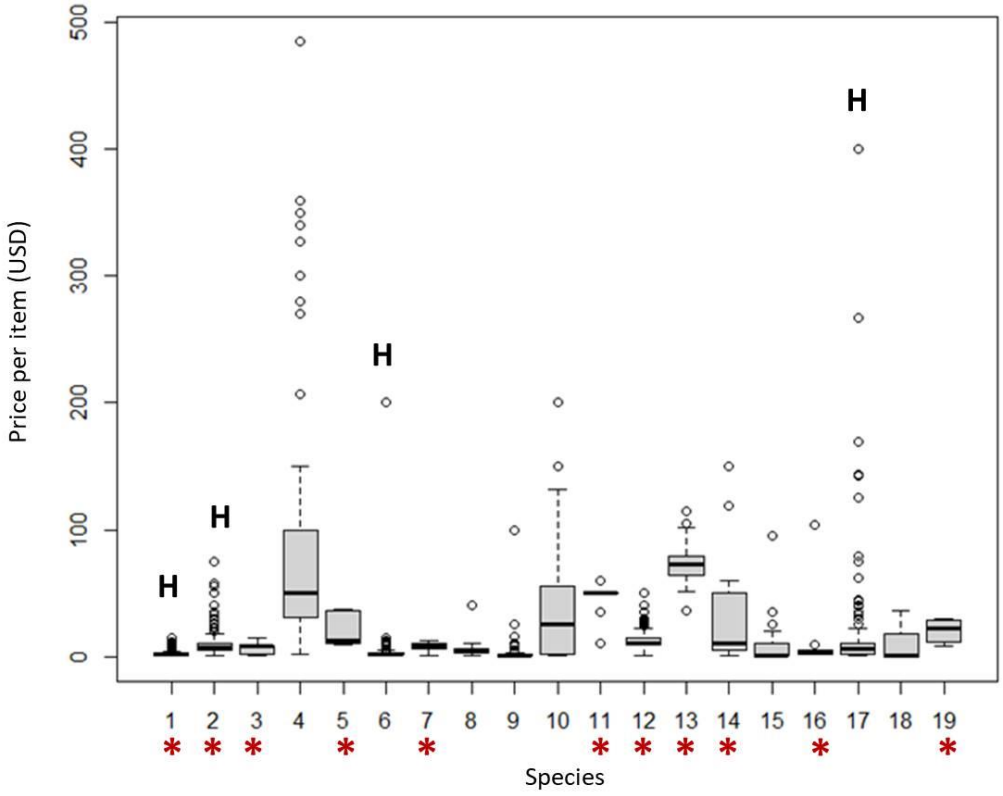
257 b)

258 Fig 4. Putative snakehead species exported live from India, January 2014 – September 2019, showing (a)
259 relative frequency (total number of individuals) of each species, and (b) relative proportion (% of total) of the
260 four most frequently exported species exported to Asian and European countries. Initials are IUCN Red List
261 categories (IUCN 2019, version 3): VU = Vulnerable, NT = Near Threatened, DD = Data Deficient, NE = Not
262 Evaluated, LC = Least Concern; "large" snakeheads (≥ 60 cm, [SL] standard length) are in boxed text. 99% of
263 individuals were assigned to species on the basis of latin names in Product Descriptions (1% by common name
264 only). Note that there may be some overlap among putative species assignments due to misidentification by
265 exporters/export authorities, or to mis-assignment of common names (see Methods), compounded by recent
266 taxonomic revisions - see Appendix 3, and Discussion. Source: www.seair.co.in.

267

The reported per item value of snakeheads at export differed among species (ANOVA: $F_{18, 1839}$=31.32, p<0.001) but there was also considerable variability within species (coefficient of variation: 0.23-3.79), ranging from a minimum of <1-2 USD to a maximum (dependent on species) of between 12 and 1500 USD (Fig. 5a). Reported mean (but not maximum) per item values were higher for less frequently exported species (overall mean = 30.2 USD) than for frequently exported species (overall mean = 7.2 USD; t=-2.22, df=15.52, p=0.042; maximum values = 172.5 USD vs. 169.6 USD; t=0.02, df=11.51, p=0.982). There was no difference in the reported mean per item value between those species that had been newly described and others (overall means = 23.5 vs. 27.3 USD; t=0.22, df=10.98, p=0.833, Fig. 5a). Maximum (but not mean) reported per item value at export appeared to increase over time for three of the four most highly exported species (*C. andrao*, *C. aurantimaculata*, *C. stewartii*) but not for *C. bleheri* (Fig. 5b).



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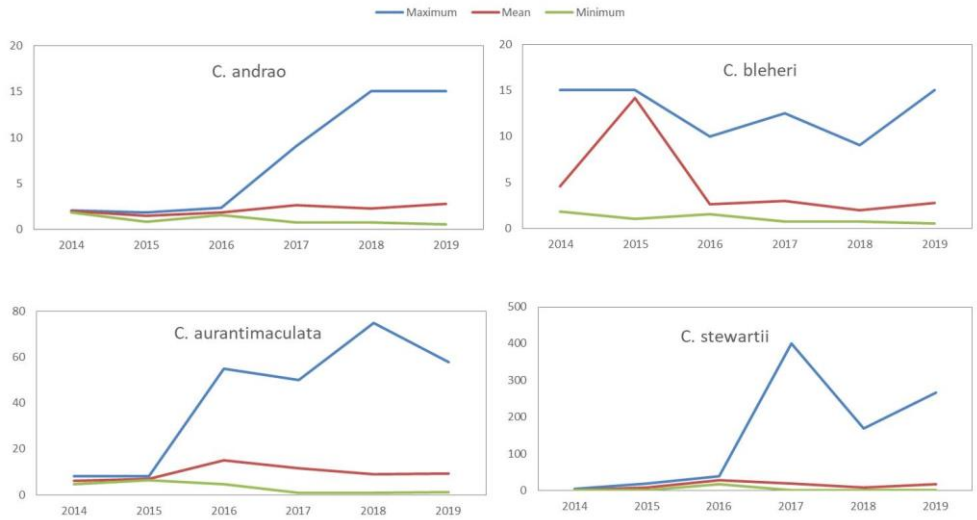

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Fig. 5. Reported species-specific per item value (in USD), shown (a) per species (median, inter-quartile range, and potential outlying values), and (b) per year (minimum, mean, and maximum) for the four most frequently exported species. Species in (a) are: 1. *C. andrao*, 2. *C. aurantimaculata*, 3. *C. aurantipectoralis/lipor*, 4. *C. barca*, 5. *C. bipuli*, 6. *C. bleheri*, 7. *C. brunnea*, 8. *C. diplogramma*, 9. *C. gachua*, 10. *C. marulius*, 11. *C. melanostigma*, 12, *C. pardalis*, 13. *C. pomanensis*, 14. *C. pseudomarulius*, 15. *C. punctata*, 16. *C. quinquefasciata,* 17. *C. stewartii*, 18. *C. striata*, 19. *C. torsaensis*. The four most frequently traded species are indicated with a **H**, and newly described species with a ***.** Maximum values for *C. barca* are not shown.

4 DISCUSSION

4.1. Overview

Export records show an increasing (apparently emerging) trend in the export of snakeheads from India, with total exports in 2018 approximately six-fold that reported for earlier years due primarily to a significant increase in export volume from West Bengal (primarily, but not exclusively, from Kolkata) (Fig. 1, 2a, b). Kolkata is the closest export point to north east India and the Eastern Himalayan biodiversity hotspot, which harbours over 540 freshwater species, many of them endemic to the region (Rüber et al. 2018). Although captive production of ornamental fish species is a thriving business in India (particularly in some of the southern states, e.g. Kerala and Tamil Nadu; MPEDA, http://mpeda.gov.in) none of the registered captive centres list snakeheads amongst the species produced (MPEDA, http://mpeda.gov.in) suggesting that snakeheads exported as ornamental fish are currently exclusively wild-sourced.

Most snakehead exports were imported by Asian countries, a region where there has recently been growing interest in exotic pets (e.g. Gallagher 2017). In addition, and given the regions' role as an export hub – Singapore, for example, is reported to be the largest global exporter of ornamental fish (and is itself a significant producer of ornamental fish, Yua 2019) - it is likely that at least a proportion of Indian imports were intended for re-export. German and UK imports were an order of magnitude smaller than those of China, Hong Kong (and Taiwan, in 2019), but it is possible that indirect European imports (via Asia) were much higher. The role of the EU in the exotic pet trade, and Germany in particular, has been highlighted in other cases (e.g. Altherr and Lameter 2020), and EU requirements for a Health Certificate to accompany all live animal imports (https://ec.europa.eu/food/animals/live_animals_en) (a process that in India is complicated, time consuming, and expensive) make direct exports to the EU difficult for Indian exporters (few Indian exporters have a health certificate). The low level of North American imports was presumably in accordance with the ban established in 2002 for all *Channa* spp. (US Federal Register 02-25337);

nevertheless, we note that two shipments of c.200 unidentified snakeheads were recorded between 2014 and 2019.

Snakehead fish burrow in the mud when water levels in their preferred swamp habitats are low during the dry season (November to March, Courtney and Williams 2004), and are reportedly easier to catch during the wet season (which starts in about April, peaking in June-July) when they are most active, which coincides with observed peaks in fishing activities (Fig. 6) and exports (Fig. 1). Field observations and informal interviews with fishers (Appendix 1) suggest that although all snakehead species are edible (Courtenay and Willaims 2004), and are eaten locally (Laxmappa 2017), collection was motivated primarily by their potential value in the ornamental fish trade (Fig. 6), which may be increasing (at least in terms of maximum price possible, Fig. 5b). Variation in value among and within species, according to export records (Fig. 5a) and informal reports by fishers (Appendix 1), suggests that value is likely complex and influenced by multiple factors (e.g. size and coloration). *Channa stewartii*, for example, is a frequently exported species with a relatively low value on average, but reportedly reached a maximum per item value of c.400 USD (Fig. 5a). Consequently, motivation to fish more extensively in search of high value specimens (e.g. in previously unfished areas) is likely to be high. Inconsistencies between export records and fishers in reported relative value of particular species (e.g. *C. melanostigma* reported by fishers as sold only for food [Appendix 1], commanded a relatively high average price at export [Fig. 5a], albeit with small sample size) suggest that perception or awareness of value may also differ among actors along the supply chain (and perhaps between individual fishers), and perhaps over time in response to changes in interest among end-consumers.

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345

346 Fig. 6 (a-c, from top left, clockwise). Snakehead (*Channa* spp.) collection in north east India, showing (a) use of
347 a dragnet by local fishers (b) *C. punctata*, and (c) the colourful fins of *C. andrao*; (d) *Channa* spp. for sale in an
348 aquarium in Singapore. Photos: Neil D'Cruze, World Animal Protection.

349

350 Whatever the motivations, mechanisms, and drivers at play, the increasing harvest and export of
351 Indian snakeheads is associated with a number of risks that are common to the global exotic pet and
352 aquarium trade. This case study illustrates these risks but also highlights some of the difficulties
353 associated with a complex system where a number of different factors come into play
354 simultaneously.

355

356 **4.2. Over-exploitation risk at source**

357 Over-exploitation is a particular risk when population size is small (Lacy 2000), and range size is
358 restricted (McCullough 1996). Although snakeheads as a group are widespread in parts of India,
359 some species are thought to have small, restricted ranges (Rüber et al. 2020). Protected Areas

provide some legal protection, but we observed fishers collecting snakeheads from two different protected areas (Appendix 1). Risks for any species are accentuated by uncertainty (in population size and occupied area, Lande et al. 1997), and for species harvested non-selectively, at the generic level, indicators of over exploitation such as declining harvests are less likely. In such cases, total captures may continue to rise even as individual species disappear (Allan et al. 2005) and, in groups where individual species are difficult to distinguish from others, species may disappear unnoticed. Snakeheads, as a group, have a number of characteristics - including a number of range-restricted species (Rüber et al. 2020), a lack of baseline data (on, e.g., population status, trends, and distribution; Appendix 3), and a complex and not yet fully described taxonomy (Conte-Grand et al. 2017) – that mean that some snakehead species are likely to be particularly vulnerable to over-exploitation. It is noteworthy, for example, that fishers reported no captures of *C. barca* during our field observations in 2017 and 2018, in areas where this species was previously found (Appendix 1, pers. comm.). Additionally, all freshwater species in this area are impacted by habitat loss and degradation (Allan et al. 2010), compounding the potential impacts of harvest (cf. Symes et al. 2018).

Frequently exported snakehead species include *C. bleheri* (Fig. 5a), which continues to be the most highly exported snakehead species despite over-exploitation concerns being raised in 2010 (Chaudhry 2010a). The large proportion of snakehead species (frequently and less frequently exported) that are classified on the IUCN Red List as Data Deficient, or are not yet assessed (Fig. 5a, Appendix 2), is symptomatic of the aquatic trade more generally (Maceda-Veiga et al. 2016) (and, indeed, of the exotic pet trade more widely, e.g. Harrington et al. 2021); for these species (whether fish in NE India, or other species elsewhere), not enough is known of the species' status or distribution to manage off-take appropriately. For snakeheads, that the less frequently exported species tended to have higher mean reported values suggests that these species are less abundant (and presumably sought after), raising the possibility of anthropogenic allee effects (Courchamp et al. 2006). For other species (e.g. *C. striata*), additional use for local consumption means that total harvest is unknown.

Taxonomic issues within the *Channa* genus, and recent discoveries of a number of newly described distinct species, create further complications. Although it is not uncommon for new species to be traded before they are scientifically described (Allan et al. 2010), there is a risk that 'new' rare, or range-restricted, species may be driven to extinction before they are even described (cf. Stuart et al. 2006).

4.3. Invasive risk at destination

The release of unwanted pets has resulted in established feral populations of several taxa on almost all continents (e.g. Stringham and Lockwood 2018, Lockwood et al. 2019, Uehling et al. 2019, Okuyama et al. 2020), with significant impacts on native ecosystems and biodiversity (White et al. 2019), particularly in freshwater habitats (Cucherousset and Olden 2011, Tricarico et al. 2016). In Europe alone there are over 700 alien freshwater species introduced as a result of the aquarium trade alongside aquaculture and stocking practices (Nune et al. 2015).

C. marulius (established in Florida, USA) and *C. striata* (widely established globally including in the USA, Madagascar and Mauritius, and a number of Southeast Asian countries beyond its' native range) grow to a metre or more in length (Courtenay and Williams 2004, Appendix 2); these species are unsuitable for inexperienced aquarium hobbyists and have the potential to severely impact native biodiversity in the wild (cf. *C argus*, USFWS 2017). These two species are listed as invasive species, but the four other large Indian snakehead species (*C. barca*, *C. pseudomarulius*, *C. diplogramma,* and *C. aurantimaculata*) are not. None of the smaller snakehead species appear to be considered as potential invasive species, although Herborg et al. (2007) predict that there is a wide range of suitable habitat for *C. bleheri* in North America, highest in the southern USA and Mexico, but also along the west Canadian coast in areas climatically similar to a number of European countries, and presumably elsewhere in the northern hemisphere (e.g. China). Since all snakehead

410 species are predatory, even the smaller species should be expected to have impacts on native fish
411 and insect fauna (dependent on the size composition of the community into which they were
412 introduced).

413 Pathogens and associated diseases that could be introduced and spread through the release of
414 snakehead species outside their native range, include *Mycobacteria* a genus of bacteria known to
415 cause chronic disease in a number of animals including mammals (detected in non-native *C. argus*
416 established in the USA, Densmore et al. 2016), epizootic ulcerative syndrome caused by the water
417 mould *Aphanomyces invadans*, an OIE [World Organisation for Animal Health]-notifiable disease in
418 the UK with potential impacts on subsistence fisheries and aquatic wildlife (Herbert et al. 2019;
419 detected in *C. aurantimaculata* in an aquaria in England, OIE 2018), and *Gnathostoma spinigerum*, a
420 helminth parasite that causes gnathostomiasis [in humans] (Setasuban et al. 1991 in Courtenay and
421 Williams 2004).

422

423 **4.4. Limitations of the study**

424 Our assessment of risks associated with increasing export of snakeheads from India was based on
425 identification of the species involved, which may have involved some error (due either to
426 misidentification at export, or misinterpretation of product descriptions in the export records). For
427 example, there were a number of different product descriptions with “blue” in their name, and thus
428 potential confusion in assigning the correct species to blue varieties of *C. stewartii* and *C. pardalis*
429 where the full scientific name was not provided; in addition, “blue bleheri” does not refer to *C.*
430 *bleheri* but *C. andrao*, whilst ‘cobalt blue channa’ appears to be the common name used for *C.*
431 *torsaensis* (which may or may not be genetically distinct from *C. quiquefasciata*, which is not blue,
432 see Appendix 3). Difficulties are equally likely for export inspectors expected to distinguish between
433 species with only subtle differences in their morphology (e.g. banding on their fins) for a species that

434 may comprise a number of different colour morphs (e.g. *C. stewartii*), that may also change colour
435 among life stages (e.g. *C. diplogramma*, Benziger et al. 2011). Some individual species will also have
436 been underestimated in export records, and in the analysis, because they had not been named in
437 earlier years (see Appendix 3), and it is possible that deliberate mis-naming occurs to avoid drawing
438 attention to collection of some of the rarer species. These issues mean that relative trade volumes
439 for specific species may be inaccurate, but they do not alter the broader risks that we identify across
440 the group.

441 However, our timeline was limited; continued monitoring of off-take is needed to verify that the
442 apparent increase in export volume represents a trend, rather than a short-term phenomenon, and
443 historical data would be useful to understand long-term patterns (Jayalal and Ramachandran 2012,
444 for example, refer to exports of snakeheads prior to 2014 but provide no data on quantities
445 exported).

446

447 **4.5. Knowledge gaps**

448 Increasing capacity to monitor collections and trade has been long recommended as one of the
449 critical needs for the aquarium industry (Moreau and Coomes 2006, Rhyne et al. 2012a), but it
450 continues to be neglected worldwide. In this case, although export records provide monitoring data
451 for those that are exported, basic information on the species in the wild, and the various different
452 (potentially interacting) drivers of demand (e.g. for food, locally, nationally, and internationally, and
453 for the ornamental fish trade) is lacking. In such cases it is difficult if not impossible to predict
454 harvest pressure, or the response of populations to such pressure, especially over meaningful spatial
455 scales. For snakeheads specifically, there are a number of different policy measures that could be
456 implemented to protect their populations in India (including harvest size limits, wild quotas, trade
457 suspensions, captive breeding, inland fisheries development, and alternative livelihoods), but
458 assessment of their effectiveness and feasibility will require robust information on current

population status (taxonomy, distribution, conservation status, and trends) in the wild, as well as the biological features (target species, capture sites, specimen sizes, effort, morbidity and mortality rates), supply chain economics (structure, stakeholders, and revenues), and consumer demand (drivers, preferences, inhibitors, geographical locations, and stability) of their trade. In short, for this and many other cases of exploitation of wild animals, sustainability can only be ensured where there is adequate and appropriate baseline data and monitoring, which is currently lacking in many cases.

5 CONCLUSION

Freshwater fish in India are a legislative anomaly in a country where mammals, birds, reptiles, insects, and other aquatic species (e.g. corals and molluscs) are protected from hunting and trade, under the various schedules of the Wild Life Protection Act (1972) (see also Raghaven et al. 2013). Freshwater fish provide an important food source (Rüber et al. 2020) but the apparent current focus on collection for the aquarium pet trade suggests that a review of snakehead harvest is needed. Export data presented here portray an apparently rapidly increasing trade, which, in the absence of monitoring, risks significant impacts on a number of endemic and potentially rare species, may (in some places, e.g. national parks, Appendix 1) be being carried out illegally, and risks invasion of potentially damaging species' elsewhere (e.g. potentially China, particularly, Hong Kong). We highlight an urgent need for baseline biological data, and harvest monitoring. Further strategic decisions regarding the need for regulation (e.g. through bans, licencing, and or quota systems) and listing of the threatened species that are currently in the trade under national legislation (the WPA; Raghavan et al. 2013), or the potential for a captive breeding system (Rhyne et al. 2012), will, ultimately, be informed by, and indeed may require, a more in-depth understanding of the system. Our study focused on an endemic group occurring in two biodiversity hotspots in India but beyond the regional conservation importance of this case study, and with broader lessons in mind, our analysis of export data of this particular group demonstrates how quickly new wildlife trades can

484 develop and increase, leading to numerous potential negative impacts prior to regulatory or other
485 mechanisms being put in place. We reiterate Macdonald et al. (2021) who suggest that wildlife law,
486 with respect to trade, may be 'upside down'. Specifically, we suggest that a revaluation of the
487 snakehead trade (and wider commercial wildlife trade) status quo may be required, for example
488 there may be a need (particularly for luxury wildlife uses, such as exotic pets) for a positive list
489 approach whereby it is incumbent on traders (which could be at the demand end of the trade chain)
490 to demonstrate that trade is sustainable and safe, rather than for conservations to demonstrate that
491 it is not.

492

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500

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644

645 **Appendix 1. Field observations**

646

647 **1. Approach**

648 Additional information on the harvest of snakeheads was gathered during field research in north-eastern India,
649 January 2017-December 2018. Two researchers accompanied by a videographer carried out 35 field visits with
650 durations of one day to one week, in seven (anonymised) locations in the states of Assam (two) and West
651 Bengal (five). The team visited fishing sites and local markets and met with fishers (primary collectors) and
652 traders who aggregated the catch and forwarded it to exporters in Kolkata. The purpose of the field visits was
653 to gain insight into harvest patterns (habitats and seasons fished in), the methods used, the species caught,
654 the relative catch size of each species, their uses, and reported sale value. Information collated was based on
655 direct observation and informal interviews with fishers; no personal or identifying data were sought.

656 **2. Observations**

657 Fishing for snakeheads in north east India was carried out all year round, but predominantly between April and
658 July, in all aquatic habitats including fast flowing hill streams, and lowland swamps, using a range of different
659 traps and fishing gear, including nets (ber jal [a type of seine net or dragnet with mesh size 0.5 cm], fashi jal [a
660 gill net, 2-5 cm mesh size], khewali jal [a cast net, 2 cm mesh size], thela jal [a push net, 0.5–1.5 cm mesh size],
661 and scoop nets [0.5-2 cm mesh size]), electrofishing devices (a 12v battery, typically utilised in hill streams and
662 other fast flowing water), and, less commonly, cyclindrical bamboo fishing traps (known as shepa and dingora).
663 For species found in swamps, muddy soil was sometimes heaped to channel the water away and expose
664 snakehead burrows, whereupon the fish could be captured by hand from the mud.

665 Eight species were identified among catches: *C. andrao*, *C. aurantimaculata*, *C. bleheri*, *C. gachua*, *C. marulius*,
666 *C. melanostigma*, *C. pardalis*, and *C. stewartii* (Table A1.1). The orange spotted snakehead (*C. aurantimaculata*)
667 was reported by fishermen to the most commonly collected species and sold for the highest price (Table A1.1).
668 *C. gachua* and *C. melanostigma* were reportedly sold only for food, with *C. gachua* selling for approximately
669 one fifth of the value of those species sold as ornamental fish (Table A1.1). In comparison, reported per item
670 value at export was between one and 40 times that reported by fishers. Fish that died during collection were

kept by fishers, or sold, for food. On one occasion, local communities were observed collecting snakeheads from beels (ox-bow lakes) at two different protected sites, including in one National Park.

Table A1.1. Snakeheads observed among captures during 35 visits to seven sites in north-east India (in West Bengal and Assam); purpose, relative collection volume, and sale price as reported by local fishermen. 1 INR (Indian Rupee) = 0.0134 USD (www.xe.com, 17 August 2020). Note that *C. bleheri*, which is otherwise the most frequently exported snakehead species (Fig. 4a), is not known to occur in West Bengal, and so was presumably only infrequently encountered by fishermen further north at the southern edge of its range (see 3.5).

Species name	**Local name**	**Purpose**	**Relative collection volume**	**Value per fish, in INR (USD)**
C. stewartii	Sengeli	Food, Ornamental	Medium	100-150 (1.34–2.01)
C. aurantimaculata	Nagacheng	Food, Ornamental	High	150-250 (2.01-3.35)
C. andrao	Lalseng	Ornamental	Medium	80-100 (1.07-1.34)
C. bleheri	Lalseng	Ornamental	Low	80-100 (1.07-1.34)
C. gachua	Cheng or Seng	Food	Low	20-25 (0.27-0.33)
C. melanostigma	Nachee	Food	Low	-
C. pardalis	Nila seng	Ornamental	Low	100-150 (1.34-2.01)
C. marulius	Sal	Food, Ornamental	Low	100 (1.34)[1]

[1] for a fish of 10-15cm

Appendix 2. Main importing countries for *Channa* spp. exported from India, 2014 – 2019 (including all countries that imported >1% of total over this time period, total n = 238,356). * not a complete year.

Country	2014	2015	2016	2017	2018	2019*	Average 5-year annual export (2014-2018)	Total (%)
China	-	-	-	15855	56930	4424	-	77,209 32.4%
Singapore	7756	9002	6364	5001	9890	6566	7,603	44,579 18.7%
Taiwan	2350	1364	889	426	4496	18804	1,905	28,329 11.9%
Hong Kong	400	324	81	135	306	21529	250	22,775 9.6%
Thailand	892	1584	5021	3603	-	130	-	11,230 4.7%
Japan	483	402	-	949	5126	3630	-	10,590 4.4%
Malaysia	429	-	-	986	4404	2918	-	8,737 3.7%
Korea	-	1036	656	1300	965	1036	-	3,957 1.7%
Germany	83	100	24	3601	5245	3702	1,811	12,755 5.4%
UK	3097	1791	810	2291	1854	1646	1,969	11,489 4.8%
Netherlands	-	-	-	1160	1294	717	-	3,171 1.3%

Appendix 3. *Channa* species included in commercial export records in India: size, distribution, conservation and invasive status; Note that although the species to which some records belonged were inferred on the basis of common names given in export records as 'Product Descriptions', all species' latin names were included in at least one export record with the exception of *C. stiktos*, a newly described species. Newly described species that were listed are denoted with an asterisk together with a reference. Size and distribution from Rüber et al. (2020). Size based on standard lengths (SL) in cm. Distribution categorised as: R = restricted geographic range within India, E = endemic to the Eastern Himalaya (EH) biodiversity hotspot (Bhutan, northeastern India [Assam valley and Bengal basin], and south, central and eastern Nepal), W = widespread and distributed across several Asian countries beyond the Eastern Himalayan region; newly described species found in the EH but not listed in Rüber et al. (2020) were tentatively designated E if they were not described as being found elsewhere. Conservation status based on IUCN Red List (IUCN 2019, version 3) categories; population trends (as in IUCN Red List species entries) in brackets (d=declining, s=stable, u=unknown); - = not listed on the IUCN Red List or categorised as Not Evaluated. Overfishing is based on threats as listed in the IUCN Red List species entries, Y = overfishing listed as a threat or referred to as a possible or potential threat, N=overfishing not listed as a threat; uses in brackets: aq=aquarium fish, f=food. Invasive status based on listing in the Invasive Species Compendium (CABI.org).

Species	**Common names**	**Size, SL (cm)**	**Distribution (known occurrence)**	**IUCN Red List category (pop trend)**	**Overfishing**	**Invasive**
C. andrao*[1]	dwarf neon snakehead, blue rainbow snakehead	10	E (West Bengal)	-		
C. aurantimaculata*[2]	orange-spotted snakehead	40 (->60)	E (Assam)	DD (u)	N (aq, f)	
C. aurantipectoralis*[3]	-	16	E (Mizoram)	-		
C. barca	barca snakehead	90	E (Assam, West Bengal)	DD (u)	Y presumed (aq, f)	
C. bipuli*[4]	-	13	E (Assam)	-		
C. bleheri	rainbow snakehead	15-20	R (Arunachal Pradesh, Assam)	NT (u)	Y (aq, f)	
C. brunnea*[5]	-	-	E (West Bengal)	-		
C. diplogramma	Malabar snakehead	50 (->60)	R (Western Ghats: Kerala, Tamil Nadu)	VU (d)	Y (f)	
C. gachua	dwarf snakehead	17-20	W	LC (u)	N (f)	

C. lipor*[6]	lipor snakehead	11	E (Meghalaya)	-		
C. marulius	great or bullseye snakehead	>120	W	LC (u)	N (f)	Y*
C. melanostigma*[7]	-	15	E (Arunachal Pradesh)	-		
C. pardalis*[8]	Megalaya leopard snakehead, or "true blue"	14	E (Meghalaya)	-		
C. pomanensis*[9]	-	17	E (Arunachal Pradesh)	-		
C. pseudomarulius*[10]	-	>70	R (Western Ghats)	-		
C. punctata	spotted snakehead	30	W	LC (s)	Y (f)	N[caution!]
C. quinquefasciata* [11]	five striped channa*	18	E (West Bengal)	-		
C. stewartii	Golden or Assamese snakehead	25	E†	LC (u)	Y (aq, f)	
C. stiktos (possible)*[12]	-	19	E (Mizoram)	-		
C. striata	striped, common, or chevron snakehead	90	W	LC (s)	Y [major concern] (f)	Y
C. torsaensis*[13, 14]	cobalt blue channa	-	E (West Bengal)	-		

[1] Britz R. (2013) *Channa andrao*, a new species of dwarf snakehead from West Bengal, India (Teleostei: Channidae). Zootaxa 3731(2):287-294

[2] Musikasinthorn P. (2000) *Channa aurantimaculata*, a new channid fish from Assam (Brahmaputra River Basin, India), with designation of a neotype for *C. amphibeus* (McClelland, 1845). Ichthyological Research 47: 27-37.

[3] Lalhlimpuia DV, Lalronunga S, Lalramliana L. (2016) *Channa aurantipectoralis*, a new species of snakehead from Mizoram, north-eastern India (Teleostei: Channidae). Zootaxa 4147(3):343-350.

[4] Praveenraj J, Uma A, Moulitharan N, Bleher H. (2018) *Channa bipuli*, a new species of snakehead (Teleostei: Channidae) from Assam, northeast India. Aqua, International Journal of Ichthyology 24: 153– 166.

[5] Praveenraj J, Uma A, Moulitharan N, Kannan R. (2019) *Channa brunnea*, a new species of snakehead (Teleostei: Channidae) from West Bengal, India. Zootaxa 4624(1): 59-70.

[6] Praveenraj J, Uma A, Moulitharan N, Singh SG. (2019) A new species of dwarf Channa (Teleostei: Channidae) from Meghalaya, Northeast India. Copeia 107: 61– 70.

[7] Geetakumari K, Waikhom V. (2011) *Channa melanostigma*, a new species of freshwater snakehead from North-East India (Teleostei, Channidae). Journal of the Bombay Natural History Society 107.

[8] Knight JD. (2016) *Channa pardalis*, a new species of snakehead (Teleostei: Channidae) from Meghalaya, northeastern India. Journal of Threatened Taxa 8: 8583.

[9] Gurumayum SD, Tamang L. (2016) *Channa pomanensis*, a new species of snakehead (Teleostei: Channidae) from Arunachal Pradesh, northeastern India. Species 17: 175-186.

[10] Britz R, Adamson E, Raghavan R, Ali A, Dahanukar N. (2017) *Channa pseudomarulius*, a valid species of snakehead from the Western Ghats region of peninsular India (Teleostei: Channidae), with comments on *Ophicephalus grandinosus*, *O. theophrasti* and *O. leucopunctatus*. Zootaxa 4299(4): 529-545.

[11] Praveenraj J, Uma A, Daniel J, Knight M, Moulitharan N, Balasubramanian S, Bineesh K, Bleher H. (2018) *Channa quinquefasciata*, a new species of snakehead (Teleostei: Channidae) from Torsa River, North Bengal, India. Aqua, International Journal of Ichthyology 24: 141– 152.

[12] Lalramliana, Knight JDM, Lalhlimpuia D, Singh M. (2018) Integrative taxonomy reveals a new species of snakehead fish, *Channa stiktos* (Teleostei: Channidae), from Mizoram, North Eastern India. Vertebrate Zoology 68:165-75.

[13] Dey A, Nur R, Raychowdhury B, Sarkar D, Singh LK, Barat S. (2018) New Ornamental Species of Snakehead Fish (Teleostei: Channidae) from River Torsa of West Bengal, India. International Journal of Pure & Applied Bioscience 6:497-503.

[13] but note that these authors suggest that *C. torsaensis* is insufficiently diagnosed from *C. quinquefasciata*; Britz R, Dahanukar N, Anoop VK, Ali A. (2019) *Channa rara*, a new species of snakehead fish from the Western Ghats region of Maharashtra, India (Teleostei: Labyrinthici: Channidae). Zootaxa 4683: 589–600.

† widespread in region (and may also occur in Banglades

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