Vol. 14: 127–133, 2022
https://doi.org/10.3354/aei00433

AQUACULTURE ENVIRONMENT INTERACTIONS
Aquacult Environ Interact

Published June 23

NOTE

Culture, trade and establishment of *Polypterus senegalus* in Indonesia with first record of wild populations

Surya Gentha Akmal[1,2], Yonvitner[2,3], Rikho Jerikho[4], Fredinan Yulianda[3], Yusli Wardiatno[3], Jindřich Novák[1], Lukáš Kalous[1], Ondřej Slavík[1], Jiří Patoka[1,*]

[1]Department of Zoology and Fisheries, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Science Prague, Kamýcká 129, 165 00 Prague – Suchdol, Czech Republic

[2]Centre for Coastal and Marine Resources Studies, The Institute for Research and Community Service, IPB University, 16680 Bogor, Indonesia

[3]Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Jl. Agatis, Kampus IPB Dramaga, 16680 Bogor, Indonesia

[4]Ichthys-Alien Indonesia Project, Diponegoro Street 87, Jatirejo, Central Java, 57615 Wonogiri, Indonesia

ABSTRACT: The African grey bichir *Polypterus senegalus* is a popular ornamental fish in Indonesia. Pet trade with this species is increasing, and aquaculture production is well established. Here we present a detailed market survey and volume of domestic trade, export and import between January 2018 and February 2021. Climate similarity between the native range of *P. senegalus* and Indonesia was analysed by the MaxEnt algorithm. A significant number of areas of numerous Indonesian islands were identified as suitable for survival and establishment of this fish. This was confirmed by the records of 3 likely established populations in rivers in Java and Sumatra, where both wild type and albino juveniles were captured. The occurrence of more feral populations was suggested by local fishermen in Kalimantan, Java, and Lombok islands; however, verification via future field trips is required. The culture of *P. senegalus* is unregulated in Indonesia, and the potential risk of establishment of this predatory fish and its potential spread in this Southeast Asian country is alarming for wildlife managers. Although a total ban seems the best solution, an alternative risk mitigation strategy with minimal negative effects on the socio-economic situation in local communities is more feasible. The albino phenotype of *P. senegalus* is probably less of a risk because of its easier detection by predators, higher sensitivity to disease and stress, and disrupted social behaviour. Since albinos are popular in Indonesia, replacing the wild phenotype with this potentially less invasive phenotype could be a recommendation after experimental confirmation of the lower invasiveness of albinos.

KEY WORDS: Grey bichir · Asia · Invasive species · Ornamental fish · Aquaculture · Albino

1. INTRODUCTION

Ornamental aquaculture is one of the primary sources of invasion by non-native species globally (Novák et al. 2020). The sustainability of such aquaculture needs to consider the efficiency of breeding processes (Rohmy et al. 2010) and the prevention of the inadvertent release of non-native species to

*Corresponding author: patoka@af.czu.cz

Publisher: Inter-Research · www.int-res.com

avoid or mitigate adverse impacts (Yonvitner et al. 2020). Indonesia is one of the top suppliers of ornamental fish species globally (Akmal et al. 2020), and the non-native *Polypterus* spp. (Actinopterygii: Polypteriformes: Polypteridae) is widely traded there (Satyani & Subamia 2009). *Polypterus* spp. were imported into Indonesia for the first time in 1997 (described as introduced) (Diatin et al. 2015) and are cultured extensively in outdoor facilities, like other ornamental fish species (Putra et al. 2018, Marková et al. 2020). Alarmingly, evidence suggests that Indonesia's legislative regulations responsible for controlling invasive ornamental species are largely ineffective (Patoka et al. 2018).

The invasive potential of *Polypterus* spp., a nocturnal predatory fish, derives from aquarium studies (Arnoult 1964) that characterized them as opportunistic feeders, subsisting on insect larvae, shrimps, fish and also on artificial feed when available. The high intraspecific aggressiveness of their larvae ensures wide dispersal. In addition, they exhibit hypoxia tolerance and early maturation, as observed in *P. senegalus* (spawning in the same year as when they hatched; Schäfer 2004). Since *Polypterus* spp. can breathe and obtain oxygen from the atmosphere, they are very adaptable to low water aeration (Magid 1966). As Novák et al. (2020) noted, these fish have an advantage in areas with low oxygen levels and can be easily transported by humans to new localities. Moreover, *Polypterus* fishes are all carnivorous and capable of terrestrial locomotion with predominantly nocturnal activity (Du & Standen 2020). Thus, they seem to be perfectly equipped as potential invaders. Despite this assumption, there has been no published record of *Polypterus* spp. in the wild outside of their native range. However, Parenti & Soeroto (2004), in a report primarily focused on native fish species, indirectly stated that *Polypterus* spp. had been introduced to Sulawesi through ornamental aquaculture.

Human-driven biological invasions cause homogenisation and loss of biodiversity with substantial environmental and socio-economic losses (Pyšek & Richardson 2010, Haubrock et al. 2022). Thus, it is crucial to inform policy makers, stakeholders and managers of the potential for biological invasions and their possible adverse impacts to native biota and whole ecosystems (Yonvitner et al. 2020). Therefore, we decided to conduct a comprehensive study in Indonesia on the culturing and related risks of invasion of the African grey bichir *Polypterus senegalus* Cuvier, 1829, a species native to West Africa, and test the hypothesis that it is present in Indonesian freshwaters.

2. MATERIALS AND METHODS

2.1. Data collection

Records of *Polypterus senegalus* in Indonesian freshwaters were collected between 1 April and 30 September 2021. An inventory of *P. senegalus* in Indonesia was conducted by contacting ornamental fish hobbyists, fish sellers, the Regional Fisheries Agency and the Fish Quarantine Agency in Indonesia via telephone and WhatsApp. Findings indicating the species' presence were confirmed by data, photographs, and personal interviews with residents and fishers. Certain selected localities in Java and Sumatra were sampled incidentally between 15 July and 30 September 2021 by fishermen using nets (in Yogyakarta) and angling (hooks baited with pellets and earthworms). All activities were carried out in compliance with Indonesian laws and ethical rules and warranted by Indonesian academic staff from the IPB University. Data on domestic production and trade, export and import were obtained from the Fish Quarantine and Inspection Agency and the Ministry of Marine Affairs & Fisheries of the Republic of Indonesia. The trade amounts of *P. senegalus* in Indonesia were obtained from 2 e-commerce platforms, Shopee (www.shopee.co.id) and Tokopedia (www.tokopedia.com). Facebook (www.facebook.com) and YouTube (www.youtube.com) have created platforms with potentially valuable information about fish invasion introduction pathways that were surveyed for potential records of *Polypterus* spp. in Indonesia (using Indonesian language).

2.2. Climatic similarity

Contemporary (1970–2000) climate data were downloaded at a spatial resolution of 10 arc-minutes from the WorldClim dataset. Environmental layers of future climate data (CSIRO A1B) were obtained from the CliMond database (v.1.2, https://www.climond.org/) at a spatial resolution of 10 arc-minutes. We calculated 19 bioclimatic variables for *P. senegalus* (Table 1). These represented the average, extreme and variation of temperature and precipitation and are widely used in ecological niche modelling. Both datasets were assembled in QGIS 3.14.16-π 'Pi' (https://qgis.org/en/site/) to ASCII format for use with the MaxEnt algorithm. The MaxEnt tool was chosen because it is one of the best performing algorithms for presence-only data. The model assesses the continued likelihood of habitat relevance within the target area. Bioclimatic

Table 1. Bioclimatic variables used in the variable selection strategy to build a climate similarity model for *Polypterus senegalus* in Indonesia

Code	Bioclimatic variables
BIO1	Annual mean temperature
BIO2	Monthly mean diurnal range (max. temperature minus min. temperature)
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature seasonality (SD ×100)
BIO5	Max. temperature of warmest month
BIO6	Min. temperature of coldest month
BIO7	Temperature annual range (BIO5–BIO6)
BIO8	Mean temperature of wettest quarter
BIO9	Mean temperature of driest quarter
BIO10	Mean temperature of warmest quarter
BIO11	Mean temperature of coldest quarter
BIO12	Annual precipitation
BIO13	Precipitation of wettest month
BIO14	Precipitation of driest month
BIO15	Precipitation seasonality (coefficient of variation)
BIO16	Precipitation of wettest quarter
BIO17	Precipitation of driest quarter
BIO18	Precipitation of warmest quarter
BIO19	Precipitation of coldest quarter

variables provide a statistical summary of the climate within a set of static spatial variables that are appropriate for bioclimatic modelling. Climatic similarity based on temperature characteristics was modelled from a dataset of environmental layers and the native range of *P. senegalus* using the MaxEnt program (v.3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent) in order to test its environmental suitability. As a cumulative result, a continuous map was created and visualised in QGIS 3.14.16-π 'Pi'. If the climate suitability value reached or exceeded a certain threshold value, this was interpreted as an absence of climate constraint on the survival of the species and was indicated by a red area on the map. MaxEnt was trained using all 19 bioclimatic variables with default features and regularisation multipliers (default model), which were based on empirical tuning studies (Phillips & Dudík 2008).

3. RESULTS

The production of *Polypterus senegalus* in Indonesia has rapidly increased in recent years. The vast majority of *P. senegalus* is pet-traded on the domestic market, while a minor part is exported (Fig. 1) (e.g. to the Czech Republic). Exports started to increase towards the end of the survey period (Feb 2021). Only a few hundred individuals are imported annually to improve the quality of broodstock (Fig. 1). *P. senegalus* was found to be advertised for sale across Indonesia in Bali, Bangka Belitung islands, Java, Kalimantan, Lombok (West Nusa Tenggara), Papua, Riau Islands, Sulawesi and Sumatra (Table S1 in the Supplement at www.int-res.com/articles/suppl/q014p127_supp.pdf). The sellers included wholesalers, retailers, large-scale and small-scale producers, and

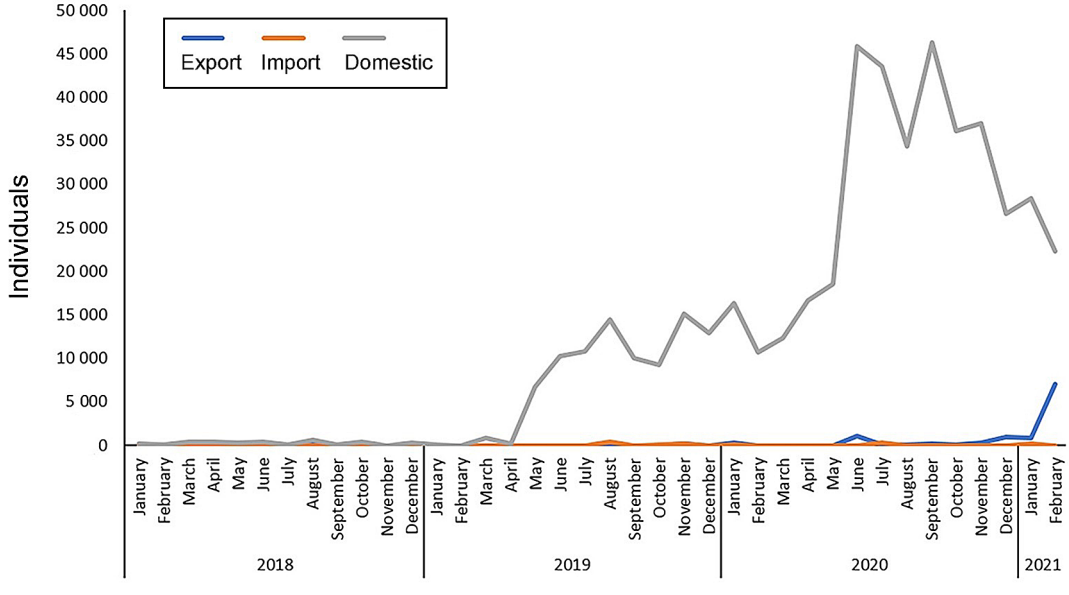

Fig. 1. *Polypterus senegalus* trade trend lines in Indonesia: individuals traded via export, import and domestic market per month from January 2018 to February 2021

the quantity of *P. senegalus* traded varied depending on the type of seller. Wholesale, retail and large-scale producers sell fish in large amounts (>50 individuals per sale), while small-scale producers average <5 individuals per sale. In ornamental aquaculture in Indonesia, the species are mostly produced and stocked in earthen ponds and concrete tanks which are connected via outflow drainages with streams in the vicinity.

Based on climate matching, the probability of establishing feral populations of *P. senegalus* in new localities was high given the vast suitable territory in Indonesia (Fig. 2a). This estimation was confirmed by 3 records of potentially established populations of this species in the wild in the Bugisan and Code Rivers in Yogyakarta, Java, and the Gedong Tataan River and in one unnamed river in Pesawaran, Lampung Province at the southern tip of Sumatra (Fig. 2b,c, Table S1). Since various size classes of *P. senegalus* were recorded, the populations found in these rivers were considered to be potentially prospering. Both wild and albino phenotypes were recorded (Fig. 2d) except in the Bugisan River, where only the wild type was recorded (Table S2). Based on personal information from local fishermen, there were 3 more potentially established populations in rivers in Central Kalimantan (East Kotawaringin: GPS –2.344630, 112.884996; Katingan Regency: GPS –2.424426, 113.314176; South Barito Regency: GPS –2.022376, 114.906431), 2 in rivers in Java (West Java: GPS –6.185917, 107.442926; Yogyakarta: GPS –7.781657, 110.419273), and 1 in a creek in Lombok (Keruak, East Lombok Regency, West Nusa Tenggara: GPS –8.743616, 116.460930; Fig. 2b,c). Additional *P. senegalus* were reported via social media in Java (see e.g. https://www.facebook.com/groups/pasiraner/permalink/1844727202217504/?_rdc=1&_rdr; https://mobile.facebook.com/groups/pasiraner/permalink/1516380868385474/?sfnsn=wiwspwa&_rdc=1&_rdr; https://www.youtube.com/watch?v=qiPqGZ1Txbs, all links accessed on 25 March 2022) and identified by visual inspection (both wild and albino phenotypes). The statuses of all mentioned records need to be verified and further monitored via future field trips.

4. DISCUSSION

Based on the survey, we found *Polypterus senegalus* to be widely traded in Indonesia in huge quantities. Even though the environmental risks and probability of establishment are high, no local or national regulations are applicable, and this species can be owned, cultured and released everywhere legally. Central policies (PermenKP/19/2020, previously PermenKP/41/2014) regulating 'banned' aquatic species in Indonesia have never included *P. senegalus* or any species of the genus *Polypterus.* Indonesian policymakers consider *P. senegalus* not to be a dangerous predator and do not plan to ban or restrict its spread in the country. This situation is exacerbated by the increasing volume of domestic trade and export of this species. Indonesian climatic conditions are eminently suitable for *P. senegalus*, so it is not surprising that the first potentially established populations were recorded there. It is predicted that more records from the wild will appear soon, and this conclusion is supported by as yet unverified personal information from local fishers and reports on social media in Java, Kalimantan and Lombok islands.

Even though there is only one species with the name 'palmas' (*P. palmas*), all *Polypterus* spp. have been traded in Indonesia using the market name 'palmas'. This creates confusion, and correct identification of the species is difficult or impossible in many cases. This inaccurate naming is suspected to have occurred because the first fish were imported using the *P. palmas* species name, after which all species in the genus *Polypterus* were generalised as 'palmas'. For this reason, previously published reports on production and trade of 'palmas' are misleading, including that of the albino morph (Sobariah & Wiryati 2013). *P. senegalus* is very popular in Indonesia, and it is likely that the majority of these albino fishes belonged to this species.

P. senegalus invasion can cause losses to ecological diversity mainly because of its predatory behaviour. This nocturnal ambush predator preys on many types of aquatic invertebrates and vertebrates (Ayoade et al. 2018); thus, there is the potential for them to negatively affect native faunal assemblages. Since Indonesia incorporates 3 biodiversity hotspots with many endemic species, the introduction of a new predator could have devastating consequences. Moreover, *P. senegalus* serves as a host of several monogenean fish parasites of the genera *Diplogyrodactylus* and *Macrogyrodactylus* (Přikrylová & Gelnar 2008). These parasitic flatworms attach to skin and gills and can easily be overlooked and transported via their host fish into the ornamental aquaculture trade. In Indonesia, the domestic trade in ornamental aquatic creatures is well-developed, and infested species could be rapidly spread over the territory through numerous routes (Yuliana et al. 2021). Since production and trade volumes have rapidly increased in recent years in Indonesia, the probability

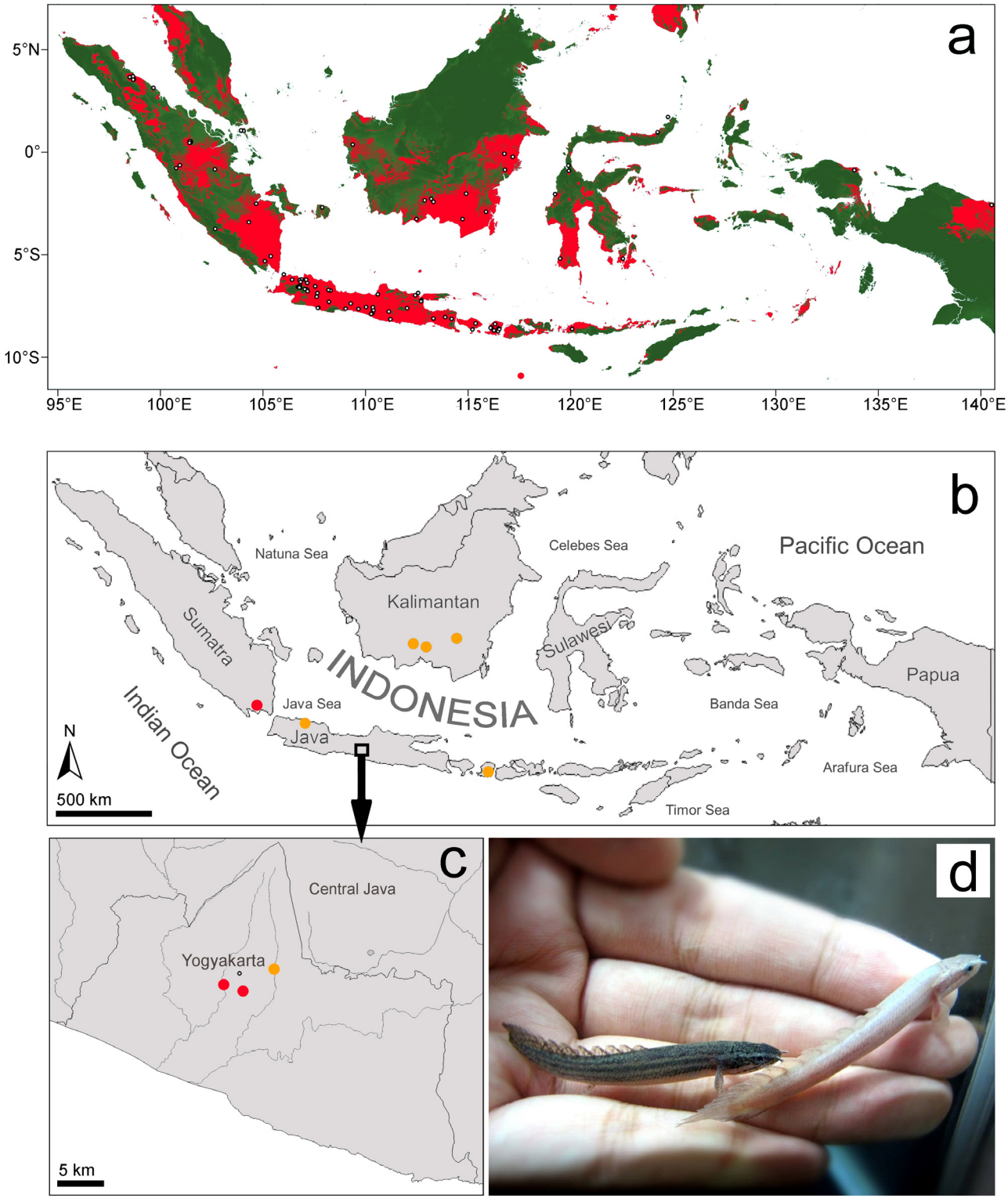

Fig. 2. (a) Map derived from the MaxEnt model for the possible establishment of *Polypterus senegalus* in Indonesia. Red: areas suitable for establishment; white dots: locations used for model training. (b,c) Red dots: first potentially established population in Indonesia; orange dots: unconfirmed populations. (d) Wild and albino phenotypes captured in the same locality in the Gedong Tataan River (Sumatra)

of both intentional release of unwanted *P. senegalus* and unintentional escape of fishes has accordingly become higher. In comparison with other *Polypterus* species recorded as being traded as pets in Indonesia, the price of *P. senegalus* is much cheaper, and owners are more likely to release these fish than more expensive species.

Considering the potential risks and consequences, a total ban on this fish in Indonesia seems a reasonable solution at first sight. Nevertheless, the increasing volume of intra- and international trade suggest that the aquaculture of *P. senegalus* is too popular and economically valuable for local producers to agree to such a restriction in Indonesia. It follows that any restrictions without effective education of the general public about possible risks would be ineffective and result in failure (Patoka et al. 2018). Similar to what has been tried with other high-risk species (Putra et al. 2018), one feasible solution would be to switch production exclusively to the potentially less-invasive albino variety. The albino *P. senegalus* is popular in Indonesia, and its culture is well-established and profitable (Rohmy et al. 2010, Sobariah & Wiryati 2013) with both online and offline markets in Indonesia, especially in Java and Sumatra. In comparison to pigmented individuals, albino fishes can be easily detected by predators (Ellegren et al. 1997), their social behaviour is abnormal (Slavík et al. 2015), and they are more susceptible to diseases (Miyamoto 2016). It can be hypothesized that physiological and behavioural limitations resulting in reduced reproductive potential may represent a lower risk for the native environment compared to that of pigmented conspecifics.

In light of research on the consequences of albinism in fish, it follows that the impact of albino *P. senegalus* on the environment could be significantly less than that of normally pigmented conspecifics. This hypothesis has to be tested experimentally before establishing mandatory regulations leading to the banning of the wild phenotype in preference to albinos in aquaculture in Indonesia. Albino *P. senegalus* is still a non-native species, but there has not been a unique albino population found in Indonesia, and the reproduction/establishment of *P. senegalus*, if it is to occur, is more likely via the wild phenotype. If the invasiveness of this species can be significantly reduced by the suggested regulation, it should have a positive effect on wildlife conservation and less of a negative socio-economic impact on local communities. For *P. senegalus*, this seems to be the most feasible and effective strategy.

Acknowledgements. S.G.A., O.S., and J.P. were supported by the European Regional Development Fund; the submitted article was supported within the frame of the comprehensive project named 'Centre for the investigation of synthesis and transformation of nutritional substances in the food chain in interaction with potentially harmful substances of anthropogenic origin: comprehensive assessment of soil contamination risks for quality of agricultural products' (No. CZ.02.1.01/0.0/16_091/0000845). J.P. and L.K. were supported by the Technology Agency of the Czech Republic within the project 'DivLand' (No. SS02030018). R.J. acknowledges the 'Ichthys-Alien Indonesia' project.

LITERATURE CITED

Akmal SG, Zámečníková-Wanma BPD, Prabowo RE, Khatami AM and others (2020) Marine ornamental trade in Indonesia. Aquat Living Resour 33:25

Arnoult J (1964) Comportement et reproduction en captivité de *Polypterus senegalus* Cuvier. Acta Zool 45:191–199

Ayoade AA, Adeyemi SA, Ayedun AS (2018) Food and feeding habits of *Hepsetus odoe* and *Polypterus senegalus* in Eleyele Lake, Southwestern Nigeria. Trop Freshw Biol 27:43–53

Diatin I, Larasati R, Ellanda RE (2015) Analisis marjin keuntungan usaha budi daya ikan hias skala mikro di Bogor. In: Prosiding Seminar Nasional Ikan ke 8. Masyarakat Iktiologi Indonesia, Bogor, p 79–86

Du TY, Standen EM (2020) Terrestrial acclimation and exercise lead to bone functional response in *Polypterus* pectoral fins. J Exp Biol 223:1–9

Ellegren H, Lindgren G, Primmer CR, Møller AP (1997) Fitness loss and germline mutations in barn swallows breeding in Chernobyl. Nature 389:593–596

Haubrock PJ, Cuthbert RN, Hudgins EJ, Crystal-Ornelas R and others (2022) Geographic and taxonomic trends of rising biological invasion costs. Sci Total Environ 817: 52948

Magid AMA (1966) Breathing and function of the spiracles in *Polypterus senegalus.* Anim Behav 14:530–533

Marková J, Jerikho R, Wardiatno Y, Kamal MM and others (2020) Conservation paradox of giant arapaima *Arapaima gigas* (Schinz, 1822) (Pisces: Arapaimidae): endangered in its native range in Brazil and invasive in Indonesia. Knowl Manag Aquat Ecosyst 421:47

Miyamoto K (2016) Effects of body color luminance and behavioral characteristics on predation risk in salmonid fishes. Hydrobiologia 783:249–256

Novák J, Kalous L, Patoka J (2020) Modern ornamental aquaculture in Europe: early history of freshwater fish imports. Rev Aquacult 12:2042–2060

Parenti LR, Soeroto B (2004) *Adrianichthys roseni* and *Oryzias nebulosus*, two new ricefishes (Atherinomorpha: Beloniformes: Adrianichthyidae) from Lake Poso, Sulawesi, Indonesia. Ichthyol Res 51:10–19

Patoka J, Magalhães ALB, Kouba A, Faulkes Z, Jerikho R, Vitule JRS (2018) Invasive aquatic pets: failed policies increase risks of harmful invasions. Biodivers Conserv 27:3037–3046

Phillips SJ, Dudík M (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31:161–175

Přikrylová I, Gelnar M (2008) The first record of *Macrogyrodactylus* species (Monogenea, Gyrodactylidae) on fresh-

water fishes in Senegal with the description of *Macrogyrodactylus simentiensis* sp. nov., a parasite of *Polypterus senegalus* Cuvier. Acta Parasitol 53:1–8

Putra MD, Bláha M, Wardiatno Y, Krisanti M and others (2018) *Procambarus clarkii* (Girard, 1852) and crayfish plague as new threats for biodiversity in Indonesia. Aquat Conserv 28:1434–1440

Pyšek P, Richardson DM (2010) Invasive species, environmental change and management, and health. Annu Rev Environ Resour 35:25–55

Rohmy S, Permana A, Subamia IW, Nur B (2010) Pengamatan pemijahan ikan palmas albino (*Polypterus senegalus* var.) dengan stimulasi hormon gonadotropin. In: Prosiding Forum Inovasi Teknologi Akuakultur Ministry of Marine Affairs and Fisheries, Jakarta, p 453–459

Schäfer F (2004) *Polypterus* – Flösselhechte Bichirs. Aqualog Animalbook, Rodgau

Slavík O, Horký P, Maciak M (2015) Ostracism of an albino individual by a group of pigmented catfish. PLOS ONE 10:e0128279

Sobariah S, Wiryati G (2013) Analisis margin pemasaran dari saluran pemasaran ikan hias di enam pasar Bogor (survei di Kota/Kab. Bogor Provinsi Jawa Barat). Jurnal Penyuluhan Perikanan dan Kelautan 7:52–62

Yonvitner Y, Patoka J, Yuliana E, Bohatá L and others (2020) Enigmatic hotspot of crayfish diversity at risk: invasive potential of non-indigenous crayfish if introduced to New Guinea. Aquat Conserv 30:219–294

Yuliana E, Yonvitner, Akmal SG, Subing RA and others (2021) Import, trade and culture of non-native ornamental crayfish in Java, Indonesia. Manag Biol Invasions 12: 846–857

Editorial responsibility: Ian Fleming, St. John's, Newfoundland and Labrador, Canada
Reviewed by: 2 anonymous referees

Submitted: January 11, 2022
Accepted: April 19, 2022
Proofs received from author(s): June 17, 2022