Conservation paradox of giant arapaima *Arapaima gigas* (Schinz, 1822) (Pisces: Arapaimidae): endangered in its native range in Brazil and invasive in Indonesia

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Abstract – Ornamental aquaculture is known to be one of the main sources of non-native species and Indonesia has been identified as one of the leading suppliers of these organisms worldwide. Released or escaped ornamental aquatic animals can establish new populations and become invasive. On the other hand, some invasive species can be also endangered in their native range, which is called the “Biodiversity Conservation Paradox”. This is true for *Arapaima gigas*, one of the popular ornamental creatures and the largest bony fish of all, which is threatened in its native range in parts of Amazonia and which has been found to occur in various localities in Java and Sumatra in Indonesia. Based on climate matching we found the vast majority of Indonesian territory to be suitable for this species establishment. Keeping in mind the size and predatory behaviour of *A. gigas*, we discussed possible consequences of its spread and impacts on native biota in Indonesia.

Keywords: Biological invasion / Osteoglossiformes / Ornamental species / Asia / Climate matching

Résumé – **Paradoxe de conservation de l’arapaima géant *Arapaima gigas* (Schinz 1822) (Poisson: Arapaimidae): en danger dans son aire de répartition naturelle au Brésil et envahissant en Indonésie.** L’aquaculture ornementale est connue pour être l’une des principales sources d’espèces non indigènes et l’Indonésie a été identifiée comme l’un des principaux fournisseurs de ces organismes dans le monde. Les animaux aquatiques ornementaux relâchés ou échappés peuvent établir de nouvelles populations et devenir envahissants. D’autre part, certaines espèces envahissantes peuvent également être menacées dans leur aire de répartition d’origine, ce que l’on appelle le “paradoxe de la conservation de la biodiversité”. C’est le cas de l’*Arapaima gigas*, une des créatures ornementales les plus populaires et le plus grand poisson osseux de tous, qui est menacé dans son aire de répartition naturelle dans certaines parties de l’Amazonie et dont la présence a été constatée dans diverses localités de Java et de Sumatra en Indonésie. En se basant sur la correspondance climatique, nous avons constaté que la grande majorité du territoire indonésien est propice à l’établissement de cette espèce. En gardant à l’esprit la taille et le comportement prédateur d’*A. gigas*, nous avons discuté des conséquences possibles de sa propagation et de ses impacts sur le biote indigène en Indonésie.

Mots-clés : Invasion biologique / Ostéoglossiformes / Espèces ornementales / Asie / correspondance climatique

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1 Introduction

Human activities are partly responsible for a decline in global biodiversity (Ilheu *et al.*, 2014). In order to mitigate devastating consequences, the importance of nature conservation is highlighted (Cristescu and Boyce, 2013; Azevedo-Santos *et al.*, 2017). Even if it is not a panacea, critically endangered species should be protected if we would like to give them a chance to survive (Ceballos *et al.*, 2015). However, as many have pointed out, there is also the other side of the coin in the case of some endangered species becoming invasive and spreading outside of their native range with various negative environmental and socio-economic impacts (Lees and Bell, 2008; Garzón-Machado *et al.*, 2012; Bellard *et al.*, 2016; Marchetti and Engstrom, 2016).

Endangered species are not usually invaders. But once in a while, certain species become both endangered within its native range and at the same time establish non-native populations in a new location, where they spread and behave as invaders. This phenomenon is generally called the “Biodiversity Conservation Paradox” (Vellend, 2017). For instance, the large omnivorous wattle-necked soft-shelled turtle (*Palea steindachneri*) is endangered in China and Vietnam but also has invasive populations in Hawaii (Ernst and Lovich, 2009), the Republic of Mauritius and the Sacramento River in California (Radford, 2011). European wild rabbit (*Oryctolagus cuniculus*), the protected keystone species in Iberia, has a well-documented destructive influence in Australia (Lees and Bell, 2008). Another invader in Australia is banteng, also known as tembadau (*Bos javanicus*), a species of wild cattle, which is endangered in Bali and Java (Bradshaw *et al.*, 2006). One can mention also the invasions of aoudad (*Ammotragus lervia*) and mouflon (*Ovis orientalis*) in the Canary Islands, while both species are endangered in their native ranges (Garzón-Machado *et al.*, 2012). Also, some species potentially endangered in the native range and more or less invasive in regions where introduced are known: for example, narrow-clawed crayfish (*Pontastacus leptodactylus*) native to East Europe and introduced to many other European regions (Kouba *et al.*, 2014).

Although the expected solution to invasive species is eradication – as most methods of conservation recommends (*sensu* Lockwood *et al.*, 2013 and citations therein; Schofield *et al.*, 2019) –, this approach is not universally advised (Casazza *et al.*, 2016). In many cases, the newly introduced species can damage the penetrated ecosystem (Schofield *et al.*, 2019). But in some other instances, the invasive species can help to protect some endangered species and its eradication could harm the already damaged species even more, as in the case of the invasive grass *Spartina* spp. in California where these plants have created new nesting habitat for an endangered bird, Ridgway’s rail (*Rallus obsoletus*) (Lampert *et al.*, 2014). In these situations, and in relation to the Biodiversity Conservation Paradox, the eradication is at least disputable and the best solution must be thoroughly discussed by experts in the field (Marchetti and Engstrom, 2016).

One of the most important pathways for introduction of non-native species is the international pet trade (Early *et al.*, 2016; Novák *et al.*, 2020; Patoka *et al.*, 2020a,b). Freshwater animals exploited for ornamental purposes sometimes escape or are both intentionally or accidentally released from aquaria

or garden ponds (Padilla and Williams, 2004; Kalous *et al.*, 2015; Patoka *et al.*, 2017; Magalhães *et al.*, 2017b; Schofield *et al.*, 2019). One can find various examples of pet traded aquatic animals behaving as invaders such as: lionfish (*Pterois volitans*) in the Atlantic Ocean (Green *et al.*, 2012) and Mediterranean Sea (Kletou *et al.*, 2016); guppy (*Poecilia reticulata*) and swordtail (*Xiphophorus helleri*) in Australia and Brazil respectively (Maddern *et al.*, 2011; Magalhães and Jacobi, 2017); red-eared slider (*Trachemys scripta elegans*) which is now present in all continents except Antarctica (Lever, 2003; Ramsay *et al.*, 2007; Ernst and Lovich, 2009; Héritier *et al.*, 2017); marbled crayfish (*Procambarus virginalis*) in European freshwaters (Lökkös *et al.*, 2016; Părvulescu *et al.*, 2017; Hossain *et al.*, 2018); and the cichlid fishes bay snook (*Petenia splendida*) and blue mbuna (*Labeotropheus fuelleborni*) in USA (Schofield *et al.*, 2019). Introduced species can cause decline or extinction of native biota by predation, resource competition, habitat alteration (Pimentel, 2014; Forneck *et al.*, 2016), and also by introducing new pathogens (Gozlan *et al.*, 2009; Putra *et al.*, 2018).

In some regions, the consequences of non-native species introductions to the wild are overlooked or ignored also at the policy level (Liang *et al.*, 2006; Marchetti and Engstrom, 2016; Patoka *et al.*, 2020a,b). Even if the pet trade in selected aquatic species is regulated by both national and international legislation in certain regions, their effectiveness is at least questionable in some cases because hobbyists often do not know reasons why stocking and keeping of mentioned species is prohibited and are not aware of risks of biological invasions (Magalhães, 2015; Patoka *et al.*, 2018a). Also, the release of unwanted pets because they require more food, overpopulate, or outgrow the tank, are not so attractive in colouration in adult stage, or become very aggressive is a relatively common practice among hobbyist generally (Duggan *et al.*, 2006; Magalhães *et al.*, 2017b).

Among the leading producers and exporters of freshwater animals for ornamental purposes is Indonesia (Wood, 2001; Patoka *et al.*, 2015). The tropical climate in this country is favourable for keeping of ornamental fish and other aquatic species in outdoor reservoirs or natural lakes and the culture of non-native species is not regulated within the country (Patoka *et al.*, 2018a). Moreover, one of six main religions in Indonesia is Buddhism, where a ceremony known as “fang sheng” (a ritual of releasing living creatures) refers to the practice of purchasing animals, particularly birds or fish, to subsequently release them to the wild to demonstrate Buddhist pity and to gather merits for a favourable judgement in the afterlife (Shiu and Stokes, 2008). The non-native animals escaped or released as unwanted pets or via the “fang sheng” rite, usually starve or are preyed on and die quickly, or, if they are able to survive, become feral pests that could threaten the native biota as invaders.

Thus, various non-native freshwater species have been recorded in Indonesia: for example the crayfish *Cherax quadricarinatus* (Patoka *et al.*, 2018b) and *Procambarus clarkii* (Putra *et al.*, 2018), molluscs *Pomacea canaliculata* and *P. insularum* (Marwoto and Nur, 2011), *Sinanonodonta woodiana* (Bolotov *et al.*, 2016), and fishes such as guppy (*P. reticulata*) (Knight, 2010), alligator gar (*Atractosteus spatula*) (Muchlisin, 2012), Amazon sailfin catfish (*Pterygoplichthys disjunctivus* and *P. pardalis*) (Muchlisin *et al.*, 2015;

Patoka *et al.*, 2020a,b) and red-eared slider turtle (*Trachemys scripta elegans*) (Ramsay *et al.*, 2007).

The carnivorous fish *Arapaima gigas* (Schinz, 1822) (Osteoglossiformes: Arapaimidae) is also called “pirarucu” in Brazil and Colombia or “paiche” in Peru, Ecuador, Venezuela and Bolivia, or simply giant arapaima. It has a native range in Central South America and it is the largest freshwater scaled fish in the world, growing up to 3 m (9.8 ft) in body length and 200 kg in weight over the course of its lifespan (Castello and Stewart, 2010). In the genus *Arapaima*, there are four species distinguished (Stewart, 2013) although molecular studies (Hrbek *et al.*, 2005; Araripe *et al.*, 2013) are contrasting with this statement, suggesting structured populations. The most probably only *A. gigas* is pet-traded (Nijman, 2010). This charismatic “ancient” creature that belongs to a primitive group of carnivorous bony-tongued fishes is an ideal candidate for ornamental fishkeeping especially in smaller sizes (*i.e.*, juveniles and subadults). It is pet-traded in Europe, North America, South America and also in Asia (Mueller and Green, 2005; Magalhães *et al.*, 2017b), although protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, Appendix II) (Nijman, 2010).

Arapaima gigas is threatened by overfishing for human consumption in its native range in Brazil, mainly due to its obligatory air-breathing behaviour (Hrbek *et al.*, 2007). Since it gulps atmospheric oxygen above the water surface every 5–15 min, it is a very easy target for harpoon-specialist fishermen (Castello, 2004; Hrbek *et al.*, 2007). The commercial fishing of giant arapaima has been limited to a sustainable level from 2001, but illegal capture still exists and about 77% of the harvest is unlawful (Hrbek *et al.*, 2007). To reduce pressure on wild populations, *A. gigas* is also produced in aquaculture in Brazil (Imbiriba, 2001; de Oliveira *et al.*, 2012). This production is increasing in recent years (Lima Junior *et al.*, 2018; Nobile *et al.*, 2019). On the other hand, young *Arapaima* individuals can be collected from the wild in Brazil, kept in captivity and subsequently exported abroad as captive-bred fish, which has been routinely done by traders (Castello and Stewart, 2010).

Despite its relatively high abundance in the past, *A. gigas* became extinct in the surroundings of big Amazonian cities after 1970s (Goulding, 1980). In this regard, it was added to The IUCN Red List of Threatened Species (Baillie and Groombridge, 1996) and classified as “Data Deficient”, because detailed data about its distribution and abundance are lacking. There are community-based initiatives protecting suitable waterbodies to allow *A. gigas* naturally reproduce and form sustainable populations within its native range (Castello, 2004). Unfortunately, decreasing abundance has led to a very low degree of polymorphism which represents one of the major problems for future conservation management (Torati *et al.*, 2019).

Out of its native range, *A. gigas* is known to behave as an invasive species in parts of Brazil (Fontenele, 1955; Ferreira, 2013; Ramos *et al.*, 2014; Casimiro *et al.*, 2018; da Costa Doria *et al.*, 2020), south-eastern Peru and north-western Bolivia where it was introduced for control of undesirable species such as piranhas (*Pygocentrus* spp., *Serrasalmus* spp.) and from intentional releases or aquaculture purposes (Miranda-Chumacero *et al.*, 2012; Van Damme *et al.*, 2015). At least in Bolivia, it has probably caused a reduction of native

ichthyofauna including species of high commercial value such as small characids (Van Damme *et al.*, 2015).

As mentioned above, once established in culture, *A. gigas* has been also exported for human consumption and as an ornamental species, from Brazil, Colombia and Peru (Mueller and Green, 2005) or from countries outside South America, such as Cambodia, India, Indonesia, and Thailand (Vidthayanon, 2005), even if this is somewhere illegal as in India (Kumar *et al.*, 2019). Authorities in the importing countries are aware about the potential invasive behaviour of large non-native predatory fish species but the restrictions are ineffective in many cases, turning laws into “dead letters”, that is, existing but unenforced laws (Patoka *et al.*, 2018a). For example, although the Indonesian Ministry of Agriculture established the law No. 179/Kpts/UM/3/1982, updated as the law No. PERMENKP/41/2014, to ban the import of certain fish species including *A. gigas* to the country, this species is widely traded as ornamental animal there (Patoka, 2018). Moreover, the continuous illegal import to Indonesia cannot be excluded (Priono and Satyani, 2010) and general knowledge about its potential escapes or release of this species in the wild is poor. Just one record from Indonesian territory was published (Fadjar *et al.*, 2019). Unfortunately, the finding was described without detailed evidence and should be perceived as somewhat uncertain.

For this reason, we decided: (i) to survey selected localities in Indonesia; (ii) to ascertain the probability that this fish occurs and survives within Indonesian waterbodies by climate matching; and (iii) to discuss the conservation paradox implications, with recommendations on how to manage the situation.

2 Material and methods

2.1 Data collection

Records of *A. gigas* in Indonesian freshwaters were gathered from June 2011 to July 2018. The inventory of its occurrences in Indonesian waterbodies was done through desk study in several local online news media and social media (Facebook®, www.facebook.com). Online findings that indicated the occurrence of the species were confirmed through photographic evidence, personal interviews with local residents and fishermen and, if possible, also by direct observations. In direct observations, body parts of captured *Arapaima* that were still possible to be analysed genetically were preserved in 96% alcohol. All activities were conducted with respect to Indonesian laws and ethical rules and guaranteed by Indonesian academic staff.

2.2 Species determination

For morphological analysis, a comparison of shape of the dorsalmost lateralis sensory cavity on the preopercle as described by Stewart (2013) was used. The species identification was verified by genetic analysis using polymerase chain reaction (PCR). DNA was isolated from tissue of the voucher individual and the region of the *cox1* gene from mitochondrial DNA was amplified in PCR reaction using primers FishF1 and FishR2 and PCR protocol according to Ward *et al.* (2005).

The PCR products were visualized and sequenced at SEQme s.r.o. in the Czech Republic (<https://www.seqme.eu/cs/>). Chromatograms were assembled and checked for potential errors. Edited sequences were aligned using Clustal W, using BioEdit software package (Hall, 1999). The sequence was uploaded to GenBank (<https://www.ncbi.nlm.nih.gov/genbank/>). The Basic Local Alignment Search Tool (BLAST) was employed to find similarities in sequences in GenBank. The result is obtained in the form of a ranked list based on a normalized percent identity score, followed by individual sequence alignments (Madden, 2013).

2.3 Climate matching

In line with previous studies focused on environmental suitability of Indonesian territory for certain invasive species (Yonvitner *et al.*, 2020), climate matching based on temperature characteristics was modelled from a dataset of environmental layers and the native range of *Arapaima gigas* using MaxEnt program (v.3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent) in order to test its environmental suitability. MaxEnt is a maximum entropy model well-suited for species distribution mapping (Phillips *et al.*, 2006; Phillips and Dudík, 2008) and is widely used for predicting of spreading non-native species (Ward, 2007; Wang *et al.*, 2010; Yonvitner *et al.*, 2020). Available GPS coordinates of the native range were obtained from published records of studied species (Hrbek *et al.*, 2007; Torati *et al.*, 2019) and native occurrence records from the international biodiversity database GBIF (<https://www.gbif.org>). Environmental layers of historical climate data were obtained from the WorldClim database in the spatial resolution of 2.5 arcmin ($\sim 1 \text{ km}^2$) and environmental layers of future climate data (CSIRO A1B) were obtained from the CliMond database (v.1.2, <https://www.climond.org/>, (Kriticos *et al.*, 2012) at a spatial resolution of 10 arcmin ($\sim 1 \text{ km}^2$). Both datasets were assembled in QGIS 3.8.2 Zanzibar (<https://qgis.org/en/site/>) to ASCII format for use with the MaxEnt algorithm (Phillips, 2005). The final set of bioclimatic predictors comprised ($^{\circ}\text{C}$): Annual Mean Temperature (BIO1), Mean Diurnal Range (BIO2), Isothermality (BIO3), Temperature Seasonality (BIO4), Max Temperature of Warmest Month (BIO5), Min Temperature of Coldest Month (BIO6), Temperature Annual Range (BIO7), Mean Temperature of Warmest Quarter (BIO10), Mean Temperature of Coldest Quarter (BIO11). The model described a continuous probability surface of habitat suitability in the target area. As the cumulative output, a continuous map was generated and visualised in QGIS 3.8.2 Zanzibar (<https://qgis.org/en/site/>). If the value of the climate match reached or exceeded the specific threshold value, this was interpreted as no evidence for climatic constraints to the survival of the species and it is shown in the red coloured area on the map.

3 Results

Based on personal investigation in the field, there are some local giant arapaima keepers who intentionally release the fishes into the wild in Indonesia (*e.g.*, see the following link in Indonesian language: <https://news.detik.com/video/180626091/video-pelepasan-ikan-arapaima-di-sungai-brantas>). In total, 27

individuals of giant arapaima were recorded in Indonesian freshwaters. Two of them were found in Sumatra and the others in Java (Fig. 1b). Recorded fish inhabited rivers, dams, natural pools beside rivers and dams, and artificial waterways recorded as canals (Tab. 1). All recorded individuals were adults with body length typically $>100 \text{ cm}$. Some individuals of *A. gigas* were found dead in shallow waters, some were captured with use of spearfishing, angling or electrofishing. The captured fish were mostly consumed by local fishermen and their families or cut up and sold for human consumption (Fig. 2c and 2d).

The voucher specimen was a female with a total body length of 179 cm (Fig. 3) and mature eggs (*i.e.*, vitellogenic oocytes) were found inside in its body cavity (Fig. 2a). Remains of unidentified *Clarias* catfish were found in its digestive tract (Fig. 2b). Based on both morphological and genetic analyses, the fish was identified as *Arapaima gigas*. The sequence of the voucher specimen is available in GenBank under Accession Number MT542128. The result obtained from BLAST showed 99.69% identity (100% Query Cover) with the reference sequence GenBank Accession number EF523611 (Hrbek and Farias, 2008). The voucher specimen is deposited in the Bogor Zoology Museum, Indonesia.

MaxEnt calculated the threshold value of 11.25 and the model had an average training AUC value (area under the receiver-operator curve) of 0.99 suggesting a high predictability of the model (Ward, 2007; Elith *et al.*, 2011). Based on climate matching, the probability of *A. gigas* to survive in vast areas of Indonesian territory is relatively high even if certain regions seem to be not so suitable and are shown as green areas on the map (Fig. 1a).

4 Discussion

Arapaima gigas is one of many species of ornamental fish pet-traded in Indonesia and we found adult individuals being released or escaping to freshwaters in Java and Sumatra. The species was first imported in 2005 (Sinovas *et al.*, 2017) and more introduction events have been carried out in following years. Whether or not established, such a large and long-lived predator, as *A. gigas*, can be a serious threat to the rich native and partly endemic Indonesian fauna (Hutomo and Moosa, 2005). Endemic fish such as species from the genus *Clarias* can be at risk as suggested by food remains found in the digestive tract of the voucher specimen.

The growth rate of young *A. gigas* is rapid, up to a body length of 80 cm and weight of 4–5 kg in its first year of life (Val and Almeida-Val, 2012). The generation period is relatively slow, because *A. gigas* reaches sexual maturity in 4–5 years with a body length of 150–170 cm and weight of 40–45 kg (Arantes *et al.*, 2010). It is obvious that all the recorded individuals presented in this study were adults. In some cases, *A. gigas* was recorded as a single or two individuals in localities in Sumatra and western part of Java, but in the vicinity of Surabaya, the capital city of the Indonesian province of East Java and the second-largest city in the country, in total 22 individuals were recorded.

Arapaima gigas is socially monogamous, forming pairs, providing partitioned parental care including building a nest as a hole in the substrate which the fish digs with its mouth; it has been speculated that the nests are built in shallow waters

Fig. 1. Map of Indonesia: (a) showing environmental suitability for *Arapaima gigas* by the MaxEnt model whereas red colour represents a high probability of establishment; (b) records of *A. gigas* in Indonesia given by red dots (size corresponds to the number of individuals recorded).

(depth ca. 1 m) in slower flowing streams and preferably in lentic lake water (Queiroz, 2000). Males stay with the brood and guard offspring while females leave and can even mate again in the same season (Castello, 2008). Both males and females have a secretory gland-like organ on the surface of their heads. This is mostly used for communication with offspring (Lüling, 1964) and it is more active in males who provides the greater part of parental care. The secretion from the glands also partially serves as a source of nutrition for fry (Du *et al.*, 2019). Some authors suggested that at a certain stage in the development of fry, the males become mouthbrooders (Mendoza *et al.*, 2015). No nesting activity or fry and juveniles were found in Indonesian wild but, since eggs were found in the adult female, successful reproduction and subsequent establishment cannot be excluded. The records of *A. gigas* from the wild fit with the output from climate matching.

Not only the biodiversity is at risk. Also, direct socio-economic losses would be related with potential invasions of *A. gigas* because there are plenty of local fishermen in the regions where most specimens were found (the Mojokerto, Surabaya and Sidoarjo Districts in Java). Similarly as in Bolivia and Brazil, these people would be negatively affected by a potential decline of abundance and diversity of the native ichthyofauna caused by big predatory non-native fish such as *A. gigas* (Hadiaty, 2017). Moreover, many local Indonesian fishermen are afraid to go fishing in waters where arapaima occurs and say that their gill nets were damaged by this huge predatory fish (Jerikho, personal observation). On the other

hand, one can speculate that some fishermen and local communities will adopt *A. gigas* for fishing and exploitation and hence, after some time this fish will be under heavy anthropogenic pressure, as it is in some places in Brazil.

On the other hand, abundance of native populations of *A. gigas* in Amazonia is declining rapidly and despite some conservation activities in Brazil, its future is at least uncertain (Parker, 2002). Thus, it is possible that this species could be eradicated out of its native range and should be very carefully considered because this fulfils the definition of the conservation paradox. In general, with regards to the conservation of endangered species, non-native populations can provide possibilities of how to help to save the species from extinction and bring some new insights into its biology and ecology (Marchetti and Engstrom, 2016). On the other hand, it is not acceptable to prefer saving of one species ex-situ and protect it at the expense of many others (in the case of the present study, the native/endemic ichthyofauna and other biota) which could become extinct due to this approach.

Using the Fish Invasiveness Screening Test (FIST), Magalhães *et al.* (2017a) indicated that *A. gigas* is a high-risk species in terms of biological invasions via aquarium dumping in Brazil. A possible solution could be a modification of legislative regulations focused on the pet trade. Caution is recommended in this regard (Patoka *et al.*, 2018a) because new regulations can be easily misunderstood by fish keepers and traders who could consequently release them to the wild (*i.e.*, aquarium dumping) to protect themselves from potential

Table 1. Records of *Arapaima gigas* in Indonesian waterbodies (one individual per line): date of sampling; locality name; GPS coordinates; habitat type; and name of the island.

Chronological date (Day/Month/Year)	Locality	GPS	Habitat type	Island
12 June 2011	Sibulang-Bulang River system	3.000815, 99.069402	Main river	Sumatra
6 February 2013	Cimanuk River system	-7.200165, 107.912092	Main river	Java
11 February 2013	Cimanuk River system	-7.191806, 107.908626	Main river	Java
29 November 2015	Ciliwung River system	-6.562191, 106.808561	Main river	Java
25 June 2018	Brantas-Porong Canal, Brantas River system	-7.441224, 112.467130	Canal	Java
25 June 2018	Rolak Songo Dam, Brantas River system	-7.445367, 112.465976	Reservoir formed by main river	Java
25 June 2018	Lengkong Dam, Brantas River system	-7.464888, 112.508113	Reservoir formed by canal	Java
26 June 2018	Rolak Songo Dam, Brantas River system	-7.451689, 112.478545	Reservoir formed by main river	Java
26 June 2018	Rolak Songo Dam, Brantas River system	-7.445355, 112.467819	Reservoir formed by main river	Java
26 June 2018	Brantas-Porong Canal, Brantas River system	-7.448562, 112.473840	Canal	Java
26 June 2018	Brantas-Porong Canal, Brantas River system	-7.448807, 112.474870	Canal	Java
26 June 2018	Nggayu Dam, Brantas River system	-7.469012, 112.531334	Reservoir formed by canal	Java
27 June 2018	Sinoman Canal, Brantas River system	-7.480021, 112.426740	Canal	Java
27 June 2018	Pulosari Dam, Brantas River system	-7.471361, 112.541310	Reservoir formed by canal	Java
27 June 2018	Jambon Dam, Brantas River system	-7.475034, 112.560827	Reservoir formed by canal	Java
27 June 2018	Nggelik Dam, Brantas River system	-7.480029, 112.575074	Reservoir formed by canal	Java
27 June 2018	Rolak Songo Dam, Brantas River system	-7.445367, 112.465976	Reservoir formed by main river	Java
27 June 2018	Brantas-Porong Canal, Brantas River system	-7.449033, 112.476024	Canal	Java
28 June 2018	Rolak Songo Dam, Brantas River system	-7.445332, 112.465860	Reservoir formed by main river	Java
28 June 2018	Rolak Songo Dam, Brantas River system	-7.445367, 112.465976	Reservoir formed by main river	Java
30 June 2018*	Songgat Canal, Brantas River system	-7.440410, 112.492855	Canal	Java
2 July 2018	Sinoman Canal, Brantas River system	-7.477273, 112.427777	Canal	Java
3 July 2018	Gunungsari-Singgasana Dam, Brantas River system	-7.308585, 112.717620	Reservoir formed by canal	Java
3 July 2018	Gunungsari-Singgasana Dam, Brantas River system	-7.307748, 112.718875	Reservoir formed by canal	Java
8 July 2018	Bangsri Canal, Brantas River system	-7.389534, 112.662527	Canal	Java
8 July 2018	Bangsri Canal, Brantas River system	-7.390213, 112.661647	Canal	Java
25 July 2018	Siak River system	0.7853614, 101.7454660	Main river	Sumatra

*The voucher specimen is indicated by an asterisk.

Fig. 2. Details about voucher *Arapaima gigas*: (a) ovary full of mature eggs (*i.e.*, vitellogenic oocytes); (b) remain of unidentified *Clarias* catfish found inside in the digestive tract of the voucher specimen; (c, d) the meat cut up and subsequently consumed by local fishermen and their families.

Fig. 3. Voucher specimen of *Arapaima gigas* captured in Indonesia: (a) adult female; (b) head in detail; (c) dissected skull.

sanctions. Simply, poorly prepared regulations would worsen the situation dramatically. Therefore, an intensive educational campaign is crucial before any further steps. The key is understanding the full impact of the introduced species on the ecosystem it is invading. Therefore, detailed monitoring focused especially on the feeding and reproductive ecology of *A. gigas* introduced in Indonesia is strongly recommended to understand its real impact on native biota and local fisheries.

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