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SHORT COMMUNICATION — OPEN ACCESS

# Two species of illegal South American sailfin catfish of the genus *Pterygoplichthys* well-established in Indonesia

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**Abstract** – Sailfin catfish indigenous to South America are very popular ornamental fish, having previously been introduced to many regions outside their native range. Two species, namely *Pterygoplichthys disjunctivus* and *P. pardalis*, are illegal but widespread in Indonesia. They have formed self-sustaining populations, exploited for feeding of domestic animals and locally for human consumption. Also possible hybrids of the two mentioned species were recorded. The surveyed populations were considered established which perfectly fits with the climate matching analysis. Further monitoring and inspection of regions highlighted to be suitable for sailfin catfish is recommended.

**Keywords:** *Pterygoplichthys pardalis* / *Pterygoplichthys disjunctivus* / Loricariidae / biological invasion / climate matching / South-Eastern Asia / fish / aquarium trade

**Résumé – Deux espèces de pléco sud-américains illégaux du genre Pterygoplichthys bien établies en Indonésie.** Le pléco léopard voile, originaire d'Amérique du Sud, est un poisson d'ornement très populaire, ayant été introduit auparavant dans de nombreuses régions en dehors de son aire de répartition d'origine. Deux espèces, à savoir *P. disjunctivus* et *P. pardalis*, sont illégales mais très répandues en Indonésie. Elles ont formé des populations autonomes, exploitées pour l'alimentation des animaux domestiques et localement pour la consommation humaine. Des hybrides possibles des deux espèces mentionnées ont également été observés. Les populations étudiées ont été considérées comme établies, ce qui correspond parfaitement à l'analyse de la correspondance climatique. Il est recommandé de poursuivre la surveillance et l'inspection des régions jugées appropriées pour le pléco commun.

**Mots-clés :** *Pterygoplichthys pardalis* / *Pterygoplichthys disjunctivus* / Loricariidae / invasion biologique / adéquation climatique / Asie du Sud-Est / poisson / aquariophilie

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Non-native species are transported by humans both intra- and intercontinentally for various purposes and related biological invasions cause biodiversity loss at both local and global scales (Lodge, 1993; Hulme, 2015; Pelicice *et al.*, 2017; Vitule *et al.*, 2019). Despite the activity of decision-makers to mitigate risks of new introductions of identified high-risk species, the number of these events has a growing tendency and many regulations seem to be ineffective (Magalhães, 2015; Patoka *et al.*, 2018). Moreover, intentional introductions ignoring the risk assessments, or based on a lack of data, still exist (Kumschick *et al.*, 2016; Garcia *et al.*, 2018).

South American sailfin suckermouth catfish species from the family Loricariidae such as *Pterygoplichthys pardalis* (Castelnau, 1855) and *Pterygoplichthys disjunctivus* (Weber, 1991) have expanded their native ranges to tropical, subtropical, and warm-water regions intercontinentally (e.g. Wakida-Kusunoki *et al.*, 2007; Gibbs *et al.*, 2008; Golani and Snovsky, 2013; Muralidharan *et al.*, 2014; Samat *et al.*, 2016). The number of introduction events and reports of newly established populations, counting also hybrids of both species, has a rising trend in recent years (Bijukumar *et al.*, 2015; Orfinger and Goodding, 2018). Various biological and ecological characteristics such as parental care; large eggs that generate stronger juveniles to escape predators; nesting; extended spawning season; high fecundity; rapid growth; lifespan of more than five years; gulping air and extracting oxygen through the gut lining in low oxygen environments; armoured body; and ability to survive several hours of desiccation favour these catfish to be successful invaders (Hoover *et al.*, 2004; Orfinger and Goodding, 2018). Even if not during the early era of modern ornamental aquaculture (Novák *et al.*, 2020), currently, due to their characteristic attractive appearance, these fishes are very popular for ornamental fishkeeping (Maceda-Veiga *et al.*, 2013). While most of the non-native populations originated from aquarium releases or escapes from fish hatcheries, evidence of introduction for other purposes such as human consumption cannot be excluded (Page and Robins, 2006; Golani and Snovsky, 2013; Sumanasinghe and Amarasinghe, 2014).

Once a new population is established, these species are very difficult to eradicate (Hill and Sowards, 2015; Orfinger and Goodding, 2018). Various negative impacts on native biota and habitats in invaded ranges are known: outcompeting of native species by altering food web dynamics (Page and Robins, 2006), inhabiting similar trophic niches (Meena *et al.*, 2016), increases of turbidity, bank erosion and instability (Nico *et al.*, 2009a), and disturbance during the foraging of manatees (Nico *et al.*, 2009b).

Among socioeconomic negative impacts of sailfin catfish invasion, one can highlight damage to fishing gears by their spiny fins, dominance over the target exploited species in fish catches, and a subsequent decline in fishermen's livelihoods (Wakida-Kusunoki *et al.*, 2007; Hubilla *et al.*, 2008). Moreover, both mentioned species of sailfin catfish have been confirmed to serve as hosts for some parasites such as the dactylogyrid monogenean *Heteropriapulus heterotylus*, which can thus be introduced associated with the fish to new localities (Rodríguez-Santiago *et al.*, 2016).

Previously, in Indonesia, *P. pardalis* was recorded in Java, Sulawesi and Sumatra, and *P. disjunctivus* in Java (Kottelat *et al.*, 1993; Page and Robins, 2006; Muchlisin, 2012) where sailfin catfish are called *ikan sapu-sapu*. These fish are partly exploited by humans but, at least in the case of *P. pardalis*, the sailfin catfish are able to adapt to the heavy-metals-polluted environment and thus use of their flesh as local food products as exists in Java is hazardous (Ernawati, 2014). Usually, sailfin catfish have only been recorded in small quantities in these publications, but information from local people, on the other hand, suggests that the abundance is much higher in many sites. Therefore, we decided to update the information on sailfin catfish occurrence in Indonesia, with an evaluation of the establishment of these fish there in relation to climate matching models.

The sailfin catfish were sampled in selected localities in Java, Sulawesi and Lombok islands from 20 April to 21 September 2019, within the dry period. Fish were captured by angling in Java, with use of gill nets in Sulawesi (mesh size 3.5–4.5 cm), and with cast nets (4 m in diameter, mesh size 1 cm). Captured fish were euthanized and preserved for later identification in formalin. All fish were sampled by researchers from Indonesian universities and local people were interviewed regarding the exploitation of sailfin catfish.

Sailfin catfish were identified using colouration patterning on the ventral part of the body: *P. pardalis* has ventral pigmentation patterns of uncoalesced, dark spots on a light background, whereas *P. disjunctivus* shows a vermiculate (worm-like) pattern (Page and Robins, 2006; Hossain *et al.*, 2018).

In Indonesia, import of both illegal *P. disjunctivus* and *P. pardalis* is banned by Regulation No. 41/PERMEN-KP/2014, updated as Law No. PERMENKP/41/2014 (Patoka *et al.*, 2018). Where non-native species have been introduced to a new locality, climate conditions together with other stressors affect the probability of becoming established and subsequently behaving as an invader (Hellmann *et al.*, 2008). To assess the suitability of Indonesia for illegal sailfin catfish establishment, climate matching was analysed based on temperature characteristics. This was modelled from a dataset of environmental layers and native occurrence records of *P. disjunctivus* and *P. pardalis* using the MaxEnt software (v.3.4.1; https://biodiversityinformatics.amnh.org/open_source/maxent) in order to determine the species environmental adaptability in Indonesia. Available GPS coordinates of their native occurrence (Orfinger and Goodding, 2018) were obtained from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org). Environmental layers were obtained from the WorldClim database (v.1.4; http://www.worldclim.org; Hijmans *et al.*, 2005) with a spatial resolution of 2.5 arcmins ($\sim$1 km$^2$) and were assembled in QGIS 3.8.2 Zanzibar (https://qgis.org/en/site/) to ASCII format for use with the MaxEnt algorithm (Phillips, 2005). MaxEnt is a maximum entropy model well suited for species distribution mapping (Phillips *et al.*, 2006; Phillips and Dudík, 2008). The model describes a continuous probability surface of habitat suitability in the target area and is widely used for forecasting alien species distribution (Giovanelli *et al.*, 2008; Patoka *et al.*, 2019; Yonvitner *et al.*, 2020). The final set of bioclimatic predictors comprised: Annual Mean Temperature (BIO1), Mean Diurnal Range (BIO2), Isothermality (BIO3), Temperature Seasonality (BIO4), Maximum Temperature of Warmest Month (BIO5), Minimum Temperature of Coldest Month (BIO6), Temperature Annual Range (BIO7), Mean

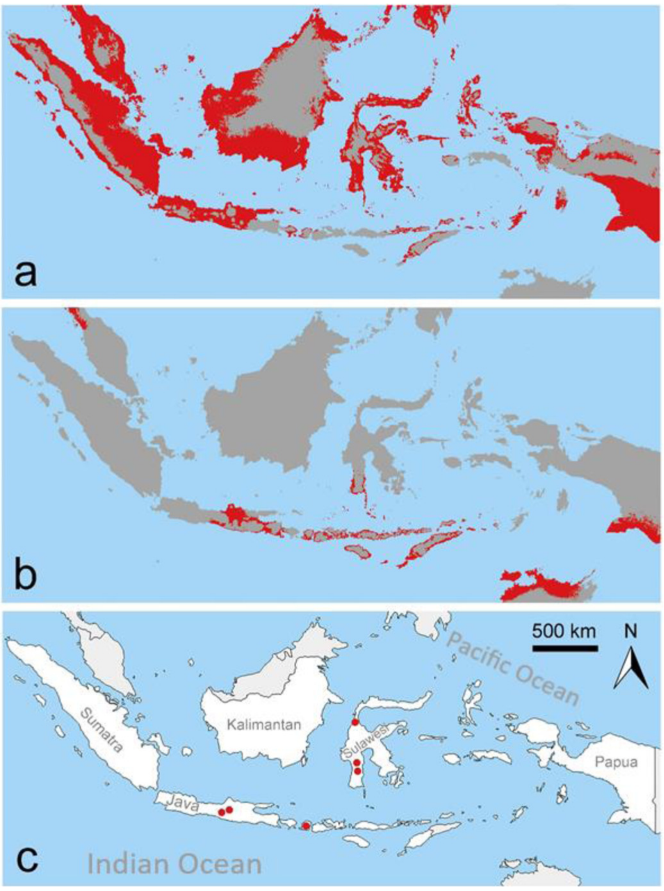


**Fig. 1.** Map of Indonesia, showing environmental suitability for *Pterygoplichthys pardalis* (a) and *P. disjunctivus* (b) computed by the MaxEnt model. Suitability shown in red colour represents the high probability of establishment. The localities with recorded occurrence of at least one of the mentioned species and/or their possible hybrids are indicated by red dots (c).

Temperature of Warmest Quarter (BIO10), and Mean Temperature of Coldest Quarter (BIO11). As a cumulative output, a continuous map was generated and visualised in QGIS 3.8.2 Zanzibar.

MaxEnt calculated a threshold value for *P. disjunctivus* = 11.91 and for *P. pardalis* = 4.81. If the value of the climate match reached or exceeded these thresholds, this was interpreted as no evidence of climatic constraints to the survival of the species and was shown in red on the map (Fig. 1). The value for the area under the receiver operator curve (AUC) was 0.995 for *P. disjunctivus* and 0.992 for *P. pardalis*, which means there was a 99% probability for both species that a random selection from presence records had a model score greater than a random selection from the absence records (Ward, 2007). Climate matching analysis showed a high probability especially for *P. pardalis* to become established in Indonesia when introduced to new localities (Fig. 1a), while *P. disjunctivus* had a much lower potential (Fig. 1b).

The found populations fit perfectly with the predicted suitable areas. Illegal sailfin catfish populations including numerous adults and juveniles were found well-established in the three Indonesian islands: Java, Lombok and Sulawesi (Fig. 1c, Tab. 1). In total, we captured 178 individuals of *P. pardalis* with an average body length of 248.7 mm ± 75.4 and average weight of 143.2 g ± 140.0, and 111 individuals of *P. disjunctivus* with an average body length of 245.9 mm ± 59.3 and average weight of 140.3 g ± 140.7. Also, 98 apparent hybrids were captured. The average body length of putative hybrids was 220.1 mm ± 75.1 and weight of 158.2 g ± 153.1. The biggest individual of *P. pardalis* had a body length of 532.0 mm and weight of 996.8 g, compared to 470.0 mm and 950.0 g for the biggest individual of *P. disjunctivus* and 430.0 mm and 499.0 g for the biggest probable hybrid.

Captures of *P. pardalis* were made in all localities surveyed in Java and Sulawesi, and in seven localities in Lombok, while *P. disjunctivus* was captured at 11 localities, only in Lombok. Possible hybrids were captured in 10 localities just in Lombok (Tab. 1). Due to the differences in size in the found populations, characterizing juveniles and adults, and because all recorded populations were very abundant, we considered them as established and self-sustaining. No associated parasites or ectocommensals were recorded. Wu *et al.* (2011) suggested that a mixture of both mentioned species might help to increase their fitness during the invasion. Despite this assumption, we found apparent hybrids only in Lombok while the other populations in Java and Sulawesi seem to be well-established, and thus in good fitness, even if no hybrids were recorded there.

Based on the interviews, many local people catch fish including sailfin catfish in the dry season, with the use of cast nets and potassium toxins. The sailfin catfish are usually used as feed for ducks and chickens, but small quantities are exploited for human consumption. Even if we have no exact information about harvesting of sailfin catfish from the wild for the ornamental trade, this purpose cannot be excluded because Indonesia is one of the leading producers and exporters of ornamental aquatic creatures worldwide (Kalous *et al.*, 2015; Patoka *et al.*, 2015) and sailfin catfish are among popular aquarium fish species for these purposes.

Although previously mentioned mechanisms of introduction of illegal sailfin catfish in South Eastern Asia were releases from aquaria and escapes from aquaculture facilities (Page and Robins, 2006; Samat *et al.*, 2016), we found one further pathway in Lombok: releasing of these fishes to mitigate another invasive pest, namely common water hyacinths (*Eichhornia crassipes*). Unfortunately, the sailfin catfish are bottom dwellers and water hyacinths are floating plants. Therefore, the purpose of the introduction was absolutely wrong and paradoxically caused the establishment of new invasive species in fresh waters in Lombok. Where both such species have been introduced by a combination of pathways or vectors, they can be defined as "polyvectic" *sensu* Carlton and Ruiz (2005).

Although the import of both sailfin species is banned by Indonesian laws (Patoka *et al.*, 2018), the ban seems to be absolutely ineffective (*i.e.*, a 'dead letter'), as both species were found to be well-established in Indonesia. Moreover, further species of sailfin catfish are traded as ornamentals, especially *P. gibbiceps* (Wu *et al.*, 2011), and therefore, introduction of this species into the Indonesian wild can be expected in the near future if it has not already happened.

**Table 1.** Recorded populations of *Pterygoplichthys disjunctivus* (Pd) *P. pardalis* (Pp) and mixture of both (H), island, locality name and GPS coordinates.

| Species | Island | Locality | GPS coordinates |
|---|---|---|---|
| Pp | Java | Majasto Canal | 7°42′15.732″S, 110°46′32.646″E |
| Pp | Java | Winongo River | 7°45′16.6104″S, 110°21′27.594″E |
| Pd, Pp, H | Lombok | Ancar River | 8°35′22.86″S, 116°4′37.10″E |
| Pd, Pp, H | Lombok | Babakan Rumak River | 8°38′27.11″S, 116°7′39.34″E |
| Pd, H | Lombok | Batujai Dam | 8°44′8.80″S, 116°15′26.65″E |
| Pd, Pp, H | Lombok | Enyet Sepaket River | 8°35′23.4″S 116°15′50.1″E |
| Pd, Pp | Lombok | Dodokan Gerung River | 8°41′27.3″S, 116°06′35.1″E |
| H | Lombok | Golong Narmada River | 8°35′35.4″S, 116°12′36″E |
| Pd, Pp, H | Lombok | Jangkok River | 8°34′23.58″S, 116°4′41.70″E |
| Pp, H | Lombok | Kermit River | 8°38′14.6″S, 116°25′24.2″E |
| Pd, H | Lombok | Loang Balok River | 8°36′06.9″S, 116°04′32.7″E |
| Pd, Pp, H | Lombok | Meninting River | 8°32′54.78″S, 116°6′39.51″E |
| Pd | Lombok | Pandan Duri Dam | 8°41′15.77″S, 116°26′18.29″E |
| Pd, H | Lombok | Pengga Dam | 8°45′30.07″S, 116°11′43.71″E |
| Pd | Lombok | Surabaya-Praya River | 8°42′47.25″S, 116°17′7.27″E |
| Pp | Sulawesi | Biromaru | 0°56′8.67″S 119°54′6.41″E |
| Pp | Sulawesi | Buaya Lake | 3°59′28.4″S 120°00′48.2″E |
| Pp | Sulawesi | Dolo, Biromaru | 0°53′0.95″S 119°51′7.47″E |

Since very limited attention has been focused on invasive fish species in general and the illegal sailfin catfish in particular by both general public and government in Indonesia (Muchlisin, 2012; Patoka *et al.*, 2018), we recommend presenting these findings to all stakeholders dealing with the sustainable exploitation and conservation of the rich biota in this region. Given that invasive species are able to survive extreme conditions, it is quite easy for the mentioned sailfin catfish of tropical origin to occupy and establish populations in water bodies with similar conditions as in Indonesia. Based on the climate matching maps, we suggest the further monitoring of those regions highlighted as suitable for sailfin catfish, to update our current knowledge about the occurrence and distribution of these species in Indonesia. Also, strong inspection of aquarium stores, ornamental fish farms, and fish importers is recommended because these species are illegal. In some localities, sailfin catfish were observed gulping atmospheric oxygen above the water level in polluted streams and this behaviour should be used for detection of the sailfin catfish in the wild without mandatory capture.

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