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Research Article

# Thermal tolerance for three ornamental tankbuster catfishes

Quenton M. Tuckett[1], Timothy J. Lyons[2], Jeffrey E. Hill[1]

1 *Tropical Aquaculture Laboratory, Program in Fisheries and Aquatic Sciences, School of Forest, Fisheries, and Geomatics Sciences, Institute of Food and Agricultural Sciences, University of Florida, Ruskin, FL 33570, USA*

2 *New Mexico BioPark Society, 903 10th St SW, Albuquerque, NM 87102, USA*

*Corresponding author: Quenton M. Tuckett (qtuckett@ufl.edu)*

## Abstract

Pet abandonment is an important introduction vector for freshwater aquarium fishes, as unwanted pets become too large for tank dimensions and are released into the environment. Concerns over pet abandonment may be particularly important for the U.S. state of Florida, which exhibits abundant access to freshwater habitats and a climate more favorable to tropical aquarium fishes than other continental U.S. states. Numerous studies have examined the factors affecting establishment for non-native species, including the importance of propagule pressure and climate suitability. For freshwater aquarium species, maximum body size can increase pet abandonment because they grow too large for the tank dimensions (i.e., "tankbusters"). Thus, large maximum body size may increase propagule pressure due to intentional release. In addition to being introduced in sufficient numbers, a match between the thermal tolerance of a species and the thermal habitat is necessary for establishment. Several large-bodied catfishes are found in the aquarium trade, including the goonch *Bagarius* spp., redtail catfish *Phractocephalus hemioliopterus*, and tiger sorubim *Pseudoplatystoma tigrinum*. Here, we experimentally determined the chronic lethal minimum temperature (CLmin) for the three catfishes. CLMin estimates for these three species were higher than many other ornamental species, highest for the redtail catfish (14.3 °C), lower for the tiger sorubim (11.0 °C), and lowest (9.9 °C) for the goonch. Given these lethal temperatures, the distribution of redtail catfish would be limited to South Florida while the tiger sorubim and goonch could live, provided other habitat characteristics are suitable, up to ~28°N Latitude in Florida.

**Key words:** Chronic lethal temperature, Florida, goonch, redtail catfish, tiger sorubim

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## Introduction

The trade in freshwater ornamental fishes operates across more than 125 countries, includes well over 1000 distinct, widely available species, and is dominated by species originating from freshwater environments (Evers et al. 2019). The large number of fish species in trade poses challenges in identifying potentially invasive species, which is of particular concern to natural resource managers. In response to

the trade diversity, invasion science research has focused on identifying the characteristics of species, habitats, and vectors that increase invasion success (Chan et al. 2019; Lawson and Hill 2022). Broadly important predictors of invasion success include propagule pressure (Lockwood et al. 2009), previous invasion history (Moyle and Marchetti 2006), and climatic similarity (Bomford et al. 2010), which are informed by species traits such as maximum body size and thermal tolerance (Schofield and Kline 2018; Lawson and Hill 2022).

Traits such as maximum body size can lead to pet abandonment when a species grows too large for the tank dimensions (i.e., tankbusters; > 305 mm TL; Holmberg et al. 2015). Pet abandonment is an important vector for ornamental fish outside areas of production but is generally difficult to detect (Magalhães et al. 2020). Large maximum body size should affect propagule pressure because many hobbyists will lack the care requirements of these species. Further, because "tankbusters" may be released at larger body sizes, survival and ecological impacts may be increased following release (Liang et al. 2020). In addition to sufficient propagule pressure and survival following release, climatic factors must also be suitable to successfully establish. Temperature is a key species trait influencing the distribution of fishes (Harrison and Whitfield 2006); therefore, experimentally determined thermal tolerance is an important predictor of non-native species establishment (Hayes and Barry 2008; Howeth et al. 2016; Schofield and Kline 2018). The ability of non-native freshwater fishes to survive low water temperatures, which are common to the temperate regions which dominate the U.S. (Tuckett et al. 2021), influences the risk of establishment and the ultimate geographic scope of the invasion (Schofield and Kline 2018).

Many freshwater siluriform catfishes reach large maximum body sizes and this group of species includes some of the largest freshwater fishes in the world (Hogan et al. 2004). For example, three catfish present in the ornamental fish trade, goonch *Bagarius* spp. Bleeker, 1854, redtail catfish *Phractocephalus hemioliopterus* (Bloch and Schneider 1801), and tiger sorubim *Pseudoplatystoma tigrinum* (Valenciennes 1840), reach large maximum body sizes, 230 cm (for *Bagarius* spp.), 135 cm, and 105 cm, respectively (Buitrago-Suárez and Burr 2007; Froese and Pauly 2022). The redtail catfish and the tiger sorubim are pimelodid catfishes native to large rivers and lakes in South America and are regularly traded within the U.S. and abroad (Borges et al. 2021). The goonch is a species complex of large-bodied sisorid catfishes native to the Indian subcontinent and Southeast Asia (Ng and Kottelat 2021). The tropical and subtropical distribution of these fishes is a possible match for some U.S. states, especially southern Florida. Here we experimentally determined the chronic lethal minimum temperature (CLmin) for the three catfish (Fig. 1). Chronic methodologies decrease temperature slowly in a stepwise process allowing for reacclimation at each lower temperature change. These data can ultimately be used to facilitate risk assessments for potential invasiveness of large-bodied catfishes and can be used to identify the potential distribution of these three species.

## Methods

Goonch, redtail catfish, and tiger sorubim were acquired from ornamental fish wholesalers in the Tampa Bay area. After transport to the University of Florida Tropical Aquaculture Laboratory, fish were acclimated at 25 °C on aerated well water for at least seven days prior to the experimental trials. Fish were acclimated to ensure feeding and to verify that they were free of disease. The three catfish species were fed thawed bloodworms (0.5 to 1 ml daily).

Because the three catfish reach large maximum body sizes, trials were run on juvenile fish. Mean body size was 126.5 g (SD = 26.2 g) and mean TL was 27.0 cm

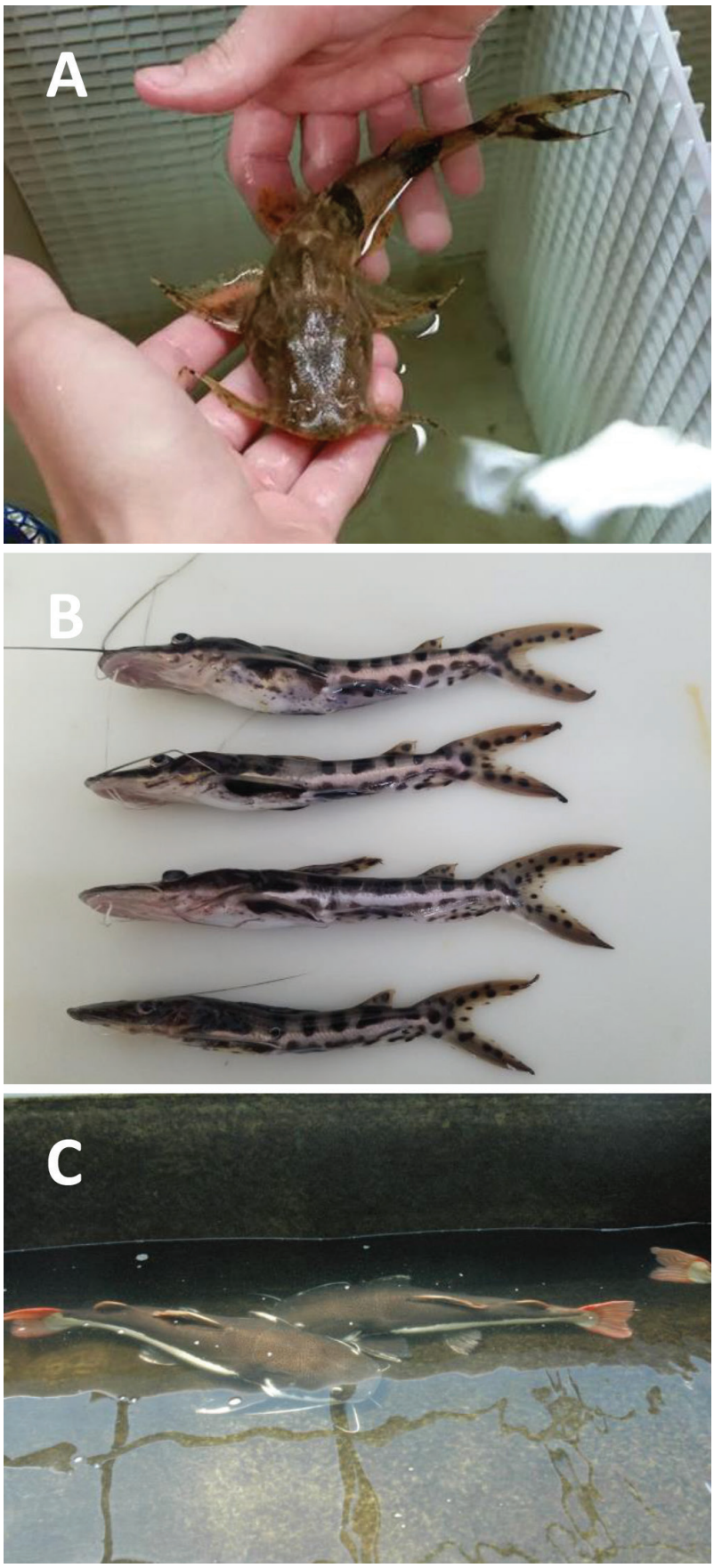


**Figure 1.** Images of goonch prior to CLMin trial (**A**), tiger sorubim following conclusion of the CLMin trial (**B**), and large-bodied redtail catfish (not the fish used in the trial; **C**). The tank partition is shown in image **A**. Photographs by the authors.

(SD = 1.8 cm) for goonch, 13.8 g (SD = 4.7 g) and 14.1 cm (SD = 1.6 cm) for tiger sorubim, and 13.3 g (SD = 3.2 g) and 11.1 cm (SD = 0.8 cm) for redtail catfish.

We determined the sensitivity of each species to cold water using chronic lethal minimum methodology (Beitinger et al. 2000). End points for all species included cessation of feeding, loss of equilibrium, and death. The experimental system for the CLmin trials consisted of eight 190-L tanks on a recirculating system with chillers and a 1,700-L reservoir with external sump, which gravity fed cold water into each of the eight tanks. A partition was placed in each of the eight tanks (see Fig. 1A for image), resulting in 16 experimental tanks. At least one control tank (experimental unit) was used for each of the catfishes.

Following capture and the acclimation period, fish of each species were transferred to experimental tanks (see Table 1 for sample size). After fish were added to the experimental system, water quality was monitored with a Hach diagnostic kit (Model FF-1A, Loveland, CO) throughout the experiment. Fish were fed once daily, and the uneaten portion was removed. Using the chronic lethal methodology, temperature in the experimental tanks was reduced by 1 °C/d following established protocols (Shafland and Pestrak 1982; Tuckett et al. 2016; Lyons et al. 2017). This methodology leads to stepwise reacclimation, which decreases CLmin, giving a conservative estimate of potential suitable habitat (Beitinger et al. 2000). The two control tanks were maintained at 25 °C with individual heaters over the course of each experiment.

**Table 1.** Endpoints for three large-bodied catfish species (Goonch, redtail catfish, and tiger sorubim). Endpoints included cessation of feeding (temperature at which fish ceased feeding), loss of equilibrium (LOE; no righting response), and death.

| Species | *n* | Parameter | Cessation of feeding (°C) | Loss of equilibrium (°C) | Death (°C) |
|---|---|---|---|---|---|
| Goonch | 6 | Mean | 16.9 | 10.8 | 9.9 |
| | | Min-Max | 15.1–17.1 | 10.5–11.2 | 9.3–11.4 |
| | | SD | 1.1 | 0.3 | 0.8 |
| Redtail catfish | 15 | Mean | 17.8 | 14.5 | 14.3 |
| | | Min-Max | 17.6–18.1 | 13.7–16.4 | 13.0–16.2 |
| | | SD | 0.2 | 0.7 | 0.7 |
| Tiger sorubim | 15 | Mean | 15.7 | 11.4 | 11.0 |
| | | Min-Max | 14.0–17.1 | 10.1–13.7 | 9.3–13.0 |
| | | SD | 1.4 | 1.2 | 1.2 |

After the trial began, tanks were monitored daily for activity and end points (cessation of feeding, LOE, and death). The temperature at cessation of feeding was noted when individual fish no longer fed. Loss of equilibrium was noted when fish no longer displayed a righting response. Finally, when fish appeared lifeless (i.e., lacked opercular activity), fish were prodded, and, if no movement was then detected, water temperature was recorded (YSI Model 30, Yellow Springs, OH) and dead fish were then weighed (± 0.1 g) and measured for total length (TL; ± 0.1 cm). Temperature at cessation of feeding, loss of equilibrium, and death were analyzed separately with analysis of covariance with independent variable species and size (TL) as a covariate.

## Results

No decrease in activity level was noted for the three species because they oriented around structure in the tank. Cessation of feeding differed among the three species (Tables 1, 2; Fig. 2) but occurred first for the redtail catfish (mean = 17.8 °C),

**Table 2.** Results from analysis of covariance (ANCOVA) comparing three endpoints for three large-bodied catfish species (Goonch, redtail catfish, and tiger sorubim) with independent variable species and length (TL) as a covariate. Endpoints included cessation of feeding (temperature at which fish ceased feeding), loss of equilibrium (LOE; no righting response), and death.

| End point | *n* | Species | | Length | | Species*length | |
|---|---|---|---|---|---|---|---|
| | | *F* | *p* | *F* | *p* | *F* | *p* |
| Cessation of feeding | 36 | 5.69 | 0.008 | 5.66 | 0.024 | 1.34 | 0.462 |
| Loss of equilibrium | 25 | 1.35 | 0.284 | 0.22 | 0.641 | 0.12 | 0.889 |
| Death | 36 | 19.16 | <0.001 | 2.09 | 0.159 | 1.90 | 0.168 |

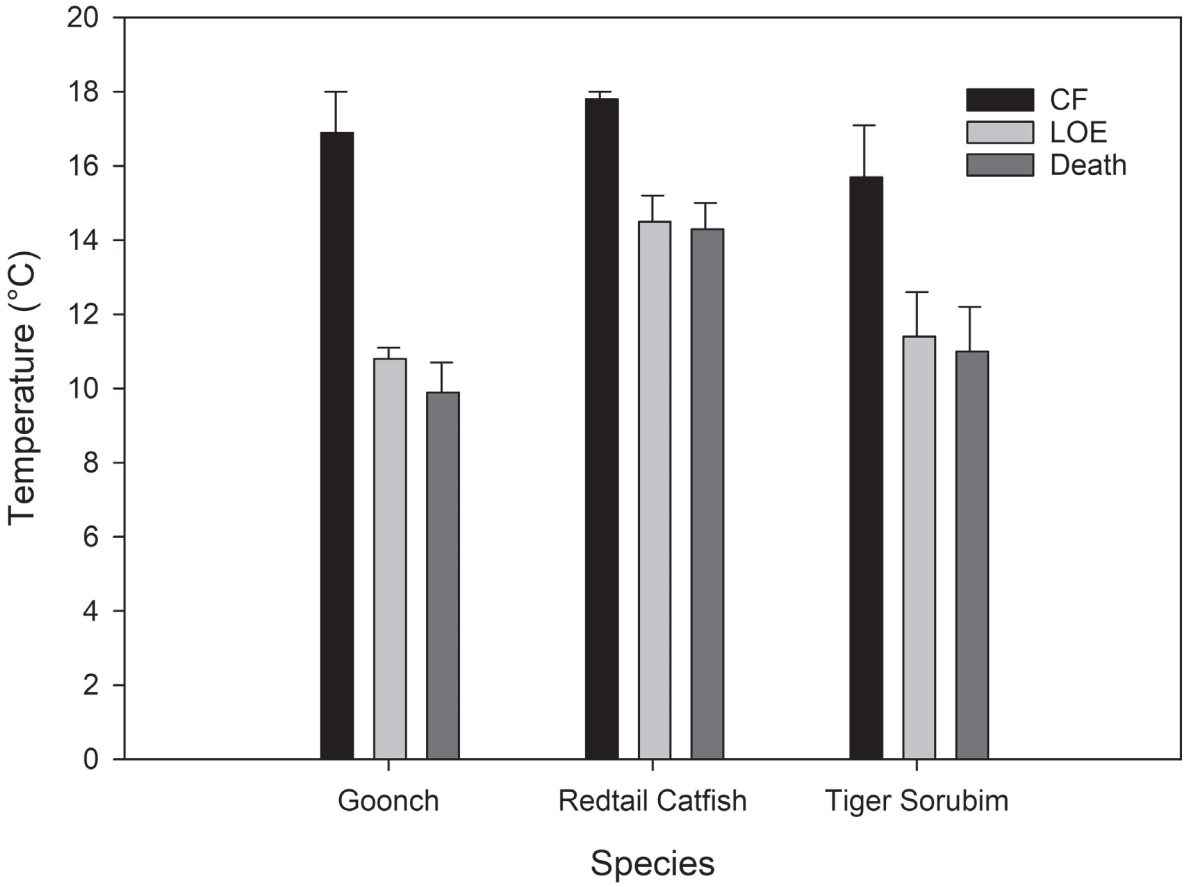


**Figure 2.** Endpoints for three species of large-bodied catfish. Endpoints included cessation of feeding (temperature at which fish ceased feeding), loss of equilibrium (LOE; no righting response), and death.

followed by the goonch (mean = 16.9 °C) and tiger sorubim (15.7 °C). The temperature at cessation of feeding decreased with increasing total length (Table 2); no interaction between species and temperature was noted. LOE was similar among the three species and was unrelated to total length (Table 2); however, the redtail catfish lost equilibrium earlier in the trial than the other two species (mean = 14.5 °C), followed by the tiger sorubim (mean = 11.4 °C) and goonch (mean = 10.8 °C). For two goonch, LOE occurred at the same temperature as death. CLmin for the redtail catfish was several degrees higher than the other two species (mean CLmin = 14.3 °C; Table 2). The remaining two species were 11.0 °C for the tiger sorubim and 9.9 °C for the goonch. CLmin was unrelated to total length and no interaction was evident (Table 2). For all species, no control fish were lost, and no signs of disease were noted during the trial.

## Discussion

Propagule pressure, the quantity and rate of introductions has been considered a null model for species invasions (Colautti et al. 2006). Deviations from these expectations, the expected positive relationship between the number of individuals released and invasion success, can be attributed to the abiotic and biotic habitat and characteristics of the species (Hill and Tuckett 2018; Lawson and Hill 2022). Thermal tolerance is one of the most important species characteristics affecting the establishment and spread of ornamental non-native fishes in the relatively cold waters of subtropical Florida (Shafland and Pestrak 1982; Schofield and Kline 2018). Based on CLmin, just under 10 °C for the goonch and 11.0 °C for the tiger sorubim and provided other habitat parameters are suitable for completing the life cycle (e.g., suitable habitat for reproduction), the goonch and to a lesser extent the tiger sorubim would have potential ranges extending far into peninsular Florida. The redtail catfish, by comparison, would be restricted to portions of South Florida. We discuss the characteristics and potential ranges for each of the three catfishes below, contrasting them with the distribution of known Florida invasives where CLMin is available. These range determinations are likely conservative as additional habitat features will limit the potential for establishment and the realized distribution.

### Goonch

The goonch is not established outside the native range and there is no documented evidence for introductions in the U.S. (USGS NAS 2022) or globally (Froese and Pauly 2022). This is likely due to its limited prevalence in the ornamental trade; this scarcity affected our ability to source fish for the CLMin trials. Further, we were unable to determine the species used in the trial due to ongoing taxonomic uncertainty. Examinations of online retail availability suggest both *B. bagarius* (Hamilton, 1822) and *B. yarrelli* (Sykes, 1839) are available; our specimens were likely one of these species, both of which reach large maximum body sizes. While the goonch is available, at least the aforementioned species, the availability is sporadic, the demand is likely low, and prices are high, which limit introductions. The ongoing taxonomic uncertainty can complicate risk assessments for *Bagarius* spp., which are widely distributed in South and Southeast Asia, particularly for *B. yarrelli*, which is present in drainage basins throughout the Indian subcontinent and southeast Asia (Roberts 1983). While these regions are largely tropical, the broad distribution of *Bagarius* spp. suggests species and population may experience differences in thermal regimes, affecting CLMin.

Goonch CLMin (9.9 °C) is similar to established non-native fish in Florida, especially the Walking Catfish (*Clarias batrachus* 9.8 °C) and Mayan Cichlid (*Cichlasoma urophthalmus* 10.3 °C) (Shafland and Pestrak 1982; Schofield et al. 2010). Most of the confirmed records for the Walking Catfish are located south of ~28°N Latitude in Florida, but scattered records are found further north (USGS NAS 2022). This distribution is similar to the Mayan Cichlid (USGS NAS 2022), with most records occurring a little further south along both the east and west coasts; however, more recently, the Mayan Cichlid has been found further north along the coast of Tampa Bay (Lawson et al. 2017). Thus, if established, and based on CLmin alone, we might expect ranges similar to the two established fishes. Beyond temperature, the goonch is found in major rivers and tributaries with strong water velocity (Hogan et al. 2004), with fish migrating upstream during the rainy season when water velocity is at its peak; rivers with strong water velocity are largely absent from much of the Florida peninsula.

## Redtail catfish

The redtail catfish exhibits distinctive color patterns, dark dorsal, white ventral, and orange to red fins, making them somewhat popular in the ornamental trade. The redtail catfish has been reported from several U.S. states, despite limited or non-existent aquaculture (Bernstein and Olson 2001; United State Geological Survey (2022), including Alabama, Florida, Indiana, Iowa, Massachusetts, Minnesota, Missouri, Nebraska, North Carolina, Tennessee, and Texas. In Florida, which exhibits the most observations, there are numerous angler reports, but no evidence of reproduction. This suggests the vector is likely hobbyist release. There are also international introductions, presumed to be sportfish enhancement, into Singapore, Malaysia, and Thailand (Froese and Pauly 2022); these introductions are not known to have produced established reproducing populations.

Consistent with their tropical distribution in Amazon and Orinoco River basins, the redtail catfish is relatively cold sensitive compared to other established non-native fishes in Florida (Shafland and Pestrack 1982; Tuckett et al. 2016). Thus, outside of thermal refuges, which are known to affect the distribution of non-native fishes (Tuckett et al. 2021), and based on CLMin alone, the range of the redtail catfish would be restricted to parts of South Florida, primarily along the southeast coast of Florida where the climate is suitably tropical (Lawson et al. 2015). Additional suitable habitat might exist along the Gulf of Mexico coast near Naples, Florida. This range would overlap, perhaps extending a little further north, with that of the Butterfly Peacock Bass (*Cichla ocellaris*), which exhibits a CLmin of 15.6 °C (Swingle 1967; Lawson et al. 2015). Ultimately, however, little is known about the reproduction of redtail catfish in the wild beyond their long river migrations to spawn (Goulding 1980); a lack of spawning habitat might limit the establishment of this species.

## Tiger sorubim

Like the redtail catfish, the tiger sorubim has a distinctive physical appearance, likely increasing its presence in the ornamental trade. The tiger sorubim exhibits an elongated and flattened head, long barbels, and a prominent pattern of spots and vermiculations on a dark dorsal and light ventral body. The tiger sorubim has no documented introductions within the U.S.; however, the congeneric *Pseudoplatystoma fasciatum* was reported from Illinois (2002) and *Pseudoplatystoma purcifer* in Louisiana (2017) and Texas (2016) (USGS NAS 2022). A possible intergeneric *Phractocephalus hemioliopterus* × *Pseudoplatystoma* sp. Hybrid was captured in Missouri in 2014 (USGS NAS 2022). The status of each of these introductions is considered failed.

In its native range, the tiger sorubim is restricted to the Amazon River. The distribution from Buitrago-Suárez and Burr (2007) suggests this species is predominantly found within tropical regions of the main river channel and proximal tributaries and backwaters. Like the goonch, the sorubim catfishes of South America have undergone recent taxonomic revisions (Buitrago-Suárez and Burr 2007; García-Dávila et al. 2013; Nirchio et al. 2013). Based on the similar CLMin to goonch, the Florida range would, as described above, be restricted to locations in Florida south of 28°N Latitude.

## Conclusion

The range predictions discussed here are based entirely on lethal thermal tolerance. CLMin is influenced by numerous other factors, including body size, population of origin, and sex (Tuckett et al. 2016). Beyond CLMin, which is

often several degrees lower than cessation of feeding, which occurred between 15.7 and 17.8 °C for the three catfishes, suggesting seasonal stressful conditions would occur throughout much of Florida. In addition to a match between thermal tolerance and the thermal environment, there must also be a suitable match between other environmental features and the traits of species. Ultimately, our range predictions, if these species were to become established, would likely represent a maximum size.

As a result of its geographic scope and the diversity of species in trade, pet abandonment has become a well-recognized vector for non-native species introductions globally (Chan et al. 2019). This is also apparent in Florida, where more exotic species have been reported than any other state in the U.S. (United State Geological Survey (2022), and where the number of established non-native fishes continues to grow each year (Schofield and Loftus 2015). Given the climatic similarity between Peninsular Florida and tropical import origins, a historically high proportion of terrestrial and aquatic vertebrate introductions have resulted in successful establishment (Fujisaki et al. 2010; Schofield and Loftus 2015; Chan et al. 2019). As a result, Florida must be proactive in determining critical data gaps such as thermal tolerance and the potential for "tankbuster" release for non-native species.

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## Author contribution

QMT, TJL, and JEH research conceptualization; QMT, TJL, and JEH sample design and methodology; QMT, TJL, and JEH investigation and data collection; QMT, TJL, and JEH data analysis and interpretation; JEH ethics approval; QMT and JEH funding provision; QMT, TJL, and JEH writing - original draft; QMT, TJL, and JEH writing - review & editing.

## Ethics and permits

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