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Original Article

Behavioral repertoire of *Arapaima gigas* (Schinz, 1822) reared in captivity and its implication for welfare protocols

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Abstract

The well-being of farmed fish has gained considerable attention in the last few decades, and finding suitable indicators of fish welfare is particularly challenging assumed the diversity of species, each with unique biological needs and requirements. Understanding the behavioral patterns of farmed fish species is crucial in developing behavior-based measures to maintain their welfare and production. However, there is limited scientific documentation on the behavioral repertoire of *Arapaima gigas*, a commercially valuable and widely farmed species in South America. We provide an ethogram of *A. gigas* when reared in captivity within a recirculating aquaculture system (RAS) indoors. Observations were conducted on a group of adult individuals (one male, two females) kept at the Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin, Germany. The ethogram describes five main behavioral categories: locomotion, feeding, social interactions, agonistic interactions, and breathing. Notably, *Arapaima* displayed a strong preference for resting motionless, often near a gravel bed area provided inside the rearing tank. Agonistic interactions were rare and mostly initiated solely by the male during feeding sessions. During feeding, pellet food was often picked from the ground, while whole fish feed (dead *Tilapia*) was mostly swallowed immediately from the surface. The male consistently occupied the provided gravel area as its territory, spending most of its time there. With this ethogram, we aim to contribute to the limited behavioral knowledge about *A. gigas*, especially when in captivity. Our findings offer valuable insights into species-specific welfare evaluations and enhancement measures with potential applications in healthy aquaculture practices.

Keywords: giant arapaima, pirarucu, paiche, animal welfare, aquaculture, behavior.

Introduction

Effective animal welfare requires measurable biological indicators to extract information about individual welfare states (Saraiva *et al.,* 2022). These welfare indicators may rely on observations made (i) on the animals themselves (animal-based), (ii) on the aquatic environment they are reared in (resource-based), or (iii) on the routines and protocols performed on-site (management-based). These three types of data sources provide complementary information about the welfare state of the farmed animals. In particular, difficulties arise in fish due to the multitude of species held in captivity, each with their own specific needs for ensuring their welfare (Macaulay *et al.,* 2020).

Behavior is often the initial and immediate expression of an individual's well-being and, therefore, an essential component of animal-based indicators that further include morphological and physiological components (Saraiva *et al.,* 2022). However, the effective integration of behavioral observations as indicators of stress, health, and well-being requires a comprehensive understanding of the focus species' behavioral repertoire. Knowledge gaps are common and standardized descriptions that can be transferred among farms and facilities, allowing unbiased observations of important behaviors, are scarce.

In the following research, we present a detailed ethological description of the behavior of the giant Arapaima, paiche or pirarucú (*Arapaima gigas*) which may serve as a starting point to facilitate the development of effective behavior-based welfare indicators for this tropical freshwater fish species.

Arapaima is considered the largest scaled freshwater fish species, reaching lengths of up to three meters and weights of around 200 kg (Arantes *et al.,* 2010; Araripe *et al.,* 2013; Malabarba & Malabarba, 2019). Due to its large size, fast growth rate, robustness, surfacing during air-breathing, and high meat quality (Torati *et al.,* 2016; Ferreira Lima, 2020), *A. gigas* is one of the most overexploited fish species in the Amazon River basin (Castello *et al.,* 2008; Stokes *et al.,* 2021; Ohs *et al.,* 2021), listed on the IUCN Red List of Threatened Species. So far, Arapaima's cultivation has been restricted to earthen ponds where reproduction happens spontaneously but not controlled, usually when waters start to rise. Besides farming, Arapaima meat and adult specimens are offered from illegal fisheries, increasing the pressure on natural stocks and market price too. Furthermore, Arapaima adults and juveniles are not only sought for aquaculture purposes but also for their ornamental value, which increases the pressure on the trade additionally. Introductions of this species for ornamental, recreational and aquaculture projects have been reported in China, Cuba, Mexico, the Philippines, Singapore, Thailand and the USA (Lawson *et al.,* 2015; Torati, 2017; Watson *et al.,* 2021).

Despite early studies on Arapaima's air-breathing characteristics, not much has been scientifically documented regarding additional behavioral patterns. To this end, Lüling (1964) presented a detailed morphological and ecological description of *Arapaima* adults and juveniles from the Peruvian Amazon. Greenwood and Liem (1984) described the breathing mechanics of *A. gigas* juveniles using high-speed X-ray and light cinematography. Yet further publications focusing on behavioral patterns are scarce until Olsen (2014), who tested synchrony for Arapaima juveniles during the day and night, hypothesizing that juveniles in shoals perform synchronized collective breathing bouts as an anti-predation defense mechanism. The breathing bouts and frequencies have further been proposed to help estimate individual abundancies in their natural habitats (Stokes et al., 2021). It is thus apparent that knowledge on Arapaima behavior in captivity is restricted to local breeders and farmers as well as zoological gardens and hobbyists and we hereby try to establish the first behavioral description of captive held Arapaima in an indoor RAS facility aiming to outline possible behavioral-based indicators of well-being for this species.

Material and Methods

Study organisms and maintenance

Our observational study took place between September 2021 and March 2022. We used adult *A. gigas* kept at the animal care facilities of the Leibniz Institute of Freshwater Ecology and Inland Fisheries Berlin (IGB) that were obtained from local breeders in Iquitos (Peru) in 2009. Observations took place in a large indoor tank (8m x 3.4m x 1.2m; water level ~ 1m) that was covered with mesh to prevent fish from jumping out. To enrich the tank structure, gravel (0.5 cm to 2 cm stone size) was added on one side of the tank (25 cm in height, 2.5 m in length, 2.0 tons in total) over a geomembrane to simulate the substrate found in their natural habitat. Once the water (18 m^3) was clear and gravel was in place, three individuals: two females (45 kg and 47.4 kg) and one male (39.4 kg, Fig. 1) were introduced and no food was offered for one week. We determined sexes using molecular methods developed by our department and described in Adolfi *et al.,* 2021 (see also López-Landavery *et al.,* 2022 for a similar approach). Animals could be identified during the observations by characteristic structures on their heads and fins, with the male being more reddish at the caudal body end.

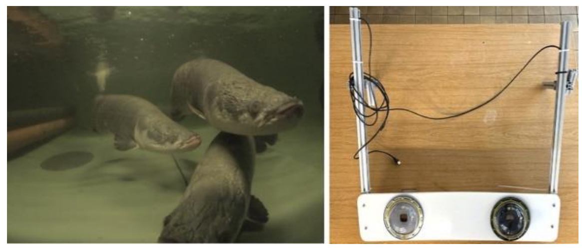

Figure 1. Adult *Arapaima gigas* in their observation tank (left) and the underwater camera setup used for behavioral recordings (right). On the left, a snapshot of a GoPro video showing the gravel area (on the left, behind a barrier to prevent the spread of gravel stones throughout the tank) that was added to enrich the holding environment during the observation period. The upper individual is the male individual. On the right, a picture of the stereo GoPro setup used for the underwater recordings. Note that GoPros were powered externally via cable to prevent battery overheating.

In order to simulate natural rainy season conditions and thus may induce reproductions (Escudero & De la Vega, 2024) we added deionized water and heated up the holding tank. Water temperature was initially at 23.9°C and gradually increased to 30°C over eighteen weeks. Physicochemical parameters were evaluated at the beginning and end of each week. Conductivity and pH were lowered from 1538 µS/cm to 440 µS/cm and 8.03 pH to 7.5 pH (Chu-Koo *et al.,* 2017; Halverson, 2013) during the observation period.

After the first week, fish were fed five days a week between 11:00 h and 12:00 h for twenty-

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two weeks, two days with dry food (1 kg per day) and three days with frozen tilapia (*Oreochromis niloticus*) (1 kg per day, thawed before fed). Feeding sessions lasted around 10 to 15 minutes, counted from the moment the first fish started interacting with the food until no food was observed in the tank.

To observe behavioral patterns a GoPro camera set-up (consisting of two Hero 8 cameras distanced 15 cm from each other, placed on an acrylic surface with an aluminum frame to hold on the edge of the tank, see Figure 1) was installed on one of the tank walls above the gravel area at 25 cm height from the bottom of the tank for a better coverage of the tank area. The camera set-up focused on the center of the water column. The GoPro set-up was left in place for the fish to familiarize themselves with it and was used to record for two continuous hours starting just before feeding at 30 FPS, with a linear lens and 4k of resolution in cinematic mode.

Behavioral observations

Since our objective was to document the spontaneous behavior displayed by the fish as a group and individually, preliminary observations took place to become familiar with *A. gigas* movements and rhythms. For this preliminary process, the first three weeks of recording were selected. The decision of which subjects to watch (sampling rule) was made depending on whether it was possible to follow one specific individual's movements throughout the recording. Hence, *ad libitum* sampling and behavior sampling were the chosen strategies to follow. Concerning the methodology to record the behaviors (recording rule), all recordings were sampled continuously meaning that the observer recorded each behavior with the time of occurrence (Bateson and Martin, 2021). We analyzed approximately 3000 minutes of videos for the provided ethogram.

Behaviors described in the ethogram were classified as events or states, where events were defined as behaviors of short duration with frequent occurrence that could be counted; while states were defined as behaviors of long duration (Bateson and Martin, 2021). Behaviors were recorded from observations of the three individuals at the same time. Whenever one of them left the focal frame, the label "Out of sight" was recorded until the same individual reappeared in the picture. Behaviors were first scored by one author and reviewed by collaborators to confirm that descriptions were accurately and objectively made. All observations comply with internal animal welfare regulations of the Leibniz-Institute for Freshwater Ecology and Inland Fisheries (IGB) and were approved by IGB's animal welfare committee (Tierschutzkommission). No further permits were needed to conduct the research described herein.

Results

We categorized observed behaviors into five main categories: (1) locomotion behavior, (2) feeding behavior, (3) social interactions, (4) agonistic interactions, and (5) breathing. During the entire observation period, courtship behavior such as vertical swimming with the head pointed downwards was not observed. Our main findings are outlined below and more detailed behavioral descriptions can be found in Table 1 as well as in Figure 2.

Table 1. Behavioral catalogue of *Arapaima gigas* recorded during feeding sessions between 11:00 h and 12:00 h in an indoor RAS system. Given are main behavioral categories, behavioral units and their descriptions.

Behavioral category	Behavioral unit	Description
(4) Agonistic interactions	Bite attempt (ba)	Two fish swim closely together. One of the fish approaches with an open mouth and attempts a bite (most often no direct contact visible), the recipient fish swims away. Bite attempts usually target the ventral area of the head, ventral fin area, caudal peduncle or caudal fin.
	Push on flank (pf)	A fish approaches another fish from behind and pushes its head against the other's flank with or without making contact, while both swim slowly. The movements are moderately faster than the usual swimming speed. This behavior was observed in a gravel area, with a male fish approaching a female.
	Ventral snout touch (vt)	One individual approaches another fish at a slow swimming speed and directs its snout towards the ventral fin area to touch it. Observed on female towards male.
(1) Locomotion	Resting (R)	Individual lays motionless on the bottom of the tank, in the gravel area or at the bare plastic bottom. Fins are folded and close to the body.
	Change direction (cd)	While swimming, fish changes direction to left or right, moving sometimes in the complete opposite direction.
	Circling (c)	Individual swims slowly in a circular way, no interactions with other fish.
	Normal swimming (ns)	Fish swims with a constant speed spreading pectoral fins and rhythmic undulations of the caudal fin. Speed on average is very slow.
	Open mouth underwater (om)	Fish opens the mouth while swimming calmly, at the same time operculum opens without releasing air bubbles, behavior happens without surfacing and without the presence of food and it is not directed towards another fish. Observed mostly on females.
	Dashing on side (ds)	While displaying normal swimming, fish sprints with a vigorous caudal peduncle move turning to one side almost 90°. Left or right lateral side of the body touching the bottom of the tank. Behavior observed mostly on the gravel area of the tank.
(5) Breathing	Calm breathing (cb)	Fish approaches the surface and breathes air with gentle but vigorous movement of caudal fin, all 4 steps of breathing are well visible but mouth is not opened widely.
	Fast breathing (fb)	Fish approaches the surface and breathes air open-mouthed with an immediate rapid movement of caudal fin, and swims fast and immediately back towards the bottom. This fast movement of the caudal fin and the surfacing produces an audible sound. This behavior happens without interaction with other fish.
(2) Feeding	Feeding on the bottom (ft)	While swimming in the water column, fish turns sideways on an angle of at least 30° either right or left and approaches from an upper position at the same swimming speed to get food from the bottom of the tank.
	Feeding from surface (fs)	Fish approaches the food floating in the water surface or sinking in the water column, sucking the food item into the mouth, swallowing, and chewing it while slowly swimming away. At the surface, the quick opening of the mouth is well hearable.
	Spitting out (so)	While swimming normally, fish brings swallowed food back into the mouth and expels it through mouth and opercular openings, other fish detect the food in the water and eat it. Behavior observed in females.
(3) Social interactions	Parallel swimming (pw)	Two (or three) fish swim in the same direction in parallel positions towards the same area for a short amount of time until they all gather in random positions or change directions independently.
	In-line swimming (is)	One fish (or two) follow the one in close frontal proximity swimming in the same direction forming a line (one after the other) towards the same area for a short amount of time until they all gather in random positions or change directions independently.
	Avoidance reaction (ar)	Female reacts to male fish breathing bout by swimming rapidly away from him.

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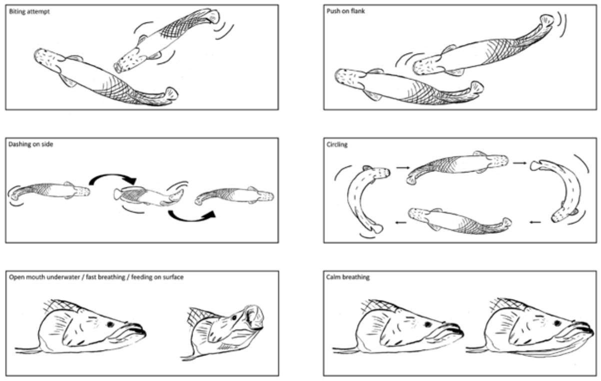

Figure 2. Selected behaviors as schematic drawings. Please see detailed descriptions of these behaviors in table 1.

First, we noticed that the male occupied the gravel area as his territory and spent the vast majority of his time there. Whenever one or both females entered that area, the male escorted them closely but without overt aggressive interactions. Although Arapaima often swam calmly through the tank by undulating caudal fin movements, they spent a considerable amount of time resting motionless on the tank bottom. This was observed most often by the male, who rested predominantly in the gravel area, while females showed resting behaviors less often than the male, mostly in other areas of the tank. All fish used the gravel area to perform a 'dashing on a side' behavior by accelerating to turn sideward and touching the gravel with the flanks rapidly.

When food was provided, fish came close to the feeding side of the tank, waiting below the surface before often approaching food items immediately when they hit the water surface (surface feeding). Small pellet food was picked from the tank bottom and fish bent laterally for this (bottom feeding). Occasionally fish gulped up some food items and spitted them out.

The social (non-agonistic) interactions involved mostly parallel or in-line swimming and were observed mainly by two individuals at the same time and rarely by the three of them. However, all three fish showed the tendency to follow each other as a loose group.

Behaviors that involved direct contact or contact attempts were categorized as agonistic behaviors. These were the most infrequent behaviors, including bite attempts; push on flanks, and ventral snout touches. Often the male initiated the behaviors, mostly during the feeding period.

As described in detail by previous studies, we also observed two distinct breathing behaviors: calm, almost soundless breath-taking and fast breaths that were loud due to the sudden air intake and rapid movement towards and away from the water surface.

In addition to our recordings, *A. gigas* is prone to jumping, which has been observed by caretakers at the institute; however, no jumps were observed in the set of recordings used to develop the current catalogue.

Discussion

Although the behavioral research in finfish aquaculture is extensive (Bardera *et al.,* 2018), limited effort has been dedicated to Amazon freshwater species like *A. gigas*, despite its high commercial importance. The current study provides the first ethogram for *A. gigas* kept in an indoor aquaculture facility. Our observations revealed (1) a strong preference of this species to rest motionless on the ground especially when gravel is provided, (2) feeding from the bottom when pellet food is given, (3) low levels of agonistic interactions even under low density and (4) a strong tendency of the male to occupy certain areas as territories (the gravel bank in our case).

The main objective of the gravel area covering roughly one third of the tank bottom was to provide a solid substrate for nest building activities in case a breeding couple would have been formed. However, after twenty-two weeks, the recordings did not show any apparent pair formation. Nevertheless, we found the male to occupy the gravel area as a territory since it spent most of its time there, often resting motionless on the ground, a behavior performed less often by females and in other parts of the tank. It remains open whether females would rest more if more gravel area would have been provided or whether the resting behavior is part of the territory defense behavior of the males.

All individuals performed the dashing on a side behavior, mainly in the gravel area. Similar behaviors are common in some fish species that prefer strong water currents to display variable swimming velocities, such as brown trout (*Salmo trutta*) (Peake and McKinley, 1998; Cano-Barbacil *et al.,* 2020); however, *A. gigas* is a species known for its preference for lentic and calm water bodies. Therefore, it is interesting to observe the dashing episodes even without a strong water current in the tank.

We observed a low number of clearly agonistic interactions. Although no actual bites were seen, the observed bite attempts suggest they are likely to happen. Other agonistic behaviors have been mentioned before for *A. gigas* as pre-copulatory behavior involving chases and fights associated with territorialism, mating competition and possibly subordination in earthen ponds (Franco Rojas, 2005; Torari, 2017), yet they were not spotted in the recording period for the current study. On the other hand, not every agonistic behavior should be understood as a pre-copulatory sign, since aggressions towards other individuals are common traits and are usually displayed as a way to acquire or control resources like food (Damsgård and Huntingford, 2012).

While feeding at the bottom mainly occurred when dry feed was offered, feeding from the surface occurred in the presence of dead tilapia. In most cases, fish were waiting to be fed in the feeding area at the scheduled time, revealing high motivation to be fed and an ability for spatial learning. When frozen tilapia was offered, the frequency of aggression among the three individuals increased, and the male was most eager to fight for food.

The ethogram presented in this study was generated by observing sexually mature individuals at low densities in a recirculating aquaculture system (RAS), reared in captivity, during the daytime and when food was provided. This means that this ethogram is specific and valid for fish reared under the same or similar circumstances and may not accurately reflect the behavior of another set of fishes from the same species reared under different conditions (Bateson and Martin, 2021). However, presenting the first catalogue of behavioral patterns for *A. gigas* is the initial step towards a better and holistic behavioral understanding that can be applied to aquaculture and conservation management. For example, it allows the formulation of species-specific health and well-being control and management measures like score sheets for daily health status evaluation and enrichment actions aiming to increase the animals' well-being. This approach has been adopted over the years for many other commercially important aquaculture species such as Atlantic cod (*Gadus morhua*) (Meager *et al.,* 2017; Fernö and Huse, 1983), arctic char (*Salvelinus alpinus*), Atlantic salmon (*Salmo salar*), and brown trout (*Salmo trutta*) (Bolgan *et al.,* 2016; Bolgan *et al.,* 2015).

Often, a daily visual check-up (most often during feeding times) is the obligatory interaction between the animal and the caretakers and allows the use of animal-based welfare indicators. Although there are difficulties in establishing the "normal behavioral repertoire" of a species, we can nevertheless attempt to identify certain behaviors that are species-specific and displayed in specific health and well-being situations. For Arapaima, our observations support the assumption that fish are doing well and are healthy when they (a) are lying on the ground motionless, (b) perform side rubbing/dashing on the tank bottom, (c) spit out food items occasionally, (d) breathe both fast and calmly, (e) pick up food from the bottom after a while, (f) open their mouths under water and (g) touch each other with their heads. Deviations from these patterns, such as relatively fast and steady swimming without resting periods, only fast breathing, and injuries due to wrong bottom material where fish rub, may then well fit into care sheets for daily check-ups in scientific and commercial facilities, enabling caretakers to rapidly detect and respond to changes in well-being and health.

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Conflict of interests

The authors declare no conflict of interest.

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