Aquaculture Research

Aquaculture Research, 2011, **42**, 815–822 doi: 10.1111/j.1365-2109.2011.02886.x

Reproductive success and fry production of the paiche or pirarucu, *Arapaima gigas* (Schinz), in the region of Iquitos, Perú

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Abstract

Arapaima gigas (paiche) is the largest scaled fish species living in the Amazon basin. Its biology is both fascinating and misunderstood. In a context of overfishing, hence reduced natural populations, aquaculture of a fish with such interesting characteristics (large size, high growth rate, no intramuscular spines) is an important issue. The development of farming production would also reduce the fishing pressure on natural populations and allow restocking programmes in certain areas. To determine what factors may influence the reproductive success in captivity, data from breeding reports for 2007–2010 were collected among fish farmers in the region of Iquitos. In parallel, we carried out physicochemical measurements in different ponds where these paiches breed, and conducted personal interviews about the general fish management conditions. The results show that reproduction occurs throughout the year but with a higher intensity during the rainy season. It also highlights farms that have performed much better than others, but no single factor except feeding level has been clearly associated with reproductive success. The environmental control of reproduction in paiche, therefore, remains partly mysterious. To deepen this study, we recommend the systematic sexing of breeders, extending reproductive behavioural studies, and examining the limnological factors involved in fry mortality.

Keywords: arapaima, pirarucu, paiche, reproduction, peru, fish culture

Introduction

Arapaima gigas (Schinz) is the largest scaled fish species living in the Amazon basin (Chu-Koo & Alcántara, 2009). It is an emblematic species of the Amazonian fish fauna, also known as the Paiche in Peru and Pirarucu in Brazil. This species is very attractive for aquaculture in the Amazon region, owing to its many advantages. *Arapaima gigas* has the best growth rate among Amazonian cultivated fish species, of 10–15 kg per year (Bard & Imbiriba, 1986; Pereira Filho & Roubach, 2005; Nuñez, 2009; Rebaza, Rebaza & Deza 2010), and its filet, which is very popular, does not have intramuscular spines. It also accepts low water dissolved oxygen levels, due to its obligatory aerial breathing. Finally, it has a carnivorous diet but is still flexible because it can accommodate consumption of dead fish or fish feed pellets. However, natural populations have been subjected to excessive fishing in the past decades for human consumption and ornamental fish trading (Chu-Koo & Tello, 2010), and already for more than 15 years, *A. gigas* has become a very uncommon species in the Amazon, except in some natural reserves (Pacaya Samiria in Peru or Mamirauá in Brazil). The Paiche is now in the CITES II list, which means that its trade and use are strictly controlled. Scarce available information concerns mainly the reproductive biology in the wild (Guerra, 1980; Saavedra Rojas, Quintero Pinto & Landines Parra 2005); however, it is in the interest of fish farmers to develop a controlled production of this species (Pereira Filho & Roubach, 2005; Nuñez, 2009) and one of the collateral expected effects of Paiche domestication is a decreased fishing pressure on wild populations. Nevertheless, many attempts have been made in recent decades to develop its production in captivity (Bard & Imbiriba, 1986; Imbiriba, 1991; Alcantara & Guerra, 1992; Guerra, Alcántara, Padilla, Rebaza, Tello, Ismiño, Rebaza, Deza, Ascon, Iberico, Montreuil & Limachi 2002; Pereira Filho & Roubach, 2005; Saavedra Rojas, Quintero Pinto, Lopez Hernandez & Pezzato 2005), but this task is made difficult by the dispersed knowledge on *A. gigas* biology in captivity, especially in crucial aspects like reproduction and feeding.

Paiche domestication faces the difficulty of gender determination, which is virtually impossible from external characteristics except during the reproductive period; otherwise, sex has to be determined in blood or plasma samples by biochemical methods using vitellogenin or sex steroid ratios (Chu-koo, Dugué, Alván Aguilar, Casanova Daza, Alcántara Bocanegra, Chávez Veintemilla, Duponchelle, Renno, Tello & Nuñez 2009). Moreover, the ovary is composed only by a single naked lobe or gymnovarium (Godinho, Santos, Formagio & Guimaraes-cruz 2005; Saavedra Rojas, Quintero Pinto & Landines Parra 2005; Núñez & Duponchelle, 2009) that makes the practice of canulation to determine oocyte development, induction of oocyte maturation and artificial fertilization almost impossible. As the production of fingerlings actually relies only on spontaneous reproductions in ponds, the knowledge of the optimal requirements for reproductive success is a prerequisite to substantially increase the fingerling offer in this region. Nevertheless, a noticeable development of *A. gigas* production is expected as most of the actual fingerling production is destined for aquaculture instead of ornamental fish trade as before (Chu-Koo & Tello, 2010). This study aims at analysing the reproductive data collected from *A. gigas* farmers in the region of Iquitos between 2007 and 2010. The results reported here represent the first attempt to provide answers on the magnitude of a sustained production level of fingerlings with the current knowledge and management conditions. It also evaluates the variations of some physicochemical and environmental factors that could promote or inhibit *A. gigas* reproduction in controlled environments.

Material and methods

Fish origin

Between 2000 and 2007, a programme to assist fish farmers in the region of Iquitos enabled the Instituto de Investigaciones de la Amazonía Peruna (IIAP) to provide six paiche breeders to selected local fish farmers. *Arapaima* breeders had been bred previously in ponds for 3 years in the IIAP's facilities of Quistococha.

Fish reproduction supervising, mandated by law, started in 2007 and fish farmers had to report to local authorities all events (births, fry harvest, etc.) that occurred in their farms, thus facilitating data collection. Some farms already owned paiches before the assistance programme; they did not originate from IIAP's stock but contributed to some reproductive events. *Arapaima* breeder weights varied approximately from 60 to 100 kg.

Fish rearing and feeding

The paiches are fed live fish (forage fish), dead fish (trash fish from local market) and sometimes downgraded chicken or chicks, fish or chicken viscera, fish feed pellets and even fruits, although fish-based food is predominant in every farm. The amount of food per capita (calculated as kg food paiche biomass $^{-1}$) varied greatly among farms, and most farmers could not precisely quantify how much food they had distributed to fish daily, monthly or even yearly. For this reason, we had to split the farms in three feeding levels: 1, small quantity (the forage fish are distributed about once a month); 2, average quantity (the fish are fed about once a week) and 3, large quantity (the fish are fed daily). In the first level, the food is essentially forage fish consumed progressively by paiches. In the other two levels, the food is mainly composed of trash fish supplemented, or not, with the other cited foodstuffs.

Physicochemical parameters

The physicochemical characteristics of pond waters were measured within a weekly period for all farms during the rainy season (February–March), using the Lamotte AQ-2 kit (Drop Count Titration, Chestertown, MD, USA). The following parameters were considered:

carbon dioxide (CO_2): absent if values were < 1.25 mg mL^{-1} corresponding to the detection limit, present if values were > 1.25 mg mL^{-1};
nitrites (NO^{2-}): absent if values were < 0.05 mg mL^{-1} corresponding to the detection limit; present if values were > 0.05 mg mL^{-1};
ammonia (NH^{4+}): absent if values were < 0.02 mg mL^{-1} corresponding to the detection limit; present if values were > 0.02 mg mL;
pH and temperature were measured using a YSI® digital meter (Yellow Springs Instrument Company, Yellow Springs, OH, USA) at 15 cm from the surface;
hardness (mg L^{-1} of $CaCO_3$) levels < 60 mg mL^{-1} are considered to be low;
transparency was determined by the Secchi disc method.

Hydromorphological parameters

The environmental parameters susceptible to play a role in the reproductive success of the paiche have been recorded in all farms. Six environmental parameters have been studied: pond area; pond maximum depth; presence of vegetation on pond water surface; shape of the shoreline (slow or steep slope); soil type (clay, sandy clay or sandy-muddy) and water (flow through or stagnant water).

Field data collection and analysis

We went to different fish farms, and there we requested to speak to the people who tend the paiches. Then, we explained the reason for our presence, and requested permission to make measurements of their pond water quality. During the interviews, we enquired about the total number of paiches and the food types and quantities distributed. During the visit, we also evaluated the total pond area, soil type and water surface vegetation.

Data were analysed with the free statistical software R, version 2.6.2 and Statgraphics Plus (StatPoint Technologies, Washington, DC, USA).

Results

Pond characteristics

The visited farms are located along the road between Iquitos and Nauta (Fig. 1). Farms are generally composed of a few ponds of different sizes and shapes, including small water bodies created in the lower parts of small water streams that drain the abundant rainfall in the area. Most of the farms have running water almost all year round. A few have limited water flow or even depend exclusively on rainfalls. The maximum depth is generally comprised between 1.5 and 4 m (Table 1) with variable floating vegetation cover, and with shorelines generally covered by grass or other small plants, which were exceptionally steep.

The physicochemical parameters measured varied within a small range (Table 1) and were characteristic of good quality and soft water. In two cases, pH values attained relatively high levels (6.5 an 8.0), whereas the majority of other farms had pH values around 5.0 and hardness never exceeded 25 mg L^{-1}. These values correspond to acidic soft waters typical of these environments. Water transparency (Table 1) was generally low (mean of 33 cm). This low transparency is also typical of local waters and sometimes after rainfall the sediment content contributes to dramatically decrease water transparency. Carbon dioxide, NO^{2-} and NH^{4+} levels were, in most cases, below the detection limits of the measurement kit and never reached critical values for fish, indicating that rearing conditions were compatible with the known species preferenda.

Reproductive activity

The reproductive activity of *A. gigas* was determined during the period 2007–2010 on the monthly number of spawning events reported by the farmers. Spawning generally occurred in a shallow area of the pond in a small depression or nest dug by the two brooders. Reproductions occurred all year round, although a marked seasonality was apparent (Fig. 2). The maximum number of spawning events was observed between December and April (73 out of 100 spawnings over the 4-year period), corresponding mainly to the rainy season, short photoperiod and higher temperatures (Fig. 3). During the dry season (May–September), reproductive activity (Fig. 2) was lower (27 out of 100 spawnings).

Seasonality of fry production

The seasonality of fry production (Fig. 2) was more pronounced than that of spawning activity. The monthly fry production peaked during October–

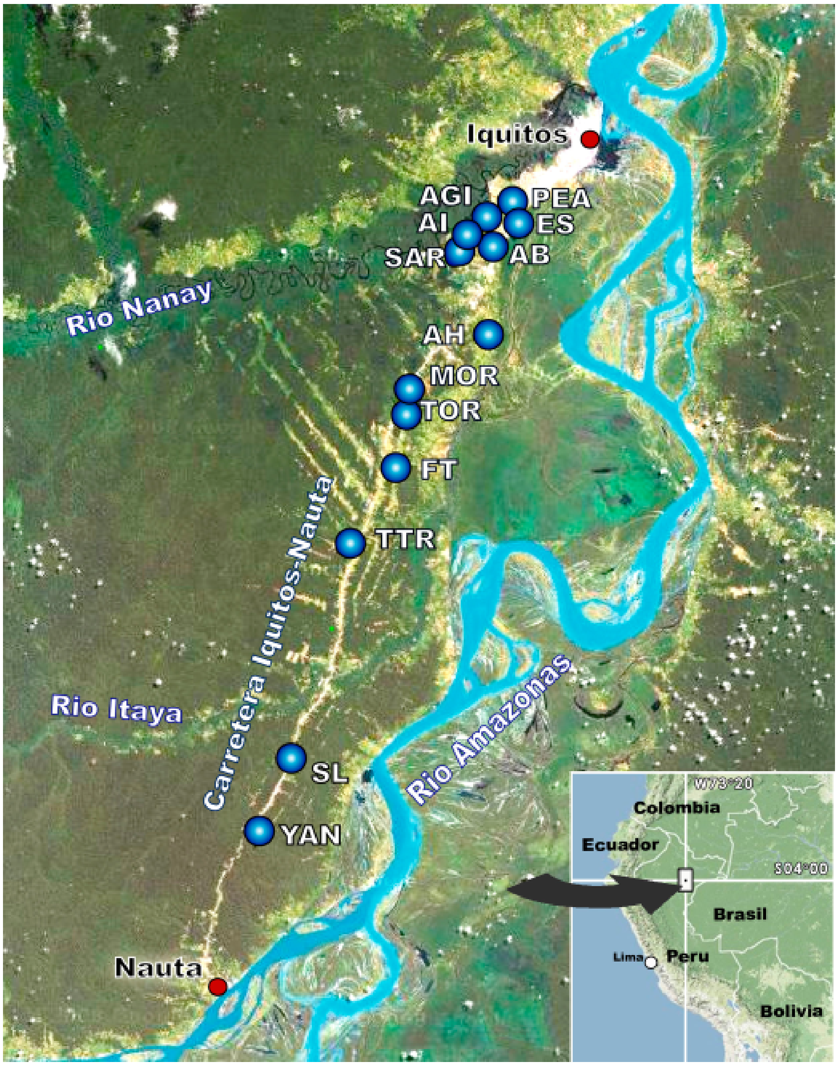

Figure 1 Aerial view of the 'Carretera Iquitos-Nauta' Loreto, Peru. Points indicate the location of the main farms.

Table 1 Summary of some physicochemical and physical characteristics of *Arapaima gigas* breeding ponds in the region of Iquitos, Peru (Iquitos-Nauta road)

	Carbon dioxide	Nitrites	Ammonia	pH	Hardness ($mg\,mL^{-1}$)	Transparency (cm)	Temperature (°C)	Area (m^2)	Depth (m)
Minimum	2	0.05	0.2	4.25	7.0	7	27.5	500	1.5
Maximum	22	0.15	3	7.5	25.0	124	32.4	8 000	4
Mean	8.85	0.089	1.06	5.47	15.4	33	29.9	2 923	2.12
(± SD)	6.24	0.121	0.82	0.86	4.32	30	1.46	2 142	0.82

March, and a very limited fry production was observed during the dry season from April to September, corresponding to longer days and lower temperatures (Fig. 3). Patterns of fry production and number of fry per spawning were quite similar from April to November, but differed strikingly from December to March (Fig. 2). During this second half of the maximum reproductive activity period, the monthly number of fingerlings per spawning decreased remarkably to reach its minimum in April.

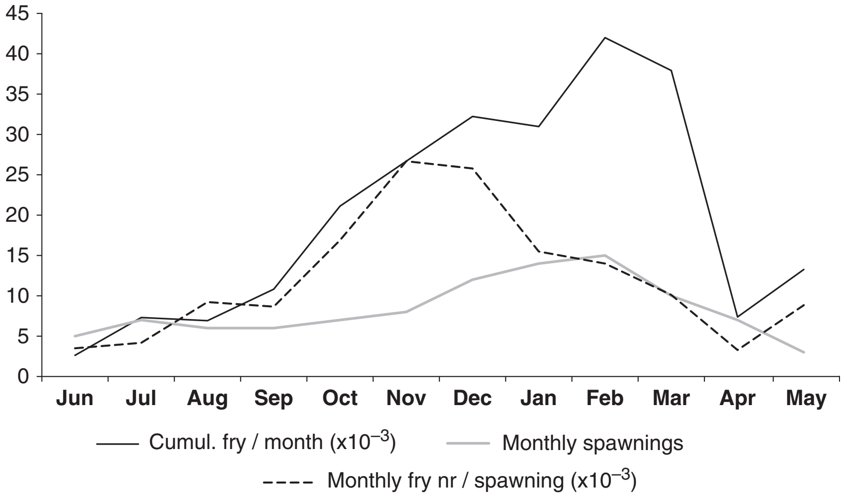

Figure 2 Four-year (2007–2010) cumulated monthly number of *Arapaima gigas* spawnings (thick grey line), total fry (solid dark line) and fry number per spawning (dotted dark line) of 16 farms along the Iquitos-Nauta road. Values must be multiplied by 10^3 for total fry and fry per spawning.

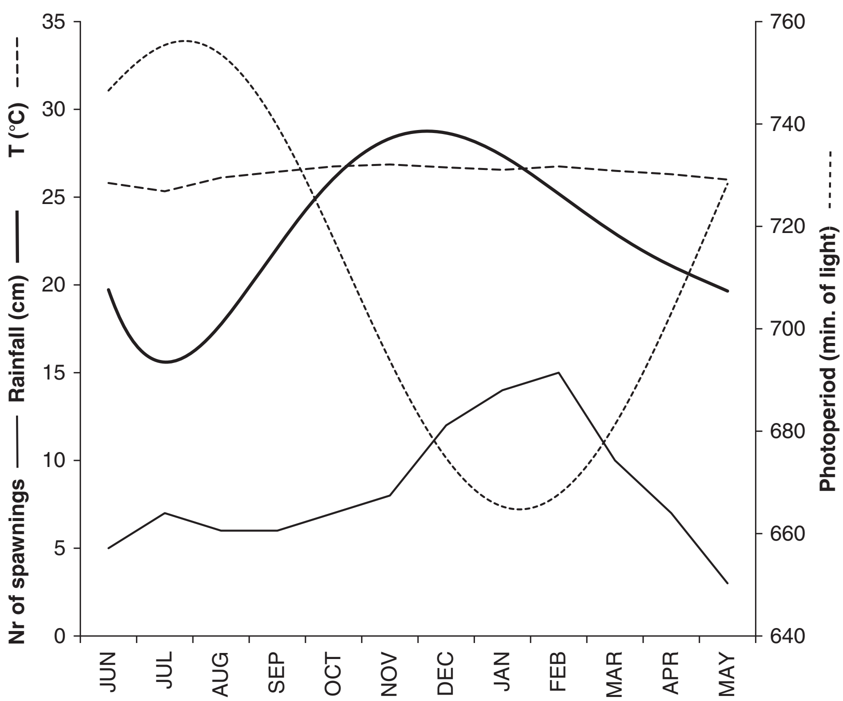

Figure 3 Monthly variations of rainfall (left axis, thick dark line), temperature (left axis, dotted dark line), cumulated (2007–2010) number of spawnings of *Arapaima gigas* females (left axis, light dark line) and photoperiod (right axis, dotted black line) in the region of Iquitos. Sources: IIAP (temperature and rainfall) and Bureau des Longitudes: http://www.bureau-des-longitudes.fr (photoperiod calculations for Iquitos).

In terms of fingerling production per spawning, the best period corresponded to October–December; nevertheless, the higher fingerling production rate was observed in February–March (Fig. 2).

Farm efficiency on reproduction and fry production

Total fry production, which was highly variable among farms, reached over 13 000 in certain farms

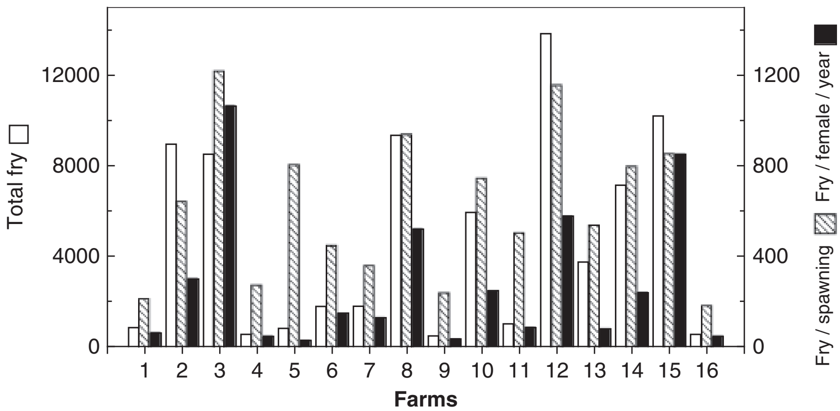

Figure 4 Cumulated monthly fry number (left axis, open bars), fry per spawning (right axis, shaded bars) and fry per female per year (left axis, black bars) of *Arapaima gigas* over a 4-year period (2007–2010) for 16 farms along the road Iquitos-Nauta.

during the 4-year period, while being <500 in others (Fig. 4) and was positively correlated with the number of females ($P = 0.044$) and the feeding level ($P = 0.01$). No significant correlation was found with other factors. The number of fry per spawning over the 4-year period (Fig. 4) was highly variable too (208–1215), but was not correlated with feeding level ($P = 0.06$).

The total number of fry produced per female during the 4-year period (results not shown) ranged from 106 to 4254, corresponding to 26–1063 fingerlings per female and per year (Fig. 4) and this parameter was correlated with feeding level ($P = 0.02$), but not with other physicochemical or hydromorphological factors.

Discussion

During this study, spawning generally occurred in a shallow area of the pond in a small depression or nest dug by the two brooders, which corresponded to previous description in the wild (Bard & Imbiriba, 1986; Castello, 2008). One of the most important findings of this study is the almost continuous reproductive activity of *A. gigas* reared in pond conditions, while this species is reported as an annual spawner with the capability of few spawning events during the rainy season in Peru (Guerra, 1980) and Brazil (Imbiriba, 1991). Nevertheless, even if these results demonstrate that a residual reproductive activity persists during the dry season, the overall survival of fingerlings on harvest, 1 month in average after spawning, is very weak during the dry season as attested by the low fry number per spawning observed in this study. This situation can be explained by putative adverse ecological factors prevailing during the dry season in the ponds, which induced higher mortalities in larval and fingerling stages. This means that even if the environmental conditions are still favourable enough for fish reproduction, the conditions are not optimal for larvae and fingerling survival. During the rainy season, maximum fingerling survival is observed during the first months of the flood period (October–December), but survival decreased progressively with rainfall decline. As no specific study has been completed on plankton or other available food sources for larvae feeding, it is difficult to conclude on the predominance of the feeding factor over other environmental variables on larvae survival.

The lack of information on the real fecundity of females also hampers the interpretation of the data, as the average number of spawned eggs may also be lower during the dry season. In the Iquitos-Nauta area, the maximum number of fry collected 1 month after hatching from a single spawning was 3941, which is considerably less than the maximum fecundity evaluated by various authors (reviewed by Imbiriba, 94). The reported absolute fecundities ranged from 58 000 to 86 000 maturing oocytes in wild fish or a maximum of 11 000 juveniles in pond conditions in Brazil (Bard & Imbiriba, 1986). From previous observations (Godinho *et al.* 2005; Núñez & Duponchelle, 2009), the oocyte development of *A. gigas* is group synchronous with three vitellogenic oocyte cohorts at different stages of development in the ovaries of maturing females. This means that the effective fecundity per spawning is probably closer to one-third of the reported maximum fecundity or could be equivalent to the oocyte number of the larger oocyte diameter cohort. Even if one takes into account this hypothesis (i.e. around 20 000 spawned eggs), the total number of hatched larvae is very far below this figure in view of our observations during this 4-year study. The probability that such high rates of eggs and young stages mortality exist in a species providing elaborated bi-parental care seems unlikely. This species may experience high rates of atresia just before spawning or poor egg survival during the embryogenesis stage, occurring in the nest at the bottom of the pond, which might partly account for why estimated fecundities on ovaries in final maturation stage are much higher than the observed number of guarded fry. Clearly, additional work is needed to shed light on this issue and to better understand the reproductive potential of the *A. gigas* in captivity.

The number of fry produced per female and per year has been positively correlated with the feeding level; the farms where the food distribution was very low exhibited also a lower number of spawning. Among all other factors studied, none appeared to play a key role on the number of spawning or the total number of fry produced. In particular, the presence or absence of floating vegetation seemed to have no influence in the reproductive activity of *A. gigas* in captivity. Concerning NH^{4+}, the absence of correlation with the number of spawning indicated that NH^{4+} had no direct effect within the measured range on female reproductive activity, and did not affect fish behaviour because *A. gigas* can tolerate much higher concentrations than those observed in this study (Cavero, Pereira-filho, Bordinhon, Fonseca, Ituassú, Roubach & Ono 2004).

Regardless of the number of spawning events, the quantity of fry produced per brood varied greatly from one farm to another. These differences can be explained by lower fecundities or differential mortalities during the 1-month average period before fingerling harvest. The most likely hypothesis to explain these variable mortalities is that feeding of fry depends greatly on the productivity of ponds. As juveniles and fingerlings feeding in the wild consists mainly of zooplankton, insects, insect larvae and small gastropods (Oliveira, Poleto & Venere 2005), the main causes of mortality are probably an insufficient food availability. This hypothesis needs to be tested by a detailed study of the limnological parameters and plankton productivity in the different farming environments. If confirmed, considering the huge variations observed on harvested fry among farms, fingerling production could be improved by properly fertilizing the ponds to allow optimal primary and secondary production.

The results described in this study emphasize the high impact of feeding level on reproductive activity and probably also on the survival of young stages and it appeared that in most farms the feeding level of the breeders was insufficient. The importance of nutritional aspects has been also reported by (Saavedra Rojas, Quintero Pinto, Lopez Hernandez *et al.* 2005) for the quantity and quality of fry produced in captivity, but this is the first experimental observation of direct influence of the feeding level on reproductive activity of *A. gigas*. In the Iquitos-Nauta area, feeding of *A. gigas* is achieved mainly with frozen or live fish, this feed appeared to be effective for breeding stocks at 2% of biomass per day, although a more detailed study is needed to establish the exact amount and quality of food that would allow for optimal reproductive rate and fry survival in this species.

In conclusion, this study shows that under good management conditions including sufficient food supply, the production of *A. gigas* fingerlings in captivity can be substantial (more than 1000 fry per female per year) and holds a good potential for improvement, despite the low fecundity of this species. These results also substantiate the possibility of sustained fry production almost during 8 months year round from September to April. Finally, our study confirms the possibility of aquaculture development of *A. gigas* through an improvement of broodstock management.

Acknowledgements

This study was carried out as part of the scientific collaborations between the IIAP and the Institut de Recherche pour le Développement (IRD), both part of the research network known as RIIA (Red de Investigación sobre la Ictiofauna Amazónica, http://www.riiaamazonia.org).

The authors wish to thank all the farm owners and people who contributed to the field work.

This work has been funded in part by the Peruvian research programme INCAGRO.

This is a publication IRD-DIVA-ISEM 2011-042.

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