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Short communication

Effects of stocking density on the performance of juvenile pirarucu (*Arapaima gigas*) in cages

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A B S T R A C T

Pirarucu, *Arapaima gigas*, is a carnivorous freshwater fish that exists along the Amazon Basin. This study investigated the effect of stocking density on growth performance and economic return of pirarucu in cages. Fish were stocked at densities of 10 or 12.5 fish/m^3 in 4.0-m^3cages installed in Sítios Novos Reservoir (Ceará State, Brazil), with three replicate cages for each density. Fish were fed a formulated diet containing 40% crude protein and 14.2 MJ/kg of feed and cultured for 140 days. The following physicochemical parameters of the water were always at satisfactory levels for fish culture throughout the experiments: water temperatures ranged from 26.3 to 30.2 °C, DO 3.2 to 7.7 mg/L, pH 6.9 to 7.7 and transparency 100 to 130 cm. Survival was high and ranged between 100.0% and 94.7 ± 5.0% in cages at 10 and 12.5 fish/m^3, respectively. Density significantly affected ($P<0.05$) final mean weight (2630.4 ± 213.7 and 2138.0 ± 148.2 g) and weight gain (2516.9 ± 202.0 and 2043.1 ± 142.9 g). In contrast, specific growth rate (2.25 ± 0.09 and 2.22 ± 0.06%/day), feed conversion ratio (1.2 ± 0.1 and 1.2 ± 0.2) and production (26.3 ± 2.1 and 25.4 ± 2.6 kg/m^3) were not significantly ($P>0.05$) affected by stocking density. Economic analysis was emphasized mostly on sales price and pirarucu juveniles and feed costs. The total costs of production were estimated at US$4.52/kg and US$5.31/kg for stocking densities of 10 fish/m^3 and 12.5 fish/m^3, respectively. At a local market price of US$5.55/kg, the model used suggests that a commercial enterprise can be profitable only for density of 10 fish/m^3. Furthermore, the economic viability of implementing of pirarucu culture in cages was analyzed using profitability indicators such as internal rate of return (IRR), net present value (NPV) and payback period. The high survival, very fast growth and moderated production rates of pirarucu stocked demonstrate that cages are a viable alternative method to standard ponds for the commercial production of pirarucu. The economic indicators appear to be attractive, thus pirarucu cage culture can become a profitable industry.

1. Introduction

In recent years, the Brazilian aquaculture industry has attempted to select new species of fish in order to diversify its production. In this context, the viability of aquaculture has been studied for some fish species like matrinxã, *Brycon cephalus* (Gomes et al., 2000); jundiá, *Rhamdia quelen* (Barcellos et al., 2004); cachara, *Pseudoplatystoma fasciatum* (Leonardo et al., 2004); tambaqui, *Colossoma macropomum* (Gomes et al., 2006a; Silva et al., 2007); pacu, *Piaractus mesopotamicus* (Abimorad et al., 2009); piabanha, *Brycon insignis* (Tolussi et al., 2010); dourado, *Salminus brasiliensis* (Braun et al., 2010); and pirarucu, *Arapaima gigas* (Gomes et al., 2006b; Menezes et al., 2006; Núñez et al., 2011).

The potential success of a species is based on market analysis, growth performance and on the availability of juveniles. Pirarucu is an exclusively air breathing fish native from the Amazon Basin. This species is considered to be one of the largest freshwater scale fishes in the world, as well as one of the species with the greatest potential for being cultivated in the Amazon (Roubach et al., 2003). According to Saint-Paul (1986), pirarucu reaches up to 200 kg in weight and up to 3 m in length, and is capable of living longer than 50 years. However, previous studies have not lead to economically feasible culture because of limitations with hatchery production (Ono et al., 2003). Pirarucu has the fastest growth among Amazonian cultivated fishes, growing at 27–41 g/day and reaching 10–15 kg/year (Bard and Imbiriba, 1986; Imbiriba, 2001; Núñez, 2009; Pereira-Filho et al., 2003; Rebaza et al., 2010). Although pirarucu is an essentially carnivorous species, the replacement of natural diets for prepared dry feed has produced satisfactory results (Crescêncio, 2001; Ono et al., 2004).

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 (Alcantara, 1991). Furthermore, the development of farming production would

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also reduce the fishing pressure on natural populations and allow restocking programs in certain areas (Núñez et al., 2011).

Cage culture is one of the most productive aquaculture systems widely used for intensive fish culture (Chua and Teng, 1980; Guo and Li, 2003). Cage culture techniques are well-established for many fish species and cages are becoming a significant contributor to production in some countries (Beveridge, 1996; Chua and Tech, 2002; Liao et al., 2004; Mariojouls et al., 2004; Marte et al., 2000; Takashima and Arimoto, 2000; Watanabe et al., 2002; Wu et al., 2000). Cage culture is one of the major priorities of the Ministry of Fisheries and Aquaculture, Brazilian Government, especially in the northeast region where there are many reservoirs suitable for culturing fish in cages.

Stocking density is one of the most important variables in aquaculture because it directly influences survival, growth, behavior, health, water quality, feeding and production. Increasing stocking density results in stress (Leatherland and Cho, 1985) which leads to enhanced energy requirements causing reduced growth and food utilization (Hengsawat et al., 1997). Optimum stocking densities need to be determined for each species and production phase to enable efficient management and to maximize production and profitability (Rowland et al., 2006). This study aimed to evaluate the effects of stocking density on the performance of pirarucu in cages in a reservoir located in Ceará State, Brazil.

2. Materials and methods

2.1. Location and experimental procedure

Pirarucu juveniles (33.0 ± 3.5 g; 18.1 ± 1.8 cm; mean ± SD) were obtained from Aquaculture Research Center of National Department of Works Against Droughts (DNOCS; Pentecoste, Ceará, Brazil) and were transported to Sítios Novos Reservoir (Caucaia, Ceará, Brazil). Sítios Novos Reservoir has a surface area of 2010 ha, a volume of 126,000,000 m^3 and an average depth of 12 m with a maximum depth of 22 m. Open fishery and tilapia aquaculture are the main uses of the reservoir.

Prior to stocking, fish were transferred to a 2000 L indoor tank for 60 days to wean onto a commercial extruded diet. After weaning, pirarucu (104.2 ± 16.7 g; 23.6 ± 2.5 cm; mean ± SD) were randomly selected, counted and stocked into 4 m^3 cages, each measuring 2.0 × 2.0 × 1.0 m deep, at densities of 10 or 12.5 fish/m^3 with three replicate cages for each density. The low number of treatments and proximity of stocking densities occurred due to low supply of fingerlings in Ceará State. This occurs due to the absence of specific studies on plankton or other available food sources for larvae feeding, resulting in low survival in larval and fingerling stages (Carreiro et al., 2011; Núñez et al., 2011). Cage frames were made of steel pipes covered with a 30-mm galvanized wire mesh coated with UV resistant PVC. Plastic bottles, attached along the four sides of each cage, were used as floats. Cages were installed at a distance of 20 m from the reservoir margin, where water depth ranged from 3 to 5 m according to water level. The distance between cages was 2 m and cages were docked with anchoring poles fixed inshore.

Pirarucu juveniles were reared for 140 days and fed four times a day with a commercial pelleted feed with 40% crude protein and 14.2 MJ/kg of feed (TC 40; Purina®, São Paulo, Brazil). Fish were fed at rates of 3.0% body weight/day for the first 84 days and 2.0% body weight/day from the 85th day until termination. Fish were sampled every 28 days to evaluate growth in weight and length. For this 20% of fish in each cage were captured, anesthetized with 100 mg/L of benzocaine, weighed and measured. After each sampling period the amount of feed given was adjusted to the mean weight and biomass in each cage.

Temperature and dissolved oxygen (DO) were monitored twice daily at 08:00 h and 17:00 h with an oximeter (YSI model 55). The pH and transparency were measured daily at 12:00 h with a digital pH meter and Secchi disk, respectively. Water samples were collected from inside of all the cages and from two different points in the reservoir at a distance of 20 m from the cages.

Fish were harvested after 140 days and survival, finals weight and length, specific growth rate (SGR = ln final weight − ln initial weight/days × 100, %/day), absolute growth rate (AGR, g/fish/day), fish survival (%), production rate (kg/m^3) and feed conversion ratio (FCR, weight of feed/gain in wet weight of fish) for each cage and treatment were calculated.

2.2. Economic analysis

The economic analysis followed Gomes et al. (2006a) and all values used were current in December 2007. The mean weight of fish at harvest was used to determine total value. In the local market, whole fresh pirarucu between 2000 and 5000 g are sold at US$5.55/kg (US$1.00 = R$1.80). Stocked pirarucu juveniles (105 g mean weight) cost US$6.34 per unit. The feed costs US$0.81/kg (40% CP).

The following assumptions were made for the economic analysis: cage cost including material and assembly and labor cost including eight fish farmers that can handle routine work of 200 cages of 4 m^3 and working benefits in compliance with the law. The maintenance and repair costs included cleaning of cage mesh after harvest and the repair of a wooden boat. Annual depreciation was calculated by the straight-line method and considered the economic life and salvage value of the equipment (Jolly and Clonts, 1993). The investments were classified as capital and operating costs. Interest on investment and operating capital was calculated by multiplying the total investment and the total operating capital by the annual interest rate of 8%, which represents the current rate for loans destined to small agribusiness enterprises, multiplied by 0.4 (2.4 crops/year).

Enterprise budgets were prepared for each stocking density tested according to Jolly and Clonts (1993). Based on the parameters of the best stocking density, a scenario was created to project the cash flow of an enterprise with 200 4.0-m^3 cages, over a 10-year period (Kubitza and Ono, 2004). The internal rate of return (IRR), net present value (NPV) and payback period of the enterprise cash flow were calculated according to Lapponi (2000), Larson et al. (2002) and Kubitza and Ono (2004). Mathematically, IRR is the discount rate that yields an NPV of zero for an investment (Larson et al., 2002). Internal rate of return is a rate used to evaluate the feasibility of an investment which reflects the rate of return the project earns (Solomon and Pringle, 1977). NPV is computed by discounting the future net cash inflows at the required rate of return from the project, and then subtracting the initial amount invested (Larson et al., 2002). NPV was calculated considering a discount rate of 12%/year based on the current interest rate paid by bank savings for investments under US$143,051.43 and the same discount rate was applied in the cash flow analysis. Payback period was defined as the expected period to recover the initial investment amount (Kubitza and Ono, 2004). An economic sensitivity analysis was modeled simulating changes in fish sales price and feed cost (which produces the same effect as changing FCR) based on production efficiency of fish raised at 10 fish/m^3.

2.3. Statistical analysis

All data were expressed as mean ± SD. One-way analysis of variance (ANOVA) was used to determine the effects of stocking density on the performance and Tukey test was used for post hoc comparisons.

3. Results and discussion

3.1. Water quality parameters

The physical and chemical parameters of water during the experiment were maintained within the tolerance range for most teleost species used in aquaculture, as reported by several authors (Beveridge, 1996;

Boyd, 1990; Boyd and Tucker, 1998; Popma and Lovshin, 1996). The water characteristics did not present any significant difference among fish densities or the two points monitored in reservoir. Water temperatures ranged from 26.3 to 30.2 °C (mean 28.6 °C), DO 3.2 to 7.7 mg/L (5.7 mg/L), pH 6.9 to 7.7 (7.3) and transparency 100 to 130 cm (117.5 cm).

3.2. Survival, growth, production and FCR

Survival was high and not significantly ($P>0.05$) affected by stocking density. Mean survival rates were 100.0% and 94.7±5.0% in cages at 10 and 12.5 fish/m^3, respectively (Table 1). Survival was similar to that observed for pirarucu reared in ponds according to Pereira-Filho et al. (2003) and Menezes et al. (2006) reported survival rates varying from 91.7 to 100% in cage culture of pirarucu. Similarly, many studies have not found any significant effects of density on survival (Bombeo-Tuburan et al., 2001; Gomes et al., 2006a; Mazzola et al., 2000; Wallat et al., 2004). Diseases are a potential problem in the cage culture of fish. Apparently, the mortalities of pirarucu juveniles were not associated to diseases. Mortality was observed only at the beginning of the experiment in cages at densities of 12.5 fish/m^3. This was probably the result of low acceptance of some fish to the commercial fish diet since dead fish presented clear signals of emaciation. Therefore, mortality rates were not related to stocking density as might be expected. Similarly, mortality of African catfish, *Clarias gariepinus*, raised in cages was not dependent upon by stocking density (Hengsawat et al., 1997). Rowland et al. (2006) related that aggression between fingerlings of silver perch, *Bidyanus bidyanus*, at the intermediate densities of 25 and 50 fish/m^3 reduced survival in comparison to cages stocked at 12, 100 or 200 fish/m^3.

In contrast, final weight was significantly ($P<0.05$) influenced by densities (Fig. 1). Mean final weights were 2630.4±213.7 and 2138.0±148.2 g at 10 and 12.5 fish/m^3, respectively (Table 1). Various studies with pirarucu report similar results according to the type of culture. Cavero et al. (2003) in a 200 day study with 1.0-m^3 cages and a density of 20 fish/m^3 reported a final fish mean weight of 1380 g when pirarucu juveniles were stocked at an average weight of 84 g. Bard and Imbiriba (1986) reported pirarucu in ponds reached weights ranging from 4037 to 4497 g in only 152 days when stocked at an initial weight of 126 to 388 g. According to Pereira-Filho et al. (2003), this species cultured under intensive production system in ponds reached a maximum weight of 7000±1100 g after 365 days.

The growth rates for pirarucu juveniles in cages submitted to different treatments are given in Table 1. AGR was significantly different ($P<0.05$) in two densities. Similar studies have found that AGR decrease with increasing stocking densities (Gomes et al., 2006a; Petit et al., 2001; Rowland et al., 2004). In this study, AGR ranged from 14.6±1.0 to 18.0±1.4 g/day while Pereira-Filho et al. (2003) found AGR values of 18.9 g/day to pirarucu juveniles cultured during 365 days. The growth

Table 1
Survival, initial and final weights, weight gain, specific growth rate (SGR), absolute growth rate (AGR), production and feed conversion ratio (FCR) of pirarucu juveniles (initial mean weights, 113.5–94.9 g) cultured for 140 days at two stocking densities in cages.

Parameter	Stocking densities (fish/m^3)	
	10	12.5
Survival	100.0	94.7±5.0
Initial weight	113.5±18.2	94.9±10.1
Final weight	2630.4±213.7^a	2138.0±148.2^b
Weight gain	2516.9±202.0^a	2043.1±142.9^b
SGR (%/day)	2.25±0.09	2.22±0.06
AGR (g/day)	18.0±1.4^a	14.6±1.0^b
Production (kg/m^3)	26.3±2.1	25.4±2.6
FCR	1.2±0.1	1.2±0.2

Data are means±S.D. of three replicate cages. For each row, means with different letters as superscripts are significantly different ($P<0.05$).

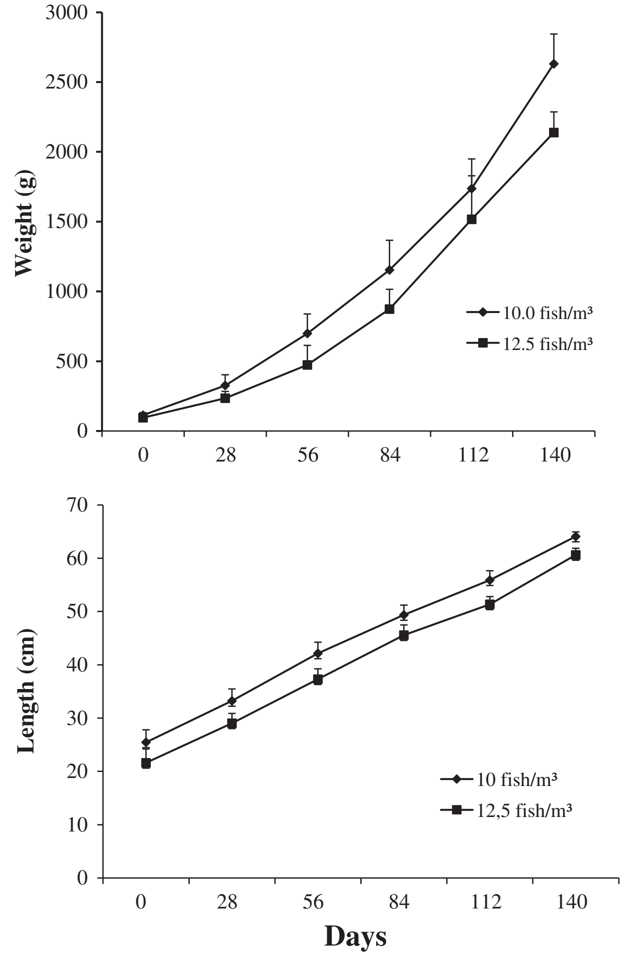

Fig. 1. Growth of pirarucu stocked at 10 or 12.5 fish/m^3 in 4 m^3 cages and cultured for 140 days. Data are means±SD of three replicate cages in Sítios Novos Reservoir (Ceará State, Brazil).

rates exhibited by pirarucu were generally faster than most other cultured fish, including yellowtail jack, *Seriola rivoliana*; African catfish, *Clarias gariepinus*; mutton snapper, *Lutjanus analis*; tambaqui, *Colossoma macropomum*; and silver perch, *B. bidyanus* (Benetti et al., 1995, 2002; Gomes et al., 2006a, 2006b; Hengsawat et al., 1997; Rowland et al., 2006).

Despite significant differences in AGR, fish density did not affect SGR (Table 1). SGR were 2.25±0.09%/day at 10 fish/m^3 and 2.22±0.06 at 12.5 fish/m^3. Pereira-Filho et al. (2003) reported an SGR of 1.09%/day to pirarucu juveniles. These SGR values are comparable to juveniles of other species such as cobia, *Rachycentron canadum*, at 2.46%/day (Denson et al., 2003); winter flounder, *Pleuronectes americanus*, at 2.10 (Hebb et al., 2003); and silver perch, *B. bidyanus*, at 2.78–2.84 (Rowland et al., 2004).

Stocking density did not significantly affect ($P>0.05$) production. Although production at 10 fish/m^3 was higher than at 12.5 fish/m^3, the rates were not significantly different (Table 1). Similar stocking densities and production rates have been reported for the cage culture of other carnivorous fishes: 6.1–12.3 kg/m^3 for Mediterranean amberjack (*Seriola dumerili*) in 75-m^3 cages (Mazzola et al., 2000); 14.0 kg/m^3 for cobia (*R. canadum*) in 1000–1800-m^3 cages (Liao et al., 2004); and 14.5 to 34 kg/m^3 for Atlantic salmon (*Salmo salar*) in 120–2000-m^3 cages (Oppedal et al., 2011; Turnbull et al., 2005). However, other studies using varied densities found production rates ranging from 42.0 kg/m^3 for spotted wolffish (*Anarhichas minor*) in 100-m^3 cages (Mortensen et al., 2007) to 35.0–61.2 kg/m^3 for rainbow trout (*Oncorhynchus mykiss*) in 1.0-m^3 cages (Wallat et al., 2004).

Stocking density did not significantly affect ($P>0.05$) on feed conversion ratio (Table 1). FCRs of fish stocked at 10 fish/m^3 (1.2 ± 0.1) and 12.5/m^3 (1.2 ± 0.2) were lower than the FCRs determined for other studies. Pereira-Filho et al. (2003) and Crescêncio et al. (2005) reported FCR of 1.5 and 1.3–1.9 to pirarucu juveniles, respectively. The FCR of grouper, *Epinephelus coiodes*, cultured in ponds and fed with pellets diet was 3.2 (Bombeo-Tuburan et al., 2001). Mazzola et al. (2000) reported FCR of 3.5 to Mediterranean amberjack, *S. dumerili*, fed with pellets diet. During harvest small fish and prawns were found in the cages. As pirarucu is a carnivorous fish, an explanation for the relatively low FCR in this study is the availability of natural food to fish inside of the cages. Furthermore, according to Eroldogan et al. (2004), with low feeding rates fish tend to optimize their digestion to extract more nutrients efficiently, as observed in this study.

3.3. Economic analysis

There were several factors affecting economic return of the system such as yield, sales price, feed cost, fingerlings or juveniles cost, system investment and operating cost (Muangkeow et al., 2007). Economic analysis in this study was then emphasized mostly on sales price and pirarucu juveniles and feed costs. The comparative cost and return analysis of pirarucu juveniles cultured for 140 days at two stocking densities in cages is shown in Table 2. The major components of variable costs were pirarucu juveniles and feeds. The total costs varied with the costs of pirarucu juveniles that accounted for 53.3–58.9%. This can be attributed to the short culture period of this study since pirarucu reaches marketable size of 7–10 kg after 8–12 months of culture when this species is used traditionally for the production of fish fillets. The purpose for the production of pirarucu of 2–3 kg was the sale at the live fish market that has been growing rapidly in Ceará State (Brazil). Furthermore, the transportation and trade of live fish can be more feasible for pirarucu of 2–3 kg than for pirarucu of 7–10 kg. According to Zonneveld and Fadholi (1991), the highest economic yield may be determined not by maximum production but by preferred market size and price. In addition, the high cost of pirarucu juveniles is related with insufficient production of fingerlings in captivity, due to the low fecundity of this species (Núñez et al., 2011). Feeding costs represented only 17.7–20.6% of total costs, contrasting to the feed cost in cage production of various fish species that represents 30–60% of total costs (El-Sayed, 1998; Gomes et al., 2006a; Huguenin, 1997; Silva et al., 2007). The total costs of production were estimated at US$4.52/kg and US$5.31/kg for stocking densities of 10 fish/m^3 and 12.5 fish/m^3, respectively. At a local market price of US$5.55/kg, net incomes per kg of fish were US$1.03 and US$ .24 at 10 and 12.5 fish/m^3, respectively. Therefore, net income was not directly related to stocking density, conflicting with the findings of Hengsawat et al. (1997) and Gomes et al. (2006a, 2006b). On the other hand, the high density of tilapia in shrimp–tilapia integrated systems showed low net income due to small average size of shrimps and low price of tilapia (Muangkeow et al., 2007).

The results of the sensitivity analyses of pirarucu production in 200 4.0-m^3 cages stocked at a density of 10 fish/m^3 are summarized in Table 3. In current conditions, the projected model resulted in IRR of 34.4%, NPV of US$ 150,127.34 and payback period of 2.8 years. An increase in sales price by 10% registers an increase in IRR of 34.4 to 55.1%, NPV of US$ 150,127.34 to US$ 308,227.94 and a decrease in payback period of 2.8 to 1.8 years. Moreover, a decrease in sales price by 10% results in low IRR, negative NPV and high payback period. On the other hand, an increase or a decrease in feed cost does not have greater effect over the IRR, NPV and payback period since variations of $\pm$10% in feed cost produced similar results to those observed by current conditions. This analysis showed that under simulated conditions the IRR maintained a direct and more than proportional link to changes in sales price of pirarucu. This results were similar to the observed for grouper, *E. coiodes*, in ponds (Bombeo-Tuburan et al., 2001); for tambaqui, *Colossoma macropomum* in cages (Gomes et al., 2006a); for Murray cod, *Maccullochella peelii peelii*, and Short finned eels, *Anguilla australis*, in recirculating aquaculture systems (Ionno et al., 2006); and Nile tilapia, *Oreochromis niloticus*, and Australian redclaw crayfish, *Cherax quadricarinatus*, in a scenario simulation model (Ponce-Marbán et al., 2006).

Table 2
Cost and return analysis of pirarucu juveniles cultured for 140 days at two stocking densities in cages.

Parameter	Unit cost (US$)	Stocking densities (fish/m^3)	
		10	12.5
Total harvest (kg)		315.6	304.4
Revenue		1751.86	1689.42
Revenue per kg of fish		5.55	5.55
Capital investment		1055.55	1055.55
Wooden boat	166.67	55.55	55.55
Cage	333.33	1000.00	1000.00
Variable cost		1322.49	1510.74
Variable cost (% of total cost)		92.6	93.5
Pirarucu juvenile (unit)	6.34	760.80	951.00
40% CP feed	0.81	294.03	286.01
Labor (month)	45.00	225.00	225.00
Interest on operation capital (year)	8%	42.7	48.7
Variable cost per kg of fish		4.19	4.96
Income after variable cost		429.37	178.67
Fixed cost		105.07	105.07
Fixed cost (% of total cost)		7.4	6.5
Licenses (year)[a]	7.50	3.15	3.15
Maintenance and repair (year)	52.75	22.16	22.16
Depreciation (year)	105.50	44.31	44.31
Interest on investment (year)	8%	35.4	35.4
Fixed cost per kg of fish		0.33	0.35
Total cost		1427.56	1615.81
Total cost per kg of fish		4.52	5.31
Net income		324.30	73.61
Net income per kg of fish		1.03	0.24

[a] Licenses for use of a surface area of 1.0 ha for 1 year. Values are in US dollars (US$1.00 = R$ 1.80).

4. Conclusion

This study has shown that pirarucu can be efficiently grown to market-size in cages and its growth is much faster than other fish species that have the advantage of decades of research and genetic improvement. The data obtained suggest that pirarucu reared in a stocking density of 10 fish/m^3 show better zootechnical indices. However, the optimal stocking densities have not been identified and further research is necessary using several culture phases (100–500 g; 500 g–1 kg; 1–2 kg; 2–5 kg). Additional experiments could be conducted to determine optimal feeding rate of pirarucu in cages for the production of fish with desired size for restaurants, outlets and fish processors. The economic analysis indicated that the aquaculture of pirarucu in cages at moderated stocking densities was feasible. The continuance of the study with this species is important to provide data and gain knowledge to optimize the production, improving the management of this species in captivity.

Table 3
Economic sensitivity analysis of pirarucu production in 200 cages of 4 m^3 stocked at a density of 10 fish/m^3.

Situations	Internal rate of return (IRR, %)	Net present value (NPV, US$)	Payback period (years)
Current conditions	34.4	150,127.34	2.8
10% increase in sales price	55.1	308,227.94	1.8
10% decrease in sales price	10.5	−8474.87	6.0
10% increase in feed cost	30.7	123,256.69	3.0
10% decrease in feed cost	37.9	176,419.41	2.5

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References

Abimorad, E.G., Favero, G.C., Castellani, D., Garcia, F., Carneiro, D.J., 2009. Dietary supplementation of lysine and/or methionine on performance, nitrogen retention and excretion in pacu *Piaractus mesopotamicus* reared in cages. Aquaculture 295, 266–270.
Alcantara, F., 1991. Observations on reproductive behavior of paiche, *Arapaima gigas*, in captivity. Folia Amazonica 2, 165–168.
Barcellos, L.J.G., Kreutz, L.C., Quevedo, R.M., Fioreze, I., Cericato, L., Soso, A.B., Fagundes, M., Conrad, J., Baldissera, R.K., Bruschi, A., Ritter, F., 2004. Nursery rearing of jundiá, *Rhamdia quelen* (Quoy & Gaimard) in cages: cage type, stocking density and stress response to confinement. Aquaculture 232, 383–394.
Bard, J., Imbiriba, E.P., 1986. Piscicultura de pirarucu, *Arapaima gigas*. EMBRAPA-CPATU, Belém, Brazil, No. 52. 17 pp.
Benetti, D.D., Acosta, C.A., Ayala, J.C., 1995. Cage and pond aquaculture of marine finfish in Ecuador. World Aquaculture 26, 7–13.
Benetti, D.D., Matera, J.A., Feeley, M.W., Stevens, O., Alarcón, J.F., Banner-Stevens, G., Minemoto, Y., O'Hanlon, B., Eldridge, L., 2002. Growth, survival and feed conversion rates of hatchery reared mutton snapper Lutjanus analis raised in floating net cages. Journal of the World Aquaculture Society 33, 349–357.
Beveridge, M.C.M., 1996. Cage Aquaculture. Fishing News Books, Carlton. 346 pp.
Bombeo-Tuburan, I., Coniza, E.B., Rodriguez, E.M., Agbayani, R.F., 2001. Culture and economics of wild grouper *Epinephelus coioides* using three feed types in ponds. Aquaculture 201, 229–240.
Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Auburn University, Alabama . 482 pp.
Boyd, C.E., Tucker, C.S., 1998. Water Quality and Pond Soil Analysis for Aquaculture. Alabama Agricultural Experiment Station, Alabama, USA. 700 pp.
Braun, N., Lima, R.L., Baldisserotto, B., Dafre, A.L., Nuñer, A.P.O., 2010. Growth, biochemical and physiological responses of *Salminus brasiliensis* with different stocking densities and handling. Aquaculture 301, 22–30.
Carreiro, C.R.P., Furtado-Neto, M.A.A., Mesquita, P.E.C., Bezerra, T.A., 2011. Sex determination in the Giant fish of Amazon Basin, *Arapaima gigas* (Osteoglossiformes, Arapaimatidae), using laparoscopy. Acta Amazonica 41, 415–420.
Cavero, B.A.S., Pereira-Filho, M., Roubach, R., Ituassú, D.R., Gandra, A.L., Crescêncio, R., 2003. Biomassa sustentável de juvenis de pirarucu em tanques-rede de pequeno volume. Acta Amazônica 33, 723–728.
Chua, T.E., Tech, E., 2002. Introduction and history of cage culture. In: Woo, P.T.K., Bruno, D.W., Lim, L.H.S. (Eds.), Diseases and Disorders of Finfish in Cage Culture. CABI Publishing, Oxon, pp. 1–39.
Chua, T.E., Teng, S.K., 1980. Economic production of estuary grouper, *Epinephelus salmonides* Maxwell, reared in floating net cages. Aquaculture 20, 187–228.
Crescêncio, R., 2001. Treinamento alimentar de alevinos de pirarucu, *Arapaima gigas* (Cuvier, 1829), utilizando atrativos alimentares. 2001. 26 f. Dissertação (Mestrado em Ciências Biológicas) – Instituto Nacional de Pesquisa na Amazônia, Universidade Federal do Amazonas, Manaus.
Crescêncio, R., Ituassú, D.R., Roubach, R., Pereira-Filho, M., Cavero, B.A.S., Gandra, A.L., 2005. Influência do período de alimentação no consumo e ganho de peso do pirarucu. Pesquisa Agropecuária Brasileira 40, 1217–1222.
Denson, M.R., Stuart, K.R., Smith, T.I.J., Weirich, C.R., Segars, A., 2003. Effects of salinity on growth, survival, and selected hematological parameters on juvenile cobia, *Rachycentron canadum*. Journal of the World Aquaculture Society 34, 496–504.
El-Sayed, A.F.M., 1998. Total replacement of fish meal with animal protein sources in Nile tilapia, *Oreochromis niloticus* (L.), feeds. Aquaculture Research 29, 275–280.
Eroldogan, O.T., Kumlu, M., Aktas, M., 2004. Optimum feeding rates for European sea bass *Dicentrarchus labrax* L. reared in seawater and freshwater. Aquaculture 231, 501–515.
Gomes, L.C., Baldisserotto, B., Senhorini, J.A., 2000. Effect of stocking density on water quality, survival, and growth of larvae of the matrinxã, *Brycon cephalus* (Characidae), in ponds. Aquaculture 183, 73–81.
Gomes, L.C., Chagas, E.C., Martins-Junior, H., Roubach, R., Ono, E.A., Lourenço, J.N.P., 2006a. Cage culture of tambaqui (*Colossoma macropomum*) in a central Amazon floodplain lake. Aquaculture 253, 374–384.
Gomes, L.C., Chagas, E.C., Brinn, R.P., Roubach, R., Coppati, C.E., Baldisserotto, B., 2006b. Use of salt during transportation of air breathing pirarucu juveniles (*Arapaima gigas*) in plastic bags. Aquaculture 256, 521–528.
Guo, L., Li, Z., 2003. Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China. Aquaculture 226, 201–212.
Hebb, C.D., Castell, J.D., Anderson, D.M., Batt, J., 2003. Growth and feed conversion of winter flounder (*Pleuronectes americanus*) in relation to different protein-to-lipid levels in isocaloric diets. Aquaculture 221, 439–449.
Hengsawat, K., Ward, F.J., Jaruratjamorn, P., 1997. The effect of stocking density on yield, growth and mortality of African catfish (Clarias *gariepinus* Burchell 1822) cultured in cages. Aquaculture 152, 67–76.
Huguenin, J., 1997. The design, operations and economics of cage culture systems. Aquacultural Engineering 16, 167–203.
Imbiriba, E.P., 2001. Potencial de criação de pirarucu, *Arapaima gigas*, em cativeiro. Acta Amazonica 31, 299–316.
Ionno, P.N.D., Wines, G.L., Jones, P.L., Collins, R.O., 2006. A bioeconomic evaluation of a commercial scale recirculating finfish growout system—an Australian perspective. Aquaculture 259, 315–327.
Jolly, C.M., Clonts, H.A., 1993. Economics of Aquaculture. The Haworth Press, Binghamton. 319 pp.
Kubitza, F., Ono, E.A., 2004. Projetos Aqüıcolas: Planejamento e Avaliação Econômica, 1st. ed. Fernando Kubitza, Jundiaí. 88 pp.
Lapponi, J.C., 2000. Projetos de Investimento: Construção e Avaliação do Fluxo de Caixa: Modelos em Excel. Lapponi Treinamento e Editora, São Paulo. 376 pp.
Larson, K.D., Wild, J.J., Chiappetta, B., 2002. Fundamental Accounting Principles, 16th edition. McGraw-Hill Irwin Publishing, USA.
Leatherland, J.F., Cho, C.Y., 1985. Effect of rearing density on thyroid and interrenal gland activity and plasma hepatic metabolite levels in rainbow trout, Salmo *gairdneri*, Richardson. Journal of Fish Biology 27, 583–592.
Leonardo, A.F.G., Romagosa, E., Borella, M.I., Batlouni, S.R., 2004. Induced spawning of hatchery-raised Brazilian catfish, cachara *Pseudoplatystoma fasciatum* (Linnaeus, 1766). Aquaculture 240, 451–461.
Liao, I.C., Huang, T.S., Tsai, W.S., Hseuh, C.M., Chang, S.L., Leaño, E.M., 2004. Cobia culture in Taiwan: current status and problems. Aquaculture 237, 155–165.
Mariojouls, C., Khumsri, M., Worawattanamateekul, W., 2004. Tilapia cage farming in Thailand. Global Aquaculture Advocate 30–32.
Marte, C.L., Cruz, P., Flores, E.E.C., 2000. Recent developments in freshwater and marine cage aquaculture in the Philippines. In: Liao, I.C., Lin, C.K. (Eds.), Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok, pp. 83–96.
Mazzola, A., Favaloro, E., Sarà, G., 2000. Cultivation of the Mediterranean amberjack, *Seriola dumerili* (Risso, 1810), in submerged cages in the Western Mediterranean Sea. Aquaculture 181, 257–268.
Menezes, G.C., Tavares-Dias, M., Ono, E.A., Andrade, J.I.A., Brasil, E.M., Roubach, R., Urbinati, E.C., Marcon, J.L., Affonso, E.G., 2006. The influence of dietary vitamin C and E supplementation on the physiological response of pirarucu, *Arapaima gigas*, in net culture. Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology 145, 274–279.
Mortensen, A., Toften, H., Aas, K., 2007. Cage culture of spotted wolffish (*Anarhichas minor* Olafsen). Aquaculture 264, 475–478.
Muangkeow, B., Ikejima, K., Powtongsook, S., Yi, Y., 2007. Effects of white shrimp, *Litopenaeus vannamei* (Boone), and Nile tilapia, *Oreochromis niloticus* L., stocking density on growth, nutrient conversion rate and economic return in integrated closed recirculation system. Aquaculture 269, 363–376.
Núñez, J., 2009. Domestication de nouvelles espèces d'intérêt aquacole en Amazonie. Cahiers Agricultures 18, 136–143.
Núñez, J., Chu-Koo, F., Berland, M., Arévalo, L., Ribeyro, O., Duponchelle, F., Renno, J.F., 2011. Reproductive success and fry production of the paiche or pirarucu, *Arapaima gigas* (Schinz), in the region of Iquitos, Perú. Aquaculture Research 42, 815–822.
Ono, E.A., Roubach, R., Pereira, M.F., 2003. Pirarucu production—advances in Central Amazon, Brazil. Global Aquaculture Advocate 6, 44–46.
Ono, E.A., Halverson, M.R., Kubitza, F., 2004. Pirarucu—o gigante esquecido. Panorama da Aqüicultura 14, 14–25.
Oppedal, F., Vågseth, T., Dempster, T., Juell, J.E., Johansson, D., 2011. Fluctuating sea-cage environments modify the effects of stocking densities on production and welfare parameters of Atlantic salmon (*Salmo salar* L.). Aquaculture 315, 361–368.
Pereira-Filho, M., Cavero, B.A.S., Roubach, R., Ituassú, D.R., Gandra, A.L., Crescêncio, R., 2003. Cultivo do pirarucu (*Arapaima gigas*) em viveiro escavado. Acta Amazonica 33, 715–718.
Petit, G., Beauchaud, M., Buisson, B., 2001. Density effects on food intake and growth of largemouth bass (*Micropterus salmoides*). Aquaculture Research 32, 495–497.
Ponce-Marbán, D., Hernández, J.M., Gasca-Leyva, E., 2006. Simulating the economic viability of Nile tilapia and Australian redclaw crayfish polyculture in Yucatan, Mexico. Aquaculture 261, 151–159.
Popma, T.J., Lovshin, L.L., 1996. World prospects for commercial production of tilapia. Research and Development Series 41 International Center for Aquatic Environment, Department of Fisheries and Allied Aquaculture, Auburn University, Alabama. 24 pp.
Rebaza, M., Rebaza, C., Deza, S., 2010. Densidad de siembra para cultivos de Paiche en jaulas flotantes. Aquavisión 6, 26–27.
Roubach, R., Correia, E.S., Zaiden, S., Martino, R.C., Cavalli, R.O., 2003. Aquaculture in Brazil. World Aquaculture 34, 28–35.
Rowland, S.J., Allan, G.L., Hollis, M., Pontifex, T., 2004. Production of silver perch (*Bidyanus bidyanus*) fingerlings at three stocking densities in cages and tanks. Aquaculture 229, 193–202.
Rowland, S.J., Mifsud, C., Nixon, M., Boyd, P., 2006. Effects of stocking density on the performance of the Australian freshwater silver perch (*Bidyanus bidyanus*) in cages. Aquaculture 253, 301–308.
Saint-Paul, U., 1986. Potential for aquaculture of South American freshwater fishes: a review. Aquaculture 54, 205–240.
Silva, C.R., Gomes, L.C., Brandão, F.R., 2007. Effect of feeding rate and frequency on tambaqui (*Colossoma macropomum*) growth, production and feeding costs during the first growth phase in cages. Aquaculture 264, 135–139.
Solomon, E., Pringle, J.J., 1977. An Introduction to Financial Management. Goodyear Publishing Company, Santa Monica, California. 614 pp.
Takashima, F., Arimoto, T., 2000. Cage culture in Japan toward the new millennium. In: Liao, I.C., Lin, C.K. (Eds.), Cage Aquaculture in Asia: Proceedings of the First

International Symposium on Cage Aquaculture in Asia. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok, pp. 53–58.
Tolussi, C.E., Hilsdorf, A.W.S., Caneppele, D., Moreira, R.G., 2010. The effects of stocking density in physiological parameters and growth of the endangered teleost species piabanha, *Brycon insignis* (Steindachner, 1877). Aquaculture 310, 221–228.
Turnbull, J., Bell, A., Adams, C., Bron, J., Huntingford, F., 2005. Stocking density and welfare of cage farmed Atlantic salmon: application of a multivariate analysis. Aquaculture 243, 121–132.
Wallat, G.K., Tiu, L.G., Rapp, J.D., Moore, R., 2004. Effect of stocking density on growth, yield and costs of producing rainbow trout, *Oncorhynchus mykiss*, in cages. Journal of Applied Aquaculture 15 (3/4), 73–82.
Watanabe, W.O., Losordo, T.M., Fitzsimmons, K., Hanley, F., 2002. Tilapia production systems in the Americas: technological advances, trends, and challenges. Reviews in Fisheries Science 10, 465–498.
Wu, Z., Guo, J., Yang, Y., 2000. Current status and sustainability of cage culture in reservoirs: a case study in China. In: Liao, I.C., Lin, C.K. (Eds.), Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia. Asian Fisheries Society, Manila, and World Aquaculture Society – Southeast Asian Chapter, Bangkok, pp. 259–265.
Zonneveld, N., Fadholi, R., 1991. Feed intake and growth of red tilapia at different stocking densities in ponds in Indonesia. Aquaculture 99, 83–94.