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IMPACT OF CONTROL OF THE GOLDEN MUSSEL ON THE PRODUCTION COSTS OF TILAPIA BRED IN NET CAGES

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ABSTRACT

The economic impact of the control of the golden mussel on tilapia bred in net cages, with different volumes and production scales, is evaluated. Twelve fish farms were selected in Ilha Solteira Reservoir, on the Paraná River (between the states of São Paulo and Mato Grosso do Sul), and in the Canoas II and Chavantes Reservoirs on the Paranapanema River (between the states of São Paulo and Paraná), Brazil. A semi-structured questionnaire provided data on expenditure and capital required for calculating control costs. Expenses on labor, maintenance and depreciation of infrastructure and equipments, cage maintenance, additional depreciation and costs with electricity or fuel for cleaning were accounted. Large-size enterprises had the lowest costs, regardless of net cage volume. Cage depreciation and maintenance greatly influenced costs for mussel control, reaching an average rate of 69.89%. Lowest added costs were reported in large-size fish farms (R$ 0.45 kg fish^{-1}), followed by medium- and small-size ones (R$ 1.00 kg fish^{-1}). Mean economic impact reached 11.48% (large-size), 27.25% (medium-size) and 25.81% (small-size). Impact varied between 7.83% and 19.22%, respectively, in 108m^3 and 6m^3 net cages.

Key words: economic impact; *Limnoperna fortunei*; fish farming; reservoir.

IMPACTO DO CONTROLE DO MEXILHÃO-DOURADO NO CUSTO DE PRODUÇÃO DE TILÁPIA EM TANQUES-REDE

RESUMO

Este trabalho avaliou o impacto econômico do controle do mexilhão-dourado na criação de tilápia-do-nilo em tanques-rede de diferentes volumes e escalas de produção. Foram selecionadas 12 pisciculturas situadas no reservatório Ilha Solteira, no rio Paraná (SP/MS), e em Canoas II e Chavantes, no rio Paranapanema (SP/PR). As informações de desembolsos e capital necessários para calcular o custo do controle do mexilhão foram obtidas por meio de questionário apresentado aos piscicultores. Foram contabilizados os gastos com mão de obra, manutenção e depreciação da infraestrutura e equipamentos utilizados na limpeza; manutenção e depreciação adicional dos tanques-rede; e energia elétrica ou combustível gastos em serviços de limpeza. As empresas de grande porte foram as que tiveram os menores custos incrementais, independentemente do volume dos tanques-rede. A depreciação e a manutenção dos tanques-rede foram os fatores que mais impactaram o custo para o controle de mexilhão, a uma taxa média de 69,89%. O menor custo incremental foi observado nas pisciculturas de grande porte (R$ 0,45 kg fish^{-1}), seguido das de médio e pequeno porte (R$ 1,00 kg fish^{-1}). O impacto econômico médio foi de 11,48% (grande porte), 27,25% (médio porte) e 25,81% (pequeno porte). Considerando o volume dos tanques-rede esse impacto variou entre 7,83% em tanques de 108 m^3 e 19,22% em tanques de 6 m^3.

Palavras-chave: impacto econômico; *Limnoperna fortunei*; piscicultura; reservatório.

INTRODUCTION

The Nile tilapia is one of the most bred fish in Brazil, mainly cultivated in net cages in reservoirs and rivers (AYROZA *et al*., 2014; IBGE, 2014; NOGUEIRA and RODRIGUES, 2007; PEDROZA-FILHO *et al*., 2015). However, fish cultivation in the above environments has to cope with such problems as infestation by the golden mussel (*Liminoperna fortunei*, Dunker, 1857), actually one of the main impairments for the development of fish enterprises, with significant environmental and economic impacts.

The golden mussel is a fresh water bivalve mollusk of the Mytilidae family, native to South-Eastern Asia. It was probably introduced in South America around 1991 by ship ballast water and it gradually colonized aquatic environments in Argentina, Uruguay and Brazil (PASTORINO *et al*., 1993; DARRIGRAN and PASTORINO, 1995; DARRIGRAN and DAMBORENEA, 2009; MANSUR *et al*., 2012). The mollusk spread from the Paraguay River to all Brazilian water basins, with the exception of the northern region of Brazil.

The meshes of net cages in fish cultures are an excellent substrate for the fixation of *L. fortunei*, whilst fish farms have enormous food availability due to the organic load provided by fish production. In fact, the golden mussel adheres preferentially to hard and fixed substrates (MORTON, 1983; DARRIGRAN and DAMBORENEA, 2009; IWASAKI, 2015), preferring deep water environments, between 6 and 10 m (MORTON, 1977, 2015; NAKANO *et al*., 2010) or more (BRUGNOLI *et al*., 2011). In the main water bodies of South America inhabited by *L. fortunei*, the available substrates are largely man-made, comprising piers, dykes, stakes, gabions and barks of boats or ships (CORREA *et al*., 2015) and even the structures in net cages.

The fixing of the golden mussel to the nets of the cages obstructs mesh aperture and decreases water circulation. Consequently, there is a reduction in the support capacity in cultivation units and an increase in morbidity due to body harm done when fish touch the mollusk´s shell. Maintenance and cleanliness of the net cages is imperative, with a decrease in their useful life and additional costs that would not exist if the mollusk were absent. This fact increases risks in the enterprise since producers are required to be more efficient in a highly competitive market featuring imported fish, high prices in material used in the production process and low prices in the selling of the product (PEDROZA-FILHO *et al*., 2015).

Current analysis assesses the economic impact of the golden mussel on the production of tilapia in net cages by calculating the additional costs for the removal of mollusks fixed to net cages. Lack of similar studies makes difficult consensus in methodology and hinders comparison of data provided by different authors. On the other hand, current analysis underscores the impact of different factors, taken separately, that influence the incremental costs derived from the introduction of the golden mussel in fish farming.

METHODS

Possible items involving fish farming costs affected by golden mussel infestation were identified and a questionnaire was prepared to provide information that would determine the economic impact of the bio-invasion within the breeding system. The semi-structured questionnaire was applied to 12 fish farms enterprises with different production scales and net cage volumes in the Ilha Solteira reservoir on the Paraná River, state border between São Paulo and Mato Grosso do Sul, and in Canoas II and Chavantes on the Paranapanema River, state border between São Paulo and Paraná. The following criteria were employed for the selection of the fish farms: 1- infestation with golden mussels; 2- production scales complying with Resolution CONAMA n. 413/2009 (BRASIL, 2009) (small < 1,000 m^3; middle size = between 1,000 and 5,000 m^3; large > 5,000 m^3); and 3- different sizes of net cages (between 6 and 136 m^3). However, there were net cages with different volumes on the same fish farm. Four fish farms of each size were assessed. Table 1 shows the fish farms analyzed and the characteristics of the fish farms employed in the calculations.

Only additional costs required for the removal of the golden mussel fixed to the net cages were taken into account so that the economic impact caused by the golden mussel in fish cultures could be determined. Expenditure costs comprised cleaning, maintenance and depreciation of infrastructure and equipments used; additional maintenance and depreciation costs of net cages; electricity or fuel bill for cleaning.

Yearly depreciation of cleaning equipments and infrastructure was calculated by the linear method, taking junk value equal to zero. Value was divided by hours/year and rate per hour was obtained. The result was then multiplied by the hours needed to clean each net cage during the year, given in R$ m^3 $year^{-1}$. Depreciation of net cages was similarly calculated. Incremental rate of net cage depreciation was determined by taking into account the equipment´s useful life, with and without mussel infestation. Data from questionnaires showed that there was a 50% decrease in the useful life of *L. fortunei* infested net cages. Yearly depreciation rate of net cages was divided by volume (m^3) of each fish farm and given in US$ m^3 $year^{-1}$.

Labor, maintenance, electricity and fuel costs were calculated by multiplying unit rate (R$ $hour^{-1}$) by the amount of hours required for golden mussel control operation. Results are given in R$ m^{-3} $year^{-1}$. Labor costs amounted to a monthly wage of R$ 1,000.00 plus fringe costs at 43% of wage, totaling R$ 1,430.00 a month, divided by 200 hours per month, at a rate of R$ 7.15 h^{-1}.

Maintenance rates for infrastructure, net cages and other equipments were calculated per year in cases where these data were available. Therefore, the above data provided the percentage rate/year of the (new) object. Yearly maintenance costs of each item were thus determined.

Additional expenditure in electricity or fuel was determined by multiplying mean consumption of equipments (Kw h^{-1} or L h^{-1}) by the unit cost of fuel (R$ L^{-1}) or electricity (R$ Kwh^{-1}) and the result multiplied by labor hours/year required for the activity.

Yearly costs (R$ $year^{-1}$) in mussel control were divided by yearly production (kg $year^{-1}$), with rate in R$ kg $fish^{-1}$. Consequently, the impact of mussel control on the costs of tilapia production for each fish culture is thus provided. Rates were obtained for July 2016 (1.00 R$ = US$ 3.278). Addition costs in R$ kg $fish^{-1}$ were divided by the operational costs of tilapia production and multiplied by 100, for percentages. Operational costs followed COSTA (2016) who calculated the cost of the tilapia in the mid-River Paranapanema region on the fish farms under analysis. Data, retrieved from the Campo Futuro project, published by Embrapa Pesca e Aquicultura, were employed to determine the impact due to volume of net cages (MUNOZ *et al*., 2014a, 2014b;

Table 1. Fish farms analyzed to calculate added costs due to infestation by the golden mussel.

Fish farm	Size	Reservoir	Total Volume (m^3)	N and volume of net cages
1	S (<1,000 m^3)	Canoas II	132	19 ; 6 m^3 1 ; 18 m^3
2		Canoas I	270	10 ; 27 m^3
3		Canoas II	1,110*	18 ; 6 m^3 42 ; 18 m^3
4		Ilha Solteira	996	100 ; 6 m^3 22 ; 18 m^3
5	M (1,000 m^3 - 5,000 m^3)	Canoas II	2,040	130 ; 6 m^3 70 ; 18 m^3
6		Canoas II	3,060	120 ; 6 m^3 130 ; 18 m^3
7		Canoas I	4,080	120 ; 7 m^3 150 ; 18 m^3
8		Canoas I	3,600	200 ; 18 m^3
9	L (>5,000 m^3)	Chavantes	20,700	650 ; 18 m^3 250 ; 36 m^3
10		Chavantes	5,424	172 ; 6 m^3 122 ; 36 m^3
11		Ilha Solteira	6,768	376 ; 18 m^3
12		Ilha Solteira	12,636	270 ; 18 m^3 72 ; 108 m^3

*Although this enterprise has available a total volume larger than 1,000 m^3, the breeder uses a maximum water volume of 1,000 m^3 because of the Environmental Licensing restriction.

MUNOZ *et al*., 2015a, 2015b; MUNOZ and BARROSO, 2016a, 2016b; MUNOZ and REZENDE, 2016a, 2016b).

Cost difference between net cage volumes and between different sizes of fish farms was calculated by Kruskal-Wallis test, followed by the comparison of Wilcox´s mean at 5% significance. Statistical tests were performed with R 3.2.5.

RESULTS AND DISCUSSION

Additional costs greatly varied in the different fish cultures and ranged between R$ 36.73 m^{-3} (L) and R$ 122.92 m^{-3} (S) (Table 2). Depreciation and maintenance of net cages had the greatest impacts on additional costs at a mean rate of 69.89%. High impact rates of these items revealed that the main economic impact of mussel is related to the physical damage in net cages since they require periodical maintenance and average a 50% decrease. Impact rate may be lower if the mesh of the net cages were manufactured or coated by some material that would impair the adherence of mussels and reduce frequent procedures for the removal of the mollusk. Several studies have shown that *L. fortunei*´s byssus adherence force to the substrate and the rupture pattern of byssus filaments may be different for each material (MATSUI *et al*., 2002). Ohkawa and Nomura (2015) report that different materials and surface treatments influence the production of byssus threads by mussels and their adherence to the substrate.

Large-size projects had the lowest added costs per kg of fish (mean R$ 0.45±0.15 kg $fish^{-1}$), and differed from costs forwarded by medium-size fish farms (mean R$ 1.00±0.61 kg $fish^{-1}$) and small-size fish farms (mean R$ 1.02±0.45 kg $fish^{-1}$), with great similarity (Kruskal-Wallis $x^2(2)=9.07$; p=0.01). Costa (2016) calculated the operational production costs in the region of the mid-River Paranapanema, with mean rates at R$ 3.99 kg $fish^{-1}$ (S), R$ 3.67 kg $fish^{-1}$ (M) and R$ 3.92 kg $fish^{-1}$ (L). When rates and added costs for each fish farm size are taken into account, one may calculate that mussel impact amounted to 11.48% (L), 27.25 (M) and 25.81% (S).

There was no difference in costs per cubic meter between the enterprises´ different sizes. Mean rates reached R$ 54.94±16.07 m^3 (L), R$ 51.28±11.08 m^3 (M) and R$ 85.42±44.60 m^3 (S) (Kruskal-Wallis $x^2(2)=3.66$; p=0.16). Costa (2016) assessed production costs in cages with 6-31 m^3, in the mid-River Paranapanema, and demonstrated that larger farms had the lowest production costs when compared with those of smaller ones.

The highest costs in small-size fish farms may be associated with the cleaning machine (maintenance and depreciation) and to the cleaning system of the net cages, including the time spent to transport the net cages to the cleaning site. This fact also implies labor costs. Highest increase in additional costs in small-size fish

Table 2. Technical coefficients and **a**dditional costs in golden mussel infestation in the breeding of tilapia in net cages, with different volumes and production scales, in 2016. 1US$ = R$ 3.278.

Item	S (<1000 m³; n=4)			M (1000 to 5000 m³; n=4)			L (>5000 m³; n=4)			
	6 m³ (n=3)	18 m³ (n=3)	27 m³ (n=1)	6 m³ (n=2)	7 m³ (n=1)	18 m³ (n=4)	6 m³ (n=1)	18 m³ (n=3)	36 m³ (n=2)	108 m³ (n=1)
Technical coefficient										
Cleaning per year (times a year)	3.33	3.00	4.00	1.25	2.00	1.88	6.00	2.63	6.75	3.00
Cages handling time (hours.cage^{-1})	2.17	2.60	2.30	3.00	1.00	3.50	1.50	3.18	1.75	3.50
Cages cleaning time (hours.cage^{-1})	1.90	2.23	2.00	1.25	0.50	1.88	0.75	2.65	1.00	3.00
Costs (R$.m^{-3})										
-Yearly costs	124.31	61.90	39.26	63.48	45.10	46.72	79.40	58.25	36.73	53.68
-Labor costs	9.14	3.14	0.85	4.77	2.04	2.63	10.73	2.75	3.15	0.70
-Electricity or fuel	3.31	1.04	0.24	0.72	0.38	0.43	2.01	0.95	0.78	0.22
-Depreciation										
Net cages	27.78	13.24	4.44	29.17	17.14	17.92	16.67	28.56	13.43	31.11
Cleaning infrastructure	3.64	1.53	5.93	0.79	0.60	0.79	2.40	1.69	0.68	0.15
Cleaning machine	17.08	6.28	5.93	0.58	0.24	0.42	7.21	0.50	2.38	0.10
-Maintenance										
Net cages	32.50	21.39	6.03	25.54	23.88	23.02	23.21	22.29	11.36	21.11
Cleaning infrastructure	3.73	3.57	7.92	0.56	0.33	0.47	2.70	1.03	0.78	0.17
Cleaning machine	27.14	11.71	7.92	1.37	0.49	1.04	14.46	0.48	4.17	0.12
Added costs per unit (R$.kg fish^{-1})	1.29	0.96	0.42	0.80	1.90	0.88	0.72	0.42	0.41	0.35

Note: "n" is the number of fish farms; S = Small; M =Medium; L = Large.

farms may also be associated with great infestation rates in such conditions. Taking for granted that depth is adequate, small-size fish farms lie in more protected sites, closer to river banks and with a slower water current, featuring a simpler and less expensive infrastructure for anchorage, access and displacement in the water. However, this condition provides greater accumulation of wastes, primary productivity and probably greater availability of food for the filtering golden mussels, with more cleaning time or frequency and, thus, more depreciation of net cages. The colonization of new *L. fortunei* specimens occurs preferentially in areas which have already been colonized by similar species and on surfaces with well-developed periphytal biofilms in places protected from predators and natural disturbances, and provided with food availability (SARDIÑA *et al*., 2008; CORREA *et al*., 2015; IWASAKI, 2015). CAMPOS *et al*. (2013) reported that flow increase may be a barrier for the installation of the species, making difficult the establishment of larvae and, consequently, decrease in survival rates and recruitment of young specimens.

Lowest additional costs occurred in the biggest production scale and in cages larger than 108 m³, due to costs related to fixed capital of the net cages which was more representative of calculated costs. Consequently, it may be expected that increase in production scale lowers costs since fish farming is an activity with decreasing costs (ONO and KUBITZA, 1999; VERA-CALDERÓN and FERREIRA, 2004).

There were differences in added costs per m³ between the different volumes of net cages (Kruskal-Wallis $x^2(5)=13.83$; p=0.02). Costs decrease in proportion to volume increase. The following mean rates were calculated: 6 m³ = R$ 96.55±39.98 m³; 18 m³ = R$ 55.15±12.56 m³; 36 m³ = R$ 36.73±7.30 m³, with all averages different from each other. However, there was no difference in costs per kg fish^{-1} (Kruskal-Wallis $x^2(5)=9.70$; p=0.84). Taking production capacity into account, the costs per kg in the fish farms under analysis averaged R$ 1.03±0.36 (6 m³), R$ 0.74±0.48 (18 m³) and R$ 0.41±0.04 (36 m³).

Table 3 shows average added cost per kg for golden mussel control, taking the volume of the net cage into account. Added costs decreased when the volume of the net cage increased, at 19.22% for 6 m³; 16.19% for 18 m³; 8.02% for 36 m³ and 7.83% for 108 m³.

The high impact of the golden mussel on fish farming production costs is due to fast colonization and to biological invasion-friendly reservoirs (BERTNESS, 1984; VITOUSEK *et al*., 1996). As a rule, Brazilian water bodies enhance the reproduction and development of the golden mussel since its limits are wide, as several publications reveal (DARRIGRAN, 1995; DARRIGRAN and PASTORINO, 1995; DARRIGRAN, 2002; CAPÍTOLI and BEMVENUTI, 2004; BRUGNOLI *et al*., 2005; KARATAYEV and BOLTOVSKOY, 2015).

Table 3. Production costs of tilapia in net cages in several Brazilian regions (money corrected by IGP for July 2016) and added costs per kg due to golden mussel.

Site	Period	Volume of net cage (m^3)	TOC (R$ kg fish^{-1})	*Added costs (R$ kg fish^{-1})
Gloria-BA	11/2014	6	4.73	
Londrina-PR	05/2015	6	6.17	
Morada Nova – MG	04/2016	6	5.17	
Average			**5.36**	1.03
Felixlandia-MG	03/2016	18	4.68	
Santa Fé do Sul-SP	07/2016	18	4.47	
Average			**4.57**	0.74
Catanhã-CE	08/2015	36	5.11	0.41
Santa Fé do Sul-SP	07/2016	108	4.47	0.35

TOC = Total Operational Costs; * Mean rate of added costs in current research.

CONCLUSION

The economic impact of mussel infestation in the production costs of the tilapia bred in net cages is high, especially in small-size fish farms. In relation to TOC, mean economic impact per kg was 11.48% (L), 27.25% (M) and 25.81% (S). When the volume of net cages was taken into account, the impact varied between 7.83% in 108 m^3 cages and 19.22% in 6 m^3 cages.

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