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Bioenergetic budget of juveniles of fat snook *Centropomus parallelus* (Perciformes, Centropomidae) as a function of salinity acclimation

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Abstract. The energy allocation from food consumption (C) to fecal losses (F), routine oxygen consumption (Rr), ammonia excretion (U) and body mass production (P) was assessed in juveniles of *Centropomus parallelus* acclimated for 15 and 30 days to 5, 20 and 30 salinities, and temperature of 21º C. Oxygen consumption and ammonia excretion were linear related to fish wet weight and differences were significant either between salinities and acclimation periods. The body mass production suggests this salinity range as better conditions for rearing *C. parallelus* at this stage of life cycle. The energy balance as food consumption ranged from: 101.86 to 105.43%; 79.85 to 92.90%; 91.16 to 111.66%, at salinities 5, 20 and 30, respectively. This energy balance was comprised with metabolic maintenance that expended from 40 to 70% and with 20 to 42% saved as body mass production, in accordance to the salinity and period of acclimation. The energy lost as feces and ammonia excretion represented ca. of 8.70 - 11.90% and 0.50 – 1.30%, respectively from the general balance. Suitable environmental conditions for the fat snook aquaculture are discussed in accordance to the present results.

Keywords: bioenergetic budget, *Centropomus parallelus*, salinity

Resumo. Orçamento bioenergético de juvenis de robalo-peva *Centropomus parallelus* (Perciformes, Centropomidae) em função da aclimatação à salinidade. A alocação de energia a partir do consumo alimentar (C), para as perdas fecais (F), consumo de oxigênio de rotina (Rr), excreção de amônia (U) e produção de massa corpórea (P) foi avaliada em juvenis de *Centropomus parallelus*, aclimatados durante 15 e 30 dias, às salinidades 5, 20 e 30 e à temperatura de 21º C. O consumo de oxigênio e a excreção de amônia, linearmente correlacionadas com o peso úmido, apresentaram diferenças significativas entre as salinidades e períodos de aclimatação. O aumento de massa corpórea sugere que este intervalo de salinidade representa condições melhores para a criação de *C. parallelus* neste estágio do ciclo de vida. O consumo de energia alimentar variou de: 101,86 a 105,43%; 79,85 a 92,90%; 91,16 a 111,66% nas salinidades 5, 20 e 30, respectivamente. Este balanço energético correspondeu ao gasto metabólico que variou de 40 a 70% e à produção de massa corpórea de 20 a 42%, conforme a salinidade e período de aclimatação. A energia perdida nas fezes e na excreção amoniacal representou respectivamente, cerca de 8,70 - 11,90% e de 0,50 - 1,30% do balanço geral. Condições ambientalmente adequadas para a aquicultura de robalos são discutidas de acordo com os presentes resultados.

Palavras chave: orçamento bioenergético, *Centropomus parallelus*, salinidade

Introduction

The fishes fat snook, *Centropomus parallelus* (Perciformes, Centropomidae) live in estuaries and lagoons on the coastal zones from South Florida to Southeast Brazil (Rivas 1986), in brackish, freshwater or, occasionally, in saltwater. They feed on small invertebrates and fishes (Figueiredo & Menezes 1980) and can reach up to 500-700 mm in body length (Tucker 1987, Neidig *et al*. 2000). They are valuable for commercial and for recreational fisheries due to the quality of their flesh and are recognized in Brazil as promising to aquaculture (Temple *et al*. 2004). Fat snook usually spawns near shore and after hatching, larvae are drifted along the currents to the protected estuarine areas (Gilmore *et al*. 1983, McMichael & Parsons 1989). Depending on the life stage, fat snook explores different estuarine habitats where salinity ranges from 0 to 30 PSU (Practical Salinity Unit). This wide variation certainly implies in metabolic energy constraints for development and growth (Peterson & Gilmore Jr. 1991, Aliaume *et al*. 1997, Peters *et al*. 1998). These constraints have been observed as resulting from the energetic costs of ionic and osmotic regulation (Morgan & Iwama 1991, Altinok & Grizzle 2001).

Biological processes are differently affected by environmental factors, such as seasonal or daily changes. Bioenergetic studies help to understand the function of organisms and populations in terms of energy flow in ecosystems by reflecting interactions of physiological processes with the environmental factors (Rocha *et al*. 2001). Fish bioenergetic assessments comprise the partitioning of ingested energy into the major physiological components of the energy budget equation (Jobling 1994). Relationships of energy transformation between consumption, losses and production rates can be quantified by ecological units (Phillipson 1975, Allen & Wooton 1982) whose data contribute to ecological modelling and help to manage the fishing pressure on wild stocks of marine ecosystems (Pauly *et al*. 2002). Thereafter bioenergetic budget is an important tool for the management of living marine resources for environmental protection and aquaculture purposes (Karas & Thoresson 1992, Lesser *et al*. 1996, MacIsaac *et al*. 1997, Lemos & Phan 2001, Lemos *et al*. 2001). Furthermore, scientific recommendations for fish artificial breeding such as how to optimize feed ration by minimizing wastes and water pollution as well as supporting high energy conversion and fast growth are needed in aquaculture (Sun *et al*. 2006).

Several studies have focused on the effect of salinity on fish energetics such as feeding rates, food conversion efficiency, metabolism, nitrogen excretion and growth (Wright *et al*. 1995, Altinok & Grizzle 2001, Foss *et al*. 2001, Frick & Wright 2002, Eroldoğan *et al*. 2004). However, no one of them addressed the effects of environmental factors by integrating results from all the components into the energetic budget.

The purpose of this study was the assessment of the integrated energetic budget of juveniles of *C. parallelus* acclimated for 15 and 30-day periods at different salinities. Live feed ingestion, feces, oxygen consumption, ammonia excretion and growth were measured in order to establish the energy balance. These data provide means to evaluate the effects of environmental factors on ecosystems and to find out the better conditions of fish growth and energy conversion.

Materials and methods

Fish capture and experimental design

Juveniles of *C. parallelus* (~1.5 g) were collected at the tidal inlet of Cananéia estuary, South Coast of São Paulo State, Brazil (25°05’ S – 47°55’ W). Fishes were captured by using a beach seine, 4 m wide, 1.5 m high and mesh size of 0.5 mm. Individuals were immediately brought to the laboratory of the “Instituto Oceanográfico-USP”, where they were gradually acclimated to 5, 20 and 30 experimental salinities during 30 days, in 500 Liters tanks for each experimental salinity. At this acclimation period, fish were fed once a day, by offering live juveniles Caridae shrimp, *Macrobrachium sp*. and *Potimirim glabra* (Holthuis, 1993), natural diet items of *C. parallelus* in the environment. Thereafter, 90 fishes were randomly picked up and weighted. Three groups (one for each salinity) with 30 individuals each were transferred to 50 Liters plastic boxes, following experimental periods of 15 and 30 days, at the controlled temperature of 21° C and under natural photoperiod. The water of the maintenance tanks and experimental boxes were constantly and artificially aerated. All the water of both systems was daily replaced and feces removed. The water at the experimental salinities were prepared daily and stored in 500 Liters to be used at the following day. A light refractometer ATAGO was employed to calibrate the different mixtures of seawater and freshwater at the chosen conditions. Both the seawater and the freshwater, which came from unpolluted sites, were filtered at 1μm previously to water mixtures.

Food Consumption (C)

Food was supplied once a day and consisted of live juveniles Caridae shrimp, *Macrobrachium sp*. and *Potimirim glabra* (Holthuis, 1993), natural diet items of *C. parallelus* as previously reported. Food was weighted and offered at the mornings (8:00h), up to 15% of individual mean weight of fishes. Uneaten shrimp was removed and weighted afterward. Specific Feeding Rates (SFR%) were calculated for each acclimation period at different salinities, according to the equation SFR = $C_t W_t^{-1}$*100% (Wuenschel *et al*. 2004), where C_t = the wet weight of prey consumed on day *t*, and W_t = the fish wet weight on day *t* estimated from exponential growth model (Ricker 1979).

Fecal losses (F)

Fecal losses were daiy quantified by collecting feces, which were siphoned and carefully rinsed to eliminate salt content with distilled water. Samples were dried at 60° C for 72h to constant mass determination using a Precisa 92SM-202A analytical balance (± 0.01mg).

Routine metabolic (Rr) and excretion (U) expenditures

The routine metabolic and excretion expenditures were assessed through the routine oxygen consumption (Rr) and ammonia-N excretion (U) rates, as previously reported (Rocha *et al.* 2005). Regression analyses were performed between metabolic rates and individual body mass by log transforming data of oxygen consumption, ammonia-N excretion and fish wet weight. Data were expressed as milligram of oxygen consumption per hour (mg O_2 h^{-1}) and micro molar of ammonia-N excretion per hour (μM-N h^{-1}), were corrected for Specific Dynamic Action (SDA) due to post prandial effects, according to Muir & Niimi (1972) and to Brett & Zala (1975) considering the 50% increase in oxygen consumption and a 4.6 times increment of ammonia excretion rates, respectively, 3 h after feeding.

Body mass production (P)

Body mass production was determined by differences of final and initial wet weight of fishes exposed to different salinities for each experimental period. Mean (±SD) Specific growth rates (SGR%) previously calculated and published in Rocha *et al.* (2005) are reported (Table II).

Energy values

The components of food consumption (C), fecal losses (F) and body mass production (P) had the values converted to their respective energy. Samples of the whole shrimp (food) and fish were dried at 60° C for 72 h to constant weight. Amounts of 8-12 mg dry samples were converted to energy by wet combustion (Karzinkin & Tarkovskaya 1964) and expressed as calories Cal g^{-1} WW. Oxygen consumption (Rr) and ammonia-N excretion (U) rates were transformed to energy by 4.64 Cal mL^{-1} O_2 (Brett 1985) and 5.94 Cal mg^{-1} N (Elliott & Davison 1975), respective energetic equivalents. Absorption efficiency (AE%), which expresses the percentage of consumed energy allocated to metabolism and growth was calculated as $AE = (C - F)\ C^{-1}*100$, where C is the total energy of prey biomass ingested and F is the total energy of fecal material. Gross growth efficiency (K_1%) and net growth efficiency (K_2%) were also calculated respectively as $K_1 = PC^{-1}*100$ and $K_2 = P\ (P + R)^{-1}$ where P is the energy of fish growth, C is the energy of prey biomass ingested and R is the energy expended as metabolism. Daily values of F, Rr, U and P were expressed as daily percentage of energy consumed (C) as calories (%Cal day^{-1}) and grouped on energetic budgets for each acclimation periods at the different salinities.

Statistical analysis

Regressions significance was checked by Pearson product moment correlation, after the confirmation of normal distribution and homogeneity of variances. Significant differences of regressions between salinities were tested by ANCOVA of the oxygen consumption and ammonia excretion rates with fish wet weight as covariate, followed by Newman-Keuls post-hoc comparison test at $p<0.05$ (Zar 1996). Differences of mean values of the SFR, K_1 and K_2 among acclimation periods and salinities were checked by two-way ANOVA, followed by Newman-Keuls post-hoc test at $p<0.05$ (Zar 1996). AE values were checked by non-parametric statistics Mann-Whitney U test.

Results

The mean values of individual food consumption, fecal losses and body mass of juveniles of *Centropomus parallelus*, at different salinities and acclimation periods are shown on Table I.

Mean (±SD) oxygen consumption, ammonia-N excretion and specific growth rate are referred on Table II.

Both oxygen consumption and ammonia-N excretion rates increased significantly with body mass at different salinities and acclimation periods (Figs. 1 and 2).

Differences in slopes of regression equations of the oxygen consumption and ammonia-N excretion between salinities were not significant for both acclimation periods. As indicated by the regression elevations, the oxygen consumption of fat snook acclimated to 20 salinity was lower than those of 5 and 30 salinities after 15 days of acclimation (Fig. 1A). After 30 days, the oxygen consumption of fishes acclimated to 20 salinity was higher than those of 5 and 30 salinities (Fig. 1B). The ammonia-N excretion decreased significantly as a function of salinity, being the lowest rate in the 30 salinity at both acclimation periods (Figs. 2A and B).

Table I. Mean values (±SD) of food consumption, fecal losses and body mass increment of juvenile of *Centropomus parallelus*, at different salinities and acclimation days.

Salinity	Acclimation (days)	Food consumption (g WW ind^{-1} day^{-1})		Fecal losses (mg DW ind^{-1} day^{-1})		Body mass increment (g WW ind^{-1} day^{-1})	
5	15	0.182	±0.038	4.17	±0.74	0.017	±0.013
	30	0.208	±0.034	4.34	±0.85	0.018	±0.003
20	15	0.156	±0.036	3.36	±0.91	0.020	±0.011
	30	0.171	±0.034	3.44	±0.60	0.007	±0.001
30	15	0.161	±0.040	2.42	±0.74	0.011	±0.006
	30	0.156	±0.042	2.80	±0.80	0.004	±0.002

WW: wet weight; DW: dry weight

Table II. Mean (±SD) oxygen consumption (mg O_2 g^{-1} WW h^{-1}), ammonia-N excretion (NH_4 μM g^{-1} WW h^{-1}) and specific growth rate (SGR%) of juvenile of *Centropomus parallelus*, at different salinities and acclimation periods (Rocha *et al*. 2005).

Salinity	Acclimation (days)	O_2 mg g WW^{-1} h^{-1}		NH_4 μM g WW^{-1} h^{-1}		SGR%	
5	15	0.309	±0.061	0.988	±0.255	0.82	±0.59
	30	0.261	±0.027	0.718	±0.106	0.71	±0.15
20	15	0.222	±0.019	0.620	±0.108	1.21	±0.67
	30	0.316	±0.051	0.504	±0.112	0.35	±0.04
30	15	0.282	±0.051	0.358	±0.163	0.42	±0.22
	30	0.245	±0.047	0.239	±0.076	0.15	±0.07

WW: wet weight

There were significant differences in SFR, AE, K_1 and K_2 of fishes between salinities (Table III). Mean (±SD) SFR and AE values were higher at the 20 salinity either after 15 or 30 days of acclimation. K_1 and K_2 values were higher at the 20 and 5 salinities after 15 and 30 days of acclimation, respectively. Regarding periods of acclimation, there were not significant effects on SFR values. Nevertheless, differences in AE, K_1 and K_2 values were significant at 20 and 30 salinities.

The energy partitioning of juveniles of *C. parallelus* are shown on Figure 3. The final balance as energy food consumption (C) ranged from 101.86 to 105.43%; 79.85 to 92.90%; 91.16 to 111.66% at the salinities 5, 20 and 30, respectively. The general balance was comprised of metabolic energy maintenance (Rr) that expended from 40 to 70% and saved from 20 to 42% as body mass production (P) according to the salinity and period of acclimation. Fecal losses and ammonia-N excretion represented 8.70 - 11.90% and 0.50 – 1.30%, respectively from the general balance.

Discussion

For carnivorous fishes consuming natural prey, absorption efficiency (AE) frequently ranges from 70 to 95% (Jobling 1994). Accordingly, fishes consumed from 5.57 to 9.85% of their body weight per day, and they absorbed from 89.34 to 92.29% of the food energy ingested. These values perfectly fit the expected for young carnivorous fish. The growth indices K_1 and K_2 ranged from 5.20 to 25.27% and from 8.50 to 42.88%, respectively. Growth of healthy young carnivorous fish in an ideal environment is expected to represent around 30% to 50% of the energy budget (Du Preez *et al*. 1990). In fact, at salinities between 5 and 20 growth was near the expected ranges. Lemos *et al*. (2006) reported 9.2 and 9.9% as the respective K_1 and K_2, of juveniles of *C. parallelus* at the experimental temperature of 25ºC and salinity 20. The authors attributed the unexpected low growth indices to an elevated metabolic demand represented by 82% of the ingested energy, what is certainly above the common values. At our study, the metabolic demand of fishes acclimated to 20ºC accounted for 40.75 to 69.53% of the total energy of the food consumed. In addition, significant correlations were also found between the metabolic energy demand and the body mass of *C. parallelus* governed by allometric functions similar to those described for exothermic marine animals (Levinton 1995). A temperature increase of 10 ºC usually causes a twofold raise on fish metabolic rates, referred as Q_{10}, which varies throughout the range that an animal can tolerate (Schmidt-Nielsen 1990). Accordingly, differences between metabolic rates of both studies may be attributed to the experimental temperature adopted by them, which also influenced the growth indices.

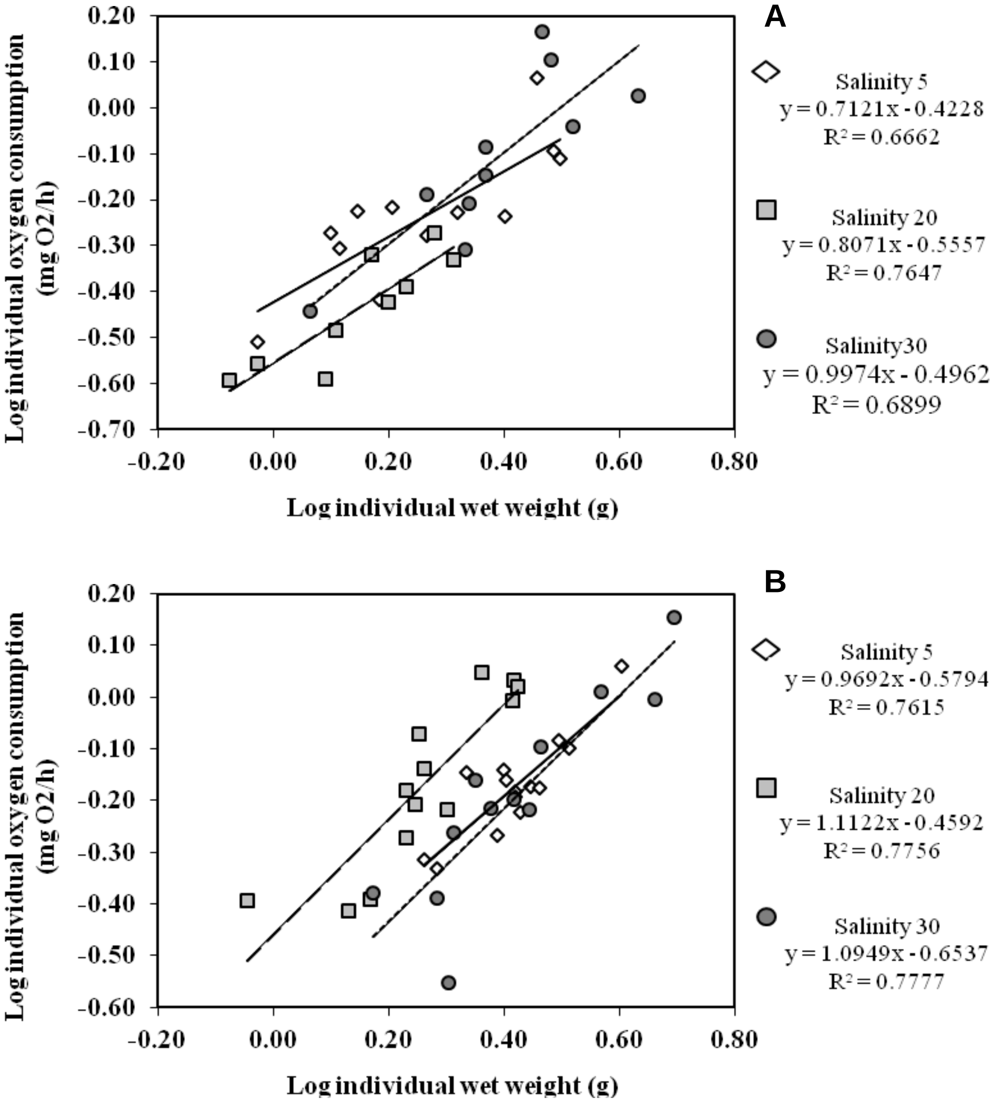


Figure 1. Regression analysis between oxygen consumption and individual wet weight (g) of juveniles of *Centropomus parallelus* acclimated for 15 (A) and 30 days (B) to different salinities.

Many fish species at the juvenile stage inhabit protected areas, such as estuaries and coastal lagoons, where the conditions are suitable for their development. In the natural environment of the Cananéia estuary, *C. parallelus* is well adapted to the daily salinity range influenced by strong tidal cycle (Miranda *et al*. 2002). This range encompasses the variation adopted in this study. Since ion-osmotic regulation affects the energy available for fish growth (Morgan & Iwama 1991, Soengas *et al*. 1995, Altinok & Grizzle 2001), a range of salinity that provides better energy conversion efficiency and growth must be achieved in order to optimize the fish culture (Wang *et al.* 1997). For instance, Tsuzuki *et al.* (2007) demonstrated that fat snook reared at 15 salinity has efficient digestibility, as well as nutrients and protein absorption.

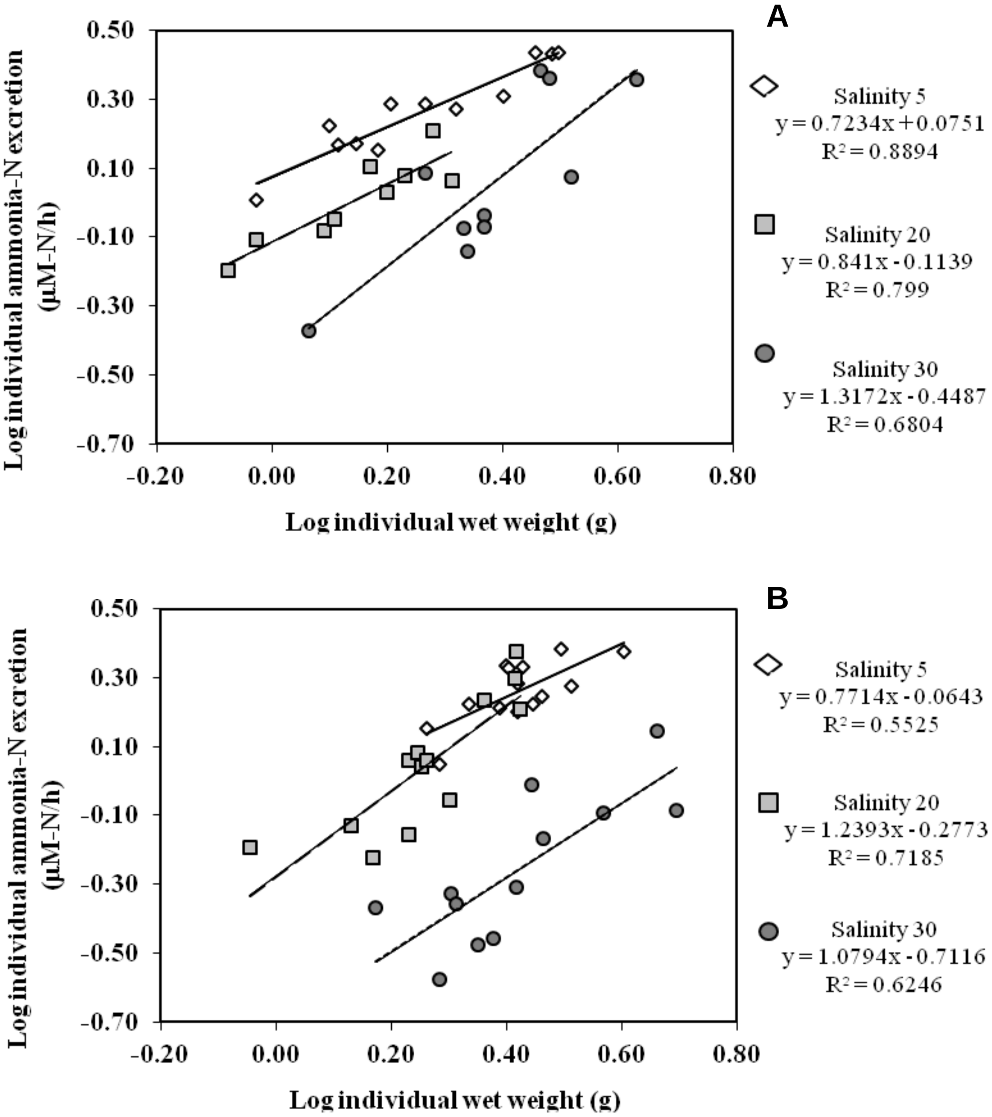
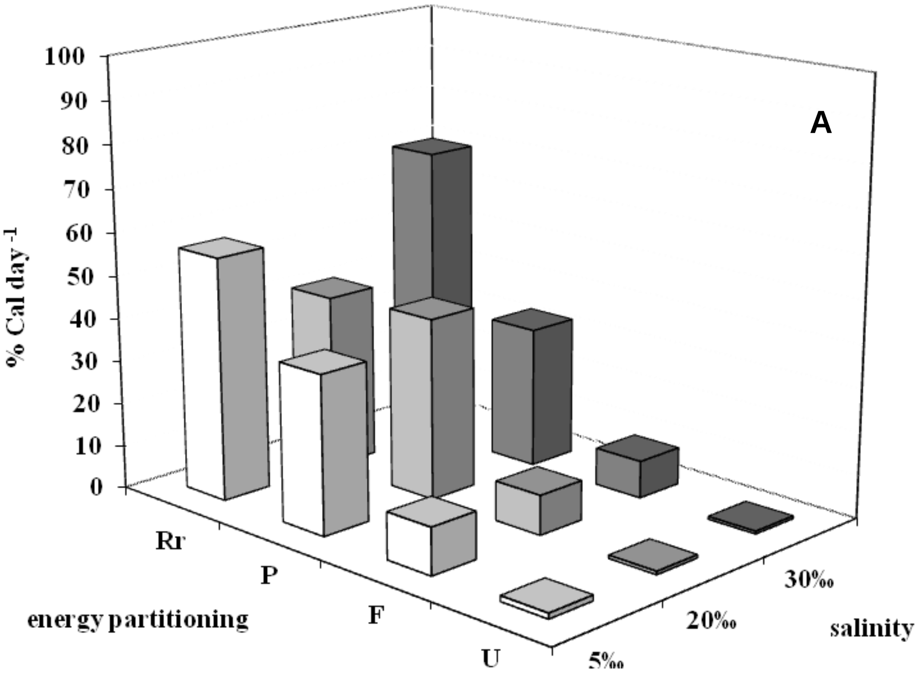


Figure 2. Regression analysis between ammonia-N excretion rates and individual wet weight (g) of juveniles of *Centropomus parallelus* acclimated for 15 (A) and 30 days (B) to different salinities.

Table III. Mean (±SD) specific feeding rate (SFR%), absorption efficiency (AE%), gross growth efficiency (K_1%) and net growth efficiency (K_2%) of juvenile of *Centropomus parallelus,* at different salinities and acclimation periods.

Salinity	Acclimation (days)	SFR%	AE%	K_1%	K_2%
5	15	a 8.95 ±2.04	b 90.23 ±1.76	b 17.66 ±4.30	b 27.59 ±7.11
	30	a 8.38 ±1.57	bc 89.34 ±1.15	bc 15.40 ±2.53	b 24.21 ±4.17
20	15	a 9.85 ±2.57	a 92.29 ±1.37	a 25.27 ±6.99	a 42.88 ±5.78
	30	a 8.88 ±1.86	bc 90.64 ±1.72	d 7.76 ±1.43	d 12.55 ±3.48
30	15	b 6.23 ±1.60	ab 91.54 ±2.56	c 2.92 ±3.13	c 18.11 ±5.21
	30	b 5.57 ±1.55	c 89.69 ±1.01	d 5.20 ±1.20	d 8.50 ±3.28

Different letters indicate significant differences between salinities and acclimation periods; WW: wet weight.



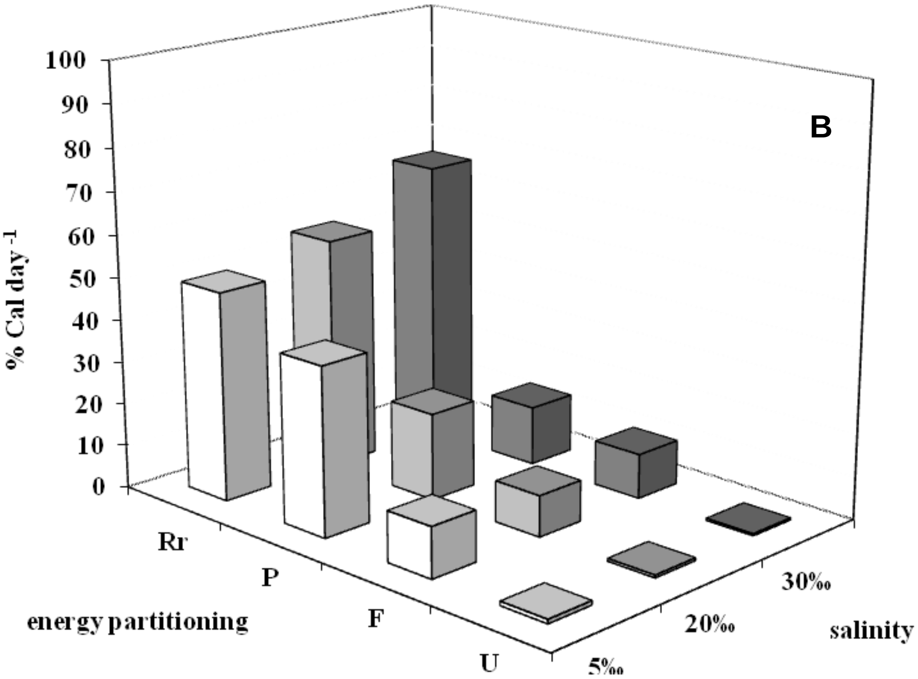


Figure 3. Energy partitioning (%) of juveniles of *Centropomus parallelus* acclimated for 15 (A) and 30 (B) days to different salinities.

Our data indicate pronounced effects of salinity on the energy balance of juveniles of *C. parallelus*. Besides the values of food consumption, the highest SFR rates were also found between 5 and 20 salinities for both acclimation periods, indicating a preferable feeding condition at this salinity range. As a measure of the amount of digestible energy, the highest AE at the 20 salinity during 15 days of acclimation means that more energy is available for metabolism and growth (Getchis & Bengtson 2006). Accordingly, once the metabolic demand was low in fishes acclimated for 15 days at the 20 salinity, the available energy was demonstrated by the highest absorption efficiency, which could be suitably channeled to growth as shown by the highest values of SGR, K_1 and K_2. However, fishes acclimated for 30 days at the 20 salinity presented elevated metabolic rates, constraining K_1 and K_2 that were similar to the respective values at the 30 salinity. The cost of osmoregulation at the extreme salinities may limit the energy available for production unless the fish can compensate by increasing its feeding rate (Wootton 1990). Perhaps the lowest growth rate of fishes acclimated to the 30 salinity in both periods were due to the low food intake and the elevated metabolic demand. On the other hand, the metabolic energy demand of fish acclimated for 15 and 30 days to the 5 salinity was compensated by the energy available from the food intake, resulting in SGR, K_1 and K_2 values that favored the growth rate. Ammonia excretion accounts for up to 80% of the total nitrogen as final products from the protein catabolism in marine fish (Wright *et al.* 1995). Decreasing rates in ammonia excretion at the highest salinities is a consequence of reduced amino acid catabolism and retention of free amino acids (FAA) as osmotic effectors in fish blood stream (Frick & Wright 2002, Tseng & Hwang 2008). Probably, this explains the reduction in the ammonia excretion rates of juveniles of *C. parallelus* at higher salinities.

Methods employed to quantify energetic budget parameters may be reliable as pointed out by Lemos *et al.* (2006). The authors found a balance for the energy partitioning (P + R + U + F) approximating to 90-100% of the ingestion energy calculated for grouped and individual fat snook. In the present study, the energy balance ranged from 80 to 112% of the total food energy consumed by juveniles of *C. parallelus*. Percentage of feces energy demonstrates how digestible are the both Caridae shrimps species, as previously suggested by absorption efficiency values. It was similar to the value reported for tropical marine teleost (Du Preez *et al*. 1990). Despite the decrease as a function of salinity, the energy excreted as nitrogen was lower than that reported for other teleost fishes (Xie *et al*. 1997, Owen *et al.* 1998, Han *et al*. 2004). On the other hand, the highest proportion of the assimilated energy allocated to production, which matches with low percentages of metabolic demand, suggests that the better conditions for growth seems to be between 5 and 20 salinities. The data obtained at these salinities are in accordance with theoretical values expected for young carnivorous fish, and the growth rate is quite acceptable for aquaculture.

This study is the first attempt to understanding the effects of salinity on the physiology of *C. parallelus* by employing the assessment of the integrated bioenergetics parameters. Although other authors have questioned the feasibility of commercial rearing of fat snook due to unsatisfactory growth rates (Alvarez-Lajonchère 2004), these results demonstrate that the aquaculture of juveniles of *C. parallelus* depends at least on the availability of a favorable salinity conditions. However, further studies such as the assessment of other life stages, feeding quality and digestibility are needed to achieve suitable conditions for fat snook commercial aquaculture, at all stages of life cycle.

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