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Seasonal analysis of condition, biochemical and bioenergetic indices of females of Brazilian flathead, *Percophis brasiliensis*

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Percophis brasiliensis is a demersal species that constitutes an important resource of Argentine coastal fisheries. Nevertheless, information about bioenergetic dynamic of reproduction has not been reported. Therefore, seasonal variations of condition factors, biochemical composition and energy density of different tissues were analyzed in order to determine the strategy of energy allocation during the reproductive cycle of this species. Condition indices (hepatosomatic and K) showed a seasonal pattern opposite to that observed for gonadosomatic index, which was characterized by higher values during the reproductive period (spring-summer), decreasing at the end of spawning. Biochemical composition of different tissues also showed a clearly seasonality associated to reproductive cycle. Analysis of energy density variation of liver indicates that *P. brasiliensis* accumulate reserves in winter before reproduction, which later decrease during the spawning season. In contrast, the energy density in muscle did not show significant differences among seasons, indicating that individuals could be also using an external source of energy during spawning. Therefore, it is possible that *P. brasiliensis* respond to an intermediate strategy of energy allocation, combining characteristics of both capital breeders (stores energy previous to the onset of reproductive activity) and income breeders (acquire energy by active feeding during spawning period).

Percophis brasiliensis é uma espécie demersal que constitui um recurso importante para a pesca costeira na Argentina. Não obstante, a informação sobre a dinâmica bioenergética da reprodução não tem sido reportada. Assim, as variações sazonais dos fatores de condição, composição bioquímica e densidade de energia de diferentes tecidos foram analisados para determinar a estratégia de alocação de energia durante o ciclo reprodutivo da espécie. Os índices de condição (hepatossomático e K) mostraram um padrão sazonal oposto ao observado para o índice gonadossomático, o qual foi caracterizado por valores mais elevados durante o período reprodutivo (primavera-verão), diminuindo no final da desova. A composição bioquímica de diferentes tecidos também mostrou uma sazonalidade claramente associada ao ciclo reprodutivo. Análise da densidade de energia do fígado indica que *P. brasiliensis* acumula energia no inverno, antes da reprodução, que mais tarde decresce durante a época de desova. Em contraste, a densidade de energia no músculo não mostrou diferenças significativas entre as estações do ano, indicando que os indivíduos poderiam ter também uma fonte externa de energia durante a reprodução. Portanto, é possível que *P. brasiliensis* responda a uma combinação das estratégias "capital breeder" (armazenam a energia antes do início da atividade reprodutiva) e "income breeder" (adquirem energia através da alimentação ativa durante o período de desova).

Key words: Biochemical composition, Condition, Energy density, Reproduction.

Introduction

Seasonal fluctuations in temperature and productivity, characteristics of high-latitude environments (Clarke, 1983), affect the availability and quality of food for both adults and juvenile fish (Wotton, 1990; Beamish & Bouillon, 1995). Consequently, energy storage is likely to show temporal variations related to environmental production cycles (Dygert, 1990). The energy available to animals has to be allocated among maintenance, somatic growth, and reproduction (Calow, 1985; Sibly & Calow, 1986), and has been correlated with changes in energy density of different organs (Jobling, 1995; Lucas, 1996). An immature female used assimilated energy to metabolism and growth, however, when gonadal maturation begins some of that energy is intended or oocyte development and reproductive behavior. It has been observed that energy reserves change during the spawning season (Lucas, 1996). Maternal attributes and condition affect fish maturity (Marteinsdottir & Begg, 2002; Morgan & Lilly, 2006; Grift *et al*., 2007), fecundity and egg production (Kjesbu *et al*., 1991; Rijnsdorp *et al*., 1991; Lambert & Dutil, 2000; Marshall *et al*., 2006) and offspring viability (Brooks *et al*.,

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1997; Heyer *et al*., 2001; Berkeley *et al*., 2004). In summary, these factors affect the stock reproductive potential, so they should be included in assessment models (Morgan, 2008). The fish condition can be evaluated using several criteria, ranging from simple morphometric measurements (length-weight relationship or K) to physiological (hepatosomatic and gonadosomatic indices) and biochemical measures (proximate composition, such as lipids, proteins and other components in the tissues). Morphometric indices, which assume that heavier individuals of a given length are in better condition, are simple indicators of energy storage, even though they are used reiteratively because they are constructed with simple weight and length data (Lloret *et al*., 2002). Physiological condition indices, like liver index, measure the energy reserves of fish more accurately than morphometric information (Shulman & Love, 1999), but a more precise approach to describe fish condition is biochemical indices, such as lipid content (Sargent & Henderson, 1986; Huss, 1988; Alonso Fernandez, 2011).

Percophis brasiliensis (Brazilian flathead) is a demersal coastal species of the Southwest Atlantic (23°S - 44ºS) (Tomo, 1969; Cousseau & Perrota, 1998) that constitutes an important resource for the Argentine coastal fisheries. As a result of a drastic decrease in total biomass of traditional fishery resources (Argentine hake *Merluccius hubbsi*), fishing efforts have been directed to other fisheries based on coastal species (Aubone *et al*., 1998; Jaureguizar & Milessi, 2008) including *P. brasiliensis*, whose landing has increased over past years (from ~ 4000 t in 2002 to 8000 t in 2011)[1]. As regard the reproductive biology, this species is considered a multiple spawner with indeterminate annual fecundity that typically spawns small eggs from November to April (Austral spring-summer) (Militelli & Macchi, 2001; Rodrigues, 2009). In this type of reproductive strategy the number of oocyte batches during spawning, fecundity and quality of the eggs will be affected by food supply, temperature and other environmental factors (Wootton, 1990). It is unknown whether Brazilian flathead stores energy previous to the onset of reproductive activity ("capital breeder" strategy) or has the ability to acquire energy by active feeding during spawning period ("income breeder" strategy). So the aim of this study is to analyze seasonal changes in condition, biochemical composition and energy density during an annual cycle in order to establish the pattern of energy distribution and storage in relation to sexual development of *P. brasiliensis* females.

Material and Methods

Samples of Brazilian flathead females (N=34) were obtained from commercial landings carried out in Mar del Plata Port from September 2009 to July 2010, and were grouped into seasons (Table 1). In order to avoid possible variations in biochemical composition that are dependent on females size, it was used a defined length range (52-56 cm TL) to analyze seasonal patterns.

Total length (TL) to the nearest cm and total weight (TW), gutted weight (GuW), gonad weight (GW) and liver weight (LW) to the nearest gram were recorded. Individuals were sexed and the maturity development stages macroscopically determined. To that end, following Macchi & Acha (1998), a five stages maturity key was employed: (1) immature; (2) developing or partially spent; (3) gravid (with hydrated oocytes) or running; (4) spent; and (5) resting.

Three general condition indices were calculated for all sampled females: gonadosomatic index (GSI), hepatosomatic index (HSI) and condition factor (K; g/cm^3). These indices were defined by the following equations:

$$GSI = \frac{\text{Gonad Weight}}{\text{Gutted Weigth}} \times 100 \qquad HSI = \frac{\text{Liver Weight}}{\text{Gutted Weigth}} \times 100$$

$$K = \frac{\text{Gutted Weigth}}{\text{Total Lenght}^3} \times 100$$

Proximate composition (water, ash, protein, and lipid) and calorific content of liver, gonads and muscle (fillet without skin) were determined to establish the pattern of energy distribution according to Doyle *et al.* (2007). For this, liver, gonads and muscle (fillet without skin) were extracted from all selected specimens and preserved frozen at "22 %C in plastic bags vacuum sealed until their analysis in laboratory.

To determine lipid content, sub-samples of different size were taken according each tissue: liver (3 to 5 g), gonads (5 to 10 g) and muscle (10 to 20 g). This component was extracted by Bligh & Dyer (1959) method modified by Undeland *et al.* (1998), and gravimetrically quantified by Herbes & Allen (1983) method. Protein content was determined from frozen tissue (1 g) using bovine serum albumin (BSA) concentrated at 1mg/ml as standard and following the protocol of Lowry *et al*. (1951).

In order to obtain water content (moisture) and inorganic matter (ash) subsamples up to 10 g were taken, as allowed the size of each tissue. The samples were dried for 24 h at 105 ºC, and weighed at ambient temperature. Later the dried samples were placed in a muffle furnace for 8 h at 550°C (AOAC, 1995). After this period the ash thus obtained were weighed at ambient temperature.

Energy density (KJ g^{-1}) was estimated for each tissue (ovary, liver, muscle) by multiplying lipid and protein content (mg/g of wet mass) by the appropriate energy equivalents (lipid = 39.5 KJ g^{-1}, protein = 23.6 KJ g^{-1}; Kleiber, 1975). Carbohydrate content was not measured because that component is generally low in marine species and its contribution to total energy content is close to zero (Anthony *et al*., 2000; Eder & Lewis, 2005; Spitz *et al*., 2010).

All determinations were performed in triplicate. Analysis of variance (ANOVA) was performed and means were compared with Tukey's test with 0.05 significance level.

Finally, mean values of female characteristics (total length, gutted weight, liver weight, and gonad weight), condition indices (HSI, GSI, and K), and biochemical components were estimated for each season in order to analyze temporal trends.

Table 1. Morphometric variables and maturity stages of *Percophis brasiliensis* females collected from commercial landings during different seasons. TL: total length, GuW: gutted weight, LW: liver weight, GW: gonad weight.

Season	Month	TL (cm)	GuW (g)	LW (g)	GW (g)	Maturity stage
Spring	November	54	528.23	6.68	37.09	gravid
	November	52	569.66	9.96	38.38	gravid
	November	53	560.78	13.68	32.54	developing or partially spent
	November	56	749.56	11.22	79.22	developing or partially spent
	December	54	649.55	12.24	38.21	gravid
	December	54	629.73	9.90	30.37	gravid
	December	54	575.32	7.08	17.60	developing or partially spent
	December	55	649.99	8.44	22.57	developing or partially spent
Summer	January	53	626.36	17.69	27.95	gravid
	January	54	595.88	10.46	46.66	gravid
	January	54	696.58	10.29	32.13	developing or partially spent
	January	53	666.46	11.98	41.56	developing or partially spent
	January	53	627.63	7.71	21.66	developing or partially spent
	February	54	694.82	13.86	41.32	developing or partially spent
	February	54	622.58	9.47	49.95	developing or partially spent
	February	56	573.27	10.99	29.74	developing or partially spent
	February	55	722.88	11.00	78.12	developing or partially spent
	March	53	575.72	5.50	22.78	developing or partially spent
	March	54	553.97	8.68	22.35	developing or partially spent
	March	53	484.36	8.00	16.64	developing or partially spent
	March	55	624.65	8.71	14.64	spent
Autumn	April	55	692.44	10.28	15.28	spent
	April	55	649.65	4.90	7.450	resting
	May	54	716.13	7.99	8.88	resting
	May	53	665.47	8.68	6.85	resting
	May	55	717.24	11.86	6.90	resting
Winter	July	55	729.39	11.50	9.11	resting
	July	53	632.2	11.12	11.68	resting
	September	53	669.54	13.11	17.35	developing
	September	54	744.95	18.10	14.95	developing
	September	54	776.75	11.72	25.53	developing
	September	54	693.47	8.66	39.87	developing
	September	54	675.54	14.32	18.14	developing
	September	54	745.35	14.94	44.71	developing

Results

It was determined that both, GSI and K, showed significant differences among seasons (Fig. 1). The values of GSI were higher in spring and summer (5.92 and 5.41 respectively), declining significantly in autumn and winter (1.32 and 3.18). This seasonal pattern was coincident with the major proportion of developing or partially spent and gravid organisms observed during November – March (Table 1). Mean K only showed significant differences in winter, when this index was maximal (0.45). In this season also was reported the highest HSI, however the differences were not significant.

Lipids seasonal variation. Significant differences were observed in lipid content of the three tissues analyzed during each season (Table 2, Fig. 2). In muscle and liver the pattern of lipid content was similar, the lowest mean values were recorded during spring and summer, 0.7 and 0.8 g/100g in muscle, and 5.7 and 5.9 g/100g in liver. During cold seasons it was observed an increase of lipid concentration reaching record highs in winter (1.7 and 16.1 g/100g on average for each tissue, respectively). In gonads the mean lipid content was significantly lower in autumn (2.1 g/100g) and remained at similar values for the rest of seasons (6.6 g/100g on average) (Fig. 2).

Proteins seasonal variation. Muscle protein content did not differ significantly between seasons (Fig. 3), with a mean value of 19.2 g/100g. Proteins in gonads and liver showed opposite patterns. In ovaries, values of concentration were higher during the spawning season (spring-summer), declining in autumn (end

Table 2. ANOVA results performed to study seasonal changes of all biochemical components and energy density in each tissue.

	Muscle			Gonad			Liver		
	N	F	p	N	F	p	N	F	p
Lipids	34	20.34	<0.001	34	10.41	<0.001	34	17.64	<0.001
Proteins	34	0.19	0.901	34	4.06	0.015	34	3.48	0.028
Water	34	10.65	<0.001	34	6.65	0.001	34	16.80	<0.001
Ash	34	1.78	0.136	34	2.32	0.09	34	3.05	0.05
Energy density	34	0.66	0.58	34	8.61	<0.001	34	14.42	<0.001

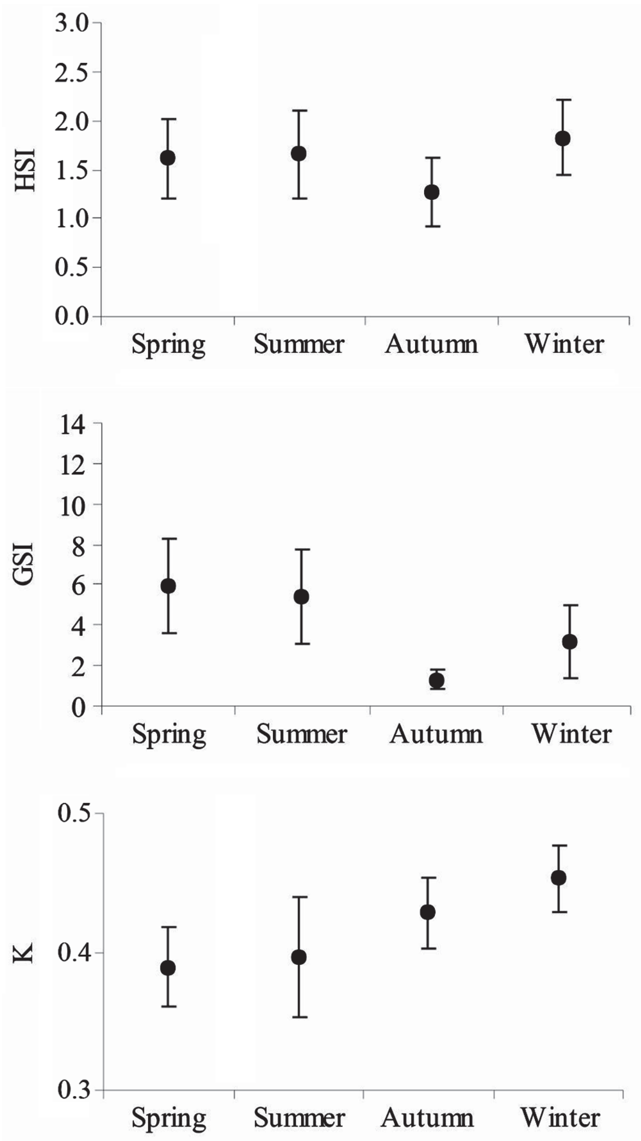

Fig. 1. Seasonal variation of mean and standard deviation of hepatosomatic index (HSI), gonadosomatic index (GSI) and condition index (K) estimated for *Percophis brasiliensis*.

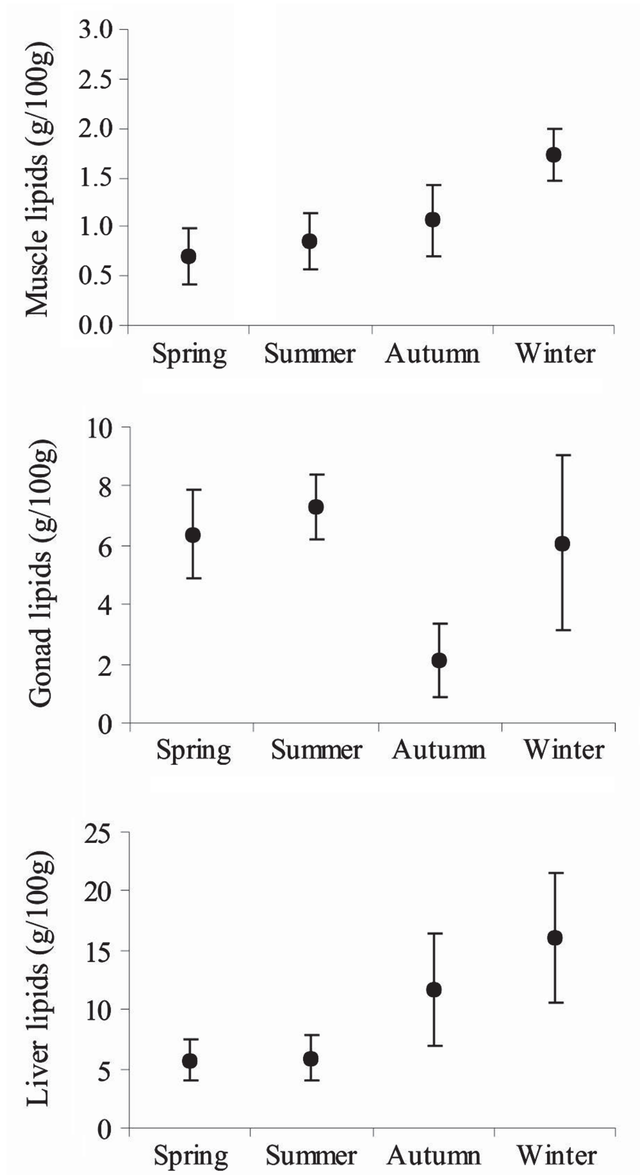

Fig. 2. Seasonal variation of lipid content in muscle, gonad and liver of *Percophis brasiliensis*.

of the reproductive period), and finally increasing in winter, when most of the females are in resting stage. The highest liver protein concentration was registered during autumn, being significantly different from that obtained during summer (Table 2, Fig. 3).

Water content (moisture) seasonal variation. Water content of the three tissues analyzed varied during the seasons (Table 2, Fig. 4). In muscle significant differences were observed in spring in regard with the other seasons, with maximum water content in spring and minimum in winter (78.5 g/100g and 76.7 g/100g, respectively). In gonads major differences were observed between summer (69.5 g/100g) and autumn (78.1 g/100g), during the transition between the reproductive period and the post-spawning phase. Liver showed the highest water content in spring and summer (72.8 g/100g and 73.1 g/100g), and reached the lowest values in autumn and winter (68 g/100g and 64.8 g/100g).

Inorganic matter (ash) seasonal variation. Inorganic matter content showed no significant differences in tissues among seasons (Table 2, Fig. 5), being the mean values 1.35 g/100g, 1.80 g/100g and 1.63 g/100g in muscle, gonads and liver, respectively.

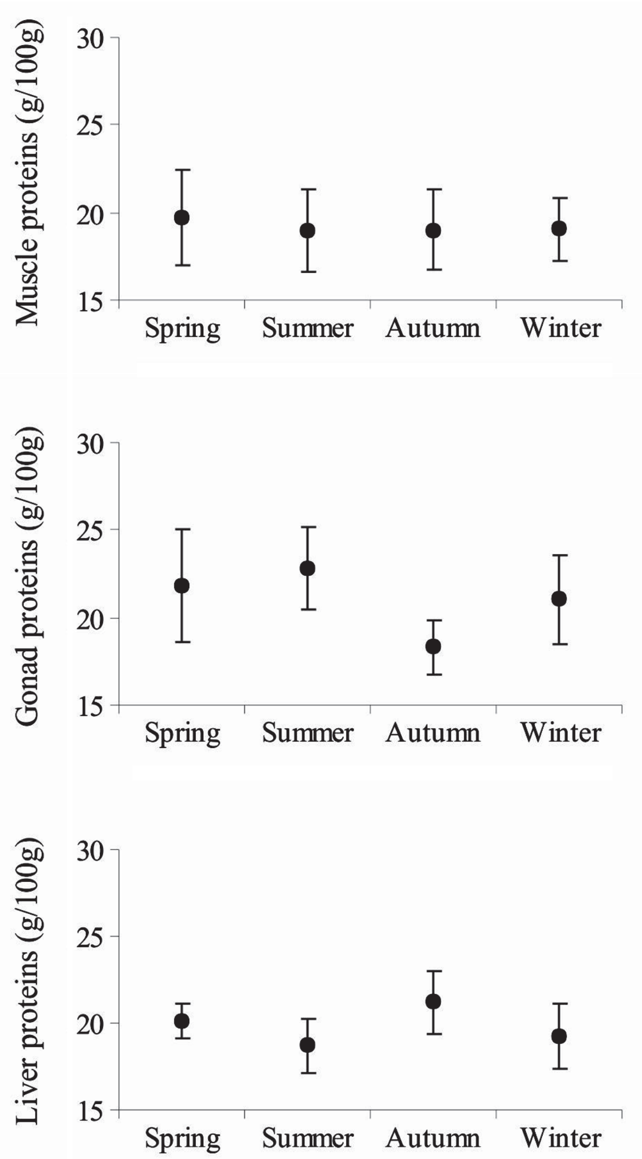

Fig. 3. Seasonal variation of protein content in muscle, gonad and liver of *Percophis brasiliensis*.

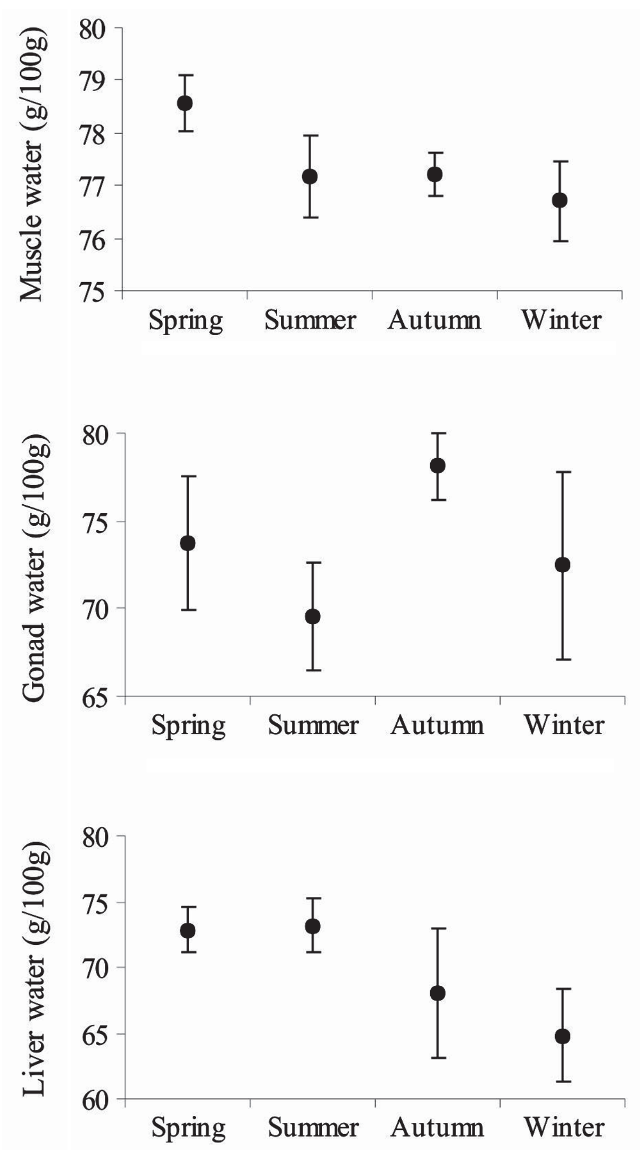

Fig. 4. Seasonal variation of water content (moisture) in muscle, gonad and liver of *Percophis brasiliensis*.

Energy density seasonal variation. Mean energy density was estimated by season for each tissue, and the temporal trend was analyzed. This variable in muscle did not show significant differences among seasons, being the average 4.96 KJ/g (Table 2, Fig. 6). In ovaries energy density was significantly lower during autumn (5.14 KJ/g), at the end of reproductive period (Fig. 6). As for liver energy density, unlike the previous case, during spring and summer it showed the lowest values (6.87 KJ/g average), whereas after reproduction this variable increases reaching a mean value of 9.61 KJ/g in autumn and 10.91 KJ/g in winter (Fig. 6).

Discussion

The traditional morphological indices as gonadosomatic (GSI), hepatosomatic (HSI) and condition factor (K) have been generated in order to express dynamics in endogenous energy utilization of gonads, liver and muscle, respectively (Collins & Anderson, 1995). These are important indices to consider in stock reproductive potential, together with energy reserves and proximate composition of females (Domínguez Petit, 2006).

Temporal analysis performed with females of a very narrow size range (52-56cm Lt) showed that both GSI and K

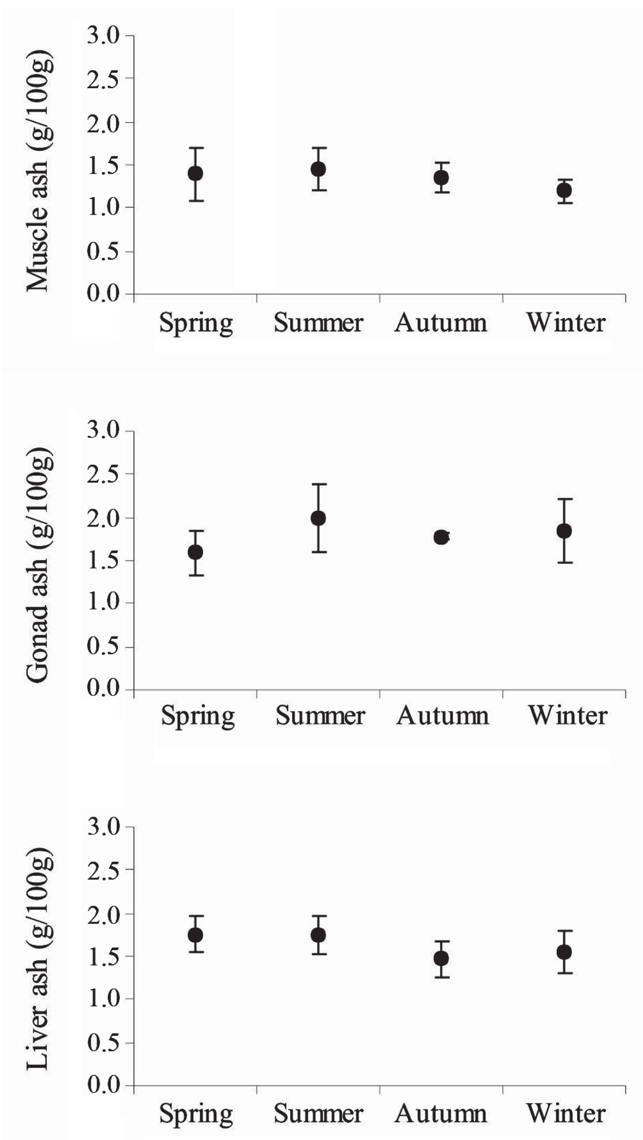

Fig. 5. Seasonal variation of inorganic matter content (ash) in muscle, gonad and liver of *Percophis brasiliensis*.

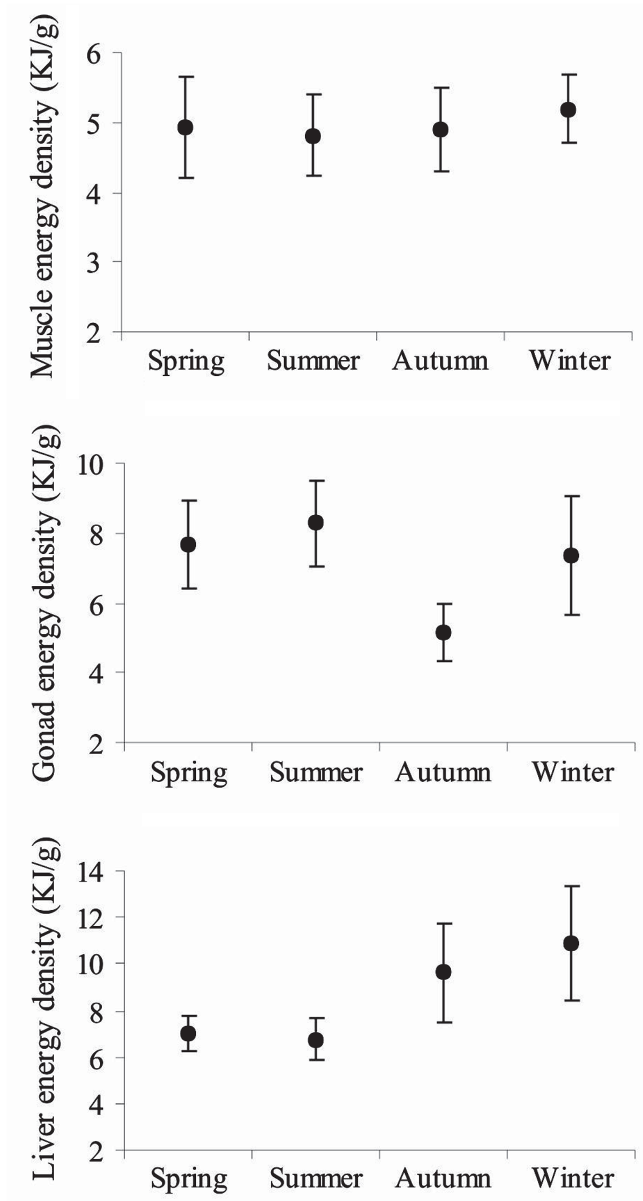

Fig. 6. Seasonal variation of energy density in muscle, gonad and liver of *Percophis brasiliensis*.

varied significantly among seasons, with opposite patterns. GSI values were higher during the reproductive period (spring-summer), falling towards the end of spawning season (autumn); while K and HSI showed the highest values before the onset of reproductive activity (winter). However, in case of HSI, differences among seasons were statistically not significant. In other species such as *Hippoglossoides platessoides* has been observed an increase of HSI in the feeding season and a marked decrease during spawning season (Maddock & Burton, 1999); in Atlantic cod the highest HSI and K were recorded between summer and autumn in post-spawning period, and the lowest value was found in spring during the reproductive peak, opposite to the GSI pattern (Lambert & Dutil, 1997; Dutil *et al*., 2003; Mello & Rose, 2005).

HSI results the best variable in several fish species to describe female condition (Marshall *et al*., 1999; Marteinsdottir & Begg, 2002; Domínguez Petit *et al*., 2010; Leonarduzzi, 2011). In some species HSI is also considered a good indicator of recent feeding (Tyler & Dunn, 1976), *i.e.* decrease of this index during the reproductive season might suggest both participation of liver in vitellogenesis and that fish do not would feed much during spawning period (Maddock & Burton, 1999). In case of Brazilian flathead, as it was mentioned, although there were not significant differences between seasons, the highest HSI value was observed in winter, before the beginning of spawning, and the lowest was registered in autumn, at the end of reproductive season.

The lowest values of K were detected in spring and summer, this observation was probably the result of mobilization of somatic energy reserves needed for reproduction, as suggested in other species (Maddock & Burton, 1999; Rätz & Lloret, 2003). Wright & Trippel (2009) include this morphological index within demographic factors that can disturb the reproductive cycle. The strong increase of GSI and percentage of active females in spring and summer (Rodrigues, 2009) indicates a high rate of yolk deposition in oocytes, as proposed by Alonso-Fernandez (2011).

Chemical composition of different tissues can vary considerably, in particular lipid and water content (Haug, 1990). During high feeding periods lipids can be stored in somatic tissue and liver, as well as around the viscera (Collins & Anderson, 1995; Hoque *et al*., 1998), so that lipids can be used as markers of physiological condition because they can show periods of annual cycles associated with changes in fish nutrition (Shulman & Love, 1999). During the annual cycle variation of lipid content was observed, ranging from 0.25 to 2.05% in muscle, from 1.22 to 10% in gonads and from 3.6 to 24% in liver. There is very little record on biochemical composition of the Brazilian flathead tissues. Chiodi (1968) estimated for this species an annual average content of lipids in muscle of 1.7%, without sex distinction. The values found in gonad and liver were similar to those obtained for weakfish (*Cynoscion guatucupa*) in waters of the Buenos Aires province, minimum and maximum concentration were 1.50% - 5.90% in muscle, 1.00% - 8.70% in gonads, and 3.80% - 27.50% in liver (Chiodi, 1962). Lipids in Brazilian flathead decreased markedly during spawning season in muscle (0.7%) and liver (5.7%), while in gonads most notable decrease was observed in autumn (2.1%), at the end of reproductive period. This would indicate a significant intake of energy destined for reproduction, which is coincident with the seasonal pattern observed for somatic indices. That is, lipids concentration in both liver and muscle shows the same cycle observed for K and HSI, while in ovaries the pattern was similar to that recorded for GSI. This is coincident with tests carried out on weakfish gonads, which revealed that ovaries have the highest lipid concentrations during pre-spawning, and the lowest in post-spawning and resting periods (Chiodi, 1962). Consistent with these data, in Argentine hake (*Merluccius hubbsi*) the highest lipid concentrations were estimated in liver of females at resting stage, that is starting to accumulate reserves during this phase of the reproductive cycle (Leonarduzzi *et al*., 2010).

Protein content of all females analyzed varied between 14.1 to 24.3% in muscle, from 16.75 to 25.5% in gonads and from 16.2 to 24% in liver. Proteins in muscle did not differ significantly among seasons, being on average 19.2%. This value was similar to that reported for Brazilian flathead muscle (19.8%) and weakfish (17.88%) both without sex distinction (Chiodi, 1962; 1968). Unlike this, proteins of gonads and liver varied significantly and had opposite patterns. In ovaries, as seen with lipids, protein values declined in autumn, showing a decreased in energy content in gonads at the end of the spawning season, which may be associated with the reduction in number of yolked oocytes. In liver the highest protein concentration occurred during the end of spawning season (autumn), being significantly different from summer.

Since spawning is a process of high energy demand, lipid reserves and proteins in gonads fall as the reproductive season progresses, in contrast to that observed for liver, characterized by higher protein concentration in autumn.

Water content varied between 75.4% and 79.2% in muscle, from 64.6% to 80% in gonads and from 60.4% to 75.3% in liver. The average estimated by Chiodi (1968) for *P. brasiliensis* muscle was 77.2%. In weakfish muscle, a minimum value of 74.2% and a maximum of 79.25% were found (Chiodi, 1962). Water content in the tissues analyzed showed an inverse pattern to lipid concentration (in the three tissues) and to protein quantity (in gonads and liver). Ash values estimated during all seasons analyzed to any tissues were 1.1% - 2.0% in muscle, 1.2% - 2.6% in gonads and 1.2% - 2.0% in liver, which were in the same range to those estimated by Chiodi (1968) for muscle of Brazilian flathead (1.28 %) and weakfish (1.52%).

In short there would be seasonal changes in lipid, protein and water composition in muscle, liver and viscera associated with gonadal growth processes and spawning, since lipid accumulation is directly dependent on food availability, and it is very important in recovery during post-spawning (Eliassen & Vahl, 1982; Shulman & Love, 1999).

Energy density in muscle presented similar values among seasons. As regards the liver and gonads, the energy density seasonal pattern seems to be opposed. That is, liver accumulate energy before spawning (winter) that will then decline in the reproductive period (spring and summer), then increased again during post-spawning (autumn). In gonads this pattern is opposite, with maximum concentrations in spring and summer and a marked decrease in autumn, but then slightly increases in winter, in coincidence with the beginning of developing (Table 1). This is consistent with that observed for other species, as *Merluccius hubbsi*, characterized by the highest energy density values in liver during the resting stage and in gonad during spawning (Leonarduzzi *et al*., 2010). In *Merluccius merluccius* the highest energy density in ovaries were recorded just before spawning, when the oocytes contain the maximum amount of yolk (Domínguez

Petit, 2006). In agreement with these data, Leonarduzzi *et al*. (2010) argue that changes in ovary stage result in significant variations of lipid and protein content in gonads, and hence the stored energy. So, to complement this study should be analyzed variations in energy density according to maturity stages.

In conclusion it was found two main sources of energy in the tissues analyzed: lipids and proteins of liver and lipids in muscle. These energy reserves are accumulated before the onset of maturation (winter) and are depleted at the spawning season progress (spring-summer). The liver energy density reaches a minimum towards the end of the reproductive season (autumn), but in muscle no variation was observed. So, on one hand the energy allocated for reproduction is stored mainly in liver, and it is mobilized to provide the resources necessary for physiological functions, as it was observed there are changes in energy levels that respond to mobilization of lipids and proteins stored in liver. On the other hand, no variations were observed in energy stored in the muscle indicating that there could be an external source of energy (feeding for example) that maintains levels of energy more or less constant in this tissue.

This means that Brazilian flathead would respond to an intermediate strategy combining capital and income breeding, such as observed in other species like *Trisopterus luscus* (Saborido Rey *et al*., 2010; Alonso Fernandez, 2011). Since the energy for reproduction is mainly obtained from reserves stored in liver during the nonbreeding season, but possibly by feeding during the spawning period too. Thus, to corroborate this hypothesis, are necessary future studies on biochemical composition of *P. brasiliensis* tissues in relation with feeding activity during the reproductive season.

Finally, it is important to emphasize the contribution of this work, not only in the study of reproductive aspects of Brazilian flathead, but also for food industry, because there is little information on proximate composition of this species in literature, even so it is considered a very important fishery resource for Argentina.

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