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Energy acquisition and allocation to the gonadal development of *Cynoscion leiarchus* (Perciformes, Sciaenidae) in a tropical Brazilian bay

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ABSTRACT

The process of energy acquisition and allocation to the gonadal development involves the use of reserves obtained from the food intake and/or stored in different parts of the body. Some fish species acquire and store energy prior the spawning season (capital breeders). For others species, the energy acquisition through by feeding activity continues actively throughout the spawning season (income breeders). This process of acquisition/allocation of energy to gonadal development was investigated for *Cynoscion leiarchus* an important fishery resource in southeastern Brazil. Monthly measurements of the gonadosomatic, hepatosomatic, condition factor and stomach repletion indices were carried out. Size at the first maturation was also assessed. Fish, mainly teleosts, were the main source of energy in the diet suggesting a carnivorous behaviour. We found evidences of use of stored body energy reserves during the spawning period, associated concomitantly with a decrease of feeding activity, suggesting a capital breeder. However, the wide spawning season, together with asynchronic oocyte development and indeterminate fecundity (typical of income breeders) suggest that the mixed-breeder strategy should be more suitable for this species. The high plasticity regarding the capital-income breeder strategy during the reproductive cycle of the genus *Cynoscion* is discussed.

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Introduction

Feeding activity includes complex mechanisms whereby species get energy that is distributed mainly for growth (addition of body mass), for maintenance of the basal metabolism that are lost as heat, and for the reproductive process (Wootton 1990; Simon et al. 2009). The acquisition, storage and use energy or nutrients across the annual cycle are key components of life history strategy and important determinants of lifetime fitness (Williams et al. 2017). Energy allocation can vary, depending on the life history strategy of a fish species. The amount of food ingested during the spawning season may partially offset the cost of reproduction (Aristizabal 2007) since that the reproductive process comprises several endocrine and metabolic changes that mobilize and re-allocate both materials and energy (Jobling 1995).

The maturation of the gonads and reproductive activity involves the use of energy reserves obtained from the food intake and stored in different parts of the body (Henderson et al. 1996; Aristizabal 2007). During the reproductive cycle, the availability of

suitable food at appropriate times is one of the most important exogenous factors for the reproductive success. In addition, reproductive features such as individual fecundity and egg size are influenced by the availability and quality of energetic reserves, or by food intake (Tyler and Calow 1985), which directly affect spawners condition, and at the same time determine the maturation of the individuals (Saborido-Rey and Kjesbu 2009).

The dynamics of energy allocation involves different roles of lipids, proteins and other components in fish tissues as energy reserves. Lipids play an important role as regulators of body density, cellular metabolism and reproduction (Love 1980; Chellappa et al. 1989; Jonsson et al. 1997; Blanchard et al. 2005) being closely related to ovary development, fecundity, fertilization, egg quality and hatching rates (Shearer and Swanson 2000; Hendry et al. 2001; Kurita et al. 2003; Lambert et al. 2003). It is also widely known that egg-shell and egg yolk proteins use the liver as their main site of synthesis and these substances are then transported to the oocyte for uptake (Arukwe and Goksoyr

2003). In addition, the energy stored in muscular tissue as body proteins is used to ovary growth (Tyler and Calow 1985; Black and Love 1986).

Marine teleosts develop complex life history strategies searching for food to reproduce and to make feasible their life cycles in rich and dynamic environments such as coastal systems. Often, they use the stable conditions of the inner platform as grounds for reproduction, growth and feeding (Godefroid et al. 2001; Robert and Chaves 2001; Fávoro et al. 2003; Branco et al. 2005; Robert et al. 2007). During the spawning season, some teleosts species exhibits a cessation or reduction in feeding activity (capital breeders). Consequently, the energy cost with the stages of gametogenesis and behavioural activities associated with reproduction must be met from reserves built up when the fish were actively feeding (McBride et al. 2015). This pattern is characteristic of many species that exhibit total spawners or species with determinate fecundity (Albo-Puigserver et al. 2017; Wright et al. 2017). Since stored energy requires maintenance itself, capital breeders are not maximizing conversion efficiency (Jönsson 1997), although, storing resources by adults is an advantage for their offsprings (Reznick and Braun 1987).

There are other teleosts (income breeders), in which feeding continues actively throughout the reproductive cycle and the energy cost with reproduction is acquired by feeding activity or by transfer from the reserves if income from feedings is insufficient (Wootton and Smith 2014). Asynchronic oocyte development, batch spawning and indeterminate fecundity are reproductive traits of many income breeders fish species (Villegas-Ríos et al. 2014; Grande et al. 2016; Albo-Puigserver et al. 2017; Ashida et al. 2017). These species can show a rapid response relative to nutritional control of oogenesis and are metabolically efficient, since they have the advantage of fine-tuning reproductive output relative to the current environment pertaining to both maternal condition and potential survival of the offspring (McBride et al. 2015). Some species may adjust their reproductive investment to maximize their fitness (Roff 2002) and breeding patterns are not limited to capital or income types. It is also possible that an intermediate type may exist, such as the mixed-breeding that can supply egg production with stored energy and energy obtained during the reproductive activity (McBride et al. 2015; Dhurmeea et al. 2018).

Condition factor, hepatosomatic and gonadosomatic indices have been used to assess the energy storage process and to interpret the direct mobilization of that energy from liver and muscle to gonadal development (Komova 2002; Blanchard et al. 2003; Lambert et al.

2003; Dominguez-Petit and Saborido-Rey 2010; Alonso-Fernandez and Saborido-Rey 2012). In relation to energy acquisition, the stomach weight index (repletion index) allows to assess spatial and temporal variations in feeding activity, revealing the dynamic of energy input in fish (Guedes et al. 2004; Martins et al. 2005). Therefore, the use of these indices allows to assess the process of energy transfer encompassing from the food intake (beginning) to the gonadal development (end of pipe).

Fish of the family Sciaenidae, especially the genus *Cynoscion* are abundant in tropical and subtropical coastal systems and have complex strategy for energy acquisition and allocation (Brown-Peterson et al. 1988; Taylor and Villosio 1994; Vieira and Haimovici 1997; Brown-Peterson and Warren 2001; Marciano and Alió 2001; Brown-Peterson et al. 2002; Militelli and Macchi 2006; Gherard et al. 2013). The smooth weakfish *Cynoscion leiarchus* (Curvier, 1830) is an euryhaline fish species with wide range of geographical distribution, from Panamá to southern Brazil (Froese and Pauly 2018) that uses different coastal environments during its life cycle (Chaves and Umbria 2003; Araújo et al. 2006; Pereira et al. 2015). In the Sepetiba Bay (22°54'–23°04'S, 43°34'–44°10'W), a 450 km² embayment on the coast of the Rio de Janeiro State in southeastern Brazil, this species ranks among the most abundant fish species, occurring mainly in the outer bay zone (Araújo et al. 2006, 2017) that has waters predominantly polyhaline (salinity average = 30), and the mean temperature ranges between 21.5°C in winter and 27°C in summer (Araújo et al. 2002). *Cynoscion leiarchus* feeds mainly on fishes (Chaves and Umbria 2003; Guedes et al. 2015). There is no available information on reproductive migration but juveniles of this species were recorded in small numbers in the Sepetiba Bay (Pessanha and Araújo 2003; Pereira et al. 2015). Spawnings occur in the inner platform near estuarine semi-enclosed systems, but individuals with post-ovulatory follicles were recorded in the outer zone of the bay (Silva et al. 2016). This species is an important fishery resource, with catches showing a trend towards stability in 2008 and 2010 (910–948 t) (MPA, 2012). Some relationships between energy resources (feeding/body reserves) and the reproductive process based on the condition factor, eggs size and fecundity have been reported for *Cynoscion* species (e.g. Lowerre-Barbieri et al. 1996; Roumillat and Brouwer 2004; Militelli and Macchi 2006). However, no information was available on the energy acquisition and allocation to the reproductive process of these species yet.

The objective of this study was to investigate reproductive and feeding traits of *C. leiarchus* in a tropical Brazilian bay, evaluating the process of acquisition, allocation

and transfer of energy to reproductive cells development. We assessed condition factor, hepatosomatic and gonadosomatic indices and the stomach repletion index. The tested hypothesis was that this species is able to compensate for inadequate energy deposits with concurrent food intake during the spawning season in order to maximize the oocyte production.

Materials and methods

Fish collection and handling

Thirty fish were collected monthly from July 2013 to June 2014, from catches carried out by the artisanal fleet that operates in the Sepetiba Bay. Fish were collected by gill nets of 1500 m long \times 3 m high \times 3 three different mesh size panel (35, 40 and 45 mm between opposite knots).

The collected fish were preserved in ice, and the total length – TL (in mm) and the body mass – BM (in 0.1 g) were taken. A ventral incision was made to expose the stomach, gonads and liver. Stomachs were removed, weighed (SM) to the nearest 0.01 g for determination of stomach repletion index (RI). Food items were identified under a stereomicroscope. Each identified food item was separated, counted and weighted to the nearest 0.001 g.

Gonads were removed for sex determination and macroscopic classification of the gonadal development phases, and weighed (GM) to the nearest 0.01 g for determination of the gonadosomatic index (GSI). Identification of the gonadal maturation phases followed the criteria of Brown-Peterson et al. (2011). Macroscopy gonadal phases were categorized according to shape, size, mass, colour and vascularization. This classification included reproductively inactive (immature, regenerating) and reproductively active (developing, spawning capable, regressing) to reduce the chance of error in the identification of individual phases. The liver was removed and weighed (LM) to the nearest 0.01 g for determination of hepatosomatic index (HSI).

Size structure

Length-frequency distributions of the individuals grouped in 30 mm TL size classes were analysed. The sex ratio was assessed for the different size classes. A chi-square test (χ^2), with level of significance of 5%, was used to compare the sex ratio.

Gonadal development phases

Size at first maturation (L_{50}) was determined for each sex and was used for discriminating the inactive

individuals from those in process of reproduction. The proportion of individuals in the reproductive process (% mature individuals) included individuals in developing, spawning capable and regressing. These were assigned as already reached the reproductive process (adults). A logistic curve was fitted to the dataset for estimation of the size at first maturation (L_{50}) and size when all individuals reached maturity (L_{100}). This curve was adjusted through a non-linear adjustment model that uses an interactive algorithm that minimizes the sum of squares of the residuals, implemented through the SOLVER routine contained in Microsoft Excel, using the formula proposed by King (1995): $P = 1/(1 + \exp^{-r(LT-L_{50})})$, where P is the relative frequency of mature individuals, L_{50} corresponds to the size in which 50% of individuals are fit for reproduction, r is the parameter related to slope of the curve. The following analyses were performed considering only the individuals that reached L_{50} , i.e. adult individuals, because they mobilize part of the acquired energy to the reproductive process.

Reproductive effort and condition indices

The gonadosomatic index (GSI) was calculated for each individual through the following equation: $GSI = (GM \times 100)/BM$. The hepatosomatic index (HSI) was calculated to evaluate relationships between the reproductive process and the liver weight from the following equation: $HSI = (LM/BM) \times 100$.

The length-weight relationship was estimated through the power equation (Le Cren, 1951), $BM = a \times TL^b$, for females ($BM = 0.0097 \times TL^{3.046}$; $r^2 = 0.98$; $n = 190$) and males ($BM = 0.013 \times TL^{2.9581}$; $r^2 = 0.986$; $n = 170$), with the b parameter (slope) related to the rate of weight gain as a function of length, used to calculate the condition factor (K). The condition factor (K) was calculated to relate energy reserves with body mass and among of energy transferred to gonads: $K = BM/TL^b$.

Feeding index

The stomach repletion index (RI) was used to assess food activity. The index considers the stomach weight ratio (SM) as function of the body mass (BM), ($RI = SM/BM \times 100$) (Santos 1978).

Food composition was expressed for each food item as a percentage of index of relative importance (IRI) developed by Pinkas et al. (1971), which described the relative contribution of food items in the diet as the calculation of the frequency of occurrence (%FO) and percentage composition by number (%N) and by mass (%M) (Berg, 1979; Hyslop, 1980; Clark, 1985).

The IRI was calculated using the equation: $IRI = (\%N + \%M) \times \%FO$ and expressed on a percent basis, such that %IRI for a specific food category (IRI_i) becomes:

$$IRI_i = 100 \times IRI_i / \sum_{i=1}^n IRI_i$$

where n is the total number of food categories considered at a given taxonomic level (Cortés 1997).

Relationships between GSI, HSI and K were assessed with an r -Pearson correlation coefficient. An analysis of variance (ANOVA) and a *post hoc* Tukey test were applied to compare GSI, K , HSI and RI averages among the months for females and males, separately.

Results

Size structure

From the 360 examined individuals of *C. leiarchus*, 190 were females (TL = 205–486 mm, mean \pm SD = 309 \pm 59) and 170 were males (TL = 205–493 mm; mean \pm SD = 293 \pm 58). The sex ratio was well-balanced (1.1 female:1 male) and did not differ significantly between sexes ($\chi^2 = 1.11$, $df = 9$, $P > .05$), although a non-significant trend for higher number of females with TL > 290 mm was observed. Females with size ranging between 290 and 319 mm TL were predominant in numbers ($\chi^2 = 8.89$, $df = 1$, $P < .05$), whereas males predominate in size ranging between 260 and 289 mm TL ($\chi^2 = 6.36$, $df = 1$, $P < .05$) (Figure 1).

Reproduction

Females in spawning capable phase occurred throughout the year and were more frequent in August (46%),

from October to January (60–94%), and in May (76%), indicating a long reproductive period. Males in spawning capable phase were recorded from August to May, with the highest frequency between October and December (75–90%) and in May (62%) (Figure 2).

Size at first maturation (L_{50}) was 273 mm TL for females and 243 mm for males. All individuals were mature (L_{100}) participating in the reproductive process from 380 mm TL (females) and 360 mm TL (males) (Figure 3). Spawning capable individuals were recorded throughout the year with the gonadosomatic index (GSI) differing significantly among the months for both females ($F = 5.86$, $P < .05$) and males ($F = 5.85$, $P < .05$). Three peaks in the GSI were found for both sexes, with the more conspicuous peak being recorded in August, between October and January, and in May (Figure 4a,b).

The hepatosomatic index (HSI) for females changed significantly ($F = 3.90$, $P < .05$) with the lowest values in November, following by an increase until January, then a decline until May (Figure 4c). For males, the HSI ($F = 2.78$, $P < .05$) also changed significantly with the lowest values between July and November, a peak in January and a decline until March (Figure 4d).

The condition factor (K) changed significantly for females ($F = 9.97$, $P < .05$), with the lowest values in October, following by an increase in the following months until reach a peak in January–March, and decline until May (Figure 4e). For males, seasonal changes were also recorded ($F = 4.91$, $P < .05$) with the lowest values in August, October, March and June (Figure 4f). Significant relationships were found between GSI and HSI ($r = -0.29$, $P = .001$), GSI and K ($r = -0.52$, $P = .001$) and HSI and K ($r = 0.35$, $P = .001$).

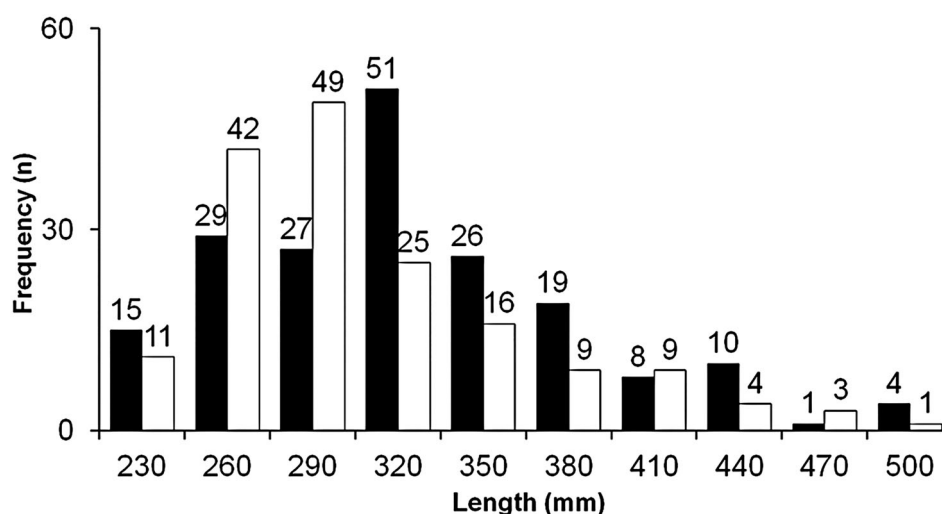


Figure 1. Frequency distribution of females (■, $n = 190$) and males (□, $n = 170$) of *C. leiarchus* in the Sepetiba Bay from July 2013 to June 2014. Numbers of individuals are indicated above the columns.

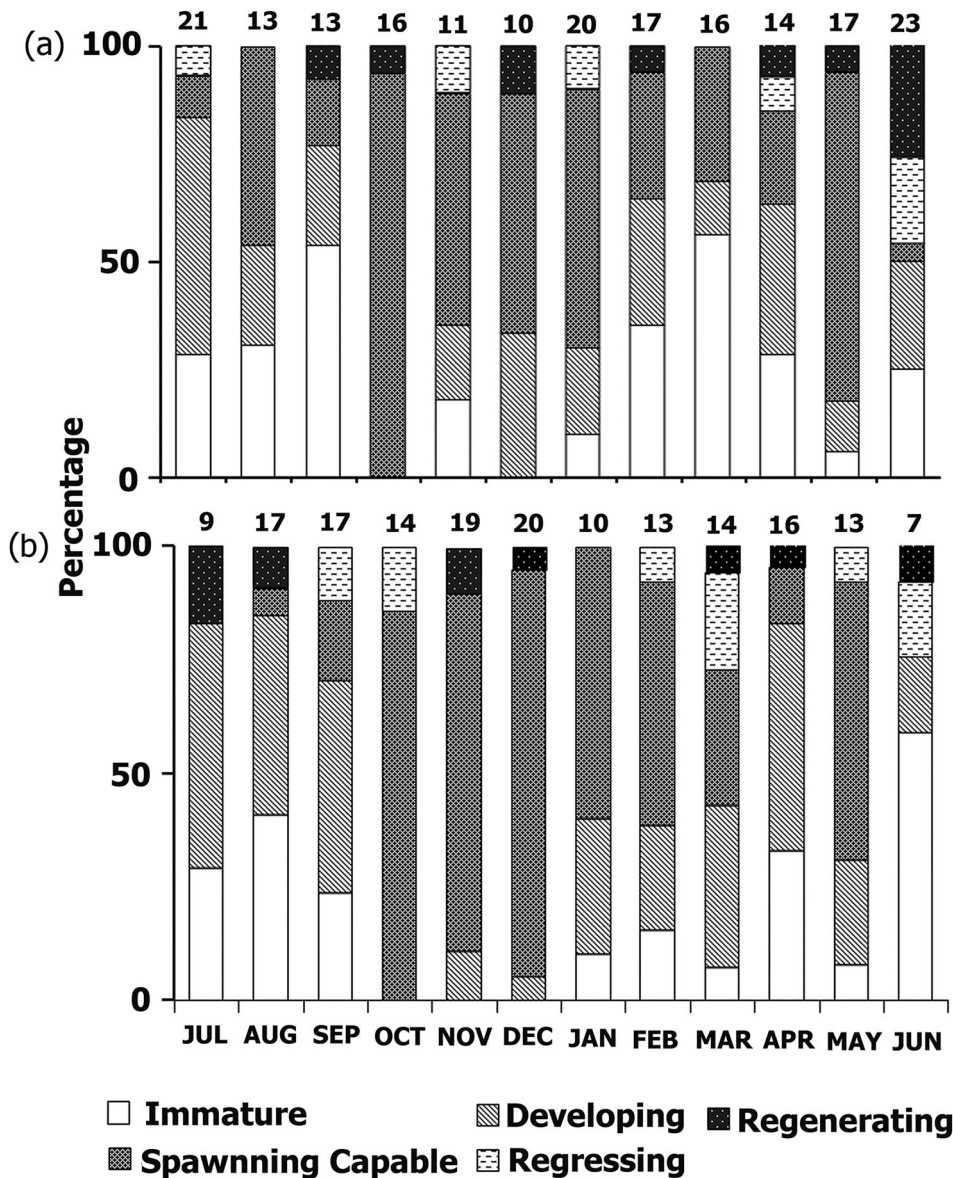


Figure 2. Relative frequency of maturation phases of females (a) and males (b) of *C. leiarchus* in the Sepetiba Bay from July 2013 to June 2014. Numbers of individuals are indicated above the columns.

Feeding

The stomach repletion index differed significantly between the months for both sexes ($F = 3.69$, $P < .05$ for females; $F = 5.03$, $P < .05$ for males). The highest values were recorded in September and April, and the lowest in August, in November-December and May (Figure 4g,h). Four food items were identified through the stomach inspection, with a conspicuous preference for teleost (Fish) (Table I).

Discussion

Our findings suggest that *C. leiarchus* presents a mixed-breeding strategy in relation to energy acquisition and

allocation to gonadal development. The decrease in the condition factor (K) and hepatosomatic index (HSI) during the peaks of GSI, evidencing the use stored body energy reserves during the spawning period concomitantly with a decrease of the feeding activity leads to a capital breeders strategy. However, the multiple spawning behaviour with asynchronous oocyte development and indeterminate fecundity that were reported by Silva et al. (2016) are characteristic of income breeders. As some income breeders often demonstrate evidence of supplementing their egg production with stored energy to maximize fitness in response to fluctuating environmental conditions (McBride et al. 2015), we suppose the mixed-breeder should be a better suited strategy for *C. leiarchus*.

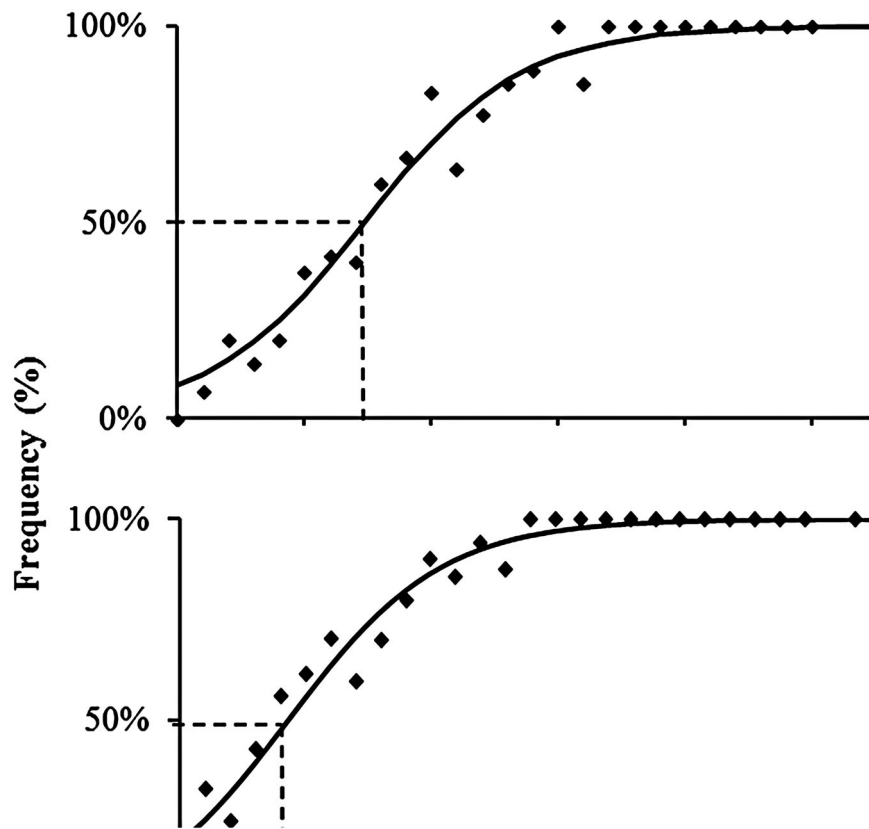


Figure 3. Size at maturity of females (a) ($L_{50} = 273$ mm) and males (b) ($L_{50} = 243$ mm) of *C. leiarchus* in the Sepetiba Bay from July 2013 to June 2014.

The strategy of acquisition and allocation of energy was first proposed by McBride et al. (2015), that named capital breeders for those species in which reproduction is financed using stored capital (*sensu* Stephens et al. 2009), whereas income breeders were those that the use of concurrent intake to pay for a reproductive attempt. The mixed breeders comprise those fishes that although with asynchronous oocyte development, appear predisposed to income breeding, but with evidence of supplementing their egg production with stored energy during a wide reproductive season. One example is the well-fed Japanese anchovy *Engraulis japonicus* Temminck & Schlegel, 1846 that continues to spawn for a few weeks if starved – demonstrating some availability of capital stores – but spawning frequency, batch fecundity and egg size declined (Kawaguchi et al. 1990). Also, the albacore tuna, *Thunnus alalunga* (Bonnaterre 1788) involves mainly stored energy for reproduction with supplementary energy derived from feeding for the later gonadal development during the spawning season (Dhurmeea et al. 2018).

Other species of the genus *Cynoscion* that exhibit multiple spawning and asynchronous oocyte development, also shown evidences of using stored energy from the body during the spawning period. For

example, *Cynoscion nebulosus* (Cuvier, 1830) has low condition during the spawning activity in the Chesapeake Bay (Lowerre-Barbieri et al. 1996). Roumillat and Brouwer (2004) reported an association between a decrease in oocyte size and condition of spawning females over the course of the spawning season, which could suggest a mixed-breeding strategy. However, this behaviour seems not to be a common feature for the genus, since *Cynoscion guatucupa* (Cuvier, 1830) showed high condition factor during the spawning period (Militelli and Macchi 2006) in the coastal waters of Argentina–Uruguay, an indication of income breeders. Therefore, a high plasticity of the *Cynoscion* genus regarding the capital-income breeder strategy during the reproductive cycle seems to occur.

The wide reproductive period of *C. leiarchus* was confirmed in this study as indicated by the GSI, with maximum spawning activity in August, between October and January, and in May. Several authors related the multiple spawning as an adaptive response to environmental variations to synchronize the release of gametes with the food availability, thus maximizing the survival of recruits and juveniles (Winemiller and Layman 2005; Fonteles-Filho 2011; Silva et al. 2016) or

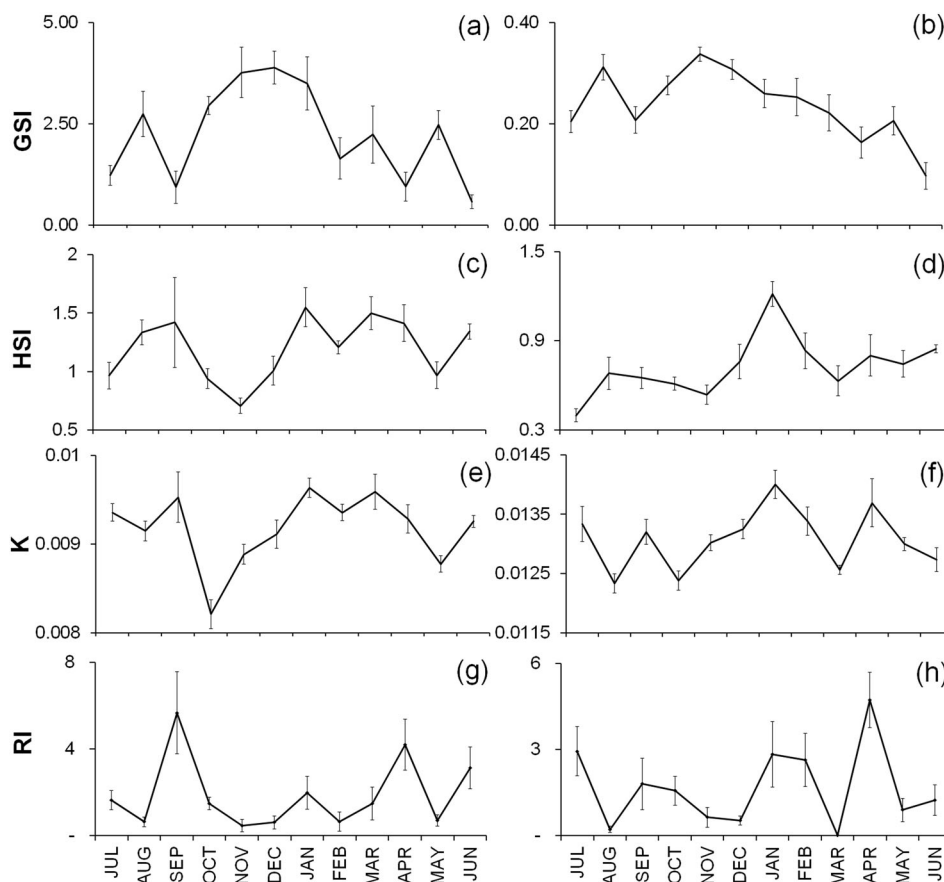


Figure 4. Monthly variation of mean gonadosomatic (GSI) and hepatosomatic indices (HSI), condition factor (K) and stomach repletion index (RI) of females (a, c, e, g) and males (b, d, f, h) of *C. leiarchus* in the Sepetiba Bay from July 2013 to June 2014. Vertical lines represent the standard errors.

to avoid interspecific competition for limited resources between closely related species (Wootton 1992; Amarasekare 2003). Other species of *Cynoscion* genus also have wide spawning season with multiple batches, such as *C. nebulosus* (Cuvier, 1830) from the Gulf coast of Mississippi (Brown-Peterson and Warren 2001) and from the South Carolina (Roumillat & Brouwer 2004), *Cynoscion othonopterus* (Jordan & Gilbert, 1882) from the California Gulf (Gherard et al. 2013), *Cynoscion jamaicensis* (Vaillant & Bocourt, 1883) from the Venezuela coast (Marcano and Alió 2001), and *C. guatucupa* (Cuvier, 1830) from the southern Brazilian coast (Vieira and Haimovici 1997) and from the Argentinian–Uruguayan coast (Militelli and Macchi

2006). These indicate that a wide reproductive period is a common feature for this genus.

The inverse relationship between both the HSI and K with the GSI suggests the mobilization of hepatic energy and body reserves to gonadal development during spawning season. Changes in HSI indicate the role of the hepatic reserves as source of energetic resource for the reproductive activity (Alonso-Fernandez and Saborido-Rey 2012), to ensure ovarian maturation even at low rates of energy intake (Allen and Wootton 1982). Several reproductive studies of *Cynoscion* genus generally refer only to the condition factor as an indicator of body energy reserves (Lowerre-Barbieri et al. 1996; Roumillat and Brouwer 2004; Militelli and Macchi 2006; Lowerre-Barbieri 2009). Although condition factor is often used to determine the amount of mass in the individual and correlated to energy reserves (Alonso-Fernandez and Saborido-Rey 2012), this is not always completely true because changes in condition may indicate shifts in all the constituents of body composition, not only in energy reserves (Schulte-Hostedde et al. 2005). Alonso-Fernandez and Saborido-Rey (2012) found that energy

Table I. Frequency of occurrence (%FO), numerical percentage (%N), mass (%M), and Index of Relative Importance (%IRI) of food items from *C. leiarchus* collected in the Sepetiba Bay.

Itens	% FO	% N	% M	% IRI
Teleost (Fish)	0.9865	0.8639	0.9423	0.9929
Clupeiform (Fish)	0.0270	0.0237	0.0301	0.0008
Decapod (Crustacea)	0.0946	0.0828	0.0262	0.0057
Isopod (Crustacea)	0.0338	0.0296	0.0015	0.0006

reserves in pouting *Trisopterus luscus* (Linnaeus, 1758) females are mainly associated with lipids stored in the liver. Dominguez-Petit and Saborido-Rey (2010) examining changes in energy storage of the European hake (*Merluccius merluccius*, L. 1758) found that the liver has more energy density compared with gonads and muscles, and that energy reserves are recovered during the spawning season because food availability is relatively constant all year round. Overall, the HSI has been reported as a more accurate condition index to measure the energy reserves of fish compared with other indices (Shulman and Love 1999; Dominguez-Petit and Saborido-Rey 2010; Alonso-Fernandez and Saborido-Rey 2012). In the present study, both indices had similar patterns indicating the use of stored energy reserves during the spawning season and corroborating the mixed-breeding strategy for *C. leiarchus*.

A slight trend for female predominance was observed in large-sized individuals (>290 mm TL) in the Sepetiba Bay. Predominance of large females occurs in areas plenty of feeding resources (Nikolsky 1969) or could also be connected with higher natural mortality of males and their shorter life span (Vetter 1988). Large females will carry large number and greater oocytes, thus increasing survival rates (King 1995). The predominance of females in the highest lengths for species of the genus *Cynoscion* was also observed in other studies such as in *C. nebulosus* from the southern Texas (Brown-Peterson et al. 1988) and *C. othonopterus* in the California Gulf (Gherard et al. 2013). The significant positive relationship between fish size and fecundity indicate the maximization of oocyte production. This could also be due to food availability, since some species are able to compensate for inadequate energy stores with simultaneous food consumption (Henderson et al. 1996).

We determined the size at the first maturation to ascertain the individuals that are in the reproductive process. Females reached size at first maturation (L_{50}) at 273 mm TL and males at 243 mm TL. These findings slightly differ from other studies, such as the case of smaller females of *C. nebulosus* in the Mississippi Gulf Coast (L_{50} = 230 mm TL, Brown-Peterson and Warren 2001) and South of California coast (L_{50} = 248 mm TL, Roumillat and Brouwer 2004), and larger females of *C. guatucupa* in the southern Brazilian coast (L_{50} = 346 mm TL, Vieira and Haimovici 1997) and of *C. othonopterus* in the California Gulf (L_{50} = 277 mm TL, Gherard et al. 2013). Such differences can be attributed mainly to reproductive tactics that may exhibit spatial and temporal variations related to local biotic and abiotic environmental conditions.

Fish is the main source of energy supporting *C. leiarchus* in the Sepetiba Bay, with predominance of teleost. The behaviour of *C. leiarchus* for feeding on teleosts was reported by Guedes et al. (2015) referring to juveniles and subadults individuals (TL = 57–218 mm), therefore below the size at first maturity. The perenniality of the diet has a direct influence on the population dynamics that keeps the population in equilibrium and maximize production (Fonteles-Filho 2011). Therefore, it is reasonable to hypothesize that stabilization on diet (Teleost guild) of *C. leiarchus* before the first maturation contributes to maximize the energy expenditure for the future reproductive success.

This study provides the first information about the energy acquisition and allocation to the reproductive process of *C. leiarchus* in the southeastern Brazilian coast. This species exhibits a mixed-breeding strategy characterized by using stored body energy reserves during the spawning period associated concomitantly with a decrease of feeding activity, multiple spawning, indeterminate fecundity and asynchronic oocyte development. This pattern was not confirmed as a common feature for the genus *Cynoscion*, suggesting a high plasticity of this group of fish.

Ethical approval

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed, including Universidade Federal Rural do Rio de Janeiro, Brazil, Animal Care Protocol (# 12179).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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