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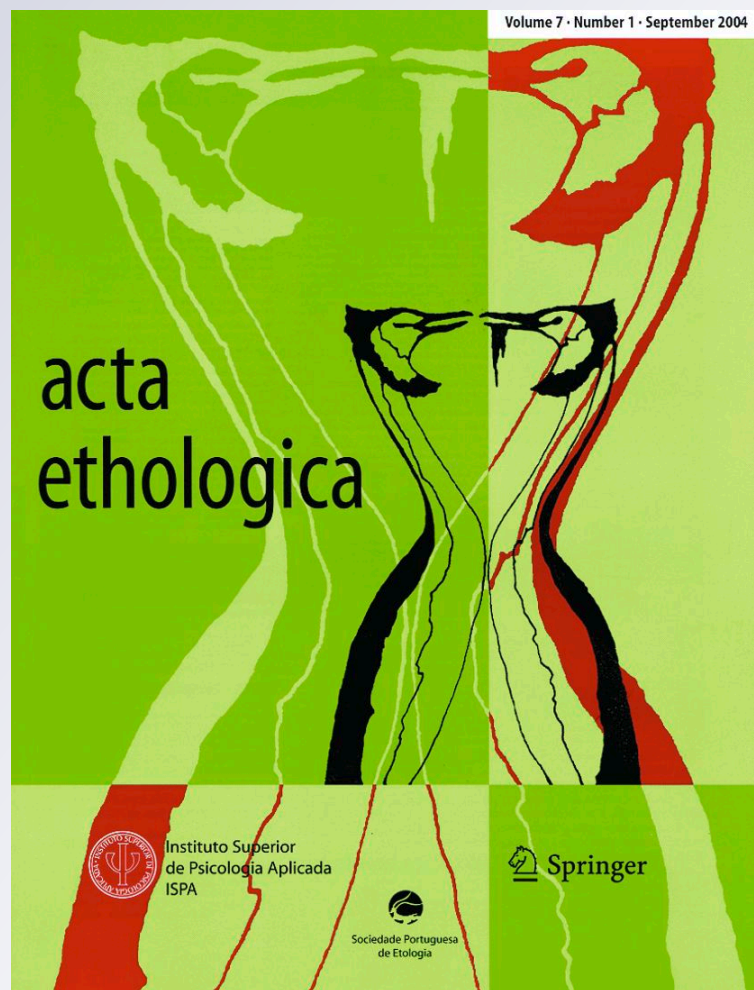
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Activity rate of the seahorse *Hippocampus reidi* Ginsburg, 1933 (Syngnathidae)

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Abstract This study aimed to compare activity levels of male and female *Hippocampus reidi* and to relate the level of activity of the males to their height and brood pouch circumference. Females appeared to be highly active, while pregnant males were less active and non-pregnant males presented more balance in time investment between active and inactive behavior. There was a positive correlation between height, brood pouch circumference, and inactive behavior.

Keywords Sedentary behavior · Seahorse · Brood pouch · Rocky reef

Introduction

Movement patterns and animal activity are considered relevant in population and community ecology (Cameron and Spencer 1985; Andrew and Mapstone 1987). Lately these

kinds of studies have been conducted to establish dimensions for marine reserves as a way to conserve reef fish species that are frequently collected (Alcala and Russ 1990; Polachek 1990; DeMartini 1993; Russ and Alcala 1996).

Sedentary behavior is common among reef fishes (Bardach 1958; Randall 1961; Sale 1991) and can be defined as showing only little movement and no migration (Péres 1961). Nonetheless, these organisms may show high levels of activity, like territorial fishes (e.g., *Stegastes fuscus*) or low levels of activity, like some cryptic fishes (e.g., Scorpaenid). The assessment of levels of an animal's activity provides pieces of information like its behavioral ecology and may be an important factor for management and conservation of certain species (Gervasi et al. 2006). One important group is seahorses which are characterized by a peculiar morphology with vertical body shape and a prehensile tail (Van Wassenbergh et al. 2011). These adaptations show cryptic and sedentary characteristics, allowing it to grasp some kind of holdfast (Foster and Vincent 2004).

Sedentary behavior leads to a small home range and limited daily movements, which is characteristic of reef fishes (Sale 1978; Schoener and Schoener 1982; Mace et al. 1983). Small home ranges in seahorses were reported by Bell et al. (2003), Perante et al. (2002), and Vincent et al. (2005). The latter also reported differences in male and female home ranges. In the few seahorse species studied, females have larger home ranges than males, indicating that males have more limited movements (Moreau and Vincent 2004; Foster and Vincent 2004). Smaller home ranges may be caused by many ecological features such as crowded environment, patchy distribution of resources, or morphological features, like the presence of a brood pouch. Seahorse males have a ventral brood pouch, which is used for incubation of the embryos until birth. During incubation, males invest much energy and physical effort, which favors decreased movement (Vincent et al. 2005). Based on this

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information, we evaluated whether *Hippocampus reidi* males are less active than females during the breeding season and possible causes for that behavior pattern.

The present study aimed to compare the activity levels of male and female *H. reidi* during the breeding season and to relate male activity to height and brood pouch circumference. A relationship between activity and pouch has been proposed by some authors, but it has never been tested for any seahorse species (Vincent 1990; Vincent and Sadler 1995; Perante et al. 2002).

Material and methods

Study area

The study was conducted in five sites in the state of Rio de Janeiro: (1) Lagoa Verde; (2) Araçatiba Beach, Ilha Grande, Angra dos Reis; (3) Forno Beach, Arraial do Cabo; (4) João Fernandes Beach; and (5) Geribá Beach, Búzios (Fig. 1). All selected sites have the same general environmental characteristics. They are all surrounded by rain forest and are

characterized by shallow water, little water movement, and rocky shores with subtidal rocks.

Data collection

Observations were conducted by snorkeling and visual census during July 2006 and November 2007. This method is commonly used in clear and shallow water (up to 6 m deep) (English et al. 1994; Samoilys and Carlos 2000; Menegatti et al. 2003).

Active behavior was defined as swimming, foraging, courtship, copulation, and defecation. Inactive behavior was defined as sedentary behavior, in which a seahorse grasps a holdfast and holds still. Activity level was measured by the focal animal method with time sampling (Hutt and Hutt 1978) of 1 h per randomly chosen seahorse. Observations were conducted during daylight (7:30 am to 6:00 pm). After the behavioral observation, individuals were caught by hand and visually identified by drawing their coronets (Freret-Meurer and Andreatta 2008) to avoid pseudoreplication (Hulbert 1984). The coronet is a bony structure on the top of a seahorse's head, which was photographed and drawn on a PVC board for further

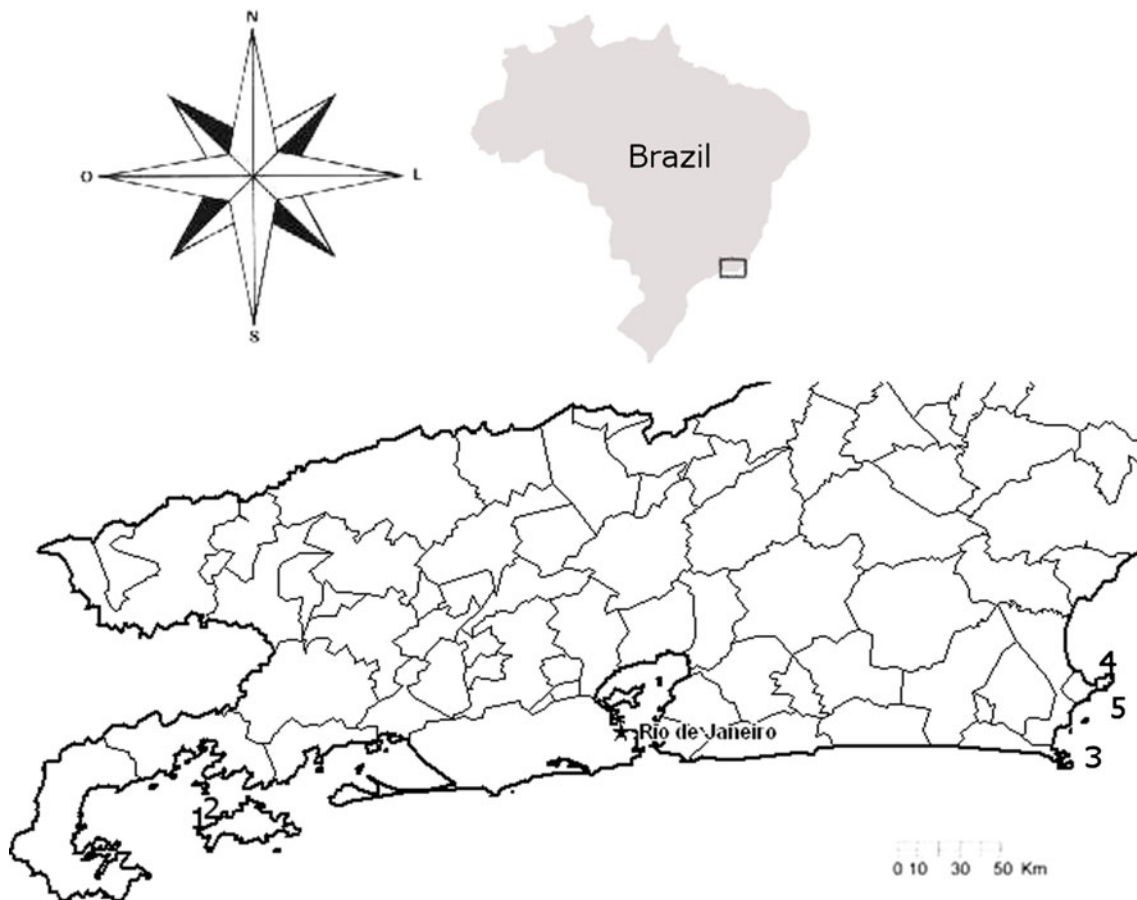


Fig. 1 Study sites in the state of Rio de Janeiro: (1) Lagoa Verde ($23^{\circ}08'S/044^{\circ}19'W$) and (2) Araçatiba Beach ($23^{\circ}09'S/044^{\circ}20'W$), Ilha Grande, municipality of Angra dos Reis; (3) Forno Beach ($22^{\circ}58'S/$

$042^{\circ}00'W$), municipality of Arraial do Cabo; (4) João Fernandes Beach ($22^{\circ}44'S/041^{\circ}52'W$); and (5) Geribá Beach ($22^{\circ}46'S/041^{\circ}54'W$), municipality of Búzios

recognition (Friday and Smith 2000). A virtual catalog has been created of each individual, which includes a code (M = male; F = female; and an additional number) for each seahorse and particular characteristics as size, reproductive state, holdfast, depth, picture of the animal, and picture of the coronet. Sex was established according to Lourie and Randall (2003), by the presence (male) or absence (female) of a brood pouch. Male reproductive states were determined according to Lourie (2003), where 0=just given birth, pouch is flabby, 1=pouch empty, pouch is flat; 2=pregnant, pouch is rounded; and 3=about to give birth, pouch is extremely rounded and shiny. Males were considered pregnant during states 2 and 3. Brood pouch circumference was determined by a cotton string and measured on a ruler (0.1 mm). Height was also measured on a ruler (0.1 mm) according to Lourie (2003) corresponding to the vertical distance from the median groove at the tip of the coronet to the tip of the outstretched tail. Both measurements were taken to establish their influence on seahorse activity. These results are not intended to be a substitute for weight but to establish a metric relation between length and brood pouch circumference of the individual.

Data analysis

Due to the statistical dependency of individual activity and inactivity data (since both behavior categories are mutually exclusive), both kinds of behavior for each sex were compared by a Wilcoxon signed-rank test (W). The difference between pregnant males, non-pregnant males, and females was established by Kruskal–Wallis test (H), followed by pairwise Dunn's post hoc tests, when data did not follow the normal distribution according to Kolmogorov–Smirnov ($p=0.05$). The relationship between inactive behavior, height, and brood pouch circumference was tested by a Spearman rank correlation (data did not follow a normal distribution according to Kolmogorov–Smirnov, $p<0.05$). We created an index based on the relationship between seahorse height and its brood pouch circumference. This index is a size-adjusted measure (SAM) of a male's reproductive investment in the current brood. The following formula represents the index: $SAM=BPC/H \times 100$, being BPC = brood pouch circumference and H = height. Spearman rank correlation was also used to relate SAM and inactive behavior. All data are reported as median and interquartile range (IQR), unless otherwise stated (Zar 1999).

Results

We observed 90 seahorses (30 pregnant males, 30 non-pregnant males, and 30 females). Females appeared to be highly active, showing a median activity period of 50 min (IQR=17) during the 60-min observation. Females invested most of their time in feeding (77 %) and swimming (3.3 %)

and less staying still (19.7 %). We observed a significant difference between activity and inactivity by using the Wilcoxon signed-rank test ($W=-454$; $p<0.001$; $df=29$). Other kinds of active behavior were also observed, such as defecation and reproduction, but these were less abundant (2 %).

Pregnant males were less active. They had a median activity period of 2 min (IQR=9). Active behavior represented only 13 % of observation time, indicating that pregnant males are significantly less active ($W=448$; $p<0.001$; $df=29$). We observed only two different kinds of active behavior for pregnant males, which were feeding (12 %) and swimming (1 %).

Non-pregnant males had more balance in their time budget between active and inactive behavior. These males had a median activity period of 35 min (IQR=12–75) during observations. The active period represented 57.8 % of exhibited behavior. Although there was a small difference between both major behaviors, non-pregnant males were significantly more active ($W=-286$, $p<0.01$, $df=29$). During active periods, non-pregnant males exhibited feeding (56 %), reproductive behavior (2.9 %), swimming (1 %), and defecation (0.1 %).

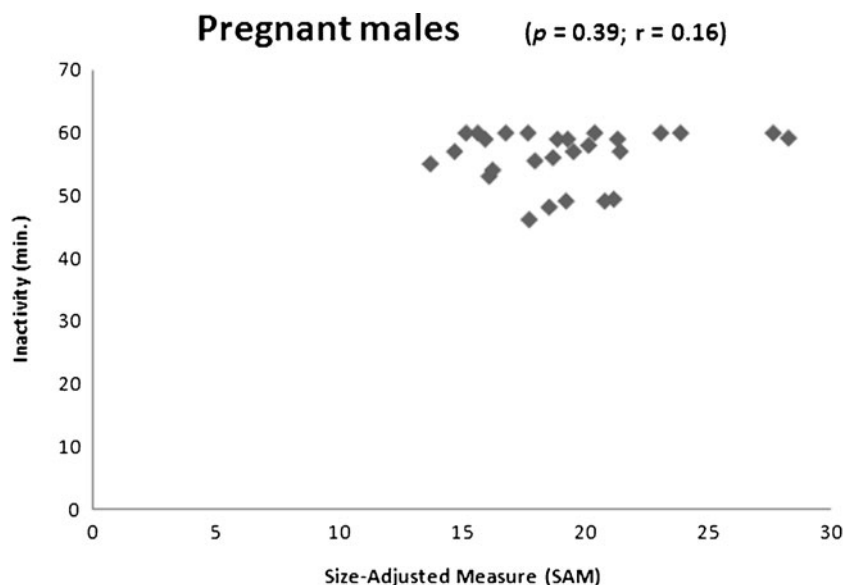
There was a highly significant difference between active behavior of females, pregnant males, and non-pregnant males ($H=56.55$; $p<0.0001$, $df=89$), and Dunn's post hoc tests showed that all three categories are significantly different from each other. Females were significantly more active than both male categories ($p<0.05$), and non-pregnant males were more active than pregnant males ($p<0.001$). Feeding behavior was the most representative active behavior and statistical analyses made for this behavior corroborates with the results of activity and inactivity. Time invested in feeding was significantly different between all three categories ($p<0.001$; $H=53.563$). Females fed more than non-pregnant males ($p<0.05$) and pregnant males ($p<0.001$). Both pregnant and non-pregnant males also differed among themselves ($p<0.001$). Swimming activity was similar for female, pregnant, and non-pregnant males ($p=0.06$; $H=5.395$). The other behaviors were not statistically analyzed because there were too few observations.

There was no correlation between SAM and inactive behavior for pregnant males ($p<0.39$; $r=0.16$; $df=29$), indicating that inactive behavior was not related to seahorses with higher values of SAM (Fig. 2). No correlation between SAM and inactive behavior was either found for non-pregnant males ($r=0.23$; $p>0.05$, $df=29$) (Fig. 3).

Discussion

Seahorses have a very peculiar morphology that favors sedentary behavior. Their vertical body position and their prehensile tail promote a typically benthic behavior and they usually can be found associated to a holdfast (Lourie et al.

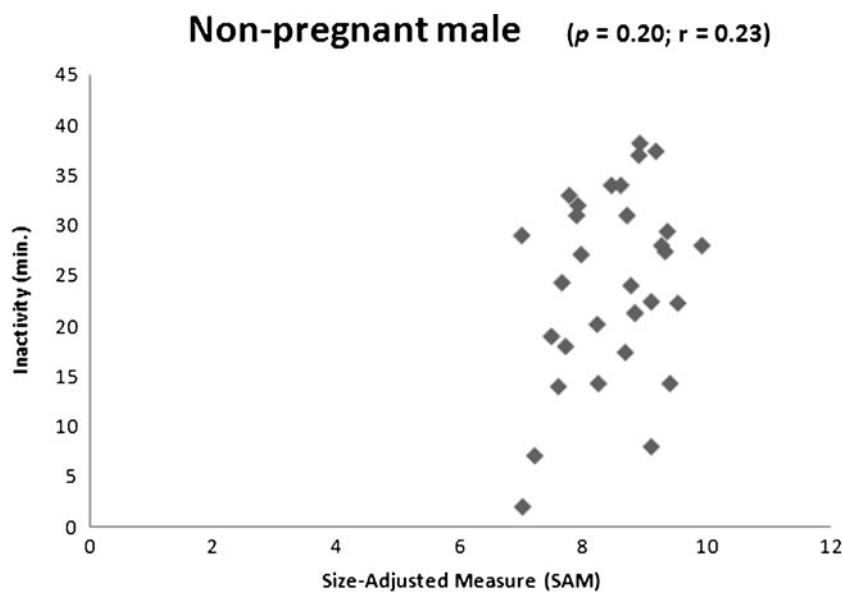
Fig. 2 Relation between size-adjusted measure (*SAM*) and inactivity (minutes) of pregnant seahorse, *Hippocampus reidi*, in the state of Rio de Janeiro, Brazil ($n=30$)



1999). The dorsal fin of the seahorse is responsible for propulsion, which undulates at high frequencies and low amplitude (Blake 1976), reducing efficiency and leading to slow swimming speed (Blake 1980). Seahorses usually are not found swimming on the reef during the day like other fishes; instead, they are usually found holding a holdfast (Perante et al. 2002; Bell et al. 2003; Dias and Rosa 2003). However, seahorses are not as sedentary as they first appear. The present study shows that seahorses are active and a male's behavior changes when he is pregnant. The greater female activity seen in *H. reidi* during the study is consistent with Freret-Meurer and Andreatta (2008). Other studies also suggest greater female seahorse activity, with a larger home range size reported for them (Vincent and Sadler 1995; Moreau and Vincent 2004; Vincent et al. 2005). The greater home range for females in other seahorses might also

indicate higher female activity for these species. The highly active behavior in *H. reidi* females was represented by foraging behavior. Our results were also consistent with results found for the pipefish *Syngnathus typhle*. Males had reduced mobility during pregnancy and females showed a more active foraging behavior (Svensson 1988). The time spent foraging is extremely important to evaluate costs of reproduction. Non-pregnant males showed similar foraging behavior to females, but even so females spent more time feeding. This pattern suggests that males have a higher cost to reproduce than females. The large proportion of feeding time might represent two reproductive trends: (a) females produce a higher number of gametes than males and/or (b) females ingest small prey items or low nutritional value prey items. Syngnathid males produce small amounts of sperm, as an evolutionary response to internal fertilization, while

Fig. 3 Relation between size-adjusted measure (*SAM*) and inactivity (minutes) of non-pregnant seahorse, *Hippocampus reidi*, in the state of Rio de Janeiro, Brazil ($n=30$)



females have a high production of eggs (Strölting and Wilson 2007). Besides gamete production, some species also ingest larger prey items during breeding season (Svensson 1988). Both could explain the large proportion of feeding time for females (Felício et al. 2006). *Hippocampus reidi* mostly has a sit-and-wait strategy (Felício et al. 2006), but in rocky reefs they are often active predators that feed on a wide range of food items (Castro et al. 2008).

Pregnant and non-pregnant males presented different activity patterns. The higher sedentary behavior in males during the reproductive phase was consistent with the results obtained by Vincent and Sadler (1995) with *Hippocampus whitei*. Vincent (1990) also reported that pregnant males were sedentary and this was attributed to the brood pouch, although no study to confirm this has been conducted. The brood pouch is a highly specialized structure for parental care, which can be found in male seahorses (*Hippocampus*) and other Syngnathid species (e.g., *Syngnathus*; Strölting and Wilson 2007). The female deposits oocytes to the brood pouch through an oviduct, and they are fertilized by the male during transfer (Vincent and Sadler 1995). After fertilization, many changes occur in brood pouch structure, and protection is not the only function of the brood pouch. There is evidence that the brood pouch is also responsible for osmoregulation by several mechanisms, such as mitochondrial-rich cells (in pipefish species) (Partridge et al. 2007; Ripley 2009) or other ion transport mechanism (in seahorses) and also for nutrition and gas exchange by high vascularization of the brood pouch epithelium during pregnancy (Boisseau 1967; Linton and Soloff 1964; Carcupino et al. 2002; Strölting and Wilson 2007). These physiological changes and pregnancy sustenance probably demand a high energy cost, which could turn males into very inactive individuals. However, embryo's show high quantity of yolk made available by their mother, indicating that males only provide nutrient supplementation. Depletion of the macronutrients in the brood pouch fluids indicates that macronutrients are consumed during embryonic development, but the degree of supplementation may be different between species, as reported for *Syngnathus fuscus* and *Syngnathus floridae* (Ripley and Foran 2006). The number of nutrient-rich eggs indicates how nutrient-rich the brood pouch fluids must be to develop the embryos and consequently the amount of energy invested by the male. Ripley and Foran (2009) have also found evidence of paternal nutrient provisioning to embryos for those two same species by radioactively labeled nutrients, and Kvarnemo et al. (2011) have also found it for *S. typhle*. Although energy cost due to brooding might be high to maintain the highly elevated metabolism of pregnant males (Masonjones 2001; Vincent et al. 2005), certain species, such as *Hippocampus guttulatus*, do not differ in activity

behavior between sexes. The absence of activity patterns in some species could possibly be explained by paternal uptake of nutrients from embryos, as reported to *S. typhle* (Sagebakken et al. 2010).

The increase of body mass might burden males during incubation, but this does not necessarily explain inactive behavior during the pregnancy. The present work found a strong relationship between male pregnancy and inactive behavior, indicating that the more advanced pregnancy is, the more sedentary the male will be. Those results indicate a relationship between reproductive state and inactive behavior instead of morphometric characteristics and inactive behavior. The pipefish *Nerophis ophidion* carries a brood in a rudimentary brood pouch. That species has a higher weight during the breeding season, but does not become inactive (Svensson 1988). It has already been reported that species with a rudimentary brood pouch spend less energy brooding their young. This means that those species invest energy mostly into carrying their young instead of both investments, physiological and carrying investments (Berglund et al. 1986).

Monogamous mating system could be another explanation to reduce displacement of reproducing males. Although mating system is variable according to ecological conditions, monogamy has already been reported to seahorses. Some species of seahorses, which form monogamous pairs bonds for at least the reproductive period (e.g., *Hippocampus fuscus*, *Hippocampus comes*, *H. whitei*, *Hippocampus subelongatus*; Wilson et al. 2003), do not show the need for large movements to search for a partner, thereby avoiding larger energy expenditures (Vincent 1996). Kvarnemo et al. (2000) reported for *H. subelongatus* that males that mated with more than one female between broods increased their interbrood interval, reducing their potential reproductive rate. Monogamy might be optimal for males, but females should engage in polyandry to increase their potential reproductive rate, once parental care is provided by the males. However, Vincent (1990) suggests that females may switch their mate, but this may also increase interspawning interval. Seahorse populations might have several mating systems according to individual's condition (Kvarnemo et al. 2000), and activity rate might be associated with mating system.

The risk of predation or injuries for those with higher activity rates should also be considered, as they reduce efficiency of crypsis. *Hippocampus reidi* is able to change color and develop skin extensions to improve crypsis. Pregnant males carry their offspring and should remain more protected having an essential cryptic behavior. Thus, lower activity rates for male might be an expression of a selection pressure. Our results showed that the males in general are typically less active than the females; however, incubating males are even more inactive than both non-incubating males and females. Svensson (1988) has evaluated the

predation risk of the pipefish *S. typhle*, and both sexes had the same vulnerability to predation. The same study evaluated predation risk for *Nerophis ophidian*, which showed a greater vulnerability to predation for reproductive males. Seahorses are an interesting group to study a possible sex role reversal, and the present study highlights the need of further studies about reproduction and behavior of the Brazilian seahorse *Hippocampus reidi*.

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