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# Fluctuating asymmetry: A tool for impact assessment on fish populations in a tropical polluted bay, Brazil

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ABSTRACT

Fluctuating asymmetry (FA), which can be defined as random morphologic changes on bilateral symmetry plan of paired morphometric and meristic characters in response of environmental disturbances, is an alternative tool to traditional methods of environmental health assessment that has an interesting potential to appraise the state of adaptation of a population before that acute contaminations affect the whole community or ecosystem. This study aimed to assess the occurrence of FA in three morphometric and three meristic characters of the Corocoro grunt *Orthopristis ruber* (Cuvier, 1830), and compare the deviations in bilateral symmetry of this reef-associated and omnivorous in Guanabara Bay (Brazil), the venue for various outdoor aquatic sports during the 2016 Olympic Games. Five indexes of FA were tested over the six characters of 66 *O. ruber*, which were caught during the dry and wet seasons of 2011 and at three areas Guanabara Bay of different environmental characteristics. In addition to validate the existence of FA for *O. ruber*, our findings revealed significant deviations in the bilateral symmetry according to the FA indexes and fish characters. Together with the FA1 index, the number of gill rakers and the number of rays of the pectoral fin provided the best methodological approach to address the levels of FA in *O. ruber* as a response to environmental stressors in each region. The levels of FA in *O. ruber* was significantly lower in the Urca region (less impacted) than for individuals caught near the Paquetá Island and Rio-Niterói Bridge sites (more degraded). Partial Redundancy Analysis also shows that the fish characters are affected in different ways by environmental stressors, but especially in response to the levels of dissolved oxygen and, secondarily, to water transparency, and that Paquetá Island is apparently less impacted than the site near the Rio-Niterói Bridge. Our results confirm the potential of FA to be used as a tool to detect environmental effects on a reef-associated fish species in a tropical polluted bay, but further studies are necessary to validate our findings for other species and ecosystems.


## 1. Introduction

Fluctuating asymmetry (FA) is defined as random morphological deviations in the bilateral symmetry planes of an organism due to the effects of adverse environmental conditions (Van Vallen, 1962; Palmer, 1994; Hermita et al., 2013). The general prediction of this theory is that FA increases with the instability of an organism through its development (Van Vallen, 1962; Palmer, 1994), decreasing its adaptative fitness (Gonçalves et al., 2002; Almeida et al., 2008; Hermita et al., 2013). Since the degree of FA also reflects the adaptive ability of the entire population, allowing inferences on the health of the whole ecosystem (Øxnevad et al., 2002; Kristoffersen and Magoulas, 2009), FA studies are increasingly used over traditional methods for environmental and biomonitoring assessments (Palmer and Strobeck, 1992; Kitevski and Pyron, 2006; Graham et al., 2010 Graham et al., 2010).

Increased levels of FA were correlated with decreased fertility, growth, reproductive success, egg size, and survival rates of some species (Somarakis et al., 1997; Morris et al., 2012), but the responses can differ with the taxa and the paired traits chosen for FA analyses (Lens et al., 2002). For example, traits of high functional

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importance are highly conservative during ontogeny, showing generally low FA values (Gonçalves et al., 2002; Trokovic et al., 2012). Since the differential response of each body structure to environmental disturbances can result in varied levels of FA (Palmer, 1994; Graham et al., 1998; Ayoade et al., 2004), the use of multiple traits is largely recommended to assess the FA at a population level, minimizing the potential bias of a particular trait (Leary and Allendorf, 1989; Palmer and Strobeck, 1992; Palmer, 1994).

Fish is the richest group among the vertebrates and spread in virtually all aquatic habitats, being thus not only susceptible to influences of environmental conditions throughout their development but also interesting candidates to test the potential of FA as an indicator of environmental health (Allenbach, 2011). Most endogenous stressors related to FA in fish are the level of inbreeding, heterozygosity, hybridization, and genetic based diseases (Palmer and Strobeck, 1986, 2003; Fries et al., 2004; Hermita et al., 2013), while commom biological stressors are the density of offspring and the degrees of competition predation, and parasitism (Palmer, 1994; Palmer and Strobeck, 2003; Allenbach, 2011). Exogenous stressors range from changes on physical habitat and variations in water salinity, pH, and temperature to the effect of pesticides, heavy metals, and even climatic changes (Palmer, 1994; Øxnevad et al., 2002; Kitevski and Pyron, 2006; Allenbach, 2011; Jawad et al., 2012). Despite the growing number of experiments demonstrating the relationships of bilateral asymmetry with fish traits (*censu* Allenbach, 2011), there are surprisingly few field studies that addressed how FA in fish is associated with habitat degradation, and similar studies for tropical marine fish are virtually unknown (Ayoade et al., 2004; Mamry et al., 2011; Jawad et al., 2012).

The Corocoro grunt *Orthopristis ruber* (Cuvier, 1830) is a Haemulid fish commonly distributed throughout the South Atlantic Ocean and widespread in several marine and estuarine systems along the Brazilian coast (Vianna and Verani, 2002). This sedentary species is one of the most abundant fish associated with rocky shores in Guanabara Bay (LNS; unpublished data), a tropical estuary located in Southeastern Brazil (Rio de Janeiro city) that historically undergoes high levels of contamination and habitat degradation (Kjerfve et al., 1997; Fonseca et al., 2013; Fistarol et al., 2015). Despite the greater abundance of *O. ruber* in the outer zones of this bay, which are less degraded and more influenced by adjacent oceanic waters (Vianna and Verani, 2002; Rodrigues et al., 2007), there is no study that addressed the effects of environmental conditions on the bilateral symmetry of this species, despite the interesting potential of resident fish species closely associated with submerged habitats to be used as indicator of the integrity of whole ecosystem (Allenbach, 2011).

In this paper, the deviation from bilateral symmetry in six morphometric and meristic characters of *O. ruber* captured in three areas of different environmental characteristics in Guanabara Bay was investigated. The objectives of this work are: (1) to test whether the deviations in bilateral symmetry can be attributed to FA or other kinds of asymmetry; (2) to test for the levels of FA among the six morphological characters of *O. ruber* and the five FA indexes; and (3) to compare the levels of FA among the three areas of Guanabara Bay and correlate them with physical and chemical water variables that are proxies of environmental conditions. The potential of applied studies using FA and fishes as indicator of the health of tropical marine system is also discussed.

## 2. Material and methods

### 2.1. Study area

Guanabara Bay (22°24′–22°57′S; 42°33′–43°19′W) is a ∼380 km$^2$ estuarine environment that accounts for the final destination of 50 rivers and streams that drain the Rio de Janeiro (the larger and most urbanised metropolis) and other 15 adjacent cities toward the sea (Fistarol et al., 2015). It is one of the most degraded coastal environments in Brazil, receiving high loads of organic matter and inorganic nutrients, and large amounts of industrial and agricultural effluents daily. Long term effects of disordered use of watershed and diffuse pollution, which started early in the XVI century but escalated especially from 1930 with the industrialization process, have increased significantly the concentration of inorganic nutrients (mainly phosphorus), heavy metals (including Pb, Cr, Cu and Ni), and several refractory organic pollutants (such as PCBs) at the water column and in the sediment (Kjerfve et al., 1997; Fonseca et al., 2013). As consequence, the current environmental and sanitary conditions of Guanabara Bay are so critical that is adversely affecting not only the entire aquatic community, from microbes to higher trophic levels of the marine life, but also human health (Fistarol et al., 2015). Currently, attention toward Guanabara Bay pollution increased significantly, because the city of Rio de Janeiro is going to host the 2016 Olympic Games and Guanabara Bay will be the venue for various outdoor aquatic sports during the games.

Water circulation in Guanabara Bay is complex, depending on the combining effects of tidal regime, freshwater runoff, and depth countour, which affect directly the gradients of water qualities in the bay (Kjerfve et al., 1997; Fistarol et al., 2015). Most of the bay (84%) has <10 m depth, ranging from a maximum depth of 58 m on its central channel to less than 1.0 m in the inner areas (Mayr et al., 1989). The presence of this deep channel allows the intrusion of more saline (34–36), oxygenated, and oligotrophic waters from the adjacent ocean, which positively affect the southeast parts of the bay and also the areas more directly affected by the central channel (Mayr et al., 1989; Paranhos et al., 1998; Valentin et al., 1999). The influence of marine water is largely controlled by tide (mainly semidiurnal), with a maximum amplitude of 1.4 m and decreasing current velocities from the mouth of the bay (80–150 cm s$^{-1}$), toward the central areas (30–50 cm s$^{-1}$), until to attain a minimum of less than 30 cm s$^{-1}$ in the inner zones. Freshwater runoff follows, however, the opposite pattern, with the greater discharges (up to 186 m$^3$ s$^{-1}$ in the rainy austral summer) largely affecting the innermost regions of the bay (due to the greater amount of rivers, lower depths, and the lower influence of marine waters), in contrast to lower effects of freshwater discharges on the outer zones of the bay, which are largely under marine influence and less affected by river drainages (Kjerfve et al., 1997). Therefore, there is an environmental gradient from the entrance of the bay to its internal areas, in which more saline, oxygenated, transparent (up to 5.0 m), and clean waters, and high levels of marine biodiversity are generally found in the southeastern part and in areas near the central channel, in contrast to the gradual decrease of water quality and species richness toward the inner zones of the bay (Mayr et al., 1989; Kjerfve et al., 1997). Recently, Fistarol et al. (2015) also demonstrated the presence of a lateral gradient in the bay, with the worst water quality on its northern and northwestern parts (as a result of synergistic interactions of greatest loads of wastewater and lowest rates of water circulation) and better conditions on the central channel and the eastern part of the bay (as consequence of higher dilution by seawater through tidal mixing).

### 2.2. Sampling design

Three sites were selected to encompass the environmental gradient along the main central channel in Guanabara Bay (Fig. 1), following to the general classification of Mayr et al. (1989) but also taking into account the recent contributions of (Fistarol et al., 2015): (1) Urca (at Fora Beach); (2) Rio-Niterói Bridge (near the Botafogo cove); and (3) Paquetá Island (the southward area). Fora