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Research Article

Comparative analysis of free and scuba diving for benthopelagic and cryptic fish species associated with rocky reefs

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ABSTRACT. This work aimed to assess, through experimental comparisons between free and scuba diving performed in Arraial do Cabo city, RJ, Brazil, the abundances of *Scartella cristata* e *Chaetodon striatus* -two reef fish species of contrasting behaviors- in different depth layers of sheltered and exposed rocky reefs. *C. striatus* was homogeneously distributed through all the depth strata (0-10 m) and scuba diving should be preferred over free diving to assess the abundance of this species at exposed rocky shores, undergoing continuous effects of waves and winds. Both free and scuba diving can be used indistinctly and with no data biases to appraise the abundances of *C. striatus* in non-turbulent reefs or in shallow zones (*i.e.*, ≤5 m) of exposed reefs, and, for *S. cristata*, in all depth layers (*i.e.*, up to 10 m) of both sheltered and exposed reefs. Although the abundances of *S. cristata* did not significantly differ between free and scuba diving, contrasting with most previous studies that stressed the risk of the first method to underestimate the abundance of small and cryptic species, it should be considered that the previous experience of the diver and the nature of our study (*i.e.*, focused specifically on a cryptic species) may have contributed to our findings. Further studies are, however, necessary to test our findings in different conditions (*i.e.*, depths, hydrodynamic characteristics, and habitat complexity) and for other tropical reef fish species, in order to increase the truthfulness of underwater visual census and reduce the risk of failure of fish conservation and management programs potentially based on biased data.

Keywords: reef fish, visual census, free diving, scuba diving, Brazil.

Análisis comparativo entre buceo libre y autónomo para especies de peces bentopelágicas y crípticas asociadas a arrecifes rocosos

RESUMEN. Este trabajo tuvo como objetivo evaluar, a través de comparaciones experimentales entre apnea y buceo realizados en Arraial do Cabo, RJ, Brasil, la abundancia de *Scartella cristata* y *Chaetodon striatus* -dos especies de comportamiento contrastante- en diferentes estratos de profundidad de arrecifes rocosos protegidos y expuestos. *C. striatus* se distribuye homogéneamente en todos los estratos de profundidad (0-10 m), siendo el buceo autónomo el más indicado por sobre el buceo libre para evaluar la abundancia de estas especies en costas rocosas expuestas, sujetas a continuos efectos de las olas y del viento. El buceo libre y autónomo se pueden utilizar indistintamente y sin sesgos en los datos, para evaluar la abundancia de *C. striatus* en arrecifes no turbulentos o en zonas de poca profundidad (*i.e.*, ≤5 m) de los arrecifes expuestos y, para *S. cristata*, en todos los niveles de profundidad (*i.e.*, hasta 10 m) de ambos arrecifes, protegidos y expuestos. Aunque la abundancia de *S. cristata* no fue significativamente diferente entre la apnea y scuba, en contraste con la mayoría de los estudios anteriores que enfatizaban el riesgo del primer método en subestimar la abundancia de especies pequeñas y crípticas, se debe considerar que la experiencia previa del buzo y la naturaleza de nuestro estudio (*i.e.*, centrado específicamente en una especie críptica) puedan haber contribuido a nuestros hallazgos. Sin embargo, se requieren más estudios para comprobar estos resultados en diferentes condiciones (*i.e.*, profundidades, características hidrodinámicas y complejidad del hábitat) y para otras especies de peces de arrecifes tropicales, para aumentar la veracidad de los censos visuales submarinos y reducir el riesgo de fracaso de los programas de conservación y manejo de peces potencialmente basados en datos sesgados.

Palabras clave: peces arrecifales, censos visuales, buceo libre, buceo autónomo, Brasil.

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INTRODUCTION

Underwater visual census techniques have been widely applied for reef fish assessments, since they are non-destructive, and easily applicable methods for estimating species richness and abundance (Braden *et al.*, 1986; Thresher & Gunn, 1986; Sale, 1991; Samoilys & Carlos, 2000; Edgar *et al.*, 2004; Kulbicki *et al.*, 2007). Both free and scuba diving is used for inventories of fish assemblages associated with rocky reefs (Menegatti *et al.*, 2003; Meyer & Holland, 2005; Mendes, 2009). Although free diving is considered less effective, for whole fish assemblage surveys, since it may underestimate the total abundance and species richness due to the inherent restrictions on divers submersion time (Dearden *et al.*, 2010), this technique has been successfully applied in many reef fish studies (Lieske & Myers, 1994; Menegatti *et al.*, 2003; Mendes, 2009). Scuba diving, however, is often applied for studies on the entire fish assemblages and long-term studies of reef fish populations (Jansson *et al.*, 1985; Turner & Mackay, 1985; Abelson & Shlesinger, 2002; Chaves, 2006; Deehr *et al.*, 2007). Despite their increasing use in scientific studies, there are surprisingly few studies comparing the effectiveness of free and scuba diving on reef fish surveys (but see Wilson *et al.*, 2007; Dearden *et al.*, 2010; Januchowski-Hartley *et al.*, 2012).

Apart from apparent performance differences between free and scuba diving, the structural complexity (*i.e.*, low or high), depth (*i.e.*, shallow or deep), and hydrodynamic conditions of rocky reefs may affect visual census efficiency. Structural complexity is considered one of the most important factors affecting reef fish assemblages in both rocky and coral reefs (Ferreira *et al.*, 2001; Floeter *et al.*, 2007), and can affect the effectiveness of visual censuses through holes and crevices where fish hide and may escape (Letourneur *et al.*, 2003; Wilson *et al.*, 2007; Shima *et al.*, 2008), especially in hydrodynamically turbulent conditions (Friedlander & Parrish, 1998; Friedlander *et al.*, 2003; Floeter *et al.*, 2007). Depth is also a critical factor, not only due to its effects on fish species distribution (Mcgehee, 1994; Ferreira *et al.*, 2001; Srinavasan, 2003), but also because of the restrictions imposed to free divers. In addition to the environmental characteristics of the rocky reefs, fish behavior also plays an important role on visual census performance, with a trend of abundance overestimation of large, colourful and curious benthopelagic species in contrast with underestimation toward small, colourless, and cryptic species (Willis, 2001; Depczynski & Bellwood, 2004).

This study aimed to compare the performance of free and scuba diving for assessing two reef fish species of contrasting behaviour -the colourful and benthopelagic *Chaetodon striatus versus* the small and cryptic *Scartella cristata*- associated with rocky reefs at the Marine Extractive Reserve (RESEX-MAR) of Arraial do Cabo, northern Rio de Janeiro coast, Brazil. We specifically tested whether free and scuba diving is effective to survey the abundance of these two fish species in rocky reefs of different levels of hydrodynamic conditions and depth ranges. We hypothesized that free diving has similar efficacy to scuba diving, but the results depends on rocky reef conditions and target fish species.

MATERIALS AND METHODS

Study area

Arraial do Cabo city is located approximately 140 km north from Rio de Janeiro municipality (Fig. 1). This region is considered a biologically rich zone because of the upwelling phenomenon that carries up deep nutrient-rich waters to the photic zone (Matsuura, 1986; Chaves, 2006). It contains a Marine Extractive Reserve (RESEX-MAR) encompassing from Massambaba beach to Ponta Beach, on the border with Cabo Frio city. Sustainable fisheries and subaquatic tourism are allowed within the RESEX-MAR, occurring intensively throughout the year (Spalding *et al.*, 2001; Chaves, 2006).

Four rocky reefs were surveyed in this study, belonging to two groups of hydrodynamic conditions and structural complexity (Fig. 1). The Cardeiro and Porcos rocky reefs are located in areas protected from the strong ocean east-northeast winds and waves. Cardeiro reef is situated at the mainland, at Forno Beach, while Porcos reef is located on Porcos Island, between the mainland and Cabo Frio Island. Cardeiro reef has a smooth relief, being composed of rock agglomerations of varied dimensions, which are situated at a maximum depth of 10 m and largely covered by the invasive soft coral *Stereonephtya* aff. *curvata*. Porcos reef is physically heterogeneous, with several rock walls and ladders that reach up to 14 m of depth. Cardeiro and Porcos reefs are structurally very complex in all depth layers. Abobrinha and Anequim reefs are located on Cabo Frio Island (Fig. 1), undergoing strong influences of east-northeast winds and waves. Abobrinha reef is composed of orangish rocks following a stair shape, located at a maximum depth of 12 m. Anequim reef has a steep relief and many rocky walls, reaching a maximum depth of 15 m. Abobrinha and Anequim reefs have high structural

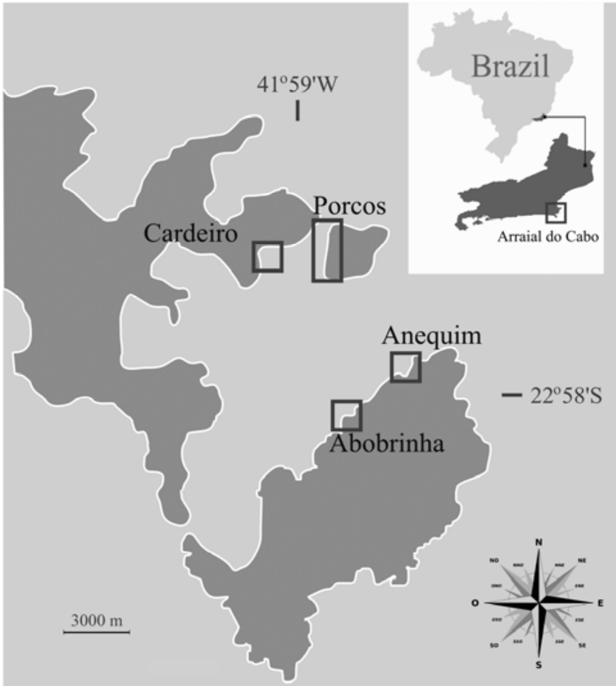

Figure 1. Geographical location of Arraial do Cabo municipality, showing the two exposed sites (Anequim and Abobrinha) and the two sheltered sites (Cardeiro and Porcos).

complexity, but especially at depths >5 m, where large amount of rocky agglomerations are prevalent.

Sampling design and data analysis

In total, 89 randomized belt transects (20×5 m) were performed from January to March 2010 (summer), parallel to the coastline, to assess the abundances of *C. striatus and S. cristata* at the four rocky. Each transect was performed by the same single diver (*i.e.*, the first author), which covered the transect stretch in a zigzag movement searching for the target fish species. Transects were conducted at each reef site in two depth layers (shallow, 0-5 m; and deep, 5.1-10 m) and with two visual census method (free and scuba diving). Approximately the same number (N = 2-4) of transects were conducted each day in the entire four reef sites, totalling 21-23 transects per reef site. The order in which the depth layer was surveyed and the type of survey method used was assigned randomly, with the subsequent survey performed in the same depth but applying the method different from that used in the previous survey. All the observed fish were identified in situ and recorded in PVC tablets together with data on depth and dive technique. A four-way Permutational Analysis of Variance (PERMANOVA; $P < 0.05$) was performed on $\log_{10}$ transformed data to compare fish abundance among reef hydrodynamic conditions (sheltered *versus* exposed), depth layer (0-5 m *versus* 5.1-10 m), dive method (free- *versus* scuba diving), and fish species (*C. striatus versus S. cristata*). Although not dependent on the conventional parametric assumptions of normality and homocedasticity, PERMANOVA requires balanced experimental designs (*i.e.*, an equal number of observations per factor), which was attained by replacing missing cells with the overall mean. The Euclidean distance was chosen as the basis of all PERMANOVA analysis and data were permutated 999 times per analysis (Manly, 1997). Pair-wise *post-hoc* comparisons were performed under 999 permutations whenever significant differences were found (see Anderson (2005) for further details).

RESULTS

Abundance of both *C. striatus* and *S. cristata* differed significantly among rocky shore, depth and dive method ($F_{1,\,96} \geq 6.0$; $P \leq 0.01$ for all), and significant interactions were recorded for site × dive technique × fish species ($F_{1,\,96} = 7.6$; $P < 0.01$) and site × depth × fish species ($F_{1,\,86} = 6.7$; $P < 0.01$). Overall, scuba diving was more effective than free diving to appraise *C. striatus* abundances, but only in exposed rocky reefs (PERMANOVA *post-hoc* test; $P < 0.01$; Fig. 2). Considering thus scuba diving as the reference method, the abundance of *C. striatus* was also greater in exposed rocky reefs than at sheltered ones (PERMANOVA *post-hoc* test; $P < 0.01$; Fig. 2). No significant differences were found between free and scuba diving for abundances of *C. striatus* at sheltered reefs and for abundances of *S. cristata* at both sheltered and exposed reefs (PERMANOVA *post-hoc* test; $P > 0.05$; Fig. 2).

S. cristata was significantly more abundant (PERMANOVA *post-hoc* test; $P < 0.01$; Fig. 3) at 0-5 m depth layer in exposed reefs. The abundances of *S. cristata* were also significantly more abundant (PERMANOVA *post-hoc* test; $P < 0.05$; Fig. 3) at 0-5 m depth layer in exposed reefs than at all depth layers in sheltered reefs. No significant differences were found for the abundances of *C. striatus* among depth layers or types of rocky reefs (PERMANOVA *post-hoc* test; $P > 0.05$; Fig. 3).

DISCUSSION

Although differences between free and scuba diving have been observed in other studies (Willis, 2001;

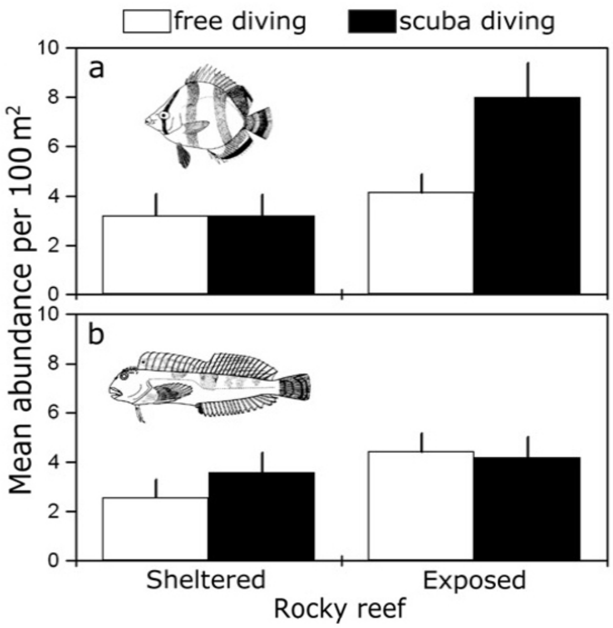

Figure 2. Mean abundance of a) *C. striatus* and b) *S. cristata* recorded with free (☐) and scuba diving (■) for sheltered and exposed rocky reefs in Arraial do Cabo municipality. Vertical lines indicate the standard error.

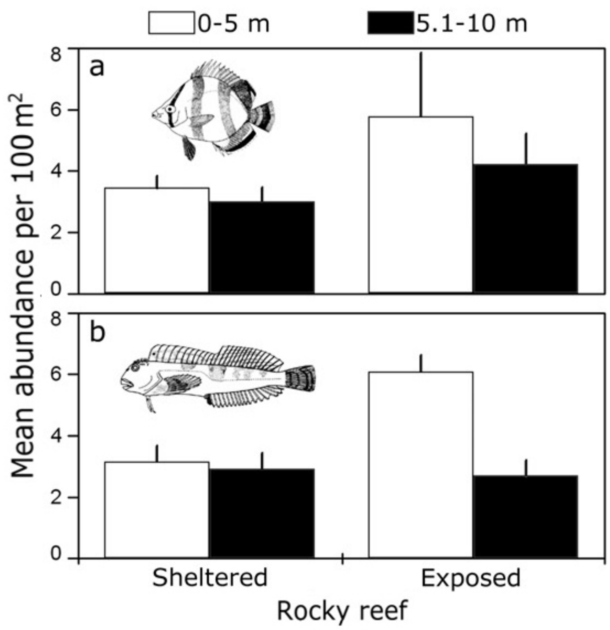

Figure 3. Mean abundance of a) *C. striatus* and b) *S. cristata* recorded with the two visual census methods (free and scuba diving together) at 0-5 m (☐) and 5.1-10 m (■) for sheltered and exposed rocky reefs in Arraial do Cabo municipality. Vertical lines indicate the standard error.

Depczynski & Bellwood, 2004; Dearden *et al.*, 2010), we surprisingly found few contrasts between these two techniques to assess the abundances of two reef species. Even more interestingly was that only the abundances of the benthopelagic and more colourful *C. striatus* differed between free and scuba diving, but not for the small and cryptic bleniid *S. cristata*. *C. striatus* is a common reef fish species, occurring generally in all the depth strata and microhabitats (*i.e.*, algae beds, mussel patches, bare rocks) of rocky reefs, often using macroalgae beds and rocky interstices as shelter (Ferreira *et al.*, 2001). Since few previous studies (Mcgehee, 1994; Willis, 2001; Wilson *et al.*, 2007) addressed the effects of hydrodynamic features (*i.e.*, sheltered *versus* exposed reefs) on the effectiveness of visual census techniques and no data was found on their possible effects on *C. striatus* abundances, we attributed our differences to the effects of turbulent conditions on the ability of free divers to perceive this species. Therefore, the dominant turbulent conditions in the exposed Abobrinha and Anequim rocky reefs, in addition to probably imposed additional restrictions to total submersion time of the free diver, may have reduced the accuracy of the diver to perceive *C. striatus* under the continuous effects of waves and bubbles (*i.e.*, turbulence). Another non-mutually exclusive explanation is that a scuba diver may have an attraction effect on *C. striatus* (Almada-Villela *et al.*, 2003), a species naturally curious about the air bubbles released by scuba diving (R.G. Giordano, *pers. comm.*). The lack of differences for the abundances of *S. cristata* further suggest that, in some situations, free diving can be as effective as scuba diving in assessing small cryptic species, particularly if free diving is conducted by experienced divers and focused specifically to record a single cryptic fish species.

While the lack of differences in the abundances of *C. striatus* with depth layers are related to the broad distribution of this species through all the reef depths and microhabitats (Ferreira *et al.*, 2001), the greater abundance of *S. cristata* at lower depths (*i.e.*, 0-5 m) of exposed reefs seems to be related to the species preference for shallow and highly-complex zones of rocky reefs. Topolski & Szeldmayer (2004) found that this species was significantly more abundant in depths lower than 5 m. Complex-structures at shallow depths may also have provided better refuge for *S. cristata* (*i.e.*, a small-sized bleniid) against predation of large piscivores than similar structures in deep waters (Barreto, 1999). Therefore, it is possible that, in addition to the species preference, the high structural complexity (*i.e.*, macroalgae and bivalves beds, and a complex mosaic of agglomerated and isolated rocks) found at shallow depths in Abobrinha and Anequim rocky reefs, together with the continuous effects of waves and air bubbles created by the prevailing turbulent conditions would have increased the protection of *S. cristata* against predators, resulting thus to the greater abundances recorded in this habitat.

In conclusion, *C. striatus* was homogeneously distributed through rocky reefs and scuba diving should be preferred over free diving to assess the abundance of this species at exposed rocky shores, undergoing continuous effects of waves and winds. Both free and scuba diving can be used indistinctly and with no data biases to appraise the abundances of *C. striatus* in non-turbulent reefs or in shallow zones (*i.e.*, ≤5 m) of exposed reefs, and, for *S. cristata*, in all depth layers (*i.e.*, up to 10 m) of both sheltered and exposed reefs. Although the abundances of *S. cristata* did not significantly differ between free and scuba diving, contrasting with most previous studies that stressed the risk of the first method to underestimate the abundance of small and cryptic species (Samoilys & Carlos, 2000; Willis, 2001; Depczynski & Bellwood, 2004), it should be attempted that the previous experience of the diver and the nature of our study (*i.e.*, focused specifically on a cryptic species) may have contributed to our findings. Further studies are, however, necessary to test our findings in different conditions (*i.e.*, depths, hydrodynamic characteristics, and habitat complexity) and for other tropical reef fish species, in order to increase the truthfulness of underwater visual census and reduce the risk of failure of fish conservation and management programmes potentially based on biased data.

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