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Comparison of remote video and diver's direct observations to quantify reef fishes feeding on benthos in coral and rocky reefs

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This study compared remote underwater video and traditional direct diver observations to assess reef fish feeding impact on benthos across multiple functional groups within different trophic categories (*e.g.* herbivores, zoobenthivores and omnivores) and in two distinct reef systems: a subtropical rocky reef and a tropical coral reef. The two techniques were roughly equivalent, both detecting the species with higher feeding impact and recording similar bite rates, suggesting that reef fish feeding behaviour at the study areas are not strongly affected by the diver's presence.

Key words: diver effect; ecosystem processes; feeding behaviour; feeding rates; functional categories.

Reef fish feeding and its potential impacts on the benthos is recognized as an important tool to assess reef ecosystems functioning (Hixon, 1997; Bellwood *et al*., 2006; Cole *et al*., 2008). As a result, several methods have been used to estimate the functional impact of reef fish feeding such as: (1) examination of fish diet through gut content analysis (Randall, 1967; Ferreira & Gonçalves, 2006), (2) algal feeding assays evaluating algal removal (Hay, 1981; Hoey & Bellwood, 2009), (3) caging experiments excluding the main consumers (Hughes *et al*., 2007), (4) evaluation of grazing scars (Rotjan & Lewis, 2005; Bonaldo & Bellwood, 2009) and (5) using a proxy of fish functional impact based on the product of species abundance, bite rates, and bite volumes (Paddack *et al*., 2006; Hoey & Bellwood, 2008).

Remote underwater video is also being increasingly used in marine ecology as an alternative to the traditional direct diver observations (Dunlap & Pawlik, 1996; Bellwood & Fulton, 2008; Burkepile & Hay, 2011) whose potential problems concerning diver's presence are discussed in the literature (Fox & Bellwood, 2008*a*, *b*). Even though the diver effect is commonly assumed to exist (Kulbicki, 1998), there

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have been few attempts to examine the relative efficiencies of remote video techniques and diver's direct observation to assess reef fish functional impact (Fox & Bellwood, 2008*b*). Furthermore, most existing efforts focused on few target species or functional groups (primarily within herbivores) and have been largely restricted to the Great Barrier Reef (Fox & Bellwood, 2007; Hoey, 2010; Hoey & Bellwood, 2010, 2011).

The aim of this study was to compare remote video and diver observation techniques to quantify the feeding rates of reef fish assemblages on the benthic community. For the first time, such a comparison has been carried out across multiple functional groups within different trophic categories (*e.g.* herbivores, zoobenthivores and omnivores) and in two distinct reef systems: a subtropical rocky reef and a tropical coral reef.

The tropical coral reef site was the fringing reefs of Portinho Norte on Santa Bárbara Island at the Abrolhos Archipelago, lying 60 km off the southern coast of Bahia state, north-east Brazil (17° 58′ S; 38° 42′ W). This reef is located within the Abrolhos Marine National Park and has been protected from fishing by federal law since 1983 (Francini-Filho & Moura, 2008). Abrolhos' coral reefs at the Archipelago are not predominantly formed by scleractinian corals, but are made up of several reef organisms (*i.e.* corals, sponges and algae) that grow over hard substrata formed from the deposition of dead coral, coralline calcareous algae and other fouling organisms, also filled by sediment deposition (Leão & Kikuchi, 2001). The subtropical rocky reef site was Xavier Island in Santa Catarina state, southern Brazil (27° 36′ S; 48° 23′ W), which is *c.* 3 km from the shore with no specific protection or conservation measures. Depth at study sites ranged from 4 to 8 m at Abrolhos and 4 to 10 m at Xavier Island. The sampling effort was during the austral summer from December 2009 to March 2010.

Reef fish feeding rates on the substrata were used as a proxy for their functional impact on the benthic community and, for the purpose of this study, impact is defined as any disturbance that might cause changes in the benthic biomass and its structure. This was quantified through the number of bites of each individual fish on benthic substrata, per unit of time and area. That is, a bite was counted every time a fish stroked benthic organisms with its jaws opened, even though these events did not always result in ingestion. Small species with cryptobenthic habits [<5cm total length; Depczynski & Bellwood (2003); *e.g.* Blenniidae and Gobiidae] were excluded from the analysis to avoid misidentification and underestimation.

Reef fish feeding on benthos was recorded using underwater HD digital video cameras [Sony SR12 HDD (www.sony.com) with an Ikelite underwater housing (www.ikelite.com)] placed on weighted tripods. All the recordings were conducted from 0900 to 1300 hours. Within each site, replicated reef areas were haphazardly selected with the camera positioned *c.* 1–1·5 m from the sample area for focus adjustments. A chain with 2 m length was used to demarcate the plot area (2 m^2) and removed after *c.* 1 min. Adjacent plots were separated by a minimum of 10 m.

Each replicate was recorded for *c.* 15 min but only the middle 5 min were analysed to minimize the potential effect of diver's presence on fish behaviour. This is a short period of deployment, but such design allowed spatial replication, paired sampling with diver observation and avoided potential diver's effect. Individuals recorded feeding on the benthic community were then carefully observed and every bite was counted during the entire observation period.

The same data were collected through replicated 5 min diver's direct observations of randomly selected 2 m^2 reef areas, determined through the same procedure described for the video plots. These observations were conducted in adjacent areas to each video (at least 10 m apart from the camera and in the same depth), concomitantly with the recording period and with the diver positioned *c*. 1–1·5 m from the sample area. Therefore, the diver's effect was higher in the direct observation technique in comparison to the video, as the observer stayed much closer to the sample area. As a result, for each video record sample, there is a paired diver's direct observation. A total of 22 and 13 paired replicates (remote video and diver direct observation) were conducted at the coral and at the rocky reef site, respectively, with no overlap of sampled area for either method.

All species recorded in this study were assigned to functional groups, defined following previous studies on Brazilian reef fishes (Ferreira *et al.*, 2004; Ferreira & Gonçalves, 2006) and confirmed through behavioural observations. There may be potential problems of grouping reef fishes into trophic and functional categories (Ferreira *et al.*, 2004), as there might be a wide variation among and within these groups. On the other hand, the functional perspective has provided several advances in the understanding of ecosystem functioning (Bellwood *et al.*, 2003, 2006). As a result, reef fish feeding impact on benthos is presented here from the perspective of multiple functional groups within different trophic categories as number of bites per unit of time (recording and observation period; 5 min) and area (recorded and observed area; 2 m^2).

Paired *t*-tests were used to assess differences in the reef fish species richness feeding on the benthic community and total number of feeding interactions between video records and diver's observation. Data were $\log_{10}(x + 1)$ transformed to meet the parametric assumptions. The non-parametric Wilcoxon *t*-test was used to assess differences in the feeding rates of each reef fish species and functional group between the techniques, as these data did not meet the parametric assumptions.

Remote video and direct observation were similar regarding the number of species detected. A total of 23 species from 10 families (Acanthuridae, Chaetodontidae, Haemulidae, Labridae, Monacanthidae, Mullidae, Pomacanthidae, Pomacentridae, Sparidae and Tetraodontidae) and seven functional groups (Ferreira *et al.*, 2004; Ferreira & Gonçalves, 2006) were detected feeding on the benthic community in the two reef systems. At the coral reef site, from the 18 species detected feeding on benthos, seven were exclusively recorded through the remote video and two exclusively through diver observation (Fig. 1). Conversely, from the 12 species detected at the rocky reef, seven were exclusively recorded by the remote video while all species observed by the diver were also recorded by the camera (Fig. 2). Although the video recording technique detected more species feeding on benthos than the diver observation in both systems, the differences were not significant (paired *t*-test, coral reef, $t_{21} = 0{\cdot}77$, $P > 0{\cdot}05$ and paired *t*-test, rocky reef, $t_{12} = 1{\cdot}98$, $P > 0{\cdot}05$).

The total number of interactions did not vary between the techniques at both reef sites (paired *t*-test, coral reef, $t_{21} = 0{\cdot}61$, $P > 0{\cdot}05$ and paired *t*-test, rocky reef, $t_{12} = 1{\cdot}36$, $P > 0{\cdot}05$). A higher number of interactions were recorded, however, for blue tang surgeonfish *Acanthurus coeruleus* Bloch & Schneider 1801 at the coral reef through the video recording in comparison to direct observation (Fig. 1; Wilcoxon *t*-test, $Z = 2{\cdot}24$, $P < 0{\cdot}05$). No significant differences were observed for any other species regarding the mean number of interactions between the two techniques.

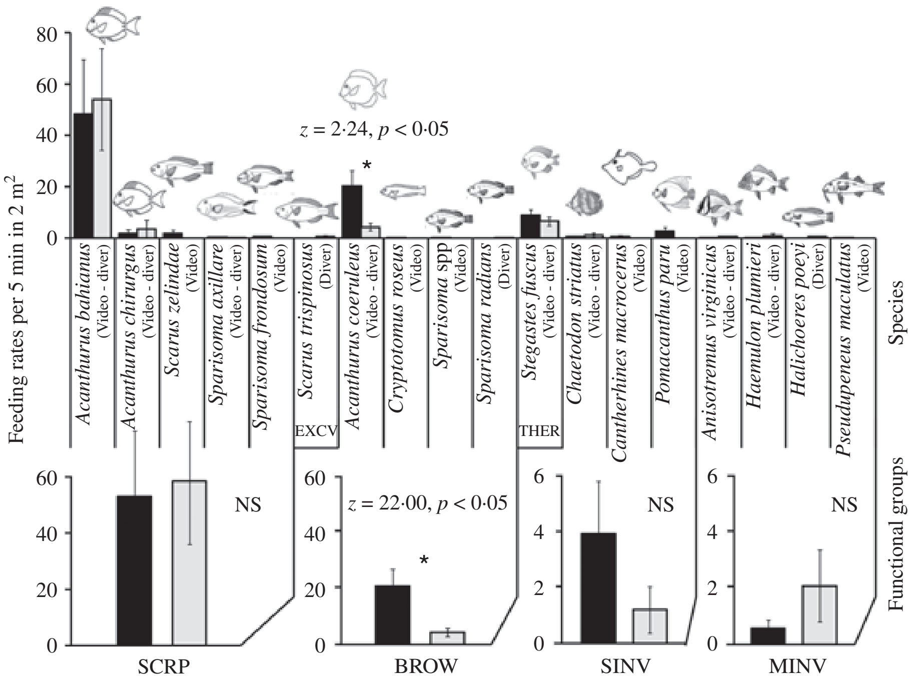

FIG. 1. Feeding rates per 5 min and within 2 m^2 (mean + S.E.) for each species and functional group through video record (■) and direct observation (□) at the coral reef in Abrolhos Archipelago, north-east Brazil (17° 58′ S; 38° 42′ W). Species are displayed within their functional groups. The techniques that recorded each species are assigned below its name (video and diver). *Significant difference between the two techniques for the assigned species and functional group. NS, non-significant differences between the two techniques ($P > 0{\cdot}05$). Functional groups: SCRP, scrapers; EXCV, excavators; BROW, browsers; THER, territorial herbivores; SINV, sessile invertebrate feeders; MINV, mobile invertebrate feeders. *Sparisoma* spp., juveniles of this genus.

Browsers at the coral reef site were the only functional group where estimates of feeding rates differed between the techniques, being higher through the remote video (Wilcoxon t-test, $Z = 22{\cdot}00$, $P < 0{\cdot}05$; see Fig. 1). This is an expected artefact of the difference recorded for *A. coeruleus*, as this species accounted for nearly 99% of the feeding impact within this functional group at the coral reef site.

The video recording and the direct observation techniques were roughly equivalent regarding reef fish species detection and feeding rates on benthos. Even though each technique had exclusively detected species, those with higher feeding impact on benthos were detected by both methods. Therefore, video recording and direct observation were suitable in both habitats.

Based on the underwater visual census conducted at the same reefs, during the same period of the day and sampling season ($n = 48$ at the rocky reef and $n = 50$ at the coral reef; unpubl. data), from the 17 species that accounted for 95% of fish biomass at the rocky reef site, only three were not detected through the video recording [reef croaker *Odontoscion dentex* (Cuvier 1830), brown chromis *Chromis multilineata* (Guichenot 1853) and comb grouper *Mycteroperca acutirostris* (Valenciennes 1828)]. While at the coral reef site, where 18 species accounted for

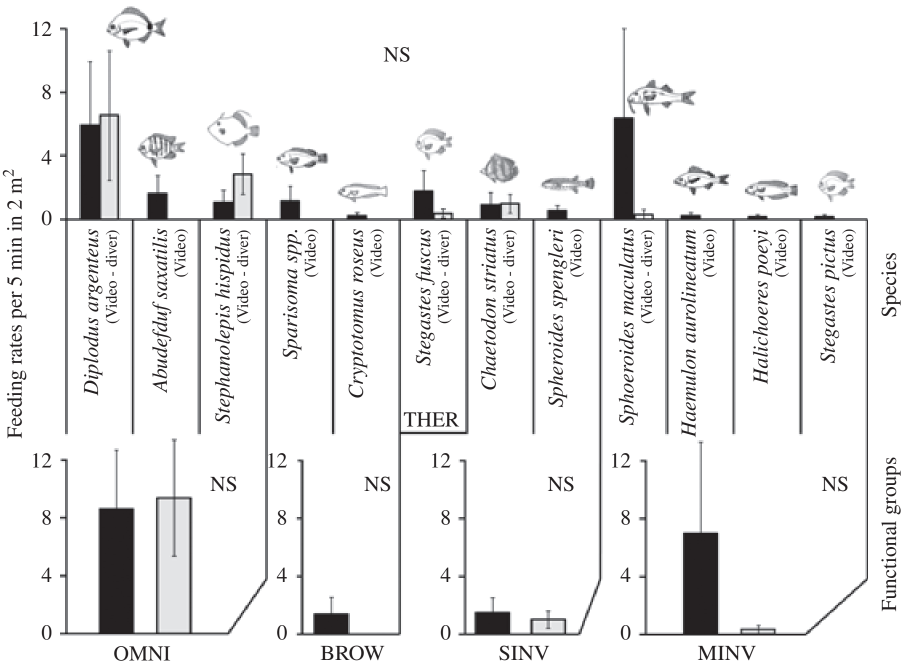

FIG. 2. Feeding rates per 5 min and within 2 m^2 (mean + S.E.) for each species and functional groups through video record (■) and direct observation (□) at the rocky reef in Xavier Island, southern Brazil (27° 36′ S; 48° 23′ W). Species are displayed within their functional groups. The techniques that recorded each species are assigned below its name. NS, non-significant differences between the two techniques ($P >$ 0·05). Functional groups: OMNI, omnivores; BROW, browsers; THER, territorial herbivores; SINV, sessile invertebrate feeders; MINV, mobile invertebrate feeders. *Sparisoma* spp., juveniles of this genus.

that proportion of fish biomass, only one was not detected by the video technique [sailor's grunt *Haemulon parra* (Desmarest 1823)]. Such species had not necessarily fed on the substratum, but were registered inside the recording area, which reinforces the limited differences in the detection of species between the diver and video observations.

Some benefits of using remote video techniques over visual assessments highlighted in the literature (Colton & Swearer, 2010) were also noted in this study such as: (1) the data are permanently recorded and can be stored for further consideration or secondary analysis, (2) video recording optimizes the field effort and (3) it might be used for longer deployment periods, in deeper reefs (> 30m), systems with strong currents and cold waters, where diving might be constrained. In addition, there are two direct benefits for studies on reef fish behaviour: (1) the ability to evaluate the reef fish community across several functional groups and trophic categories, even in high diversity systems and (2) the ability to observe in detail a single interaction at a time, also describing behavioural patterns.

On the other hand, there are also important limitations associated with this technique, such as the water transparency, which in this work ranged from 6 to 10 m at the coral reef and 4 to 8 m at the rocky reef. In aquatic ecosystems with limited visibility (<4 m), it is expected that both techniques presented here (remote video and direct observation) would be biased and less effective, and hence not recommended. Another disadvantage common to both techniques could be in identifying the benthic organisms that fishes are targeting. Although it is possible to determine the benthic substrata on which fishes are feeding on, in *c*. 80% of the video observations (unpubl. data), it is not possible to assume that fishes are really ingesting those organisms, or simply using them as microhabitats for foraging.

In addition, the difficulty in identifying species with cryptobenthic habits (*i.e.* Blenniidae and Gobiidae) and their effect on the benthic community may also be a limiting factor for the use of video assessments. Although some individuals of cryptobenthic fish species were observed in the video recordings, species identification and quantifying the number of bites taken was not possible through this technique. Cryptobenthic reef fishes are known to make a significant contribution to reef trophodynamics (Ackerman & Bellwood, 2002) and might also be underestimated in visual census techniques (Brock, 1982; Ackerman & Bellwood, 2000; Willis, 2001; Dalben & Floeter, 2012), which indicates the necessity of specific efforts to evaluate their functional roles.

The observed similarity between the techniques in this study might also be associated with the relatively low species richness in the study areas [see Francini-Filho & Moura (2008) for the coral reef site and Godoy *et al.* (2006) for the rocky reef site]. As high diversity systems have a higher probability of presenting functionally redundant and rare species (Halpern & Floeter, 2008), it is likely that the remote video would be able to detect rarer species with disproportional function compared to their abundance in such reef systems. Previous studies on the Great Barrier Reef, for instance, demonstrated, by coupling remote video recordings with algal assays, that the species most responsible for algal removal were either not recorded (Fox & Bellwood, 2008*a*) or underestimated in visual censuses of the area (Hoey & Bellwood, 2009). This fact highlights the potential dangers of inferring ecological impact from estimates of fish abundance from visual census (Fox & Bellwood, 2008*b*; Hoey & Bellwood, 2010).

In this study, the remote video technique only provided higher counts of bites for *A. coeruleus* at the coral reef site, which might be attributed to the fact that adults of this species generally forage in big schools and have high individual bite rates (Dias *et al.*, 2001). Therefore, it is difficult to obtain accurate counts of the number of interactions from direct observation in the field (Ferreira *et al.*, 1998; Dias *et al.*, 2001). In addition, several juvenile individuals of this species were recorded feeding on benthos, thus it is likely that juveniles might be more influenced by diver's presence than adult fishes (Kulbicki, 1998).

Overall, the equivalence of the two techniques suggests that the feeding behaviour of the reef fish community in the study areas was not strongly affected by the diver's presence. Although the effectiveness of these methods is balanced (*i.e.* there were limited differences in the ability to detect species and on the estimates of feeding rates), the advantages of the remote video recording technique should certainly be taken into account when designing studies involving reef fish behaviour. Additionally, the technique described in this study has the potential to be used in different aquatic (*e.g.* freshwater streams with clear water) and reef systems to elucidate ecological roles across multiple functional groups and within different trophic categories. Combining this approach with other quantitative methods (*e.g.* specific effort for cryptic species, gut content analysis and algal assays) may also allow more robust conclusions about the role of fish feeding impact on the benthos.

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