The Great Amazon Reef: a biogeographical ecotone linking the SW Atlantic and the Caribbean threatened by industrial (oil) exploration

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Abstract

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Unprecedented submersible video surveys disclose unique features of the Great Amazon Reef System (GARS). The examination of over 15 hours footage obtained by means of submarine and 15 hours footage obtained by a dropcam allowed us to advance the knowledge, put forward here. The main findings of this expedition are: 1) a new estimate of the size of the reef, which is a typical mesophotic reef, starting at about 70 m depth and extending much deeper than previously anticipated (220 m), 2) the record of a high complexity and diversity of habitats and species, 3) the occurrence of a continuous mesophotic reef corridor connecting the SW Atlantic and the Caribbean ("biogeographical ecotone") and 4) the concentration of threatened and commercially important fish and lobster species. Despite the incipient knowledge about the GARS (less than 5% of the reef area surveyed so far), the region is coveted by large Oil and Gas Companies (e.g. BHP-Billition, Total, and Petrobras). The GARS can be considered a biodiversity seed bank in periods of climate changes and exploration that are extirpating shallow reefs. In face of local and global impacts, a systematic conservation planning approach and the creation of a network of MPAs are urgently needed. These actions may help to conciliate extractive activities (fishing, mining) with effective biodiversity conservation.

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Ethics statements

(Authors are required to state the ethical considerations of their study in the manuscript, including for cases where the study was exempt from ethical approval procedures)

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PERSPECTIVE - FRONTIERS IN MARINE SCIENCE

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Unprecedented submersible video surveys disclose unique features of the Great Amazon Reef System (GARS). The first images of the GARS and associated communities were obtained using a double Deep Worker submarine (Nuytco, Canada; Earle 2010) and a dropcam in depths between 70-250 m in January-February 2017. The examination of over 15 hours footage obtained by means of submarine and 15 hours footage obtained by a dropcam allowed us to advance the knowledge, put forward here. The main findings of this expedition are: 1) a new estimate of the size of the reef, which is a typical mesophotic reef, starting at about 70 m depth and extending much deeper than previously anticipated (220 m), 2) the record of a high complexity and diversity of habitats and species, 3) the occurrence of a continuous mesophotic reef corridor connecting the SW Atlantic and the Caribbean ("biogeographical ecotone") and 4) the concentration of threatened and commercially important fish and lobster species. The region lacks Marine Protected Areas (MPAs) and is highly threatened with mega-projects for oil & gas exploration in adjacent deep waters (300-1000 m depth) already in phase of implementation. Our perspective is that broad baseline studies (i.e. geophysical, geological, physical, chemical, and biological oceanographic surveys) are badly required for future evaluations of possible global and local impacts, particularly in case of oil spills.

Although the area of the GARS was initially estimated at 9,500 km^2 (Moura et al. 2016), results from the present study indicate that the Amazon Reef is much larger than previously expected. Our results point to a continuous mesophotic reef (70-220 m depth) that covers ~56,000 km^2. Only areas shallower than 70 m where devoid of consolidated substrata and dominated by fine sand and/or mud bottoms (Fig 1). First evidences for the occurrence of a mesophotic corridor connecting Brazil and Caribbean were obtained by Collette and Rutzler (1977). These authors described a "typical reef fish fauna" composed by 45 species in the mouth of the Amazon River in depths between 48-73 m. Since then, several biogeographical studies have highlighted th connection between Brazil and the Caribbean (Rocha 2003, Floeter et al. 2008).

There is a clear gradient from the deeper portion of the reef (~220 m depth), where exposed laterite bottoms alternate with areas with a 100% of live bottom (mainly sponges, octocorals and black-corals), to the shallowest portion of the reef, which is nearly completely covered with sand (Figure 2A-D). This is the deepest limit of the lower mesophotic zone recorded so far, as mesophotic reefs are believed to occur only down to about 150 m (Lesser et al. 2009). Dominant organisms of the lower mesophotic

zone of the GARS were typical of reef communities, such as black corals, barrel sponges (*Xetospongia muta*), butterflyfish (*Prognathodes* spp.) (Rosa et al. 2016). The areas deeper than 220 m recorded during our surveys were dominated by sediments.

High bottom complexity and a great diversity of habitats were recorded at the GARS, including rhodolith beds, carbonate platforms formed by fused rhodoliths, laterite bottoms, as well as sponge, soft coral and black coral gardens (Figure 2A-D). A large reef wall was recorded in the outer shelf of the central sector of the GARS, with an average height of 80 m (115-195 m depth) and a mapped linear extension of at least 12 km. Bordering the GARS on its shallowest portion, there are large sand wave fields (Fig 2A) which are indicative of strong currents and high hydrodynamical regimes, with sand being eventually transported over the reef structure (Fig 2B). Thus, sediment deposition by the Amazon River outflow seems to determine the upper boundary of the GARS.

High turnover of species was noted within the reef, as well as between the GARS and adjacent regions (i.e. Caribbean and N/NE Brazil). This pattern is plausibly explained by both habitat heterogeneity and the formation of an ecotone between the two biogeographical provinces, i.e. Brazil and the Caribbean, with a clear faunal overlap. Examples include the occurrence of the Blue chormis *Chromis cyanea* and the Redspotted hawkfish *Amblycirrithus surinamensis*, both fish species previously recorded only for the Caribbean, hinting to a connection between South America and South Caribbean through the GARS. Fish aggregations (particularly the threatened and commercially important fish *Lutjanus purpureus* and *Hyporthodus niveatus*; Fig 2G) were clearly associated with fractures and crevices on carbonate platforms and crevices created by complex bottoms of laterite rock. Most fish aggregations were associated with cleaning stations, with juveniles of Spotfin hogfish *Bodianus pulchelius* and the Peppermint shrimp *Lysmata grabhami* acting as cleaners (Fig 2E). Besides cleaning stations, nests of the Sand tilefish *Malacanthus plumieri*, which are formed by aggregations of rhodoliths, also aggregated a high diversity of fish and invertebrates (Fig 2F). Two herbivorous fish were also recorded foraging in depths between 100-140 m, the Agassiz's parrotfish *Sparisoma frondosum* and the Doctorfish *Acanthurus chirurgus*. Large barrens of the sea urchins (unidentified Toxopneustidae) actively grazing macroalgae and leaving large paths of cleaned areas, with thousands of meters in linear extension, were also recorded (Fig 2H).

Mesophotic coral ecosystems can provide coral propagules to shallow reef (reseeding or deep reef refuge hypothesis) (Bongaerts et al. 2010, 2017). Recent genomic studies have demonstrated that some coral species from mesophotic and shallow depths in the Western Atlantic (Bermuda) share little genetic background (Bongaerts et al. 2017). In contrast to the broadcasting species *Stephanocoenia intersepta*, *Agaricia fragilis* showed limited connectivity among depths, possibly hampering reseeding of shallow reefs from deep refuges. The authors highlight that further studies are badly needed in mesophotic reefs to better understand biodiversity within these poorly understood ecosystems.

Despite the incipient knowledge about the GARS (less than 5% of the reef area surveyed so far), the region is coveted by large Oil and Gas Companies (e.g. BHP-Billition, Queiroz Galvão, Ecopetrol, Total, BP, and Petrobras) (see blocks in Fig. 1). Oil exploration within GARS poses serious threats to biodiversity and sustainability of the region and the incipient knowledge attained so far indicates precaution is needed before any initiation of any activity with large potential for reef degradation. Such as mesophotic reefs elsewhere, the GARS can be considered a biodiversity seed bank in periods of climate changes that are extirpating shallow reefs (Bongaerts et al. 2010). In face of local and global impacts, a systematic conservation planning approach and the creation of a network of MPAs are urgently needed. These actions may help to conciliate extractive activities (fishing, mining) with effective biodiversity conservation.

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Legends

Figure 1. Map of the Great Amazon Reef System (GARS) showing sampling sites. The gray area denotes de extension of the reef (Km^2).

Figure 2. Geodiversity and biodiversity of the GARS. Major structures along the inner and outer shelves. A – Sand dunes in the shallowest portion of the reef (60-70 m), B – Reef covered by sediments between 70-80 m depth, C – Diverse reef community with schools of Paranthias furcifer and bottom dominated by live crustose calcareous algae and black corals at 130 m depth, D – Deepest portion of the GARS (220 m) with nearly 100% of live benthic coverage (mostly sponges, octocorals and black corals), E – A cleaning station of the Peppermint shrimp *Lysmata grabhami* at 110 m depth, F – Rhodolith mound built by the Sand tilefish *Malacanthus plumieri*, G – A large individual (>60 cm Total Length) of the commercially important and threatened snowy grouper *Hyporthodus niveatus* (at 190 m depth) and H – an urchin barren at 130 m depth. Laser scale: 20 cm.

Figure 1.JPEG

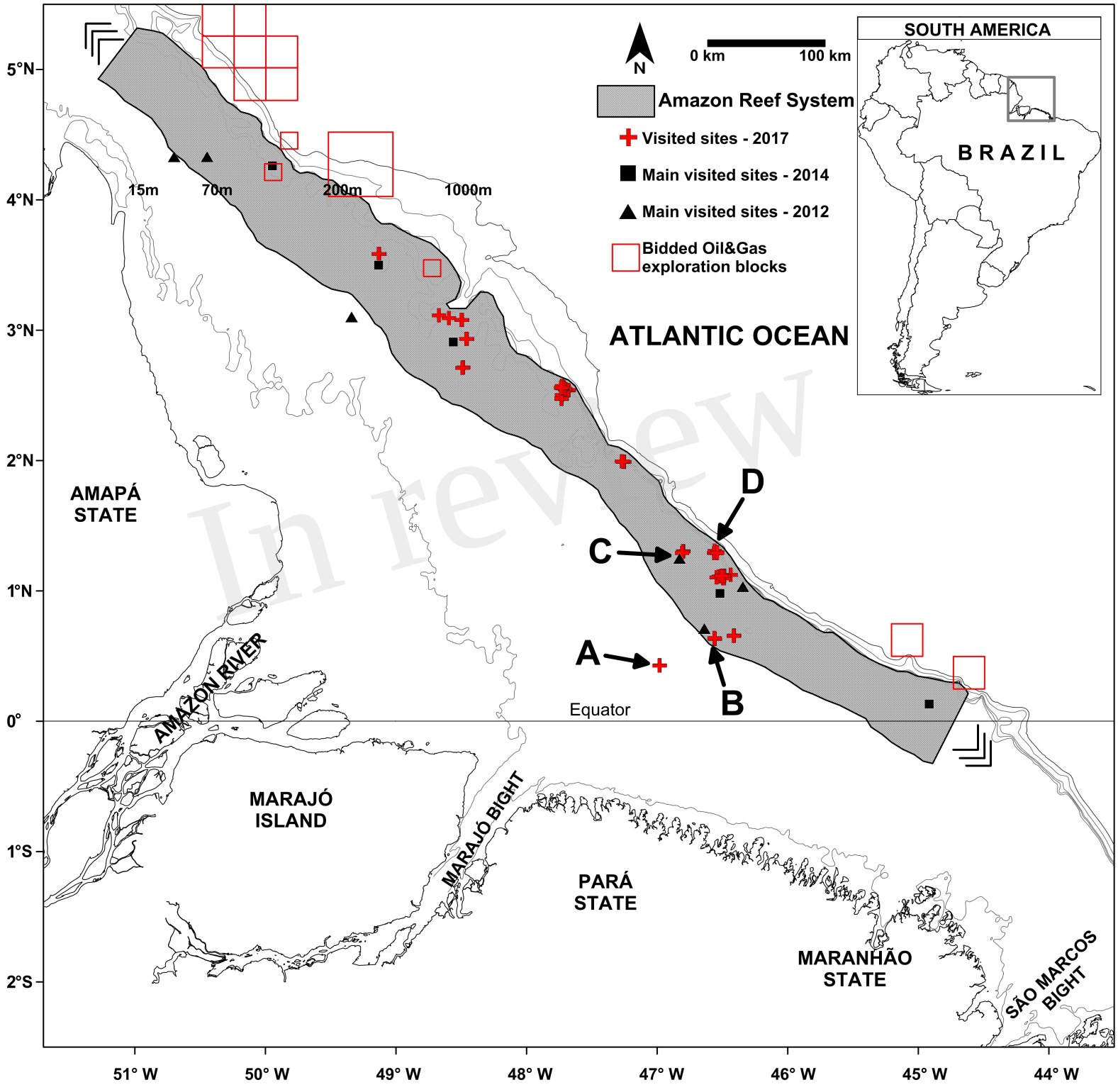

Figure 2.JPEG