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EDITORIAL

Editorial: biodiversity of Caribbean coral reefs (with a focus on the Dutch Caribbean)

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Biodiversity research on Caribbean coral reefs

Coral reefs in the Atlantic have received less attention with regard to marine biodiversity research than those in the Indo-Pacific. In an overview of articles about corals or coral reefs in the journal Marine Biodiversity and its predecessor Senckenbergiana Maritima over the years 1969–2013, 35 papers concerned the Indo-Pacific and only 13 were about the Atlantic, a ratio of 2.7/1 (Hoeksema and Van der Meij 2013). Since that overview, 137 more papers on corals and coral reefs have been published in Marine Biodiversity. These include the present issue and articles that are still online-only. The updated ratio covering 1969 to the present is 134/51, equaling 2.6/1 in favor of the Indo-Pacific, which is slightly less than the previous ratio. In comparison, of 290 papers on corals and coral reefs published in the journal Coral Reefs during the years 2015–2016, 198 were about the Indo-Pacific and 92 about the Atlantic, which is a ratio of 2.15/1. This ratio is smaller than that found in Marine Biodiversity but it is still favoring the Indo-Pacific.

It has been known for a long time that the Atlantic has less coral reef surface area and fewer species than the Indo-Pacific (Ekman 1953; Briggs 1974; Veron 1995; Spalding et al. 2001). Worldwide, the highest concentrations of reef-dwelling species can be found in the Coral Triangle, which is located in the Indo-Australian Archipelago of the Central Indo-Pacific (Roberts et al. 2002; Hoeksema 2007; Bellwood and Meyer 2009). Other Indo-Pacific reef areas that have recently received attention regarding their high biodiversity and unique fauna elements are the South China Sea (Huang et al. 2015; Reimer et al. 2015), the West Indian Ocean (Obura 2016), and the Red Sea (DiBattista et al. 2016).

Marine biodiversity research by Naturalis Biodiversity Center (NBC) in Leiden had a major focus on the Coral Triangle for 30 years (1983–2012), which started with coral reef research during the ship-based Indonesian-Dutch Snellius II Expedition (1984) in collaboration with the Research Center for Oceanography of the Indonesian Institute of Sciences, RCO-LIPI (e.g., Best et al. 1989; Fransen 1989). Other NBC expeditions in Indonesia were land-based and operated from RCO-LIPI field stations and from dive resorts, including expeditions to Bali in 2001, East Kalimantan in 2004, Raja Ampat in 2007, and Ternate in 2009 (Hoeksema and Tuti 2001; Hoeksema 2004; Hoeksema and Van der Meij 2008, 2010).

The Caribbean is recognized as the most species-rich sea in the Atlantic regarding its coral reefs (Rocha et al. 2008; Miloslavich et al. 2010). It is connected to the Gulf of Mexico, with which it has many species in common (Felder and Camp 2009; Jaap 2015), although the northern part of the Gulf is considered a warm temperate ecoregion that is separate from the tropical Atlantic ecoregions of the Gulf and the Caribbean (Spalding et al. 2007; Fig. 1a). The Wider Caribbean or the Greater Caribbean includes the Caribbean,

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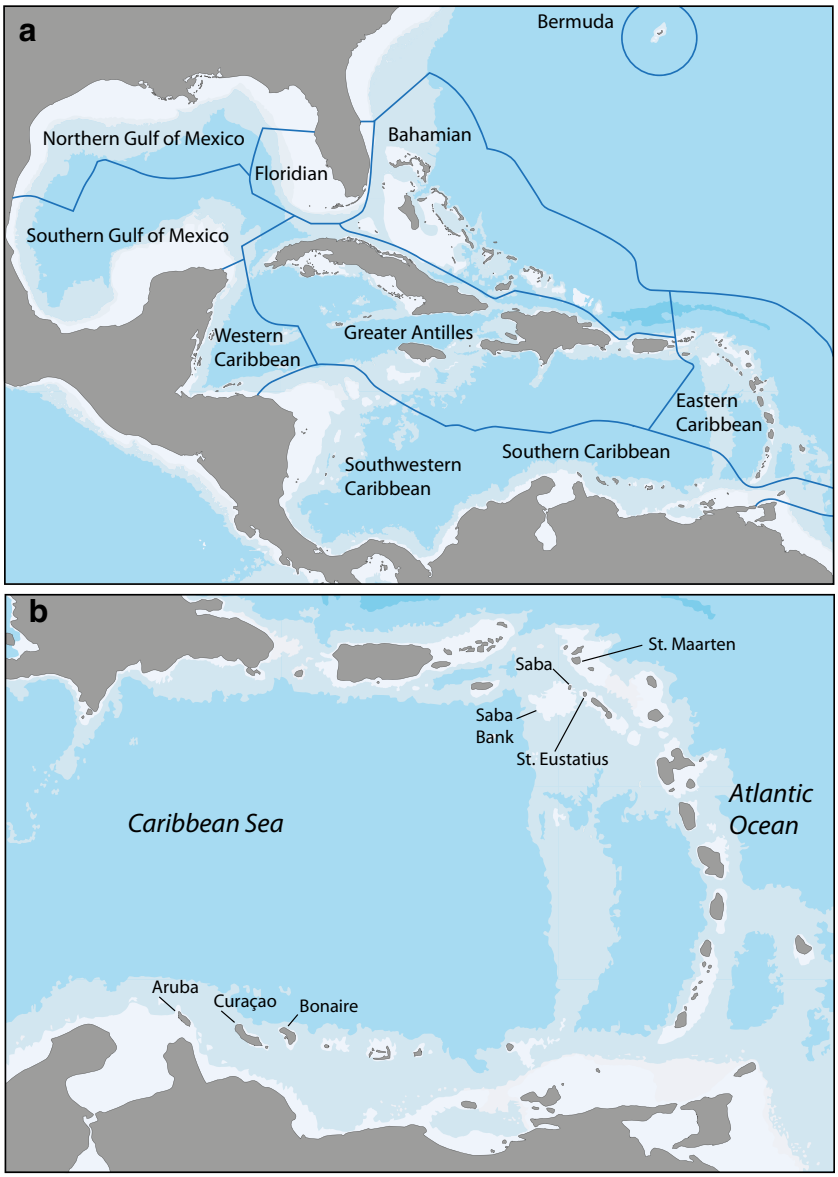

Fig. 1 **a** The Greater Caribbean with marine ecoregions after Burke and Maidens (2004) and Spalding et al. (2007). **b** The Dutch Caribbean composed of the Leeward Islands (Aruba, Curaçao, and Bonaire) in the Southern Caribbean and the Windward Islands (Saba, St. Eustatius, and St. Maarten) with Saba Bank in the Eastern Caribbean

the Gulf of Mexico, and Bermuda in the northwestern Atlantic (Burke and Maidens 2004; Rocha et al. 2008; Wilkinson and Souter 2008; Robertson and Cramer 2014). Following Burke and Maidens (2004), we refer to this larger area simply as "the Caribbean" (Fig. 1a).

Although the Caribbean has less species than the Indo-Pacific, this does not imply that the marine fauna and flora of the Caribbean are sufficiently well known or that there is little need for additional biodiversity research on Caribbean reefs. The species compositions of both regions have traditionally been known to have little in common (Ekman 1953; Briggs 1974). Higher level taxa occurring in both oceans may show close affinities, although among scleractinian corals, this has appeared less so than originally thought (Fukami et al. 2004; Kitahara et al. 2016).

Anthropogenic introductions of Indo-Pacific species onto West Atlantic coral reefs have had various consequences for the reef faunas here. The mushroom coral family Fungiidae only naturally occurs in the Indo-Pacific (Hoeksema 1989; Gittenberger et al. 2011), but individuals of one species, *Lobactis scutaria* (Lamarck, 1801), with their *Symbiodinium* symbionts were brought to Jamaica in the 1960s, although no harmful effects have yet been reported (Bush et al. 2004; LaJeunesse et al. 2005). In contrast, the introduction of Indo-Pacific *Tubastraea* coral species and their range expansions in the West Atlantic since the 1930s has caused much concern due to their capacity to compete with endemic corals and to overgrow other organisms (Mantelatto and Creed 2015; Creed et al. 2016). The most notorious introductions are those of two species of lionfish, *Pterois volitans* (Linnaeus, 1758) and *P. miles* (Bennett, 1828), which have been spreading rapidly in the

tropical West Atlantic since 1985 with increasing densities, while negatively impacting populations of local fish species. They have been reported from Rhode Island (USA) to the southeastern coast of Brazil (Dahl and Patterson 2014; Ferreira et al. 2015; Rocha et al. 2015; Chappell and Smith 2016; Hixon et al. 2016) down to mesophotic depths at <300 m (Lesser and Slattery 2011; Albins and Hixon 2011; Nuttall et al. 2014; Aguilar-Perera et al. 2017). The latest aggressive intruder on Caribbean reefs is an undescribed species of xeniid octocoral in Venezuela, where it has been observed to overgrow and kill scleractinian corals since 2007 (Ruiz Allais et al. 2014). An earlier introduced Indo-Pacific octocoral species, *Chromonephthea braziliensis* van Ofwegen, 2005, was reported from Brazil, where it has been observed since around 1995, but no range expansion into the Caribbean has been reported (Ferreira 2003; Van Ofwegen 2005). Another octocoral species recently described as new from the western Atlantic, *Stragulum bicolor* van Ofwegen and Haddad, 2011, was presumably introduced recently because it has a restricted distribution off southern Brazil, while its closest relatives live in the Indo-Pacific (Van Ofwegen and Haddad 2011; Altvater and Coutinho 2015). A similar case is that of a new hydrozoan in the same area, which is of unknown origin but it has a sister species in Japan (Haddad et al. 2014). Finally, there are reports on a rapidly spreading invasive seagrass species originally from the Red Sea, *Halophila stipulacea* (Forsskål) Ascherson, 1867, competing with native seagrass species near coral reefs in various Caribbean localities (Becking et al. 2014; Willette et al. 2014; Van Tussenbroek et al. 2016; Van der Loos et al. 2017). Many marine exotic species in the Caribbean can easily be overlooked because they usually consist of invertebrates and algae that are not easily recognized (Debrot et al. 2011) and, therefore, they are usually discovered when they become invasive and their populations reach outbreak proportions.

Because of such harmful species introductions and possible local species extinctions on Caribbean coral reefs (e.g., Carpenter et al. 2008), there is a need for baseline surveys of local reef biota with specimen sampling and follow-up monitoring in order to be able to accurately notice when species arrive or disappear (Hoeksema et al. 2011; Rocha et al. 2014; Sampey and Marsh 2015; Ballard et al. 2016). Specimen collections can help to reveal what kind of species are easily misidentified or overlooked in reef surveys, usually those that are relatively small or deep-living (Hoeksema 2015). Caribbean coral reefs also deserve biodiversity research attention because not all of their species have been reported yet, and these species are likely to participate in hitherto unknown interspecific associations (e.g., Thomas and Klebba 2007; Snijders and Fransen 2010; Ivanenko et al. 2017; Montano et al. 2017b) or appear to have incomplete geographical and bathymetrical distribution range information involving new records for the Atlantic (e.g., Montano et al. 2017a; Van der Loos and Prud'homme van Reine 2017).

The present special issue of Marine Biodiversity on Caribbean coral reefs serves to add information on these points. The idea for this special issue began during the preparations of a marine biodiversity expedition to St. Eustatius in 2015 (Hoeksema 2016). In the Netherlands, recognition of the need for more biodiversity research in the Dutch Caribbean started to develop with the reorganization of the Kingdom in 2010, and NBC was assigned to play a role herein (RLG 2009). This role was facilitated by the establishment of the Caribbean Netherlands Science Institute (CNSI) on St. Eustatius in 2014. St. Eustatius is one of the islands of the former Netherlands Antilles, presently called the Dutch Caribbean (Figs. 1b and 2). Together with St. Maarten and Saba, it belongs to the windward islands in the eastern Caribbean, which also includes the submerged Saba Bank, while Aruba, Curaçao, and Bonaire belong to the Leeward Islands in the southern Caribbean (Fig. 1b). Within the Dutch Caribbean, Aruba, Curaçao, and the southern part of St. Maarten are separate states, whereas Bonaire, Saba, and St. Eustatius belong to the Caribbean Netherlands as municipalities (RLG 2009).

Much Caribbean research by NBC and other Dutch research institutes and universities has been performed on Curaçao, which received a research boost thanks to the establishment in 1955 of the Caribbean Marine Biological Institute (CARMABI), presently known as Caribbean Research and Management of Biodiversity. This resulted in many taxonomic reports on the fauna and flora of Curaçao, which were predominantly published in the journals Studies on the Fauna of Curaçao and other Caribbean Islands (1940–1980), Studies on the Flora of Curaçao and other Caribbean Islands (1956–1968), and Studies on the Natural History of the Caribbean Region (1992–2000). The papers published in these journals are available online (http://www.repository.naturalis.nl).

Taxonomists working at CARMABI or who received specimens from Curaçao dealt with crabs (Holthuis 1958), copepods (Stock et al. 1963; Stock 1973), fishes (Randall 1963), foraminiferans (Hofker 1964, 1971), algae (Vroman 1967; Van den Hoek 1978; Stegenga and Vroman 1987), tardigrades (Van der Land 1968), serpulid worms (Ten Hove 1970; Hoeksema et al. 2015; Hoeksema and Ten Hove 2017), opisthobranch molluscs (Marcus and du Bois-Reymond 1970), anthozoans (Den Hartog 1977, 1980), sponges (Van Soest 1980; De Weerdt et al. 1999), ascidians (Goodbody 1984), gastropod molluscs (De Jong and Coomans 1988), sea spiders (Stock 1989), sipunculans (Dean et al. 2007), and shrimps (Brinkmann and Fransen 2016; Hoeksema and Fransen 2017). In a preliminary census of animal species described as new from Dutch Caribbean specimen collections in the last 100 years, at least 310 were from Curaçao, as compared to 62 from Bonaire, 52 from Aruba, 10 from St. Maarten, four from St. Eustatius, four from Saba Bank, and three from Saba (Hoeksema and Bakker, in prep.). This confirms the traditional

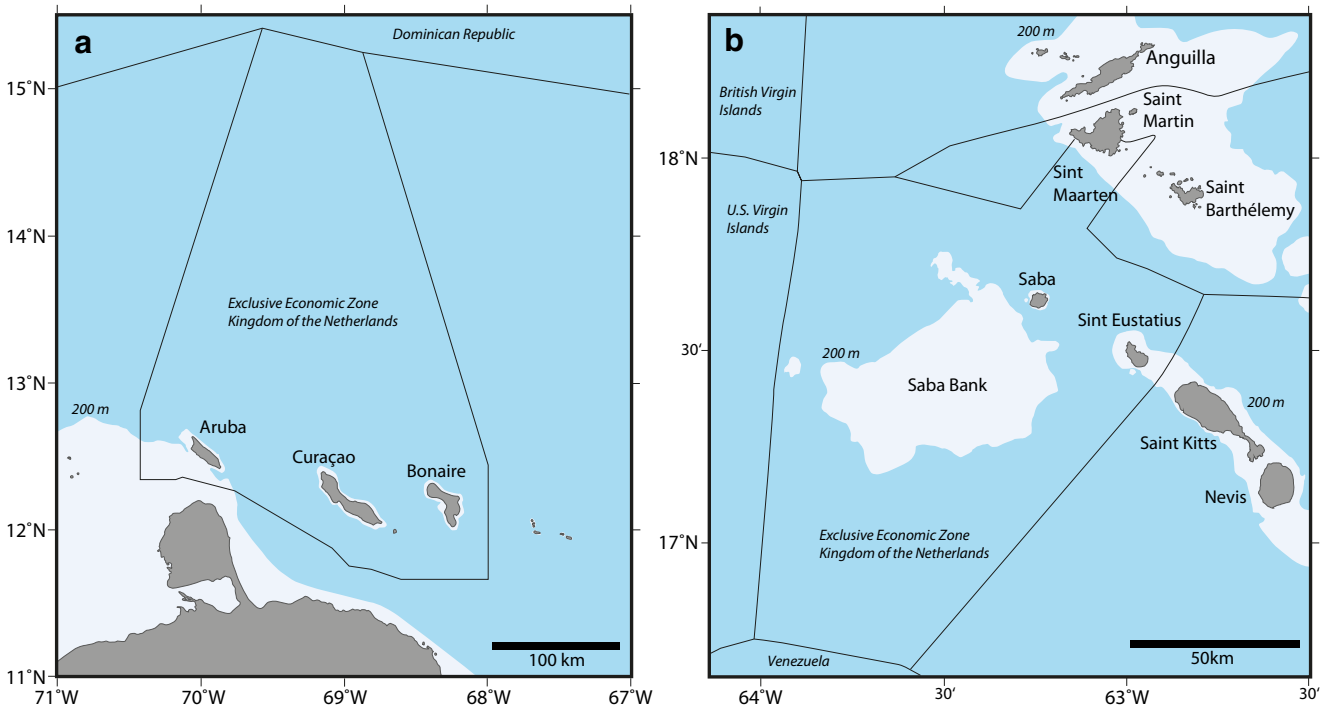

Fig. 2 Maps showing the Dutch Caribbean islands (former Netherlands Antilles) surrounded by 200-m isobaths and Exclusive Economic Zone boundaries. **a** Leeward Islands (Aruba, Curaçao, and Bonaire), **b** Windward Islands (Saba, St. Eustatius, and the southern part of St. Maarten) with the submerged Saba Bank. Sources: https://www.defensie.nl/english/topics/hydrography/contents/maritime-zones-and-boundaries; Royal Netherlands Navy maps 2020, 2023, 2110, 2211, 2212, 2213, 2716

importance of Curaçao and CARMABI for research on the taxonomy and biodiversity of Caribbean marine organisms.

In addition to professional scientists, students were also accommodated by CARMABI, which resulted in a considerable number of marine biodiversity publications based on graduate school research over five decades (e.g., Roos 1964, 1971; Bak 1975; Westinga and Hoetjes 1981; De Weerdt 1984; Van Duyl 1985; Fransen 1986; Vonk 1988, 1989, 1990; Meesters et al. 1991; Nagelkerken et al. 2001; Diekmann et al. 2002; Vermeij et al. 2003; Dorenbosch et al. 2004; Frade et al. 2008; Reijnen et al. 2010; Snijders and Fransen 2010; Van der Meij 2014; Wolf et al. 2014; De Bakker et al. 2016; Van Tienderen and Van der Meij 2016; Böhm and Hoeksema 2017; Potkamp et al. 2017). In addition, research vessels of the Royal Netherlands Navy performed scientific surveys in the Caribbean and other parts of the Atlantic, such as an expedition to Saba Bank in 1972 (Van der Land 1977; Hoeksema et al. 2011).

With the operation of the manned submersible Curasub for scientific purposes since 2010, mesophotic coral reefs and deeper environments of Curaçao and other Caribbean areas have become accessible for surveys to depths of ca. 300 m. This has already led to various new species discoveries (Van Tassell et al. 2012; Baldwin and Johnson 2014; Baldwin and Robertson 2013, 2014, 2015; Harasewych 2014; Van Soest et al. 2014; Harasewych and Tëmkin 2015; Baldwin et al. 2016; Tornabene et al. 2016a, b), new distribution records (Pawson and Pawson 2013; Fransen 2014; Lemaitre and Tavares 2015), as well as new depth records for some species (Van der Meij et al. 2015; Tornabene et al. 2016c; Hoeksema et al. 2017a).

The marine biodiversity expedition to St. Eustatius in 2015 and some recent malacological surveys have resulted in various new discoveries for the eastern Caribbean. These concerned new species (e.g., Montano et al. 2017b; Vonk and Lau 2017), new species records for the Atlantic (Montano et al. 2017a; Van der Loos and Prud'homme van Reine 2017), new host records in interspecific associations (García-Hernández et al. 2016; Hoeksema et al. 2017b; Ivanenko et al. 2017; Montano et al. 2017a, b), new records on interspecific competition (García-Hernández et al. 2017), and new records concerning the island's flora and fauna (Hewitt 2015; Hewitt et al. 2016; Davies and Piontek 2017; Van der Loos et al. 2017). These recently published reports show that much can still be discovered regarding the marine fauna and flora of Caribbean coral reefs. Many of these reports from the Dutch Caribbean are published in the present issue of Marine Biodiversity, along with papers based on research in other Caribbean regions, such as the Florida Keys (Adam et al. 2017), the southern Gulf of Mexico (Aguilar-Perera and Hernández-Landa 2017; Aguilar-Perera et al. 2017; Stampar et al. 2017), Puerto Rico (Galindo Estronza et al. 2017; Hammerman and García-Hernández 2017), and Cuba (Ruiz-Abierno and Armenteros 2017).

Caribbean biodiversity research in Marine Biodiversity

The number of journals dealing predominantly with the marine biodiversity of Caribbean coral reefs has declined in recent years. The aforementioned Dutch journals focusing on the natural history of the Caribbean islands have ceased to exist. Traditionally, the Bulletin of Marine Science has published many papers on the Caribbean and the Gulf of Mexico, as between 1951 and 1965 it was named the Bulletin of Marine Science of the Gulf and Caribbean, but since 1965, it has no longer had a strict focus on the tropical western Atlantic. Another relevant regional journal is the Caribbean Journal of Science, which has been published since 1961. Obviously, the journal Coral Reefs (since 1982) includes research focused on coral reefs, including those in the Caribbean (see above).

Marine Biodiversity (since 2009) is not strictly related to tropical ecosystems, but in the scope of the present special issue, it is interesting to see what kind of attention has been given to coral reef biodiversity (Hoeksema and Van der Meij 2013), and, in particular, which Caribbean marine ecoregions and taxa have been covered and investigated thus far. Such information may serve as a basis to generate ideas for future research. Most publications on the biodiversity of Caribbean corals or coral reefs in this journal were published from 2016 onwards, and the majority concern the Eastern Caribbean, whereas the Greater Antilles and the Southern Caribbean share second place (Table 1). It is not surprising that cnidarians (including scleractinians) rank highest according to the number of publications, which is more than double the number of the next closest taxon (Table 2).

The editors hope that this special issue will encourage authors to publish more papers on the Caribbean in the journal Marine Biodiversity. For many taxa, there are no good overview studies available that show the distribution patterns of species richness in the Caribbean or the West Atlantic as a whole (see, for example, Cairns 2007; Miloslavich et al. 2010; Petuch 2013), whereas many such studies are available for the much larger Indo-Pacific (see the review by Hoeksema 2007). As Brazilian reef biota (including invasive species and diseases) in eight marine ecoregions show both similarities and differences with Caribbean reefs (e.g. Rocha et al. 2008; Nunes et al. 2011), with reef corals found to 27°S latitude (Capel et al. 2012) and reef fishes to 28°S (Floeter et al. 2001), it would also be interesting to include more papers on coral reefs from Brazil in order to facilitate comparisons between the biota of both areas and to study their connectivity

Table 1 Representation of Caribbean marine ecoregions by numbers of articles dealing with corals or reefs published in the journal Marine Biodiversity and its predecessor Senckenbergiana Maritima (1969–2016 + 2017 present issue = total). Some articles cover more than one ecoregion

Eastern Caribbean (3 + 9 = 12): Kleemann (1986, 1990), Alvarado (2011), Davies and Piontek (2017), García-Hernández et al. (2017), Hoeksema et al. (2017b), Ivanenko et al. (2017), Montano et al. (2017a, b), Van der Loos and Prud'homme van Reine (2017), Van der Loos et al. (2017), Vonk and Lau (2017)
Greater Antilles (5 + 3 = 8): Alvarado (2011), Hochberg et al. (2014), Reuscher and Shirley (2014), Corgosinho et al. (2016), Lucas and Weil (2016), Galindo Estronza et al. (2017), Hammerman and García-Hernández (2017), Ruiz-Abierno and Armenteros (2017)
Southern Caribbean (4 + 4 = 8): Alvarado (2011), Davies et al. (2013), Santodomingo et al. (2013), Bernal et al. (2016), Böhm and Hoeksema (2017), Hoeksema and Ten Hove (2017), Hoeksema et al. (2017a), Potkamp et al. (2017)
Southern Gulf of Mexico (1 + 3 = 4): Reuscher and Shirley (2014), Aguilar-Perera and Hernández-Landa (2017), Aguilar-Perera et al. (2017), Stampar et al. (2017)
Southwestern Caribbean (4 + 0 = 4): Kleemann (1990), Alvarado (2011), Santodomingo et al. (2013), Guerrero-Kommritz and Camelo-Guarin (2016)
Floridian (3 + 0 = 3): Reuscher and Shirley (2014), Netchy et al. (2016), Adam et al. (2017)
Northern Gulf of Mexico (2 + 0 = 2): Davies et al. (2013), Reuscher and Shirley (2014)
Western Caribbean (2 + 0 = 2): Alvarado (2011), Bernal et al. (2016)
Bahamian (1 + 0 = 1): Porto-Hannes and Lasker (2013)
Bermuda (0)

Table 2 Representation of Caribbean taxa and other species groups by numbers of articles dealing with corals or reefs published in the journal Marine Biodiversity and its predecessor Senckenbergiana Maritima (1969–2017 present issue). Some articles cover more than one species group

Cnidarians (14): Davies et al. (2013), Porto-Hannes and Lasker (2013), Santodomingo et al. (2013), Lucas and Weil (2016), García-Hernández et al. (2017), Hammerman and García-Hernández (2017), Hoeksema and Ten Hove (2017), Hoeksema et al. (2017a, b), Ivanenko et al. (2017), Montano et al. (2017a, b), Potkamp et al. (2017), Stampar et al. (2017)
Fishes (6): Adam et al. (2017), Aguilar-Perera and Hernández-Landa (2017), Aguilar-Perera et al. (2017), Böhm and Hoeksema (2017), Davies and Piontek (2017), Hoeksema et al. (2017a)
Crustaceans (5): Corgosinho et al. (2016), Galindo Estronza et al. (2017), Hoeksema et al. (2017b), Ivanenko et al. (2017), Vonk and Lau (2017)
Mollusca (4): Kleemann (1986, 1990), Guerrero-Kommritz and Camelo-Guarin (2016), Potkamp et al. (2017)
Polychaetes (3): Reuscher and Shirley (2014), Hoeksema and Ten Hove (2017), Hoeksema et al. (2017b)
Reef fauna assemblages (3): Netchy et al. (2016), Hoeksema et al. (2017b), Ruiz-Abierno and Armenteros (2017)
Algae (2): Van der Loos and Prud'homme van Reine (2017), Van der Loos et al. (2017)
Sponges (2): García-Hernández et al. (2017), Hammerman and García-Hernández (2017)
Fish parasites (1): Bernal et al. (2016)
Echinoderms (1): Alvarado (2011)
Gastrotricha (1): Hochberg et al. (2014)

(see, for example, Dias and Gondim 2016; Mizrahi et al. 2016; Pinto et al. 2016; Santos et al. 2016; Soares et al. 2016a, b).

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