Marine Pollution Bulletin 146 (2019) 201–205

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Faunal mortality associated with massive beaching and decomposition of pelagic *Sargassum*

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ARTICLE INFO

Keywords:
Macroalgae bloom
Fauna mortality
Mexican Caribbean

ABSTRACT

In 2018, the Mexican Caribbean coast received a massive influx of pelagic *Sargassum* spp. that accumulated and decayed on beaches producing organic decomposition products that made the water turbid and brown. Between May and September of the same year there were several reports of mass mortality of marine biota in this area. From these reports we estimate that organisms belonging to 78 faunal species died as result of this event, with demersal neritic fish and Crustacea being the most affected groups. The cause of mortality appears to be the combined effect of high ammonium and hydrogen sulfide concentrations, together with hypoxic conditions. If massive arrival of pelagic *Sargassum* spp. continues and algae is left to decay on the beach in large volumes then deterioration in water quality could affect coral reefs close to shore. Furthermore, barriers placed in lagoons to intercept the *Sargassum* spp. before it reaches the beach could impact reef fauna if the algae is left to die and sink on site.

Mass mortality events of coastal marine fauna have been reported worldwide due to several factors including extreme temperature changes (Hsieh et al., 2008), resuspension of anoxic-hypoxic or toxic sediment (Justić et al., 1996), emerging diseases (Lessios et al., 1984; Harvell et al., 1999) and micro- and macroalgal blooms (Anderson, 2007). Furthermore, over the past few decades, macroalgae blooms have increased worldwide (Lapointe, 1997), posing a major threat to public health, ecosystem health, and to fisheries and economic development (Anderson, 2007). Mass mortality events of fish, associated with brown and green macroalgae blooms, have been reported from several coasts, such as those off Brazil (Pinheiro et al., 2010; Sissini et al., 2017), Nigeria (Oyesiku and Egunyomi, 2014; Adet et al., 2017), and the Ivory Coast (Sankaré et al., 2016).

Here we report a faunal mass-mortality event along the Mexican Caribbean coast in 2018 associated with the massive influx of pelagic *Sargassum* spp. and its subsequent decay that resulted in decomposition products that made the water brown and turbid. This turbid water extended for hundreds of meters from the shore (Supp. Fig. 1) and was reported as a *Sargassum*-brown-tide by van Tussenbroek et al. (2017) to differentiate it from the terms “golden floating rainforest” (Laffoley et al., 2011) and “golden tides” (Smetacek and Zingone, 2013), which refer to drifting masses of pelagic *Sargassum* spp. in the open ocean. Historically this shoreline has received relatively small quantities of pelagic *Sargassum* spp. that presumably drifted from the Sargasso Sea through the northern passages of the Caribbean. In 2014, pelagic *Sargassum* (*Sargassum fluitans* and *S. natans*) started to arrive to the Mexican Caribbean coast in unusually large quantities, reaching a peak in September 2015, when ∼2360 m^3 algae km^{-1} washed ashore between

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https://doi.org/10.1016/j.marpolbul.2019.06.015
Received 2 October 2018; Received in revised form 8 April 2019; Accepted 6 June 2019
Available online 15 June 2019
0025-326X/

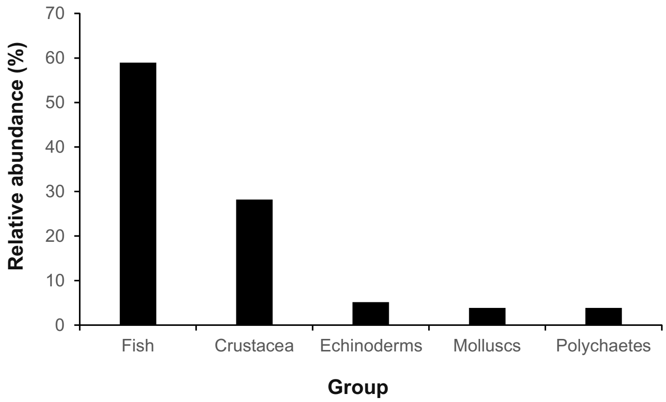

Fig. 1. Relative abundance of five groups of fauna observed dead along the Mexican Caribbean coast during the 2018 massive influx of *Sargassum* spp. event.

Cancun and Puerto Morelos (Rodríguez-Martínez et al., 2016). After a decrease in 2016 and 2017, the influx of *Sargassum* spp. resumed in 2018, peaking in May at 8793 $m^3 km^{-1}$ (SD: 12,485 $m^3 km^{-1}$) (Unpublished data). Satellite-derived observations of drifting *Sargassum* spp. masses (Gower et al., 2013) and hind cast models of *Sargassum* spp. landfalls (Johnson et al., 2013) suggest an origin off the coast of Brazil. In 2015, the *Sargassum*-brown-tide extended for over 200 m from shore at some sites (Supp. Fig. 1) and caused mortality of seagrasses and corals (van Tussenbroek et al., 2017). During this event, however, dead fauna were rarely observed along the beach, and no reports of mass mortality were made.

In 2018, between May and September, there were reports of mass mortality of fauna, from Cancun to Xcalak (Supp. Fig. 2), in association with massive arrival of *Sargassum* spp. and the subsequent formation of *Sargassum*-brown-tides. It should be noted, however, that these reports came mostly from tourist zones, where beach clean-up is frequent, so it is likely than the number of dead species is an underestimate. These reports were incorporated into a database by Universidad Nacional Autónoma de México, El Colegio de la Frontera Sur and the Puerto Morelos Reef National Park. These data show that individuals belonging to 78 faunal species were recorded in association with the *Sargassum* event of 2018. Fish were most commonly affected (59%) followed by Crustacea (28%), Echinoderms (5%), Mollusca (4%), and Polychaeta (4%) (Fig. 1). The majority of the reports ($N = 75$) were for the northern sector of the Mexican Caribbean coast, compared to the center ($N = 9$) and south ($N = 8$), where there is less tourism (and therefore less beach cleaning).

Of the 46 species of fish that were recorded, 80% have a demersal neritic habitat and are commonly found on coral reefs (cf. Claro and Robertson, 2010), while all dead organisms belonging to other faunal groups were benthic (Table 1). Only four of the recorded fish species (*Haemulon* sp., *Harengula* sp., *Caranx* sp. and *Abudefduf saxatilis*) were reported for all three sectors of the coast (Table 1). Other fauna that were frequently reported dead were the arenicolous sea cucumber *Holothuria arenicola*, the fish *Diodon holacanthus*, morays of the genera *Gymnothorax*, the crabs *Arenaeus cribarius* and *Callinectes similis* and the mollusk *Octopus* sp.

In most cases, dead organisms beached individually or in small (< 10) quantities, but on five occasions mass fish mortality (> 100 individuals) was reported at Punta Caracol, Puerto Morelos (May 2018; Fig. 2), Mahahual (July and August 2018) and Xcalak (August and September 2018). In these reports, dead organisms were mainly sardines of the family Clupeidae genera *Harengula*, in the northern and southern sectors, and grunts of the genera *Haemulon*, in the southern sector (Table 1).

The cause of faunal mortality recorded in the 2018 *Sargassum* event appears to be hypoxia and deterioration of water quality. All mass mortality events were recorded on beaches adjacent to shallow (< 3 m) reef lagoons, during calm windless days, and after several days of *Sargassum* spp. build-up on the shore. Analysis of water samples ($N = 7$, Supp. Table 2), taken between 45 and 480 m from the shore at one of these sites (Punta Caracol, Puerto Morelos), two days after the massive mortality of dead fauna (May 9th, 2018, Fig. 2), showed low concentration of dissolved oxygen (Mean: 2.9 $mg L^{-1}$; range: 1.9–4.2 $mg L^{-1}$) and high values of ammonium (mean: 6.0 $\mu mol L^{-1}$; range: 4.6–8.8 $\mu mol L^{-1}$) and phosphorus (mean: 5.0 $\mu mol L^{-1}$; range: 3.9–6.12 µmol L−1) as far as 480 m from the shore (Supp. Table 1). Oxygen values were lower than those recorded in Puerto Morelos reef lagoon in 2014, before the massive arrival of *Sargassum* spp. (mean: 5.35, SD: 0.22 $mg L^{-1}$), and ammonium and phosphorus values were an order of magnitude higher than the typical values for this area (0.03–0.24 $\mu mol L^{-1}$ and 0.32–0.57 $\mu mol L^{-1}$ respectively; Almazán-Becerril et al., 2014). Marine organisms are sensitive to low levels of dissolved oxygen; their metabolism is affected at levels below 4.0 mg O_2 L^{-1}, and mortality ensues in fish and crustaceans when it drops below 2.0 mg O_2 L^{-1} (Vaquer-Sunyer and Duarte, 2008). Also, high ammonium levels are toxic in aquatic environments (Gray et al., 2002). Although sulfide was not measured in these samples, we hypothesize that the high temperature (28.2–29.6 °C) and the large influx of organic matter from decomposing *Sargassum* spp. led to rapid reduction in dissolved oxygen and high levels of H_2S. Sulfide is toxic for most aerobic organisms, even at low concentrations (Janas and Szaniawska, 1996), as it diffuses through respiratory membranes and inhibits cytochrome oxidase function (cytochrome *c* oxidase; cytochrome *a*, a3), even in short-term exposures, especially when water temperature is high (Torrans and Clemens, 1982). In fish, sublethal exposure to sulfide has been found to induce gill and liver damage (Kiemer et al., 1995) and even in tolerant organisms (i.e. polychaetes) sulfide induces damage to RNA and DNA in coelomocytes and epithelial tissue (Joyner-Matos et al., 2010).

In conclusion, the mortality of fauna associated with the 2018 *Sargassum* event was widespread along the Mexican Caribbean coast and affected individuals of a large number of species, mostly of fish with demersal neritic habitats and crustaceans. In the absence of other algal blooms or major disturbances (i.e. storms) it appears that the combined effect of high ammonium and H_2S concentrations together with hypoxic conditions were responsible for this mortality event. It is uncertain how much of the lagoon water column was affected, but if massive influx of *Sargassum* spp. becomes an annual event it could potentially have a deleterious impact on the already degraded coral reefs of the region. This could be further exacerbated by the lagoonal placement of interception barriers to prevent the *Sargassum* spp. from reaching shore if it is left to sink and die in the lagoon. Different technologies for the removal of *Sargassum* spp. from the barriers are being developed, including the use of “Sargaboats” and pumps. Another option is to use barriers to deflect the algae to locations on the beach where collection and transport is easier. Management of beaches adjacent to coral reef lagoons that are receiving massive amounts of *Sargassum* spp. should consider these potential problems before deploying such barriers.

Table 1
Fauna species observed dead on beaches of the Mexican Caribbean coast during the massive influx of pelagic *Sargassum* spp. of 2018. The habitat of each species is indicated. Sectors: North sector: From Cancun to Puerto Aventuras, Central sector: Sian Ka'an, South sector: From Mahahual to Xcalak. Habitat determined after Claro et al. (2014) for fish and Felder and Camp (2009) for Crustacean. M: organisms observed dead in massive amounts (> 100).

Group	Species	Habitat	Sector		
			North	Central	South
Fish	*Abudefduf saxatilis*	Demersal Neritic	*	*	*
	Acanthostracion quadricornis	Demersal Neritic	*		
	Acanthostracion polygonius	Demersal Neritic	*		
	Callechelys bilinearis	Demersal Neritic	*		
	Canthigaster rostrata	Demersal Neritic	*	*	
	Canthigaster sp.	Demersal Neritic	*		
	Caranx sp.	Coastal Epipelagic	*	*	*
	Diodon holocanthus	Demersal Neritic	*		*
	Enchelycore carychroa	Demersal Neritic	*		
	Enchelycore nigricans	Demersal Neritic	*		
	Gymnothorax funebris	Demersal Neritic	*		
	Gymnothorax moringa	Demersal Neritic	*		
	Gymnothorax sp.	Demersal Neritic	*	*	
	Haemulon aurolineatum	Demersal Neritic	*		
	Haemulon flavolineatum	Demersal Neritic	*		
	Haemulon parra	Demersal Neritic	*		
	Haemulon sciurus	Demersal Neritic	*		
	Haemulon sp.	Demersal Neritic	*	*	**M**
	Halichoeres bivittatus	Demersal Neritic		*	
	Harengula jaguana	Demersal Pelagic			*
	Harengula sp.	Coastal Pelagic	**M**	*	**M**
	Hemiramphus balao	Coastal Epipelagic	*		
	Histrio histrio	Epipelagic	*		
	Kyphosus sectatrix	Pelagic Neritic	*		
	Lactophrys bicaudalis	Demersal Neritic	*		
	Lactophrys trigonus	Demersal Neritic	*		
	Lutjanus analis	Demersal Neritic	*		
	Lutjanus apodus	Demersal Neritic	*		
	Megalops atlanticus	Pelagic Neritic	*		
	Mycteroperca bonaci	Demersal Neritic			*
	Microspathodon chrysurus	Demersal Neritic	*		
	Ocyurus chrysurus	Demersal Neritic	*		
	Paraclinus sp.	Demersal Neritic	*		
	Polydactylus virginicus	Demersal Neritic	*		
	Pomacanthus arcuatus	Demersal Neritic	*		
	Scorpaena sp.	Demersal Neritic	*	*	
	Selene vomer	Demersal Neritic	*		
	Sparisoma aurofrenatum	Demersal Neritic	*		
	Sparisoma chrysopterum	Demersal Neritic	*		
	Sparisoma rubripinne	Demersal Neritic	*		
	Sparisoma radians	Demersal Neritic	*		
	Sparisoma sp.	Demersal Neritic	*	*	
	Sphoeroides testudineus	Demersal Neritic	*		
	Styracura schmardae	Demersal Neritic	*		
	Trachinotus falcatus (juvenile)	Pelagic Epibenthic	*		*
	Urobatis jamaicensis	Demersal	*		
Crustacean	*Achelous spinimanus*	Benthic	*		
	Alpheus heterochaelis	Benthic	*		
	Ampithoe sp.	Benthic	*		
	Arenaeus cribarius	Benthic	*		
	Callinectes marginatus	Benthic	*		
	Callinectes similis	Benthic	*		
	Carpias algicola	Benthic	*		
	Cataleptodius floridanus	Benthic	*		
	Chorinus heros	Benthic	*		
	Cronius ruber	Benthic	*		
	Gonodactylus sp.	Benthic	*		
	Leander tenuicornis	Benthic	*		
	Lysmata sp.	Benthic	*		
	Menippe nodifrons	Benthic	*		
	Mithrax forceps	Benthic	*		
	Panulirus argus	Benthic	*		
	Penaeidae sp.	Benthic	*		
	Portunus sp.	Benthic	*		
	Portunus sayi	Benthic	*		
	Pseudosquilla sp.	Benthic	*		
	Stenopus hispidus	Benthic	*		
	Stenorhynchus seticornis	Benthic	*		

(*continued on next page*)

Table 1 (*continued*)

Group	Species	Habitat	Sector		
			North	Central	South
Echinoderms	*Echinometra* sp.	Benthic	*		
	Holothuria arenicola	Benthic	*		
	Ophioderma sp.	Benthic	*		
	Meoma ventricosa	Benthic	*		
Molluscs	*Cyphoma gibbosum*	Benthic	*		
	Litiopa melanostoma	Benthic	*		
	Octopus sp.	Benthic	*		
Polychaetes	*Eupolymnia crassicornis*	Benthic	*		
	Hermodice carunculata	Benthic	*		
	Familia Syllidae	Benthic	*		

Fig. 2. Mass mortality of fauna associated with Sargassum-brown-tide at Punta Caracol, Puerto Morelos, in May 2018. a. Onshore accumulation of *Sargassum* spp. and *Sargassum*-brown-tide, b. Dead fish scattered along the beach, c. Different fish species found dead on the beach, d. Fish, mostly of the genera *Harengula,* that died in massive amounts. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

CRediT authorship contribution statement

R.E. Rodríguez-Martínez: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft, Writing - review & editing. **A.E. Medina-Valmaseda**: Data curation, Investigation, Writing - original draft, Writing - review & editing. **P. Blanchon**: Writing - original draft, Writing - review & editing. **L.V. Monroy-Velázquez**: Data curation, Investigation, Writing - original draft, Writing - review & editing. **A. Almazán-Becerril**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **B. Delgado-Pech**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **L. Vásquez-Yeomans**: Conceptualization, Data curation, Investigation, Writing - original draft, Writing - review & editing. **V. Francisco**: Conceptualization, Data curation, Investigation, Visualization, Writing - original draft, Writing - review & editing. **M.C. García-Rivas**: Conceptualization, Writing - original draft, Writing - review & editing.

Acknowledgments

Special thanks to Erika Hernández, Horacio Ocampo, Verónica Ramos, Alfredo Arellano, Luis Ramos, Enrique Gallegos, Ma. Jesús Hermosillo, Guadalupe Paz, Yazmin Novelo, Elva Leyva, Fortunato Herrera, Cedrella Medina, Roberto Herrera, Susana Rivero, Jully Novelo and Jorge Peniche for sharing the photographs of dead fauna associated to *Sargassum*-brown-tides and to Antonio Ortiz, Gerardo Castañeda, Antonio Lascano, Imelda Juárez, Lucia Paredes, Miguel A. Diego and Verónica Ramos for sharing the data of the volume of *Sargassum* spp. removed by hotels from the beach in 2018. The authors claim no conflict of interest with this work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2019.06.015.

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