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A checklist of dead fishes (Actinopterygii and Elasmobranchii) associated with the algal bloom event of the summer of 2022 on the Yucatan coasts, southern Gulf of Mexico

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Abstract

Harmful algal blooms (HABs) are natural phenomena that occur when colonies of microalgae grow out of control and produce toxic or harmful effects on the surrounding fauna. In August 2022, an HAB, dominated by the diatom, *Cylindrotheca closterium* (Ehrenberg) Reimann et J.C. Lewin, 1964, occurred on the Yucatan coast, southern Gulf of Mexico. In the presently reported study, two photo transects were established along the coastline, one at the onset of the bloom, at Telchac port, and the other at the final phase of the event, at Chixchulub port. The affected fish species were documented photographically and a taxonomic list, with their abundance, density, and biomass is presented, as well as a summary of the affected ecosystems according to the affinity of these species. A total of 54 species were recorded; 48 in Telchac and 21 in Chicxulub, with 15 species occurring at both sites. The affected species have a greater affinity to reef systems, beaches, and estuaries, in that order, between 3 m and 113 m depth. In the International Union for the Conservation of Nature (IUCN) nomenclature, the majority of the species are in the "least concern" category, however, species were also recorded in the "near threatened", "vulnerable", and "endangered" categories. Therefore, it is extremely important to monitor these events and report the affected species, since the increase in the frequency of these phenomena due to local and global factors can have significant repercussions on species endemic to the coastal zone.

Keywords

Cylindrotheca closterium, dead fishes, harmful algal bloom, red tide, Yucatan Peninsula

Introduction

Harmful algal blooms (HABs), colloquially known as red tides, are a natural phenomenon that occurs when colonies of microalgae (in the sea or in freshwater) grow out of control and produce toxic or harmful effects on the surrounding fauna (Hallegraeff et al. 1995). There are toxic and non-toxic HABs; in the toxic ones the algae produce toxins that affect or kill organisms, while the non-toxic ones can also cause the death of organisms, but this is because of the low concentration of oxygen in the environment due to their high density (Sidabutar et al. 2021). Although HABs are a natural phenomenon, they are magnified by changes in the concentration of nutrients (eutrophication) and in the temperature of the ecosystem, which is why these phenomena are expected to become more frequent and intense due to global warming and the increase in contamination (Anderson 1989; Smayda 1990; Hallegraeff 1993; Hallegraeff 2023).

When HABs appear on the coasts, they cause not only ecological impacts but also strong economic impacts on the local community, directly affecting fishing, as well as the restaurant and tourist industry. On 3 August 2022, fishermen noticed occurrence of live octopuses on the shore, and on 4 August dead and intoxicated fish started to deposit on the beach due to the HAB effects, dominated by *Cylindrotheca closterium* (Ehrenberg) Reimann et J.C. Lewin, 1964, a non-toxic diatom species (Herrera-Silveira et al. 2022). The stranding of dead and intoxicated fishes began at San Felipe port on the east of the Yucatan coast and gradually moved to the west until reaching the coasts of Chelem, Yucatan. On the night of 4 August, the communities at the coast began cleaning and burying the dead fish; the stranding of dead and moribund fish lasted approximately one week. HABs dominated by *C. closterium* have been documented in the area because of increased concentrations of nutrients such as nitrite, nitrate, phosphate, and urea (Poot-Delgado and Okolodkov 2020). During this phenomenon, the stranding of great diversity and abundance of fishes was documented photographically in order to present a taxonomic list of the affected species, as well as their abundance, density, and biomass, in addition to determining the affected ecosystems according to the affinity of these species.

Materials and methods

The shore was monitored based on two photo transects, the first, at the early site of the stranding, on 5 August, covering 1 km of the shore (Telchac) and the second one at the final phase of the event, on 12 August, covering 10 m (Chixchulub) (Fig. 1A). On shore, we randomly established a starting point and walked east–west, taking photographs of the organisms already deposited on the beach by using a PVC square frame of 1 m^2 and a camera held at an approximate height of 1 m (Fig. 1B). No specimens were collected.

The stranded organisms were identified up to the species level based on photographs. The identification was facilitated by the relatively fresh coloration of the specimens. Once we had a list of species, using FishBase (Froese and Pauly 2023) and Robertson and Van Tasell (2023), we collected information (1) on the size and weight of the species to make an approximation of the biomass; and (2) in order to determine the main habitat associated with the affected species, the depth range and the habitats (Fig. 1C) where the species have been recorded such as reef, estuary, and beach, among others, were recorded and used as a binary variable indicating the presence as (1) if the species have been recorded in that habitat or absence (0) if the species have not been reported in that habitat. Finally, the conservation status of the recorded species, according to the categories of the Red List of the International Union for the Conservation of Nature (IUCN), was recorded.

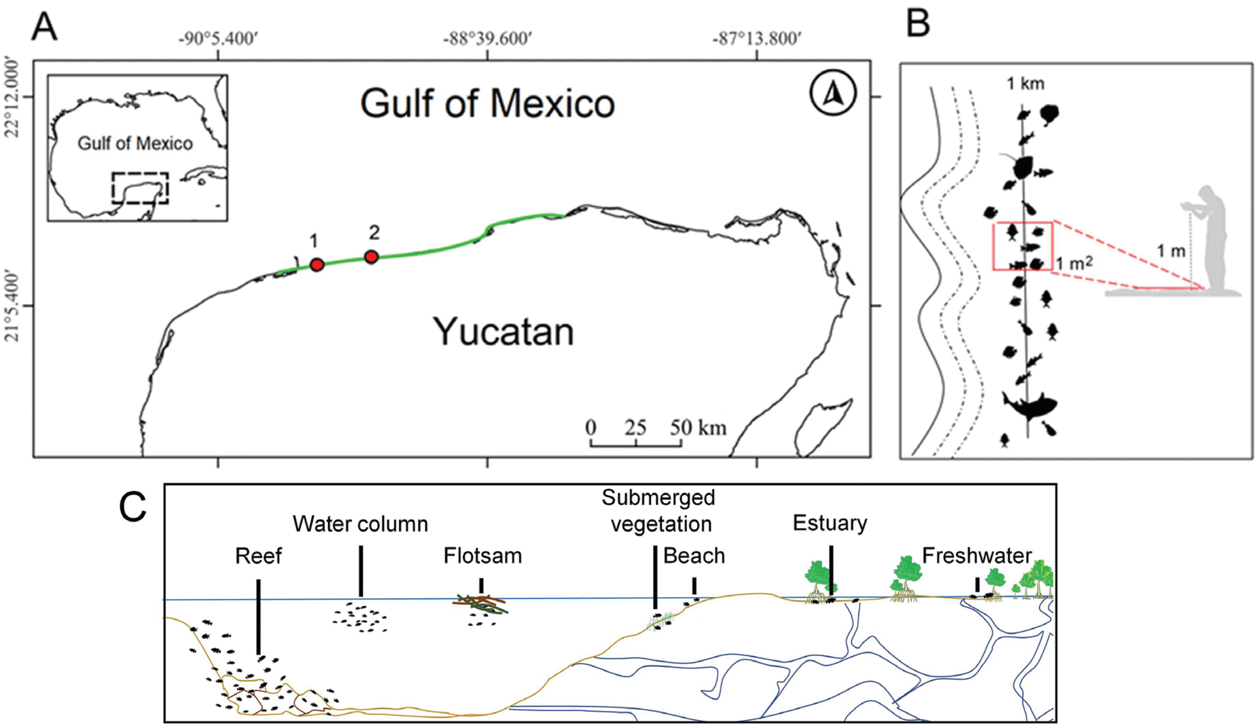

Figure 1. Diagrams showing the study area on the Yucatan coast, Mexico. (**A**) map of the study area (Sampling sites: 1 = Chicxulub, 2 = Telchac port). The green line marks the stretch of the shore affected by the harmful algal bloom in summer 2022. (**B**) Diagrammatic representation of a photo transect on the coastline. (**C**) Diagrammatic representation of the habitats where the affected species have been recorded.

Species richness was determined as the number of species recorded on both photo transects, abundance as the total number of individuals recorded per species, density as the number of organisms per species per 1 m^2, and biomass as the weight [g] per species per 1 m^2.

Results

Because the photo transect in Telchac was established at the beginning of the HAB, the beach cleaning campaigns had not started and a greater number of species could be observed, while in Chicxulub the photo transect was smaller and recorded less extensive diversity because the cleaning campaigns were already ongoing, however, it was possible to list species not recorded in Telchac.

Richness. A total of 54 species were recorded (Table 1), 48 in Telchac and 21 in Chicxulub. Six species not recorded in Telchac were recorded in Chicxulub: *Abudefduf saxatilis*, *Caranx hippos*, *Chilomycterus schoepfii*, *Gymnothorax saxicola*, *Ogcocephalus parvus*, and *Sphoeroides testudineus*. Of the total, five species were elasmobranchs and 49 actinopterygians. The families with the highest number of affected species were Haemulidae, Sciaenidae, and Serranidae with three species each.

Abundance. Telchac presented the mean abundance" of 6.4 individuals per species (range 1–36 ind./spec.) and Chicxulub 16.95 individuals per species (range 1–245 ind./spec.), the overall mean value was 12.4 ind./spec. (range 1–281 ind./spec.) (Table 2). Among the ten most abundant species, both localities share *Opsanus beta*, *Sphoeroides spengleri*, and *Haemulon plumieri*. In both locations, *Opsanus beta* presented the highest values of abundance and thus was the most abundant species with a total of 281 individuals recorded, followed by *Acanthostracion quadricornis* with 61 individuals, *Hypoplectrus puella* with 27, *Harengula jaguana* 26, and *Eques lanceolatus* 25 (Fig. 2).

Density. In Telchac a mean density of 0.2142 ind. · m^{-2} (range 0.03–1.2 ind. · m^{-2}) was recorded, while in Chicxulub 0.4241 ind. · m^{-2} (range 0.025–6.13 ind. · m^{-2}), the overall mean value was 0.25 ind. · m^{-2} (range 0.025–3.66 ind. · m^{-2}) (Table 2). In both locations, *O. beta* presented the highest values of density. Among the ten species with the highest density, both sites share *Opsanus beta*, *Sphoeroides spengleri*, and *Haemulon plumieri*. The species with the highest density were *Opsanus beta* 3.66 ind. · m^{-2}, *Hypoplectrus puella* 0.90 ind. · m^{-2}, *Harengula jaguana* 0.87 ind. · m^{-2}, *Eques lanceolatus* 0.83 ind. · m^{-2}, and *Acanthostracion quadricornis* 0.79 ind. · m^{-2} (Fig. 2).

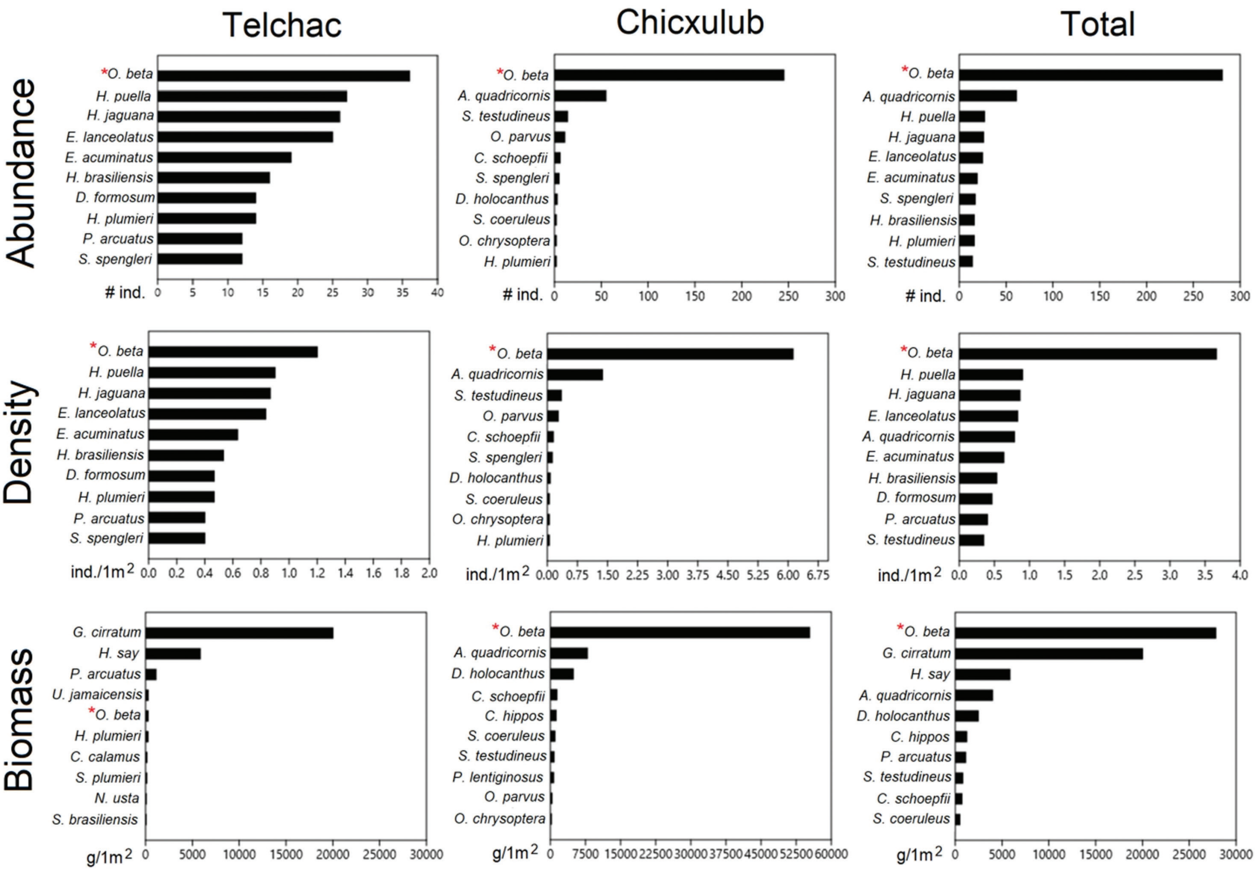

Figure 2. Community descriptors. Abundance, density, and biomass of fish species affected by the harmful algal bloom off the coast of Yucatan, Mexico in summer 2022.

Table 1. Fish species affected by the harmful algal bloom off the coast of Yucatan, Mexico in summer 2022.

Species	Family
Abudefduf saxatilis (Linnaeus, 1758)	Pomacentridae
Achirus lineatus (Linnaeus, 1758)	Achiridae
Opsanus beta (Goode et Bean, 1880)	Batrachoididae
Sanopus reticulatus Collette, 1983	Batrachoididae
Strongylura marina (Walbaum, 1792)	Belonidae
Strongylura notata (Poey, 1860)	Belonidae
Oligoplites saurus (Bloch et Schneider, 1801)	Carangidae
Caranx hippos (Linnaeus, 1766)	Carangidae
Chaetodon ocellatus Bloch, 1787	Chaetodontidae
Harengula jaguana Poey, 1865	Clupeidae
Dactylopterus volitans (Linnaeus, 1758)	Dactylopteridae
Hypanus say (Lesueur, 1817)	**Dasyatidae**
Chilomycterus schoepfii (Walbaum, 1792)	Diodontidae
Diodon holocanthus Linnaeus, 1758	Diodontidae
Anchoa hepsetus (Linnaeus, 1758)	Engraulidae
Eucinostomus gula (Quoy et Gaimard, 1824)	Gerreidae
Eugerres plumieri (Cuvier in Cuvier et Valenciennes, 1830)	Gerreidae
Ginglymostoma cirratum (Bonnaterre, 1788)	**Ginglymostomatidae**
Haemulon aurolineatum Cuvier in Cuvier et Valenciennes, 1830	Haemulidae
Haemulon plumieri (Lacepede, 1801)	Haemulidae
Orthopristis chrysoptera (Linnaeus, 1766)	Haemulidae
Chriodorus atherinoides Goode et Bean, 1882	Hemiramphidae
Hemiramphus brasiliensis (Linnaeus, 1758)	Hemiramphidae
Neoniphon marianus (Cuvier in Cuvier et Valenciennes, 1829)	Holocentridae
Lachnolaimus maximus (Walbaum, 1792)	Labridae
Lutjanus campechanus (Poey, 1860)	Lutjanidae
Ocyurus chrysurus (Bloch, 1791)	Lutjanidae
Gymnothorax saxicola Jordan et Davis, 1891	Muraenidae
Narcine bancroftii (Griffith et Smith, 1834)	**Narcinidae**
Ogcocephalus parvus Longley et Hildebrand, 1940	Ogcocephalidae
Ogcocephalus cubifrons (Richardson, 1836)	Ogcocephalidae
Lepophidium jeannae Fowler, 1941	Ophidiidae
Acanthostracion quadricornis (Linnaeus, 1758)	Ostraciidae
Pomacanthus arcuatus (Linnaeus, 1758)	Pomacanthidae
Holacanthus ciliaris (Linnaeus, 1758)	Pomacanthidae
Pseudobatos lentiginosus Garman, 1880	**Rhinobatidae**
Scarus coeruleus (Bloch, 1786)	Scaridae
Nicholsina usta (Valenciennes in Cuvier et Valenciennes, 1840)	Scaridae
Pareques acuminatus (Bloch et Schneider, 1801)	Sciaenidae
Pareques umbrosus (Jordan et Eigenmann, 1889)	Sciaenidae
Eques lanceolatus (Linnaeus, 1758)	Sciaenidae
Scorpaena brasiliensis Cuvier in Cuvier et Valenciennes, 1829	Scorpaenidae
Scorpaena plumieri Bloch, 1789	Scorpaenidae
Diplectrum formosum (Linnaeus, 1766)	Serranidae
Hypoplectrus puella (Cuvier in Cuvier et Valenciennes, 1828)	Serranidae
Serranus subligarius (Cope, 1870)	Serranidae
Calamus calamus (Valenciennes, 1830)	Sparidae
Lagodon rhomboides (Linnaeus, 1766)	Sparidae
Synodus foetens (Linnaeus, 1766)	Synodontidae
Sphoeroides spengleri (Bloch, 1785)	Tetraodontidae
Sphoeroides testudineus (Linnaeus, 1758)	Tetraodontidae
Prionotus alatus Goode et Bean, 1883	Triglidae
Prionotus longispinosus Teague, 1951	Triglidae
Urobatis jamaicensis (Cuvier, 1816)	**Urotrygonidae**

Family names set in bold font represent Elasmobranchii. All other families represent Actinopterygii.

Biomass. In Telchac the mean biomass was 593.69 g · m^{-2} and the total biomass (range 0.39–20 000 g · m^{-2}) and in Chicxulub it was 3750.46 g · m^{-2} (range 35.4–55 370 g · m^{-2}), the overall mean value was 1249.51 g · m^{-2} (range 0.39–27 820.6 g · m^{-2}) (Table 2). Among the ten species with the highest density, both sites only share *Opsanus beta*. The species with the highest biomass in Telchac were *Ginglymostoma cirratum* reaching 20 000 g · m^{-2}, *Hypanus say* 5847 g · m^{-2}, and *Pomacanthus arcuatus* 1110 g · m^{-2}, while in Chicxulub—*Opsanus beta* with 55 370 g · m^{-2}, *Acanthostracion quadricornis* 7920 g · m^{-2}, and *Diodon holocanthus* 4867.20 g · m^{-2}. In total, the species with the highest biomass were *Opsanus beta* (27 820 g · m^{-2}), *Ginglymostoma cirratum* (20 000 g · m^{-2}), and *Hypanus say* (5847 g · m^{-2}) (Fig. 2).

Table 2. Ecological variables associated with the fish species affected by the harmful algal bloom, Yucatan, Mexico, in summer 2022.

Species	*N*	ML	Weight	Depth [m]		Habitat							IUCN category				
		[cm]	[g]	Min	Max	Re	Fs	Es	Sv	Be	Wc	Fw	DD	LC	NT	V	E
Abudefduf saxatilis	1	23.0	90.6	0	41	1	1	0	0	0	1	0	0	1	0	0	0
Achirus lineatus	1	23.0	101.4	1	110	1	0	1	0	1	0	1	0	1	0	0	0
Opsanus beta	281	38.0	226.0	0	5	1	0	0	1	1	0	0	0	1	0	0	0
Sanopus reticulatus	3	42.0	226.0	0	10	1	0	0	0	0	1	0	0	0	0	0	1
Strongylura marina	1	73.0	370.0	0	5	0	0	0	0	0	1	1	0	1	0	0	0
Strongylura notata	1	45.0	71.8	0	5	1	0	0	0	0	1	0	0	1	0	0	0
Oligoplites saurus	2	35.0	118.1	0	30	0	1	0	0	1	1	1	0	1	0	0	0
Caranx hippos	1	124.0	21019.4	0	350	1	0	0	0	1	1	0	0	1	0	0	0
Chaetodon ocellatus	1	20.0	285.0	0	91	1	0	0	1	0	0	0	0	1	0	0	0
Harengula jaguana	26	27.5	45.1	0	10	0	0	0	0	0	1	0	0	1	0	0	0
Dactylopterus volitans	2	45.0	92.3	1	150	1	0	1	1	1	0	0	0	1	0	0	0
Hypanus say	9	78.0	19490.0	0	20	0	0	1	0	1	0	1	0	1	0	0	0
Chilomycterus schoepfii	9	33.0	550.0	0	77	1	0	1	1	0	0	0	0	1	0	0	0
Diodon holocanthus	4	60.0	942.0	0	104	1	0	1	0	1	0	0	0	1	0	0	0
Anchoa hepsetus	1	8.0	11.8	0	70	0	0	0	0	0	1	0	0	1	0	0	0
Eucinostomus gula	5	22.7	35.4	0	71	1	0	0	1	1	0	0	0	1	0	0	0
Eugerres plumieri	3	40.0	347.0	0	30	1	0	1	0	1	0	1	0	1	0	0	0
Ginglymostoma cirratum	1	300.0	60000.0	0	130	1	0	0	0	1	0	0	1	0	0	0	0
Haemulon aurolineatum	2	25.0	799.2	1	103	1	0	0	0	0	0	0	0	1	0	0	0
Haemulon plumieri	16	53.0	101.7	1	74	1	0	0	0	1	0	0	0	1	0	0	0
Orthopristis chrysoptera	3	46.0	108.0	5	20	1	0	1	0	1	0	0	0	1	0	0	0
Chriodorus atherinoides	3	20.6	73.6	0	5	0	0	1	0	0	1	1	0	1	0	0	0
Hemiramphus brasiliensis	16	41.0	73.1	0	5	1	0	1	0	0	0	1	0	1	0	0	0
Neoniphon marianus	3	22.0	336.0	15	151	1	0	0	0	0	0	0	0	1	0	0	0
Lachnolaimus maximus	5	91.0	119.0	0	91	1	0	0	1	1	0	0	0	0	0	1	0
Lutjanus campechanus	1	100.0	619.0	10	190	0	0	0	0	0	0	0	0	0	0	0	0
Ocyurus chrysurus	1	86.3	1005.0	0	180	1	0	0	0	1	1	0	1	0	0	0	0
Gymnothorax saxicola	1	62.0	129.2	2	213	0	0	0	0	1	0	0	0	1	0	0	0
Narcine bancroftii	4	65.0	85.0	0	189	0	0	0	0	0	0	0	0	0	0	0	0
Ogcocephalus parvus	11	10.0	34.0	29	360	1	0	1	0	1	0	0	0	1	0	0	0
Ogcocephalus cubifrons	7	38.0	34.0	0	70	0	0	0	0	0	0	0	0	0	0	0	0
Lepophidium jeannae	1	30.5	308.0	26	280	0	0	1	0	1	0	0	0	1	0	0	0
Acanthostracion quadricornis	61	55.0	215.0	2	90	1	0	0	1	1	0	0	0	1	0	0	0
Pomacanthus arcuatus	12	60.0	2775.0	1	101	1	0	0	1	0	0	0	0	1	0	0	0
Holacanthus ciliaris	2	45.0	1487.0	1	125	1	0	0	0	0	0	0	0	1	0	0	0
Pseudobatos lentiginosus	4	76.0	696.6	0	30	0	0	1	0	1	0	0	0	0	1	0	0
Scarus coeruleus	3	120.0	488.0	2	25	1	0	0	0	1	0	0	0	1	0	0	0
Nicholsina usta	8	30.0	303.0	1	73	1	0	1	1	1	0	0	0	1	0	0	0
Pareques acuminatus	19	25.0	91.0	3	113	0	0	0	0	0	0	0	0	1	0	0	0
Pareques umbrosus	4	20.0	91.0	4	110	1	0	1	0	1	0	0	0	1	0	0	0
Eques lanceolatus	25	30.0	36.5	2	230	1	0	1	0	1	0	0	0	1	0	0	0
Scorpaena brasiliensis	4	35.0	552.0	1	204	1	0	1	0	1	0	0	0	1	0	0	0
Scorpaena plumieri	7	45.0	552.0	1	80	1	0	0	0	1	0	0	0	1	0	0	0
Diplectrum formosum	14	30.0	48.3	1	132	1	0	0	1	1	0	0	0	1	0	0	0
Hypoplectrus puella	27	16.7	42.8	3	90	1	0	1	1	0	0	0	0	1	0	0	0
Serranus subligarius	1	10.0	393.0	3	80	1	0	1	0	1	0	0	0	1	0	0	0
Calamus calamus	10	56.0	433.0	1	75	1	0	0	1	1	0	0	0	1	0	0	0
Lagodon rhomboides	1	40.0	114.2	1	20	1	0	1	1	1	0	1	0	1	0	0	0
Synodus foetens	4	43.0	97.0	1	200	0	0	1	0	1	0	0	0	1	0	0	0
Sphoeroides spengleri	17	16.0	25.0	2	74	1	0	1	1	1	0	0	0	1	0	0	0
Sphoeroides testudineus	14	30.0	57.3	1	20	1	0	1	0	1	0	1	0	1	0	0	0
Prionotus alatus	1	20.0	75.4	35	611	0	0	1	0	1	0	0	0	1	0	0	0
Prionotus longispinosus	1	35.0	75.4	9	219	0	0	1	0	1	0	0	0	1	0	0	0
Urobatis jamaicensis	5	70.0	5003.0	1	160	1	0	1	0	1	0	0	0	1	0	0	0
Total	670					38	2	25	14	35	10	9	2	46	1	1	1
Mean	12.41	48.80	2250.0	3.09	113												
Min	1.0	8.0	11.8	0	5												
Max	281.0	300.0	60000.0	35.0	611												

N = number of specimens, Min = minimum, Max = maximum, Re = reef, Fs = flotsam, Es = estuary, Sv = submerged vegetation, Be = beach, Wc = water column, Fw = freshwater, DD = “data deficient”, LC = “least concern”, NT = “near threatened”, V = “vulnerable”, E = “endangered”.

Habitat. The species affected by the HAB presented a range of sizes between 8 and 300 cm, the majority, 42 species, with sizes between 8 and 62 cm and an overall mean value of 47.69 cm (Table 2). They were associated with seven general habitats, reefs, beaches, estuaries, submerged vegetation, water column, freshwater, and flotsam. A total of 28.6% of the affected species had an affinity for reefs, 26.3% for beaches, and 18.8% for estuaries, adding up to 74% of the affected species, another small percentage was divided between submerged vegetation, water column, freshwater, and flotsam (Fig. 3A). These species occur not deeper than 611 m, although, the majority had a minimum depth range between 0 and 5 m and a maximum between 5 m and 150 m, so the mean range was between 3 and 113 m of depth (Fig. 3B). The majority of the species (46 species) are in the category "least concern", *Ginglymostoma cirratum* and *Ocyurus chrysurus* in the category "data deficient", *Pseudobatos lentiginosus* "near threatened" *Lachnolaimus maximus* "vulnerable", *Sanopus reticulatus* "endangered" (Fig. 3C). A total of four individuals of *Pseudobatos lentiginosus*, five individuals of *Lachnolaimus maximus*, and three individuals of *Sanopus reticulatus* were recorded.

Discussion

Different authors recorded between 14 and 94 fish species on the Yucatan coast (Córdova-Tapia and Zambrano 2016; Palacios-Sánchez et al. 2019; Aguilar-Medrano et al. 2020), 159 in the Campeche Bank (Aguilar-Medrano and Vega-Cendejas 2019), and 183 on reefs (Núñez-Lara et al. 2015). According to the presently reported results, the species affected were most commonly associated with reefs, beaches, and estuaries in a depth range of 3 m to 110 m. We recorded in only two days of sampling, 54 species of bony and cartilaginous fishes, so it can be assumed that a greater number of species were affected during the whole duration of the HAB.

In total, 680 organisms were recorded, 281 representing *Opsanus beta*. This type of phenomenon occurs mainly in the coastal zone and *Opsanus beta* is a coastal species, distributed between 0 m and 5 m of depth, which is why it was highly affected, recording the highest abundance, density, and biomass. However, since this species is in the category of "least concern" and it is distributed from the east coast of Florida to Belize, we can assume that the HAB did not cause significant damage to its populations. However, a

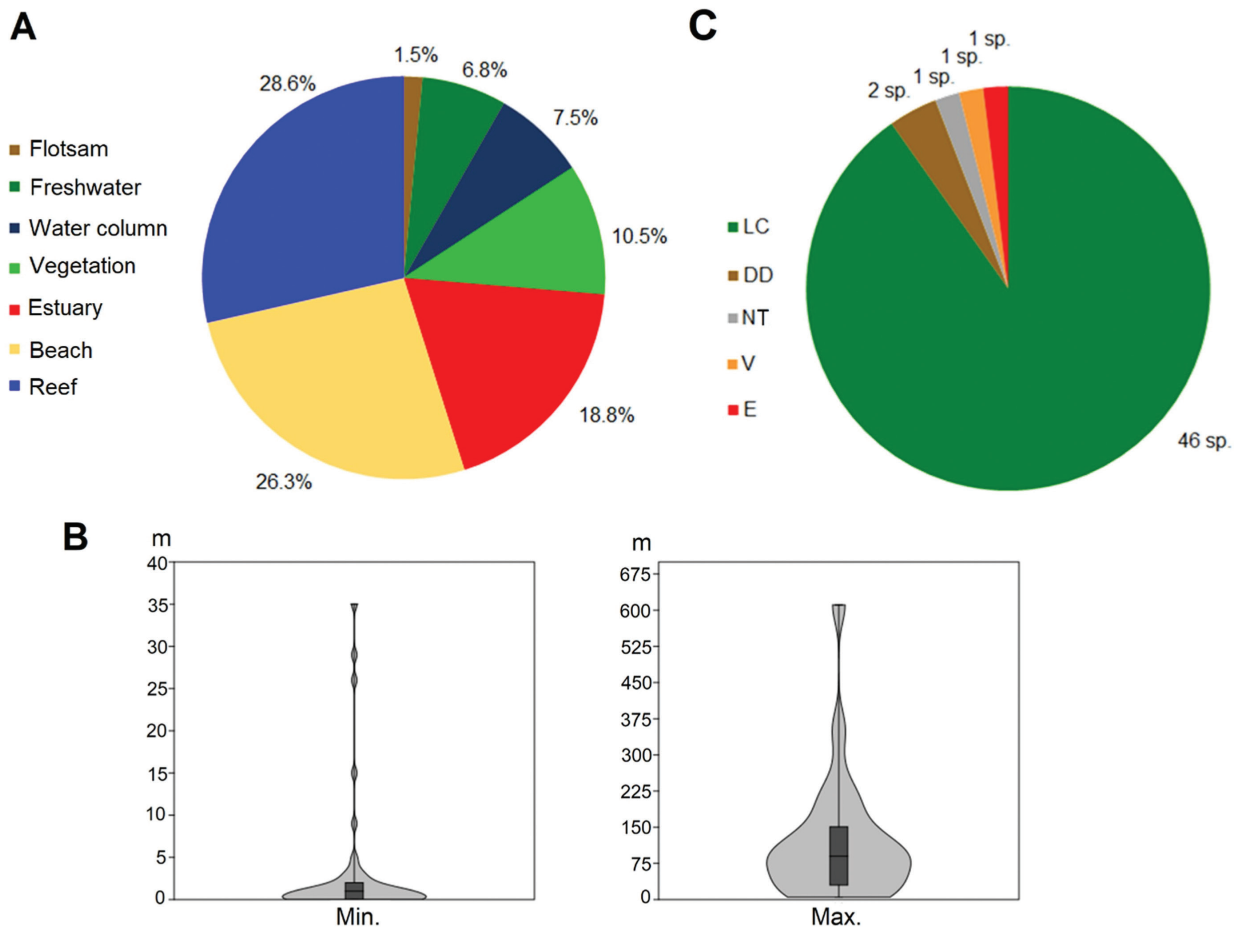

Figure 3. Ecological affinity, depth, and conservation status of species affected by the harmful algal bloom off the coast of Yucatan, Mexico in summer 2022; (**A**) percentage of species with affinity to the recorded habitats; (**B**) distribution in the water column, minimum and maximum depth; (**C**) number of species in the Red List categories. Abbreviations: Min = minimum, Max = maximum, LC = "least concern", DD = "data deficient", NT = "near threatened", V = "vulnerable", E = "endangered".

species with similar habits is *Sanopus reticulatus*, which is microendemic to the west coast of the Yucatan Peninsula and is in the "endangered" category. Although only three individuals of this species were recorded, these were recorded at the beginning of the HAB, so we can assume that more organisms were affected during the course of the HAB, and thus this could have affected their populations.

Among the species with the highest abundance and density were *Acanthostracion quadricornis*, *Hypoplectrus puella*, *Eques lanceolatus*, and *Harengula jaguana*. These species have a wide distribution in the Gulf of Mexico and the Caribbean; they are coastal inhabitants of beaches, reefs, and submerged vegetation, except for *Harengula jaguana* which is found in coastal schools in the water column, all of these species are in the conservation category "least concern". *Lachnolaimus maximus* is also widely distributed in the Gulf of Mexico and the Caribbean, it is a coastal inhabitant of beaches, reefs, and submerged vegetation; however, it is in the "vulnerable" category. Only five individuals of this species were recorded, four at the beginning of the HAB and one at the end, so we assume a low impact of the HAB on the species population.

Four cartilaginous species stand out among the species with the highest biomass, *Ginglymostoma cirratum*, which reaches 60 kg and 300 cm of total length (TL), of which only one individual was recorded, *Hypanus say* with 19.5 kg and 78 cm of TL, of which nine individuals were recorded, *Urobatis jamaicensis* with 5 kg and 76 cm TL of which six individuals were recorded, and *Pseudobatos lentiginosus* with 700 g and 76 cm of TL of which four individuals were recorded. The species *Hypanus say* and *Urobatis jamaicensis* are in the conservation category "least concern", *Ginglymostoma cirratum* in "data deficient" and *Pseudobatos lentiginosus* "near threatened." The latter species is distributed in South and North Carolina, the coast of Florida, and the whole Gulf of Mexico; however, it is an uncommon species (Lieske and Myers 1994), with a very low reproductive resilience rate, where the population doubles in a minimum time of more than 14 years (Froese et al. 2017), therefore, three individuals recorded at the beginning of the HAB and one at the end, indicate its possible effect on a greater number of individuals throughout the time duration of the HAB.

On the coast of Yucatan, tourism, urbanization, sewage discharges, livestock, agriculture, shrimp farming, and atmospheric deposition have been implicated as the most important continental sources of nutrient inputs into the coastal ecosystem (Aranda-Cirerol et al. 2011; Padilla 2015; Castillo-Pavón and Méndez-Ramírez 2017; Aguilar-Medrano et al. 2020; Poot-Delgado and Okolodkov 2020), swine being the greatest single nutrient input (Drucker et al. 2003; Aranda-Cirerol et al. 2011). The increase in the nutrients along with the non-existent or inefficient wastewater treatment plants, are the main causes of water quality problems in the area (Castillo-Pavón and Méndez-Ramírez 2017; Aguilar-Maldonado et al. 2018). As is known, nutrients can stimulate or enhance the impact of HABs (Anderson et al. 2008; Glibert et al. 2010; Aranda-Cirerol et al. 2011) thus, if nothing is done to stop the input of nutrients into the Yucatan coast, we can expect an increase of the HABs in the area. Although the majority of the species recorded are in the IUCN red list category "least concern", the increase in the frequency of these events due to local and global factors can cause damage to endemic species in coastal areas such as *Sanopus reticulatus*, which is in the category "endangered" and is microendemic to the Yucatan coastal area.

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References

Aguilar-Maldonado JA, Santamaría-Del-Ángel E, González-Silvera A, Cervantes-Rosas OD, Sebastiá-Frasquet MT (2018) Mapping satellite inherent optical properties index in coastal waters of the Yucatán Peninsula (Mexico). Sustainability 10(6): 1894. https://doi.org/10.3390/su10061894

Aguilar-Medrano R, Vega-Cendejas ME (2019) Implications of the environmental heterogeneity on the distribution of the fish functional diversity of the Campeche Bank, Gulf of Mexico. Marine Biodiversity 49(4): 1913–1929. https://doi.org/10.1007/s12526-019-00954-y

Aguilar-Medrano R, Hernandez de Santillana M, Vega-Cendejas ME (2020) Using fish assemblages to understand environmental connectivity and usage. A contribution to the conservation of the Yucatan Wetland. Estuarine, Coastal and Shelf Science 239: e106766. https://doi.org/10.1016/j.ecss.2020.106766

Anderson DM (1989) Toxic algal blooms and red tides: A global perspective. Pp. 11–16. In: Okaichi T, Anderson DM, Nemoto T (Eds.) Red tides: Biology, environmental science and toxicology. Elsevier Science, New York.

Anderson DM, Burkholder JM, Cochlan WP, Glibert PM, Gobler CJ, Heil CA, Kudela RM, Parsons ML, Rensel JAJ, Townsend DW, Trainer VL, Vargo GA (2008) Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States. Harmful Algae 8(1): 39–53. https://doi.org/10.1016/j.hal.2008.08.017

Aranda-Cirerol N, Comín F, Herrera-Silveira J (2011) Nitrogen and phosphorus budgets for the Yucatán littoral: An approach for groundwater management. Environmental Monitoring and Assessment 172(1–4): 493–505. https://doi.org/10.1007/s10661-010-1349-z

Castillo-Pavón O, Méndez-Ramírez JJ (2017) The tourist developments and their environmental effects in the Mayan Riviera, 1980–2015. Quivera 19: 101–118.

Córdova-Tapia F, Zambrano L (2016) Fish functional groups in a tropical wetland of the Yucatan Peninsula, Mexico. Neotropical Ichthyology 14(2): e150162. https://doi.org/10.1590/1982-0224-20150162

Drucker AD, Escalante Semerena R, Gómez-González V, Magaña-Rueda S (2003) La industria porcina en Yucatán: Un análisis de la generación de aguas residuales. Instituto de Investigaciones Económicas. Universidad Nacional Autónoma de México 34(135): 105–124. https://doi.org/10.22201/iiec.20078951e.2003.135.7505

Froese R, Demirel N, Coro G, Kleisner KM, Winker H (2017) Estimating fisheries reference points from catch and resilience. Fish and Fisheries 18(3): 506–526. https://doi.org/10.1111/faf.12190

Froese R, Pauly D (Eds.) (2023) FishBase. [Version 06/2023] http://www.fishbase.org

Glibert PM, Allen JI, Bouwman AF, Brown CW, Flynn KF, Lewitus AJ, Madden CJ (2010) Modeling of HABs and eutrophication: Status, advances, challenges. Journal of Marine Systems 83(3–4): 262–275. https://doi.org/10.1016/j.jmarsys.2010.05.004

Hallegraeff GM (1993) A review of harmful algal blooms and their apparent global increase. Phycologia 32(2): 79–99. https://doi.org/10.2216/i0031-8884-32-2-79.1

Hallegraeff GM (2023) Harmful algal blooms: a global overview. Pp. 25–49. In: Hallegraeff GM, Anderson DM, Cembella AD (Eds.) Manual on harmful marine microalgae. UNESCO, France.

Hallegraeff GM, Anderson DM, Cembella AD (1995) Manual of Harmful Marine Microalgae. Intergovernmental Oceanographic Commission, UNESCO, France, 565 pp.

Herrera-Silveira J, Aguilar-Trujillo A, Merino-Virgilio F, Medina-Euán D (2022) Marea Roja en Yucatán. Boletín Extraordinario SIMAR-CONABIO.

Lieske E, Myers R (1994) Collins pocket guide. Coral reef fishes. Indo-Pacific and Caribbean including the Red Sea. Harper Collins Publishers, 400 pp.

Núñez-Lara E, Arias-González JE, Legendre P (2015) Spatial patterns of Yucatan reef fish communities: Testing models using a multi-scale survey design. Journal of Experimental Marine Biology and Ecology 324(2): 157–169. https://doi.org/10.1016/j.jembe.2005.04.011

Padilla NS (2015) The environmental effects of Tourism in Cancun, Mexico. International Journal of Environmental Science and Technology 6: 282–294.

Palacios-Sánchez SE, Vega-Cendejas ME, Hernández-de-Santillana JM, Aguilar-Medrano R (2019) Anthropogenic impacts in the nearshore fish community of the Yucatan Coastal Corridor. A comparison of protected and unprotected areas. Journal for Nature Conservation 51: 125721. https://doi.org/10.1016/j.jnc.2019.125721

Poot-Delgado CA, Okolodkov YB (2020) Bloom of *Cylindrotheca closterium* originating from shrimp farming discharges in the SE Gulf of Mexico. Harmful Algae News No 66: 10.

Robertson DR, Van Tassell J (Eds.) (2023) Shorefishes of the Greater Caribbean: online information system. Version 3.0 Smithsonian Tropical Research Institute, Balboa, Panamá.

Sidabutar T, Srimariana ES, Cappenberg H, Wouthuyzen S (2021) An overview of harmful algal blooms and eutrophication in Jakarta Bay, Indonesia. IOP Conference Series: Earth and Environmental Science 869: e012039. https://doi.org/10.1088/1755-1315/869/1/012039

Smayda TJ (1990) Novel and nuisance phytoplankton blooms in the sea: Evidence for a global epidemic. Pp. 29–40. In: Granéli E, Sundström B, Edler L, Anderson DM (Eds.) Toxic marine phytoplankton. Elsevier Science, New York, NY, USA.