Spatial and Seasonal Variations of Harmful Benthic Dinoflagellates in the Coastal Waters of Mauritius

P. Neermul, G. Dhunnoo, V. Emrith, M. Fakoo, N. Jeenally, R. Bhantooa, and K. Elaheebocus

Abstract Harmful algal bloom (HAB) events can have severe consequences such as mass fish kills and problems to public health. The Albion Fisheries Research Centre has an ongoing HAB monitoring programme at established coastal sites in Mauritius including Grand Baie, Albion, Le Morne and Blue Bay. The commonly observed benthic dinoflagellates are from the genera *Amphidinium* sp., *Coolia* sp., *Gambierdiscus* sp., *Ostreopsis* sp., *Prorocentrum* sp. and *Synophysis* sp. These are the causative agents of fish toxicity such as ciguatera. The monitoring data at the four monitoring sites for the period 2013–2017 were analysed to evaluate the temporal, spatial and seasonal variations in the densities of harmful marine microalgae species. Recurrent high densities were recorded at all the sites during the years. The genera *Prorocentrum* and *Ostreopsis* were observed at relatively higher densities throughout the years at the four study sites whilst the other genera occurred only occasionally. An increase in the mean cell densities of *Ostreopsis* sp. and *Prorocentrum* sp. were observed from 2013 to 2016 followed by a decline in the abundance in 2017 at most of the study sites. The cell densities of these two genera were found to be higher during summer seasons, and their occurrences were more significant at two sites, namely Blue Bay and Le Morne which are located in the South Coast of the Island. This warrants further studies to determine the influence of oceanographic parameters, seawater quality and environmental conditions on the cell densities of harmful marine microalgae in Mauritius.

Keywords Harmful algal bloom · Dinoflagellates monitoring · *Prorocentrum* sp. · *Ostreopsis* sp

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1 Introduction

Accumulations of phytoplankton in coastal waters are frequent phenomena around the world.

Large biomass blooms have been observed along the coasts of the United States, Inland Sea of Japan, the Black Sea and China [3]. It is estimated that 3400–4100 phytoplankton species occur in marine waters; out of which, about 300 is responsible for blooms also known as ‘red tides’. These species comprise mostly diatoms, dinoflagellates, silicoflagellates, prymnesiophytes and raphidophytes [16]. However, only 60–80 species are known to cause harmful algal blooms (HABs) due to their biotoxins, irradiance reduction, physical damage and anoxia amongst others [15].

HABs in marine environments can be attributed to two primary causes: natural such as upwelling, ocean currents and increasing temperature; and anthropogenic such as nutrient inputs and coastal developments [14]. HAB events can have devastating effects in the immediate marine environment, thereby affecting the marine life. Substantial algal blooms may lead to anoxic conditions resulting in kills of fish and invertebrates. In other instances, algal species such as raphidophytes (*Chatonella* and *Heterosigma*) and dinoflagellates (*Karenia*, *Cochlidinium* and *Karlodinium*) can produce exudates and reactive oxygen species which affect the gills of fish eventually leading to their death, thereby affecting fisheries stocks [4].

In addition, a great concern to human health is algal species which have the abilities to produce potent toxins which can find their way along the food web to man [2]. The HAB toxins can be grouped according to their syndromes as paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, diarrhetic shellfish poisoning, azaspiracid shellfish poisoning, ciguatera fish poisoning (CFP) and cyanobacteria toxin poisoning [14].

The dinoflagellate *Gambierdiscus toxicus* is considered to be one of the causative agents for ciguatoxin in fish. It occurs commonly in the tropical regions including Mauritius and Reunion Islands. These are found attached to macroalgae, dead coral rubbles or other substrates and are consumed by herbivorous fish. Ciguatoxin is bio-accumulated such that organism higher in the food chain has higher concentrations [12]. In 2001, Hamilton et al. [5] demonstrated that various ciguatoxins were involved in ciguatera in the Indian Ocean, and the dinoflagellate *Gambierdiscus* sp. was identified as the most probable causative agent for producing the toxin.

This study zeniths the temporal, spatial and seasonal variations in the density of the most commonly occurring benthic harmful dinoflagellates, namely *Amphidinium* sp., *Coolia* sp., *Gambierdiscus* sp., *Ostreopsis* sp., *Prorocentrum* sp. and *Synophysis* sp. in the coastal waters of Mauritius at the four monitoring sites, namely Grand Baie, Albion, Le Morne and Blue Bay, for the period 2013–2017.

2 HAB Monitoring in Mauritius

The Inter-Governmental Oceanic Commission of the UNESCO conducted a baseline study of species involved in HAB for the Indian Ocean region including Mauritius from 1998 to 1999. During the study, macroalgae samples were collected on a monthly basis at two sampling sites for isolation of epiphytic microalgae. Several potentially toxic species belonging to the genera *Prorocentrum, Ostreopsis, Gambierdiscus, Coolia, Amphidinium* and *Synophysis* were observed during the study [6].

Consequently, the Albion Fisheries Research Centre (AFRC) had put up in place a HAB monitoring programme at four coastal sites, namely Albion, Blue Bay, Le Morne and Trou aux Biches; whereby, macroalgae samples were collected once every two months. Grand Baie was added as an additional monitoring site as from 2014.

3 Materials and Methods

3.1 Site Description

Mauritius, Rodrigues and Reunion Islands form the Mascarene Archipelago located in the Western Indian Ocean. The republic of Mauritius has an exclusive economic zone of 1.9 million km^2 and an extended continental shelf of 396 000 km^2 in the Mascarene plateau jointly managed with the republic of Seychelles. It has Mauritius as mainland and several outlying Islands, namely Rodrigues, St. Brandon or Cargados Carajos Archipelago, Agalega, Tromelin and the Chagos Archipelagos, including Diego Garcia. The EEZ includes coral reefs, seagrass beds, rough and sandy areas, submerged oceanic banks and oceanic waters. The mainland Mauritius has a coastline of 322 km and is surrounded by 150 km of protective coral reefs, covering a lagoon area of around 243 km^2. The coastal zone consists of sandy beaches, coastal dunes, rocky shores, wetlands and mangroves, lagoon corals, fringing coral reefs and all their associated marine life [9].

Mauritius, being a Tropical Island, witnesses a maritime climate all over the year. The Island has two seasons, namely: summer from November to April and winter which extends from June to September. May and October are known as the transition months. Mean summer temperature is 24.7 ºC, and mean winter temperature is 20.4 ºC. The temperature difference between the seasons is only 4.3 ºC. January and February are known to be the warmest months with a mean day maximum temperature of 29.2 ºC whilst July and August are the coolest months with average night minimum temperatures of 16.4 ºC [8].

This study comprises HAB monitoring data for Grand Baie for the period 2014–2017; and Albion, Le Morne and Blue Bay for the period 2013–2017. Figure 1 illustrates the locations of the monitoring sites.

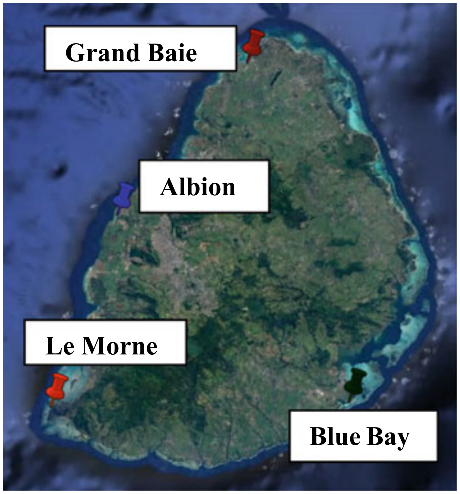

Fig. 1 Location of HAB monitoring sites [*Source* Google Earth, 2019]

Grand Baie. Grand Baie remains the most popular beach of all the northern tourist spots. The bay is heavily occupied by boats, catamarans and pleasure crafts belonging to hotels, private owners and fishermen. Rock revetments have been implemented to protect the receding shoreline on a length of 100 m. Grand Baie lies in the centre of many hotels, commercial spaces and residences. There is no natural river and canals in the vicinity of the beach, but small storm water drains are present [7].

Albion. Albion is located in the west of Mauritius and has a coastline of 1.5 km. It is enclosed by basaltic cliffs at both the northern and southern ends. The beach can be divided into three areas; (a) northern area for private residences and villas (b) central area for public beach approximately 300 m long and (c) southern area for AFRC and hotel. The lagoon is approximately 400 m wide and is used for the anchorage of pleasure crafts and fishing boats. It also receives inputs of freshwater from a river that runs through agricultural fields, animal farming areas and a wetland at the southern end of the beach [7].

Le Morne. Le Morne is located on the South-West coast of Mauritius and surrounded by reefs. The beach is used for recreational purposes. The lagoon is 500 m wide at the west and wider at the north and south. Hotels and a public beach is located along the coast. In the lagoon, kite and wind surfing are popular because of the good wind conditions at the south part. The coast is inscribed as the Le Morne Cultural Landscape of World Heritage Sites in 2008 by UNESCO [7].

Blue Bay. Blue Bay is situated in the South-East of Mauritius and is enclosed by coral reefs. It is a popular tourist spot and is extensively used for recreational purposes. There is no river mouth or estuaries at Blue Bay. The coastline has witnessed many developments projects in the coastal region including hotels, restaurants and private apartments. In addition, the seawater quality is influenced by surface runoff during heavy rainfall increasing turbidity and siltation [7].

3.2 Sampling and Analysis

The HAB monitoring programme involves collection of about 500 g of macroalgae samples at about 5 m from the shoreline. Each site comprised three sampling stations, and samples were collected once every two months. The samples were stored and transported to the laboratory in a thermos-insulated box at ambient temperature and were analysed within 24–48 h.

The macroalgae were shaken vigorously for 1 min with seawater in a 2L plastic bottle to dislodge epiphytic dinoflagellates. The resulting seawater was sieved through mesh size 150, 75 and 38 μm. The residues from the 38 μm sieves were collected in a beaker, diluted to 25 ml with filtered seawater and fixed with 0.2 ml of Lugol solution. 1 ml of this solution was transferred to a Sedgwick Rafter cell for counting under a light microscope. The number of the epiphytic dinoflagellates, namely *Prorocentrum* sp, *Ostreopsis* sp., *Gambierdiscus* sp., *Coolia* sp., *Amphidinium* sp. and *Synophysis* sp was expressed as number per 100 g of macroalgae.

4 Results

4.1 Temporal Dynamics of Harmful Marine Microalgae

The temporal variability of the studied harmful marine microalgae at Grand Baie, Albion, Le Morne and Blue Bay is summarised in Fig. 2. The genera *Prorocentrum* and *Ostreopsis* were most abundant through the monitoring period whilst other genera occurred less frequently.

The maximum cell densities recorded at the four monitoring sites from 2013 to 2017 are listed in Table 1. The highest cell densities for *Amphidinium* sp. (746), *Coolia* sp. (1312) and *Prorocentrum* sp. (28,336) occurred at Blue Bay in December 2016, January 2014 and February 2015, respectively. High densities of *Ostreopsis* (45,617) and *Synophysis* (283) were also observed at Blue Bay in June and February 2014, respectively. The maximum cell density for *Gambierdiscus* sp. (461), *Ostreopsis* sp. (55,495) and *Synophysis* sp. (341) occurred at Le Morne in March 2015, November 2016 and November 2015, respectively.

Recurrent peak densities of the dinoflagellates were recorded during the years, however, these were of short duration, and a decline in the densities was noted during subsequent monitoring. The highest cell density events for all the dinoflagellates occurred at Blue Bay and Le Morne. In addition, the high cell density events at the four monitoring sites were most prominent during 2015 and 2016. However, no high cell densities were recorded during subsequent samplings following these events.

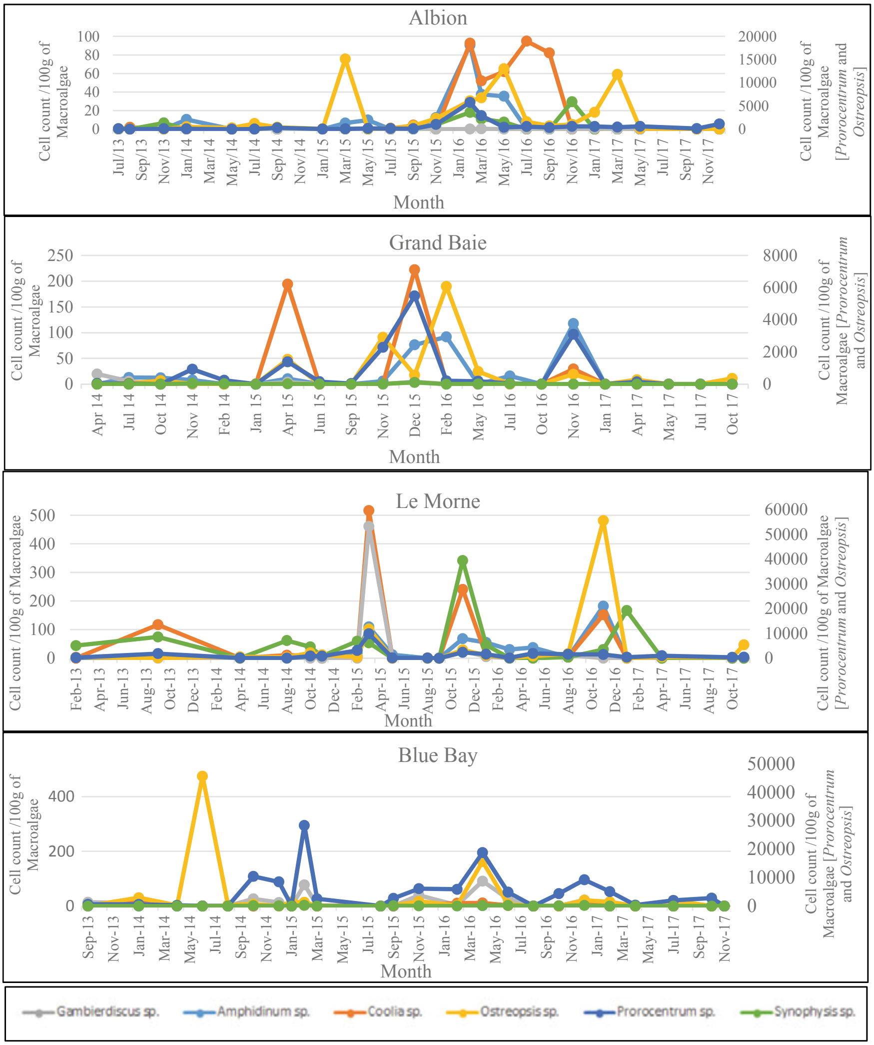

Fig. 2 Temporal variability of the genera *Prorocentrum, Ostreopsis, Gambierdiscus, Coolia, Amphidinium* and *Synophysis* at Grand Baie, Albion, Le Morne and Blue Bay

4.2 Dynamics of Prorocentrum *Sp. and* Ostreopsis *Sp.*

The SPSS software was used to determine the correlation between the cell occurrences, and the data are presented in Table 2. Given that the genera *Prorocentrum* and *Ostreopsis* were most abundant through the monitoring period; their correlation with the occurrences of other genera were evaluated. A moderate positive correlation [$0.5 < r < 0.66$] was observed between the cell densities of *Prorocentrum* sp. with those of

Table1 Maximum cell densities recorded at the four monitoring sites from 2013 to 2017

Cell	Maximum cell counts/100 g of macroalgae							
	Grand Baie		Albion		Le Morne		Blue Bay	
Amphidinium sp.	118	Nov 16	91	Feb 16	182	Nov 16	**746**	**Dec 16**
Coolia sp.	222	Dec 15	95	Jul 16	516	Mar 15	**1312**	**Jan 14**
Gambierdiscus sp.	20	Apr 14	134	Jan 17	**461**	**Mar 15**	91	Apr 16
Ostreopsis sp.	6072	Feb 16	15,111	Mar 15	**55,495**	**Nov 16**	**45,617**	**Jun 14**
Prorocentrum sp.	5784	Dec 15	5754	Feb 16	9861	Mar 15	**28,336**	**Feb 15**
Synophysis sp.	107	Dec 15	30	Nov 16	**341**	**Nov 15**	**283**	**Feb 14**

Table 2 Correlation between the occurrences of the cell densities of the genera *Amphidinium*, *Coolia*, *Gambierdiscus*, *Ostreopsis*, *Prorocentrum* and *Synophysis* at the four study sites

	AM	CO	GD	OS	PR	SY	AM	CO	GD	OS	PR	SY
	Le Morne						Blue Bay					
AM	1.0						1.0					
CO	0.7	1.0					0.4	1.0				
GD	0.4	*0.9*	1.0				0.5	0.5	1.0			
OS	0.9	0.4	0.1	1.0			0.0	0.1	0.1	1.0		
PR	*0.5*	*0.9*	*0.9*	0.2	1.0		0.5	0.3	*0.9*	0.0	1.0	
SY	0.2	0.4	0.1	0.0	0.2	1.0	0.7	0.3	0.7	0.0	*0.8*	1.0

	Albion						Grand Baie					
AM	1.0						1.0					
CO	0.6	1.0					0.4	1.0				
GD	0.3	0.2	1.0				0.0	0.2	1.0			
OS	0.4	0.3	0.2	1.0			0.5	0.1	−0.1	1.0		
PR	0.9	*0.6*	0.4	0.2	1.0		*0.6*	*0.7*	0.1	0.2	1.0	
SY	0.5	0.3	0.1	0.1	*0.5*	1.0	0.3	0.7	0.1	0.0	*0.7*	1.0

Amphidinium sp., *Coolia* sp., *Gambierdiscus* sp. and *Synophysis* sp. No significant correlation ($p > 0.001$) was noted between the cell density of *Ostreopsis* sp. and the remaining dinoflagellates.

The annual trend in the mean cell densities of *Ostreopsis* sp. and *Prorocentrum* sp. indicated an increase in densities from 2013 to 2016 followed by a decline in the abundance in 2017 at most of the study sites. A significant drop in the cell density

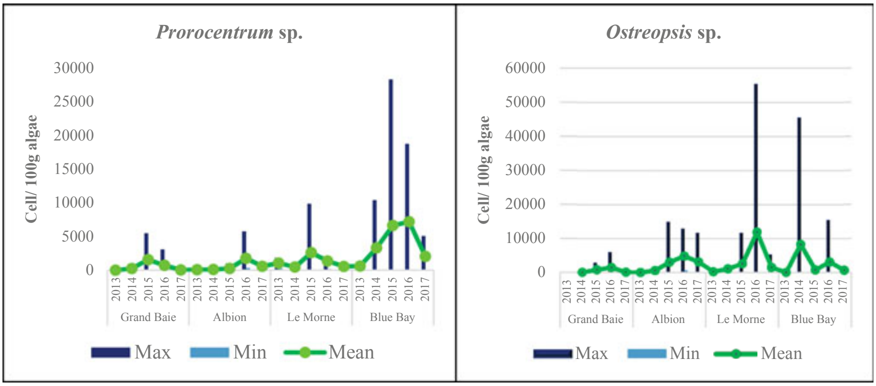

Fig. 3 The annual trends in the mean cell densities of *Prorocentrum* sp. and *Ostreopsis* sp. at Grand Baie, Albion, Le Morne and Blue Bay

of *Ostreopsis* sp. was observed at Blue Bay in 2015 as compared to 2014 as shown in Fig. 3.

Am: *Amphidinium* sp., CO: *Coolia* sp., GD: *Gambierdiscus* sp., OS: *Ostreopsis* sp., PR: *Prorocentrum* sp. and SY: *Synophysis* sp.

4.3 Seasonal Variations in the Cell Densities of **Ostreopsis** *Sp. and* **Prorocentrum** *Sp.*

The seasonal variations in the cell densities of *Prorocentrum* sp. and *Ostreopsis* sp. are shown in Figs. 4 and 5, respectively. The cell densities during summer seasons were much higher as compared to winter seasons at the four study sites. In addition,

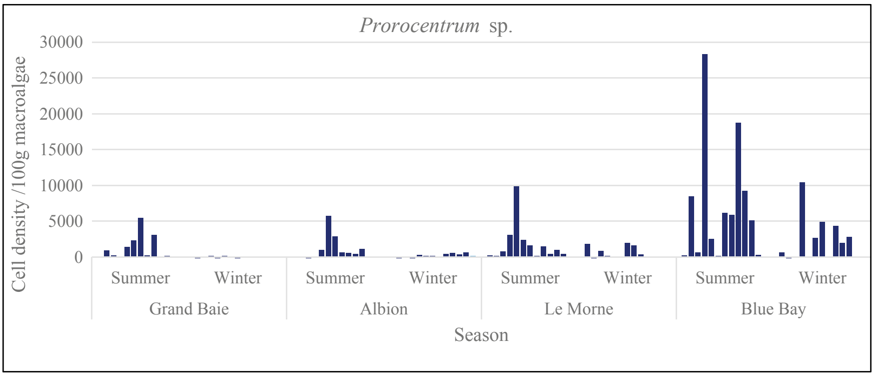

Fig. 4 Seasonal variations of *Prorocentrum* sp. at Grand Baie, Albion, Le Morne and Blue Bay

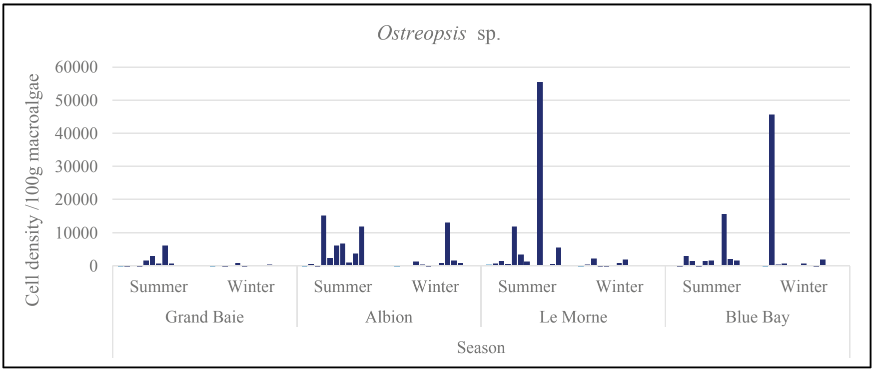

Fig. 5 Seasonal variations of *Ostreopsis* sp. at Grand Baie, Albion, Le Morne and Blue Bay

it was observed that the cell density of *Prorocentrum* sp. during summer seasons was relatively higher at Blue Bay followed by Le Morne indicating that the southern region of Mauritius is more prone to algal blooms.

5 Discussion

The ocean conditions and the environment interact to generate favourable conditions for HABs and subsequent HAB related diseases in humans and other animals [10]. Blue Bay and Le Morne are situated in the southern region of Mauritius, and the environmental conditions are directly affected by the South-East Trade Winds. In addition, summer season in Mauritius is characterised by warmer temperature and higher precipitation rate compared to winter season [8]. These may have influenced the proliferation of microalgae cells witnessed at the two sites.

Similar observations were reported along the coast of Oman; whereby, temporal and spatial distributions of microalgae cells were perceived to be affected by meteorological conditions such that monsoon winds caused an increase in HAB events [1]. Although temperature is believed to play a key role in HAB events, wind directions or flow of ocean currents and precipitation also affect variability of cell densities. Heavy rainfall may induce.

HABs due to a decline in salinity to brackish level and inflow of nutrients [11].

Furthermore, Sastre et al. [13] observed that the composition and density of certain harmful marine microalgae along the coast of Argentina showed large spatial and temporal variabilities. High densities were observed during summer in the southern, and it produced toxic accumulations. However, the high densities witnessed in winter in the northern region were below the threshold values to produce toxic accumulations.

6 Conclusion

There were variable trends in the cell densities at the four sites during the study period. However, there are some indications that the cell densities were influenced by seasons and locations with high densities being more prominent in summer and in the southern region. Further, studies are warranted to determine the influence of oceanographic parameters, seawater quality and environmental conditions on the cell densities of harmful marine microalgae in Mauritius.

In addition, peak densities of harmful marine microalgae observed during several occasions suggest that there is a real risk of HAB in the future. Accordingly, national HAB monitoring programme need to be re-designed to mitigate the environmental, socio-economic and health impacts of potential HABs events. The HAB monitoring programme shall encompass the following:

(a) Increase the number of monitoring sites and the frequency of monitoring;
(b) Establish species-specific HAB threshold values to trigger HAB alerts;
(c) Increase subsequent monitoring frequency following high density events;
(d) Isolate and enumerate benthic dinoflagellates in dead coral rubbles and sediments;
(e) Analyse seawater quality in terms of physico–chemical parameters including nutrient levels when collecting macroalgae samples;
(f) Establish a contingency plan for HAB events;
(g) Implement a surveillance programme for fish intoxication and HAB-related diseases to support management activities;
(h) Conduct detailed studies on the socio-economic losses related to HAB events.

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