Biological And Oceanographic Analyzes Of Intoxication By Marine Animal Consumption (IMAC) Precursors In Diego Suarez Bay And Northern-East Of Madagascar

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Abstract: Based on a retrospective view, the study aimed at analyzing the Intoxication by Marine Animal Consumption (IMAC) incidents occurred in north and northeastern Antsiranana. The study took place in September 2016, March 2017 and in July 2017 to February 2018 using oceanographic data (such as sea surface temperature (SST), rainfall and wind speed) and biological data, including the epidemiological data, the inventory of Dinoflagellates and chlorophyll a (chl-a). 108 cases were hospitalized. The age group most affected was 18 to 41 years (50%). The overall case fatality rate was 14%. The animals highlighted are a sea turtle, Sardinella and a Tuna. 40 genera of Diatoms and 09 genera of Dinoflagellates (*g Prorocentrum, g Protoperidinium, g Scippsiella, g Dinophysis, g Gonyaulax, g Gymnodium, g Lingulodium, g Ostreopsis, g Preperidium*) are reported throughout the Diego Suarez Bay. Parameters such as SST, rainfall, wind speed, the importance of terrigenous input and the morphological unit condition the establishment of Harmful algal blooms (HAB) which is favorable to the IMAC presence. The IMAC may possibly occur 10 days after the harmful algal bloom.

Index Terms: Planctons, Chlorophyll a, Dinoflagellates, harmful algal bloom, Intoxication by marine animal consumption, oceanographic data, northern-east of Madagascar; Diego Suarez bay.

1 Introduction

Unknown cause of the sudden death has been commonly reported in Madagascar. Intoxication by Marine Animal Consumption (IMAC) might be part of the causes. Despite the ministerial regulations on consuming certain marine animals at risk of IMAC incident during hot season, local people still do not respect them. IMAC incident victims are often recorded within the coastal area [1]. For instance, the northern part of Madagascar does not escape this situation especially during hot and rainy season [2]. Without a regional and local IMAC risk alert in a well-located area, the IMAC present a devastating effect on the area.

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It can be observed that direct negative impacts such as loss of humans, tourism activity and loss of work such as fishing and other downstream marine product trade channels occur. In order to be able to, earlier, determine the period and the areas at risk of IMAC, it is prominent to better know its precursors, which are mainly part of environmental signals leading to the blooming of toxic microalgae such as of Dinoflagellates. To do so, a retrospective study of IMAC into Diego Suarez Bay and the northern-east of Antsiranana (Diego II or Antsiranana II) were carried out in order to find out how the indicators of period and risk zone of IMAC would work. Thus, the present study has mainly focused on the monitoring of phytoplankton in Diego Suarez Bay and four parameters including chlorophyll a, sea surface temperature, wind speed and rainfall in this Bay and in northeastern Madagascar.

2 METHODOLOGY

2.1 Study areas

Two areas were covered in our study, including Diego Suarez Bay and the northeastern coast of Madagascar passing through the Diego Suarez Bay Pass to the Loky River. Those sites were chosen because of the 2017 and 2018 IMAC presence in these areas. Diego Suarez Bay consists of four small bays, including French Bay, Cul de Sac Gallois, Cailloux Blancs Bay and Tonnerre Bay (*see Figure 1*).

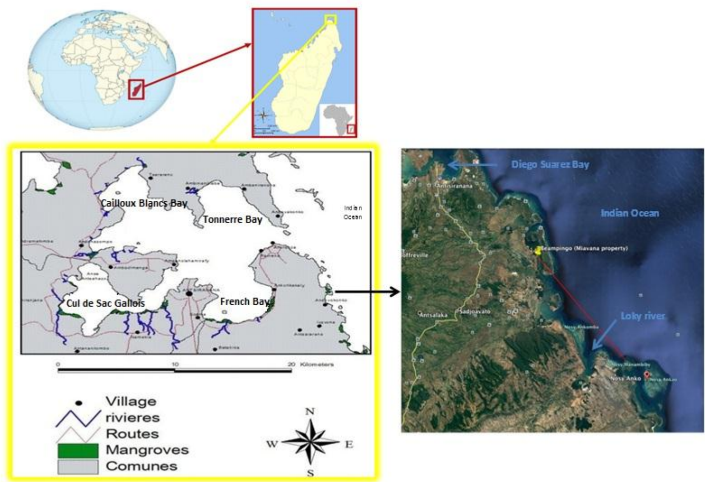

Figure 1: *Map of Diego Suarez Bay and Antsiranana II coastal*

2.2 Methods

A bibliographic study covered the whole period of the research. The presence of IMAC depends on the algal bloom (biological factor), which is in turn set and affected by many parameters, such as physical and chemical factors. The most important physical factors are source of energy, usually light and temperature. The chemical factors, whereas, are the available concentration of carbon dioxide and a contribution of macronutrient and trace elements [3] and also in mixture and the concentration of oxygen. For biological parameter view point, phytoplankton monitoring was firstly used in the four bays of Diego Suarez during dry and hot season of 2016 (September) and 2017 (March). The fieldwork follows the method described by Aminot and Kerouel [4]. They focused on sample collection at the sea surface with plankton net and pills and, also an observation of 5% formalin-fixed samples in the Antsiranana Poly Aquaculture Laboratory under an Olympus OXION microscope. Thus, the cells were identified and counted. Secondly, chlorophyll a (chl-a), a synthetic product of phytoplankton cells, was monitored from July 2017 to February 2018 via data from MODIS Aqua satellite imagery via EUMETSAT from National oceanographic Data Center (NODC) of the IH.SM (Institute of Halieutic and Marines Sciences) of the University of Toliara. These data were received every five minutes at spatial resolutions of the order of 1 Km and 4 Km and noted down in the form of rates and images on the color of the water for chl-a. Sea Surface Temperature (SST) data were collected at the same time as chlorophyll-a level via NODC satellite image data in both value and histogram form whose applied method follows that described by Bloomfield [5]. As for the parameters influencing the growth of microalgae or even Dinoflagellates and Diatoms, we collected information on temperatures, rainfall, water flow and wind speed. Rainfall data were collected from the Antsiranana Meteorological Service from 2016 to 2018. Chlorophyll-a concentration and temperature were respectively chosen as variables of the study because they play an important role in the growth of microalgae and reflect proportionally the presence of phytoplankton whose Dinoflagellates are integrated parts [6]. Mixed with the meteorological data, altogether allow the researchers to predict the favorable conditions for the formation of Harmful algal blooms (HAB). In addition, rainfall can tell us about the intake of macronutrients and trace elements in the marine environment. In turn, the wind speed can give us the relative information in oxygen concentration in the sea water and on the possibility of the existence of upwelling. Epidemiological surveys of Antsiranana hospitals have enabled us to collect data on the numbers, places of origin of IMAC victims and the number of intoxicated and dead people.

2.3 Limit of the study

Chl-a, SST, rainfall and wind speeds can't accurately identify the presence of toxic microalgae which are responsible for IMAC: they are only indicators of the possible presence of these microorganisms. Dissolved oxygen and pH as well are also factors that may come into with this IMAC phenomenon

3 RESULTS

3.1 Variation of physicochemical parameters

3.1.1 Sea Surface Temperature (SST)

3.1.1.1 In Diego Suarez Bay

The evolution analysis of the sea surface temperature (SST) shows that, respectively, the temperature varies from 23.82 °C to 26.52 °C and from 25.36 °C to 29.66 °C respectively during cold and hot season of 2017 (see Figure 2). In hot season of 2018, it ranges from 26.15 °C to 30.31 °C with an average of 27.53 °C. In all, the average SST is, respectively, 24.43 ° C and 27.28 ° C during hot and cold season of 2017.

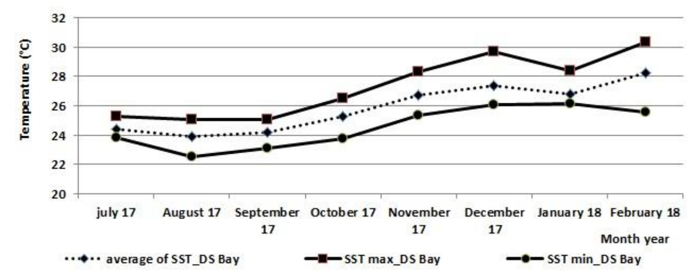

Figure 2: ***Monthly change in minimum (min), average and maximum (max) sea surface temperature (SST) from July 2017 to February 2018 in Diego Suarez Bay (DS)***

Between 04th July and 09th October 2017 in Diego Suarez Bay, the temperature of the sea surface is below 25 °C (see Figure 3). After 28 days, from 10th October to 11th November, 2017, the temperature has gradually been added by 1 °C to continue to increase by 1 °C more until 11th December 2017. In all, there was a temperature gradient of 2 °C about two months. In the following, the temperature of the surface of the sea water shows a daily variation without falling below 26 ° C.

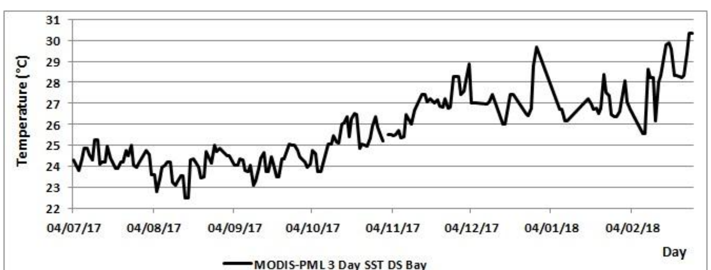

Figure 3: ***Daily variation of sea surface temperature in Diego Suarez Bay***

The Anova test suggests that the average sea temperatures from 04th July to 07th October 2017 (24, 14 °C), 10th October to 09th November 2017 (25, 6 °C) and 15th November to 11th December, 2017 (27, 41 °C), significantly differ from one another. This indicates that surface water is heating up from early October. The wet season is in full swing from mid-November 2017.

3.1.1.2 In the north-east of Madagascar: Antsiranana II

During cold season, the SST has an average of 26, 14 ° C and varies from 24, 84 °C to 27, 15 °C (see Figure 4). In hot season, however, it ranges from 24, 21 °C to 29, 94 °C with an average of 28, 09 °C.

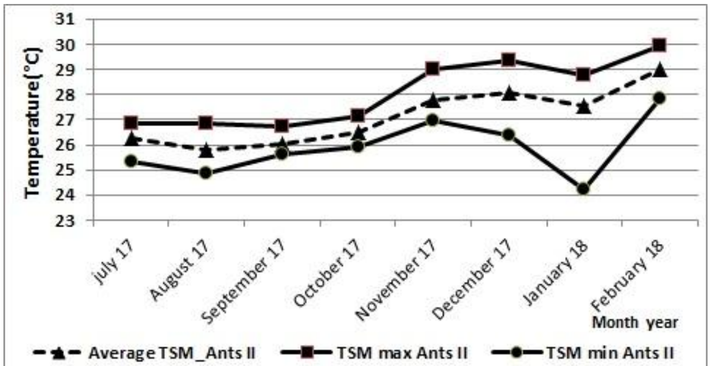

Figure 4: ***Monthly variation of the temperature of the sea surface in Antsiranana II (Ants II) in the northern-east of Madagascar***

The analysis of the daily SST shows that it oscillates around 26 °C from 04th July 2017 to 11th October 2017, or even almost during cold period of the year. It reaches 27 °C; another gradient 18 days later at 29th October 2017 (see Figure 5). After 20 days, from 30th October to 19th November 2017, the SST progressively climbed 1 °C more, or 28 °C. 10 days during 20th to 29th November 2017, the SST shows a rise of a gradient of more than 29 °C. After that, an irregularity of oscillation is met on the northeast coast of Madagascar to continue the increase of SST until 30 °C around 23th February 2018.

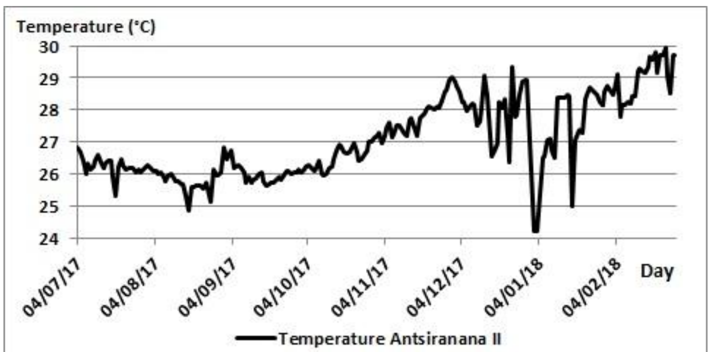

Figure 5: ***Daily variation of the temperature of the sea surface in the north-east of Madagascar***

According to the Anova test, the temperature from 04th July 2017 to 15th October 2017 differs significantly from that of 16th October 2017 to 29th November 2017. The analysis of the monthly maximum SST mean variation curve shows that it is slightly higher in northeastern Madagascar than in Diego Bay during the dry season. This is not the case during the warm season during which the shape of the curve is superimposed and indicates the same average maximum SST (see Figure 6).

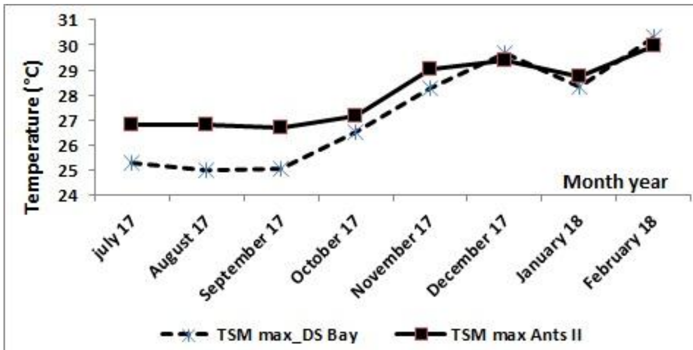

Figure 6: ***Monthly variation of maximal temperature of sea surface in Diego Suarez Bay and Antsiranana II***

3.1.2 Pluviometry

The rhythm of the monthly variation in rainfall varies from one year to another. In 2016, too much rain occurred in January has gradually decreased until April. The resumption of increased rainfall has not occurred until the beginning of the following year, from January to April, but with less rain. Also during 2017, heavy rain was observed by the end of the year, from November to December, and then continues until April of the following year. The three best rainfall records encountered during the study period were found in January 2018 (around 667mm) and 2016 (around 420mm) followed by December 2017 (around 234 mm) (see Figure 7).

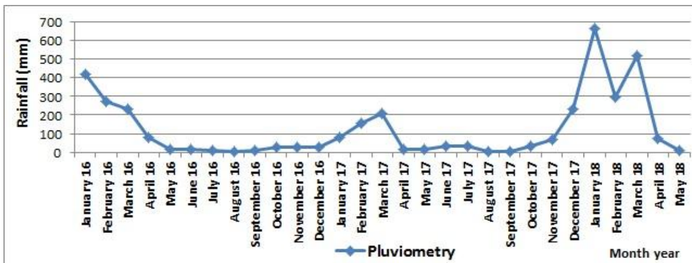

Figure 7: ***Evolution of the rainfall of Antsiranana from January 2016 to May 2018 (Source: Antsiranana Meteorological Service)***

3.1.3 Wind

The wind parameter, with high speed at 8 km/h, plays a role in the upwelling of the bottom to the surface making a large amount of nutrient available. The case of Antsiranana, the average wind speed varies from 11 to 25 km/h during hot season and from 19 to 29 km/h during cold season. Both 2017 and 2018 were significantly windier than 2016 (see Figure 8). The strong continuous wind encountered in the Diego Suarez Bay explains the existence of brewing in this place especially in dry season. Figure 8 also shows a fluctuation of the wind speed, which looks similar to the other years.

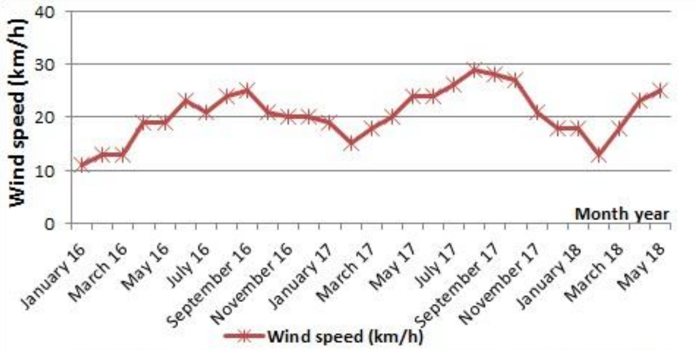

Figure 8: *Evolution of the wind speed of Antsiranana from January 2016 to May 2018 (Source: Antsiranana Meteorological Service)*

3.2 Planktonic

Phytoplankton consists of all the microorganisms plant existing in the sea. The bloom for the concentrations is assumed to be higher than one million cells per liter.

3.2.1 Taxonomic richness

The result of the plankton study shows that 88% of the planktonic individuals harvested in Diego Suarez Bay are phytoplankton. The zooplankton found in the Diego Suarez Bay is divided into 5 branches including Protozoa, Cnidarians, Mollusca, Worms and Crustaceans. 83.1% of inventoried phytoplankton cells are Diatoms of 40 genera. The latter are mainly represented by pinnate diatoms (70%). Thus, 12 genera of centric diatoms such as *g Biddulphia, g Chaetoceros, g Coscinodiscus, g Cymbella, g Dactyliosolen, g Guinardia, g Lauderia, g Odontella, g Rhizosolenia, g Skeletonema, g Thalassiosira, g Melosira* and 28 genera of pinnate diatoms (*g Actinella, g Amphipleura, g Amphiprora, g Amphora, g Asterionella, g Climacosphenia, g Cocconeis, g Denticula, g Diploneis, g Encyonema, g Fallacia, g Gomphosphenia, g Fragilaria, g Gyrosigma, g Halamphora, g Leptocylindrus, g Licmophora, g Navicula, g Nitzschia, g Nupela, g Pinnularia, g Placoneis, g Pleurosigma, g Pseudo-Nitzschia, g Seminavis, g Tabellaria, g Tabularia and g Thallassionema*) are inventoried. 4.5% of inventoried plankton cells were Dinoflagellates. 09 genera of Dinoflagellates divided into 6 families (including Calciodinellaceae, Dinophysiaceae, Gonyaulacacea, Gymnodiniaceae, Prorocentraceae, Protoperidiniaceae) were recorded throughout the Diego Suarez Bay during our study. 03 genera (*g Prorocentrum, g Protoperidinium* (see Plate 1), *g Scippsiella*) are encountered during cold season in Cailloux Blancs Bay (20%) and especially in the French Bay (80%); While, 07 genera were recorded during the warm season including *g Dinophysis, g Gonyaulax, g Gymnodium* (see Plate 2), *g Lingulodium, g Ostreopsis, g Preperidium* (see Plate 3), *g Prorocentrum* in the French Bay, Tonnerre Bay and Cul de Sac Gallois.

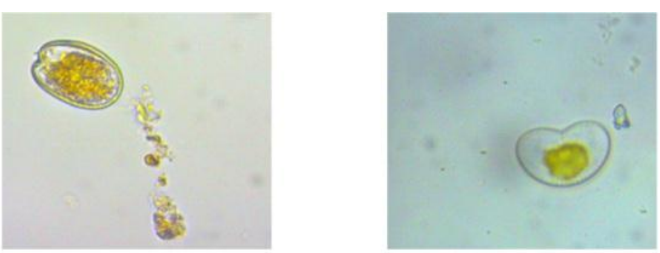

Plate 1: *g Prorocentrum* and *g Protoperidinium*

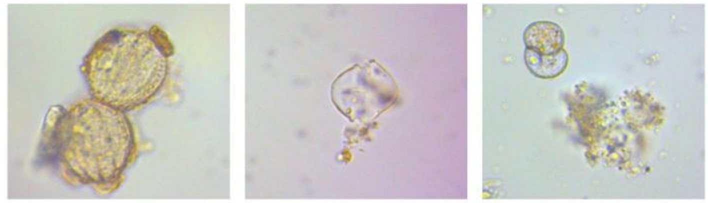

Plate 2: *g Dinophysis*, *g Gonyaulax* and *g Gymnodium*

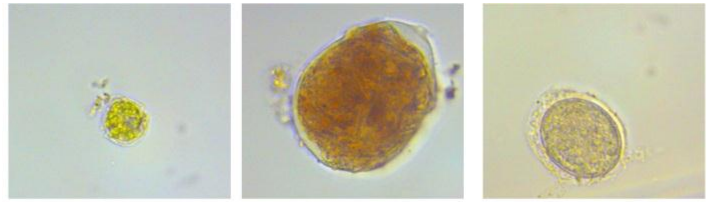

Plate 3: *g Lingulodium*, *g Ostreopsis* and *g Preperidium*

3.2.2 Density

As a result, the average density of plankton varies around 39 583 cells per milliliter. The best density is found in Tonnerre Bay. Zooplanktons have got a density varying around 3400 zooplankton/ml. For phytoplanktons, the density is slightly high during the wet season (261 000 cells / ml) than the dry season (214 000 cells / ml). The density of Dinoflagellates varies from 0 to 12,000 per ml. On average, there are 5250 and 1500 dinoflagellates per ml respectively during hot and cold season in Diego Suarez Bay. It can be argued that the concentration of dinoflagellates reaches efflorescence during cold and hot season because the observed concentration seems to have exceeded the trigger threshold of their efflorescence. It might be stated that the absence of IMAC cases in 2016 (in the second half) and 2017 (in the first half) simply means that there are other factors besides efflorescence of Dinoflagellates that can explain the incident in 7th December 2017. The best density of Dinoflagellates (i.e., 12 000 cells / ml) was observed during the hot season of the year. The French Bay has shown a moderate high density in Dinoflagellates for two seasons of the year (8000 and 4000 Dinoflagellates per ml respectively during hot and cold season). The lowest density (1000 cells per ml) in Dinoflagellates was found in Cailloux Blancs Bay. No Dinoflagellates were recorded during cold season in Tonnerre Bay and Cailloux Blancs Bay.

3.2.3 Synthetic products: Chlorophyll a

The efflorescence of ch-a presents the massive proliferation of phytoplankton which ,in turn, sets the evolution in the same direction of the toxic microalgae, Dinoflagellates, which is responsible for IMAC. This is related to the enrichment of water in nutrients. The analysis of chl-a rate is reported in Diego Suarez Bay and northern-east Madagascar from July 2017 to February 2018.

3.2.3.1. Within Diego Suarez Bay

The rate of chlorophyll a in Diego Suarez Bay is generally high, fluctuating around 2.03mg/m^3 during the study period (see Figure 9).

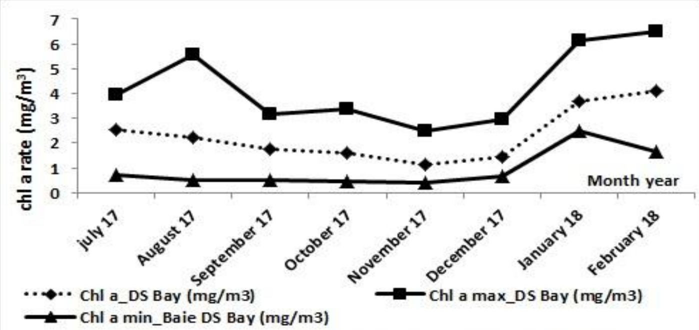

Figure 9: *Monthly variation of the average rate of chlorophyll a in Diego Suarez Bay*

The analysis of the daily progress of the chlorophyll concentration curves shows a fluctuation of growth of microalgae or even the rate of chl-a whose pace differs from one season to another. It can be seen that the growth of microalgae or even the rate of chl-a occurs throughout the year. The graph of microalgae is short duration in cold season varying from 4 to 17 days (see Figure 10) and long duration in hot season varying from one week (07 days) to 63 days (two months and three days) (see Figure 11).

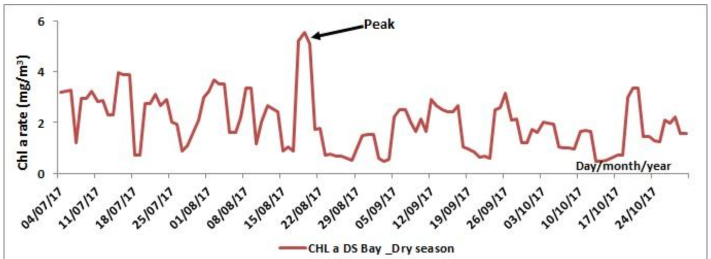

Figure 10: *Daily evolution of the rate of chlorophyll a in Diego Suarez Bay during dry season*

Additionally, the lag phase is shorter duration (varying from 1 to 5 days) during dry season explaining the importance in number of discontinuous growth cycle of microalgae found in there. The long period of lag phase in hot season can be explained by the adaptation of algae to new environmental conditions. The correlation appears to be very weak after the linkage analysis between fluctuating seawater temperature and chl-a rate. In dry season, the maximum rate of chl-a was 5,57mg / m^3 on 19th August 2017. During hot season, the best concentration of chl-a was 6,11 mg/m^3 for 2017 and 6.48 mg/m^3 for 2018.

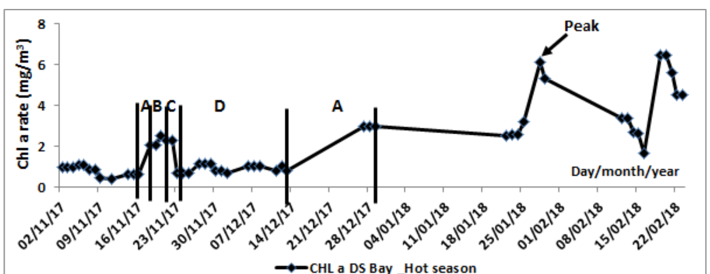

Figure 11: *Daily evolution of the chlorophyll a rate in Diego Suarez Bay during hot season (A: Exponential phase; B: Stationary phase; C: Decreasing phase; D: Latency phase)*

The chl-a growth curve consists of four phases, including the latency phase, the exponential phase, the stationary phase and the decay phase. The lag phase corresponds to the period of adaptation of the phytoplankton cells to another condition of the medium. It was observed at the beginning of hot season (early November 2017) which was showed by the beginning of nutrient enrichment in Diego Suarez Bay. It's the shift-up change. During the exponential phase, phytoplankton cells divide themselves and increase in number. Then comes the stationary phase where a balance between division and cell death occurs. The latter comes at an exponential rate during the decay phase. Throughout the year, the western part (in Antsahazo Cove and Cul de Sac Gallois) and south-east (Andovobazaha Bay along the coast to Ramena to Amoronjia-Orangea Point) of the interior of Diego Suarez Bay experience higher enrichments in Chl-a. This result is symmetrical with respect to degrading reef health in these parts of Diego Suarez Bay [7].

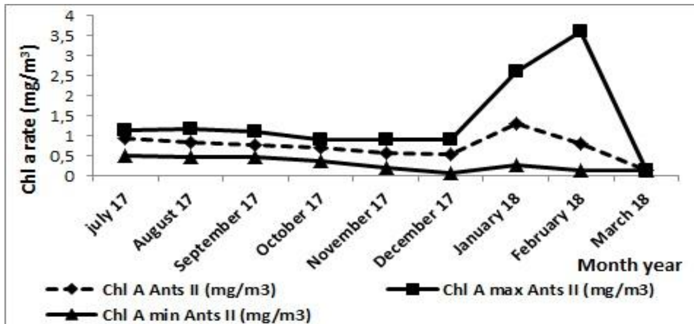

Figure 12: *Monthly variation of the average level of chlorophyll a in Antsiranana II*

The average of chlorophyll a rate is around 0.79 mg/m^3 during cold season and 0.52 mg/m^3 and 1.03 mg/m^3 respectively during hot season of 2017 and 2018. Maximum chlorophyll analysis shows that the Ch-a rate varies around 01 mg/m^3 from July to December 2017 and continue with an increase curve of the rate of a gradient per month until 3.6 mg/m^3 maximum in February 2018 (see Figure 12).

3.3. Intoxication by Marine Animals Consumption

3.3.1. Historical

The existence of IMAC in Madagascar has longer been existed and confirmed by the work as in [8] and [9]. The first work focused on a retrospective study of 28 cases of children ichthyosarcotoxism in Tuléar in 1989-1993 [10]. In 1965, a collective intoxication affecting the people of Antalaha District after consuming sea turtle *Eretmochelys imbricata*, whose 60 out of 120 consumers were poisoned and 5 died [11]. From 2010 to 2018, six episodes of IMAC were recorded in Antsiranana and in the surrounding areas. They are summarized in the table below.

Table 1: *Presence of IMAC in northern Madagascar from 2010*
Source: Hospital Registers (Hospital Be, Polyclinic Scama, University Hospital Center Tanambao I, Military Hospital), Madagascar Express and personal communication

Year	Day / Month	Area	Victims (Number)	Death (Number)	Suspicious animals
2010		Antsiranana	6		Tetraodontidae
2012		Antsiranana		3	Sardinella
2014	9th to 14th December	Ambanja	12	4	Sea turtle
2017	7th to 12th December	Antsiranana I	85	8	Sardinella, Tunas
2018	22nd January	Antsiranana II	20	7	Sea turtle
2018	28th April	Antsiranana I	3	0	Tunas

108 cases were hospitalized, with a male predominance (54%) with a sex ration 1, 16. The age group most affected age group was 18 to 41 years (50%). Compared to the IMAC phenomenon that hit Antsiranana in the past 08 years, the ones of 2017 and 2018 are the most serious and lethal (with fatality rate 14%). Regarding the average lethality rate, 9% and 35% were respectively noted after consuming Clupeidae, poisoned tunas and sea turtle. Clinical signs are dominated by general signs, neurologic and gastrointestinal. Regarding December 2017 incident, almost all the surrounding cities of Antsiranana were affected. On 24 neighborhoods in Antsiranana I, IMAC's victims were found among 15 of them. People who died as a result of sardinella consumption were adults (over 42 years old) and 6-year old children. No deaths related to IMAC were recorded for consumption of tunas in April 2018.

3.3.2. Events

The agents responsible for collective intoxication by consumption of marine animals are usually microalgae or phytoplankton. Some of them, especially Dinoflagellates, have the capacity to produce toxins called "phycotoxins" [12]. Stated by Olivier and al. [13], among the 3,400 to 4,000 species of phytoplankton, about 70 species, mostly dinoflagellates, have the ability to emit potentially toxic substances that can affect humans through the fish or shellfish he consumes. Assimilated by animals, the toxins take a different name depending on the host Dinoflagellates. During the wet season of 2017, three types of biotoxins at least, seemed to be involved in the IMAC observed in Antsiranana, including clupeotoxin which is a poisoning by consumption of Sardinella, case of food poisoning of 7th December 2017, chelonitoxism which is an intoxication derived from the consumption of turtles, case of IMAC of January 2018; scombrotoxism that is caused by ingestion of tuna, bonito, mackerel degraded by bacteria, case of IMAC in April 2018 (see Table1). Despite the prohibition on sardine fishing and consuming in Madagascar every year from 1 November to 1 March, people still do not respect it [14].

3.3.3. Transfer mechanism

With the wealth of nutrients available in the receiving environment accompanied by favorable conditions, Dinoflagellates grow and multiply. According to Nomenisoa [6], the conditions of the proliferation of toxic microalgae responsible for IMAC were found from thresholds of SST>= 30°C and chlorophyll a>= 1mg/m³. At the base of the food chain, Dinoflagellates, which are found in abundance in the water and in the superficial part of algae, will be assimilated by planktivorous animals, herbivores (fish) and filter feeders (shells). In water, Dinoflagellates directly release phycotoxins that accumulate through the different stages of the food chain [15]. In turn, these planktivores, herbivores and filter feeders will be eaten by the largest carnivores. Thus, from predators to predators, the toxin is transferred to the last link. Toxins are present in the skin, flesh and viscera of fish [16]. The toxicity of marine animals is generally related to the level those aimals occupy in the food chain. Thus, large carnivorous predators are frequently more toxic because they are consumers of planktivorous fish, herbivores and filter feeders, carrying toxins. Humans get intoxicated by taking and consuming these marine animals regardless of their levels in the trophic chain [13]. The diet of Sardinelles is based on plankton, especially zooplankton [16].Turtles can be plankton-eating or herbivores or carnivores or even spongivores depending on the species. Tunas are carnivores [17].

4. DISCUSSION AND CONCLUSION

The evolution of the sea surface temperature (SST), shows a similar trend to Chl-a, that is to say, when the sea surface temperature increases, phytoplankton proliferation increases as well. For the Sardinelles study, chl-a concentration acted as good indicator of the availability of their food [18].The variation of chl-a shows that Diego Suarez Bay constitutes the basin of proliferation of the phytoplankton cells throughout the year with a short cycle of life during dry season which is relatively long during hot season. This explains the discontinuous and continuous renewal of nutrients available in the Diego Suarez Bay during hot and dry season of the year. During dry season, despite the existence of succession of several growth curves of chl-a with the achievement of a slight high peak, the absence of stationary phase does not allow to ensure the good development of the zooplankton which are the main foods of Sardinella. That point was different on hot season because the chl-a growth curve obtained is composed of the following parameters: the growth phase, the peak, the stationary phase and the decay phase and a long lag phase (see Figure 10 and 11). If the environmental conditions required by the chl-a are met, a growth phase can be recovered at the stationary phase without following a latency phase immediately (see Figure 11, the fact of the 27th December 2017 to 28th January, 2018). This is the ongoing development of a significant concentration of phytoplanktonic algae. Obtaining succession of the complete phase of the biological cycle of phytoplankton, cells ensure the development, viability and availability of the zooplankton that feed on them at the second stage of the food chain. The environmental conditions bring on the best continuous development of chl-a including an abundance of rain, an increase of the temperature, a decrease of the wind velocity or even of the marine current and a nutrient supply by the terrigenous inputs via the runoff of 23 rivers, in which four of them flow permanently into Diego Suarez Bay. During this period, the fish arrive in the rich coastal zone and increase their metabolic activity. Also, on hot season, from the beginning of the month until 16th November 2017, the chl-a rate is around 0.77 mg/m^3. Growth phase is showed from 18th November, 2017. The stationary phase goes on until 22nd November 2017 and then, chl a rate falls to 0.65 mg/m^3 on 23rd November 2017. The lag phase continues until 13rd December, with at a rate of chl-a around 0.9 mg/m^3. This second phase of latency leads to a summer recovery of the metabolic activity of fish. According Befeno's study [19] on the plankton-eating, herbivorous and carnivorous fish in Diego Suarez Bay, the emptiness of the stomach explaining the low metabolic activity of fish is mainly encountered during the dry season. This justifies the presence of intensity of metabolic activity and the high consumption of fish food in the Diego Suarez Bay in summer as well as in winter. Thus, for the IMAC incident of 7th December 2017, it can be argued that the Bay has already experienced continuous enrichment (Chl-a rate is 2.23mg/m^3) in phytoplankton cells since 18th November; 20 days ago. The wet season is well acquired at this time. The environmental parameters encountered such as increase of temperature of the seawater (around 27.12 °C), rain (monthly 70 mm and daily record of 32 mm), wind speed decrease (around 21 km / h) have all contributed to the installation of favorable conditions for the development of toxic microalgae. The wellbeing of the latter lasted at least five days throughout the Bay. This allowed the zooplankton to take over, which explains the increase of the metabolic activity of planktivorous fish such as Sardinella. Subsequently, the rate of chl-a seems to have resumed growth only in 13th December, 2018, after the start of the IMAC incident.

Analysis of each of the four bays shows that three days before and after and,also during the IMAC incident, the blooming of phytoplankton cells in Cul de Sac Gallois, French Bay and in the Cailloux Blancs could reach the value of the highest chl-a rate (around 10mg/m^3, see Plate 4) leading High Risk of IMAC in the Bay which lasted until February 2018, where our available data is limited.

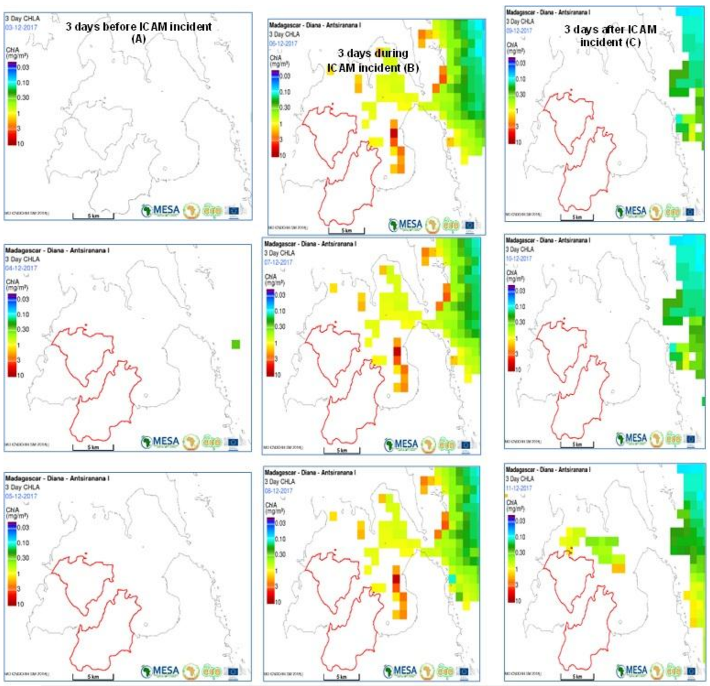

Plate 4: *Spatial and Temporal Variations in Chl-a Concentration (Risks or Vulnerability) (A): Before, (B): During, and (C): After the incidence of IMAC of 5, 6 and December 7, 2017*

Algal bloom in the three bays appears to be related to the degradation of the coral formation that is encountered there [7]. This confirms the proliferation of seagrass beds after the coral formation, that supports these algal cells, disappeared. In the case of Antsiranana II, the concentration of chlorophyll remains below 1 mg / m^3 during cold season and almost during the beginning of hot season of 2017, despite the increase in the progressive water temperature collected since the beginning of November 2017. The algal bloom is encountered 11 days earlier (12^{nd} January 2018), before Diego II's IMAC incident on 22^{nd} January 2018, a late period compared to the one in Diego Suarez Bay (Diego I or Antsiranana I). This situation can be explained by the fact that the Bay is a semi-closed sea giving importance to terrigenous influences, but the one in Diego II is due to the open sea to the Indian Ocean reflecting the strong influence of globalized change. The environmental conditions during algal bloom lead the sea surface water temperature to an interval between 28 and 29 °C and the passage of 02 tropical cyclones including AVA (5^{th}, 6^{th}, and 7^{th} january 2018) and Berguitta (18^{th} january 2018) [20]. The latter appears to be related to nutrient input into coastal areas. Beyond the IMAC incidence period, chlorophyll concentration remains high until February 04^{th}, 2018. These results indicate that the semi-closed zone is more sensitive to algal bloom than the open zone. In conclusion, the intervention of environmental parameters on the incident of IMAC acts indirectly due to different factors from hot season, cold or dry as well in the study area. One can expect, in turn, only with hot season, a direct influence of the physicochemical parameters (increase of the temperature of the sea surface, increase of rainfall, and decrease of wind speed) on the availability of nutrient which determines the algal bloom and metabolic activity of predatory marine animals. However, it is noticed that these environmental elements are not the only factors explaining the IMAC incident. There is also the morphological unit of the zone which influences the presumed period favorable to the presence of the IMAC. With a semi-enclosed area where terrigenous inputs are continuously recorded and environmental conditions such as temperature and rainfall increase; 20 days after harmful algal bloom can be expected to directly contribute to the IMAC incident. In the open sea, like the case of Antsiranana II, in the northern-east of Madagascar, where hydrology depends on the neighboring Indian Ocean, the variation in environmental parameters is slower or even delayed. The availability of nutrients can be done via upwelling due to the passage of tropical depression. The IMAC event can be expected 11 days after algal bloom. During hot season, the condition favorable to the establishment of HAB are gathered rather in the Diego Suarez Bay but staggered 20 days before the episode of IMAC. Unlike Antsiranana II, they are gathered later but shifted 11 days before the presence of IMAC. The IMAC may possibly occur 10 days after the harmful algal bloom. During the study, 09 genera of Dinoflagellates were found in Diego Suarez Bay. However, it should be noted that the concentration of chlorophyll a is not the only factor responsible to the phenomenon even if it is an excellent tracer of potential toxic water. Consequently, further studies should be considered. As a recommendation, many data and methods can be integrated one another to better identify this problem of toxic and / or harmful microalgae proliferation and improve routine monitoring and forecasting. Among the possible programs, the use of near real time satellite data is also needed instead of focusing on retrospective studies to ensure routine monitoring. The control of fishing areas or marine products is essential and oriented according to the main objectives, (Observation, new zones, new species). In addition, a toxicity study of the samples of the animals in question would also be necessary. To mitigate the risks caused by the consumption of marine products, implementation of observation strategy of these toxic and / or harmful cells, as well as its culture to identify their toxin must be integrated.

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