Have scientific studies on harmful algal blooms (*red tides*) contributed to mitigate their impact on economy and human health? The case of Mexico

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ABSTRACT. In times of global interests about phenomena affecting life worldwide, a philosophical approach is needed to assess the certainty of the statements derived from their public understanding. Most scientific reports, oral or written, and projects on harmful algal blooms (HAB) refer to its socio-economic and health impacts, in order to primarily justify a given proposal. However, an explicit relationship between these issues has not been established. Thus, questioning such assumption is posted under a philosophical perspective to determine if the information generated in scientific studies has contribute to mitigate those alleged impacts. We tested the hypothesis (Ho) that no relation exists between scientific data and public policies that may result within those affectations. Our survey yielded few reports available on health and economic impacts overall, with no formal studies that calculate an amount in Mexican currency of a given economic consequence. Moreover, in the health sector, the magnitude of the alleged impact is uncertain, primarily because of the lack of information available to medical personnel to distinguish the symptoms of the HAB related intoxications from those of infectious diseases. Thus, notwithstanding the unquestionable relevance of scientific studies on HAB, their theoretical contributions have not directly mitigated those health and economic impacts, nor have established new management strategies for the contingencies. This supports the proposed hypothesis. It may be then considered timely to couple socioeconomic impact studies to ecological research on HABs in order to generate realistic data that will justify the investigation. Scientific research should emphasize on the generation of theory (ecological, ecophysiological, toxicological) instead of resorting to strident references on health and economic consequences.

KEY WORDS. Ciguatera, dinoflagellates, phytoplankton, PSP, red tides, scientific knowledge and public policies, ecological crises, public health seafood risks.

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> March 18, 1832. We set sail from Bahía--A few days later, at a short distance from the Abrolhos islets, I observed that the sea had turned to a red brown hue. Seen with a magnifying glass all the water surface seemed covered by filaments whose extremities appeared frayed. They are small "confervas" [as it is, with an "f"] in cylindrical packages containing around fifthy or sixty of these little plants. Mr. Berkeley warns me that they pertain to the same species (Trichodesmium erythraeum) as those found in wide extensions in the Red Sea, and are responsible for the name of that sea. The number of these small plants must be infinite; our ship crossed over several bands of them, one of which was around 10 meters wide, and judging by the discoloration of the water it had to be at least two and a half miles long" (1)
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> In the logs of most long voyages there are news about said confervas. They are abundant specially in the sea surrounding Australia, and off Cape Leewin I found an analogous species, albeit smaller and apparently different. Capitan Cook, on his third voyage notes that sailors refer to it as sea sawdust
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> Darwin, 1845.

INTRODUCTION

In times of global interests about phenomena affecting life worldwide, a philosophical approach is needed to assess the certainty of statements derived from their public understanding. The main subject of this article deals on the highly questionable anthropological global warming (AGW) that, nevertheless, has many followers among the scientific community, whilst the few skeptic scientific detractors are efficiently banned authoritatively. In a similar scenario, much sensationalism surrounds the general idea about harmful algal blooms (HAB). Thus, we may find remarks such as:

> Harmful Algal Blooms (HABs) are becoming an increasing problem to human health and environment (including effects on natural and cultured resources, tourism and ecosystems) all over the world. In Mexico a number of human fatalities and important economic losses have occurred in the last 30 years because of these events. The increasement of cases of toxic and harmful marine phytoplankton and microalgae is an issue that must be assessed to understand the consequent impact to human health, fisheries and tourism (Hernández-Becerril, et al., 2007).

Similar statements have become opening premises in oral or written presentations concerning health and socioeconomic impacts, whose objectivity are in much need of an adequate dimensioning within a scientific (ecological) perspective. In the following analysis we gather support to our thesis through the review of bibliographic references and the consequent contrast with a pertinent hypothesis.

According to the above, our philosophical (critic) approach to the HAB phenomenon implies that it should be studied scientifically in a long term to be fully understood within the basis of modern epistemological methodology. We haven't done so, and then we should keep focused on the principles underlying scientific method to propose original research problems on the subject, avoiding the questionable socioeconomic and health issues that otherwise require mainly operational administrative and economic strategies to contend with the consequences of HAB occurrences. With this being said, it has to be acknowledged that important scientific research has been hitherto developed for the Mexican region, including floristic, taxonomic, ecological/ecophysiological, and toxicological studies that have been obviously consulted to allow the present essay. In fact, several research proposals have been made in this sense (Hernández-Becerril, et al., 2007) and many are underway. However, most scientific reports, oral or written, and projects on harmful algal blooms (HAB) refer to its socioeconomic and health impacts in order to primarily justify a given study on such matter. Albeit, members of the scientific community specializing in HAB challenge the objectivity of the present thesis and try to prevent that it becomes an issue within the academy. Being so, in the following analysis we gather support to our thesis through the review of related bibliographic references and the concomitant contrast of a hypothesis.

GENERAL SCENARIO

The ecological relevance of microalgal blooms relies on the fact that they are formed by organisms that constitute the basis of the trophic chain in the oceans and are thus the main food for mollusks filter feeders, as well as fish and crustaceans larvae that include commercial species (Unesco, 2004). In this sense, most blooms may be deemed innocuous and are part of regular and permanent phenomena of the marine ecosystem worldwide. Only a fraction of these may be considered harmful or toxic (Suárez-Isla & Guzmán-Méndez, 1998). In fact, a little over 300 species of phytoplankton are deemed harmful, only around 80 are toxic (Hallegraeff, et al., 2003), and not all to that matter depending on growth conditions.

HABs are events of a phenomena consisting in an accelerated growth in the number of planktonic dinoflagellates, diatoms or cyanophytes (cianobacterias), which turn out harmful to other members of the plaktonic, nectonic and benthic communities. These proliferations may be sporadic, periodic or seasonal (Steidinger & Haddad, 1981). Due to the first accounts of this sort of events, showed as a red-brown hue of the sea, they were named "red-tides." This term comprises many harmless events, and bypasses other toxic proliferations that do not cause changes in the color of water. Likewise, the said color change may vary, manifesting as yellow and green hues, or colorless. Thus, they are currently known as “harmful algal blooms” or HABs (Vivanco Font, 2016). On the basis of their overall effects, HABs have been classified into three types (Hallegraeff, 1993):

1) HABs consisting of innocuous species that by proliferating massively cause the death of other species through oxygen depletion, i.e., when the microalgae population dies out, their organic remains become oxidized during the sinking process, demanding dissolved oxygen in excess, causing hypoxic and anoxic conditions and thus the death of taxa on the ocean floor.

2) HABs by toxin producing species that are accumulated by mollusk filter-feeders or in fish viscera, and when fish and seafood is consumed by humans it causes gastrointestinal and neurological illness. This type of bloom comprises microalgae that produce both toxin and other kind of metabolites, such as reactive oxygen substances (ROS) (López Cortés, et al., 2015a).

3) HABs by microalgae taxa that can severely harm fish gills, either mechanically or by the production of hemolytic. Other microalgae may kill fish by producing extracellular neurotoxins.

Mollusk filter-feeders (shell-fish) are the main vectors in the transfer of several groups of phycotoxins (Bricelj & Shumway, 1998). When feeding on microalgae they concentrate toxins in their digestive tract, gill siphons, paleal cavity, and hepathopancreas (Ortegón-Aznar, et al., 2011), then becoming highly toxic food that can cause serious disease or even death when consumed (Smayda, 1997). Such toxins do not seem to affect the shellfish itself, nor do they alter their appearance, odor, taste, etc., precluding their differentiation from healthy specimens (Ortegón-Aznar, et al., 2011). According to their effect or symptoms on humans, the active substances have been classified as: amnesic toxins, ciguateric toxins, diarrheic toxins, marine paralyzing toxins, and neurotoxins (Herrera-Silveira, et al., 2018).

On the other hand, economic impacts are deemed greater due to what is known as “halo effect”, which is generated as a consequence of a misleading interpretation of information that promotes fear for consuming fish or seafood, whether they be contaminated or not, causing a drop in the sales of these products. Moreover, it precludes to implement costly monitoring programs that warrant the safety for human consumption (Bricelj & Shumway, 1998). Finally, it impacts in other scales: the disturbance of the landscape (aesthetical deterioration of beaches due to foam and odors) and the affectation to coastal economic activities like tourism services, aquaculture, and fishing (García-Mendoza, et al., 2016).

It is generally accepted that the frequency of HAB events have increased by natural causes since the last decades of the past century, causing health problems in the human population and harming marine flora and fauna.

Equally, the main causes of such blooms are attributed to anthropic activities (Buschmann, 2005). Among the former there is the biological dispersion of species, the natural variability of climatic patterns, and changes in environmental conditions that promote dispersal of species through storm events and marine currents. According to the latter, the transport of toxic microalgae in the ballast water of ships, domestic, industrial, and agriculture wastes that due to inappropriate handling find their way into the sea and enhance nutrient concentrations of coastal waters. This is known as 'eutrophization' which promotes excessive algal growth that eventually causes oxygen depletion in the water column (Ortegón-Aznar, et al., 2011).

Along the Mexican littorals, HABs are of common and frequent occurrence, both in the Pacific coast (including the Gulf of California) and in the Gulf of Mexico and Caribbean Sea, where records have increased substantially in the last 30 years, in part due to both natural causes and man-made alterations on the ecosystems (Band-Schmidt, et al., 2011), and it can be seen for the higher number of investigators interested on the topic. This has resulted in more official records of HABs and study areas for different purposes, including the scientific perspective. This last interest demands to criticize the scientificity or scientific quality of the proposed research, i.e., the originality and fertility of the questions to be answered (problems to be solved). If such studies are more of a technical scope or forensic quality, depending on whether the pursued objectives seek to demonstrate if the cause for a particular microalgal proliferation implies toxicity, or to determine the cause of the observed mortalities (sometime massive) of fish, birds, reptiles or marine mammals, is suspected to be intoxication by HAB.

In such sense, the frequent reference that is made on the alleged ecological impact of these events as harmful or bad is questionable, inasmuch it bypasses objectivity around a natural phenomenon that simply occurs in response to the (natural) convergence of the conditions that promote it. Albeit, a moralist position is assumed instead of a more ethical one that would serve to stimulate scientific creativity. Whatever the case, the eristics involved here revolves around the classic and frequent premise used by HAB specialists when justifying their projects or their written or oral communications, i.e., the socio-economic and health impacts caused by HABs. Then a question arises: How certain is the assumption on the relation between the scientific studies carried out and that their results and conclusions assist in mitigating the magnitude of those impacts?

According to the above, the objective of this essay is to determine if scientific studies on HABs carried out in México have assisted in mitigating economic and health impacts caused by these phenomena. Based on the premise that the scientific and technical information generated on HABs in México is significant, we launched the null hypothesis (Ho) that no link exists between the information generated by the scientific studies and the society, one that may serve to mitigate the alleged impacts caused by HABs.

METHOD

In order to support our hypothesis an exhaustive search for the available literature was undertaken, mainly online, about studies on or related to HABs in the Mexican region, where problems derived from its economic and health impacts are referred. Literature on the subject published on scientific journals was also analyzed. Thereafter, the overall gathered literature was filtered to select those documents indexed at an international level. After the primary analysis of the information, research focused mainly on paralytic shellfish poisoning (PSP), due to human consumption of seafood, and intoxications caused by *ciguatera,* which were observed to be the most recurrent. In a lesser degree, attention was also set on amnesic shellfish intoxications (ASP) and diarrheic shellfish poisoning (DSP), also caused by consumption of contaminated seafood.

Opinions on the present thesis from several reviewers appointed by two scientific journals were gathered and analyzed on the basis of principles underlying the peer review process. This was done to provide a realistic opinion on the attitude of colleagues towards an unpleasant position that exposes an actual situation concerning their field of expertise.

RESULTS

The literature searches yielded 296 documents, mostly scientific papers and technical reports, and were discriminated as cited and consulted literature. The earliest reports about HAB events (as red tides) date far back before our time, with knowledge of their occurrences recorded within the millenary cultures such as the Chinese, Japanese or Roman. The same can be said about the North American native civilizations.

In contrast, red tide records in Chile started in 1827 (Rodríguez, 1985). Whilst for the Mexican region HABs have been periodically recorded since 1955 for the Gulf of México, and around the Yucatán Peninsula off Celestún and Holbox, practically every year. According to those reports, events varied in intensity and coincided with the onset of certain environmental conditions. Anyhow, the one recorded in 1955 called the most attention due to the mortality of millions of fish along the Mexican coasts in the Gulf of México, particularly off the State of Veracruz (Ramírez-Granados, 1963).

The HAB records can be classified according to the view under which each report was approached:

a) Socio-economic impact
b) Health impact
c) Ecological impact

According to Suárez Isla, et al. (2002) the effects of economic impacts may be classified as:

1) Of immediate effect. It comprises the decline in the supply and demand of seafood with the consequent economical losses due to restrictions in harvesting or extraction of the product. This effect is immediately after the detection of a HAB and depends on the regulations banning harvest, processing and marketing of the product.

2) Medium term effect. These are derived from the former, and depend on the extension of the imposed restrictions and location of the contingencies that can cause a mid-term decrease on the workforce demand.

3) Long term effect. There are cases where the situation becomes chronic, acting as disincentive to investments in the seafood industry and, in the worst scenario, a change in the eating habits of consumers that eventually derives in a long term decrease in seafood demand.

WORLDWIDE ECONOMIC IMPACTS AS REFERENCE

Concerning worldwide economic impacts we have selected data from North America (Canada and the USA), South America (Chile), and Asia (China, Japan and South Korea); it is somehow arbitrarily but we believe that it represents an adequate reference for contrasting our objective.

CANADA

Reports from the Fisheries and Oceans Canada (2012) indicate that the aquaculture harvest value for salmon and other species in British Columbia (B.C.) in 2010 reached US $ 511,5 millions. Likewise, in 2016 Canada produced an excess of 123,522 tons of salmon, which represents a market value superior to 1,000 million Canadian dollars (CAD) (Fisheries and Oceans Canada, 2018). The principal producer is B.C., where around 740 aquaculture farms are installed, yielding year round either salmon, other fish species, and shellfish for a total harvest value of almost 534 million CAD. In this way, the B.C. aquacultural industry answers for more than half of the total aquacultural production of Canada. Evidently, salmon farming constitutes the main export farm product of this province, and whose weight and value surpasses that of the wild salmon fishery. Thus, according to the above, economic impacts caused to the salmon industry by HABs have been on the rise in the last decades. For example, in July 1999 a bloom of a dinoflagellate species of *Cochlodinium (Margalefidinium)* was recorded for the first time off the Pacific coast of Canada. This event caused the death of cultivated salmon to the West of Vancouver Island, and consequent economic losses close to 2 million CAD (Whyte, et al., 2001). Later, Trainer & Yoshida (2014) reported direct losses to the salmon farming industry due to HAB events during the 2009 – 2012 period in the order of 16 million CAD.

UNITED STATES OF AMERICA

In the USA, the total economic losses reported by producers from California, Washington and Oregon due to an onset of PSP in 1980 were approximately US$ 630,456 (Conte, 1984). While the overall losses attributed to HAB events in the USA estimated for the 1987-1992 period ranged between US$ 34 and 82 million, and an annual average of US$ 49 million. Throughout these two decades, the accumulated impacts nearly reached US$ 1,000 million. The main component being public health dispenses representing over 45% of the total cost, followed by commercial fishing impact with 37% (Anderson, et al., 2000). Unfortunately, imprecise or misleading information delivered to the consumer public brings about unreasonable fear to intoxication by PSP, that produces seasonal depressions in the oyster market, even when HABs are not occurring. This is part of what is called "halo effect" that, to make matters worse, affects negatively interstate shipping of not-contaminated oysters duly certified by the health services of unaffected areas.

CHILE

In the case of Chile, during the year 2000 Chilean seafood producers experienced an annual dispense of US$ 132,040 destined to toxin analyses, which represented 0.16% of their total seafood market sales (Suárez Isla, et al., 2002). The importance for this budget dispense contrasted with the estimated annual economic losses caused by undetected HABs could reach an excess of US$ 80 million, not considering the domestic market. Moreover, pertinent regulations included the closure of ample coastal zones of the southern part of the country (44°-55° S) to the seafood fishery of species that are potential marine toxin carriers (Suárez Isla, et al., 2002). Additionally, two other HAB events that occurred in 2016 off Chilean coasts merit mentioning. The first one by the raphydophyceae *Pseudochattonella verruculosa* at Seno de Reloncaví that caused massive mortality of farmed fish, mainly salmon. The other by the dinoflagellate *Alexandrium catenella*, that leads to the preventive closure of shellfish extraction due to the detection of high concentrations of paralyzing toxins. The magnitude and high impact of this event on the coastal communities of Región de los Lagos makes it the most meaningful HAB event in Chilean history (Buschmann, et al., 2016). In response the Chilean government destined in 2017 a total of 2,810 million Chilean pesos to support an integrative monitoring program, and an excess of 6,289,846,320 pesos for a strategic program of diversified production.

SOUTH KOREA, JAPAN, AND CHINA

A survey conducted by Park, et al. (2013) indicates that South Korea and Japan hold the greatest consumption of fishing products per capita worldwide. The first recorded economic loss attributed to HABs in South Korea occurred in 1981 and was caused by *Karenia mikimotoi.* It resulted in an estimated loss of US$ 1.7 million. Later events generated losses of up to US$ 60 million in 1995 due to the death of 10% of the farmed fish expected harvest; on the average, losses for the last three recorded decades reached US$ 121 million. Later, Trainer and Yoshida (2014) reported further impacts on the regional economy. For the Bay of Imari, Kyushu, Japan, losses in the excess of US$ 7 million in the fishing industry where recorded. In Korea losses reached US$ 95 million during 1995 and US$ 19 million in 2003. Since 2005, HAB of *C. polykrikoides* along the western and southern coasts of Korea had decreased together with the impacts on the fishing industry, until 2012, when HAB of this species occurred for a span of two months causing losses that reached US$ 3.3 million.

Elsewhere in the vicinity, 50 HAB occurrences were recorded off the China coasts between 1990 and 2009, two of which caused losses in the scallop aquaculture industry on the coastal zone of Dalian. These were estimated around 20 million Yuan (US$ 3 million) and 120 million Yuan (US$ 20 million), respectively. Further, from 2008 to 2012, 3,330 cases of HAB were recorded for the Chinese coasts, comprising an estimated total area of 53,000 km^2. These events resulted in losses close to US$ 364 million, mainly by the affectation of an indigenous abalone species. In addition, in May, 2012 a mortality of over 50% for the same species occurred in the Fujian province caused by a HAB of the dinoflagellate *Karenia mikimotoi*.

MÉXICO

GULF OF MÉXICO

As to the potential economic impact of HABs in México, as a basic reference the Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, informed (Sagarpa, 2018) that the fishing industry exported US$ 390.6 million in shrimp product, US$ 86.3 million in tuna, US$ 23.2 million in tuna cut, US$ 40.8 million in mussels, and US$ 16.7 million in fish fillet. What follows is an anecdotic account of HAB events for key localities in both coasts of the Mexican territory (Gulf of México and the Pacific coast) for which reliable records are available.

The first report by the Comisión Federal para la Protección contra Riesgos Sanitarios or Federal Bureau for the Protection against Sanitary Risks (Cofepris) regarding HABs was for the State of Tamaulipas, dated back to 2005. Protective measures included a ban on all fishing, albeit no human deaths or intoxications were recorded. Thereafter, no other report exists until 2010, when the death of 20 metric tons of fish and other species was recorded at Bagdad Beach in the Municipality of Matamoros. Likewise, in 2012 the death of 30 tons of fish were also recorded. This time the main culprit in the formation of the HAB was identified as *Karenia brevis* (dinoflagellate). Later reports are more precise, providing the species identification of affected species and/or families, along with estimated mass. For example, the one that occurred in Tamaulipas in 2015, that register the death of more than 40 tons of fish that included *Heteroconger* spp. (eels), Mugil spp. (mullet), puffer fish *Sphoeroides sp. Centropomus spp.* (bass), *Caranx* spp. (mackerel), *Mycteropeca spp.* (negrillo and cabrilla), *Ictalurus spp.* (catfish) and clupeids (sardine) (García-Mendoza, et al., 2016).

Notwithstanding, in particular the Port of Veracruz has been highly impacted by HABs; information on the subject dates back to 1792, with 36 recorded events up to 2012 in which the main species responsible was the dinoflagellate *Karenia brevis* (Aké-Castillo, et al., 2014). Thereby, in 1999 there was a decrease in the supply and demand of marine products in five localities within the Municipality of Alvarado and one in Veracruz. Because of the yellow hue of the sea and of the marine aerosol that caused respiratory discomfort in the human population, authorities suspended all fishing activities (Cofepris, 2004).

Later, in 2001 and 2002, the death of four specimens of nurse shark was recorded in the Veracruz aquarium fence at Sacrificios Island, along with two specimens, one black tip and one hammer head shark, occurred in the quarantine tanks within the facilities of the aquarium. These deaths were related likewise to HABs by *K. brevis*, although no autopsies were performed to pinpoint the cause of death (Aké-Castillo, et al., 2014). Finally, in another event, the death or 50 tons of fish were recorded, mostly reef species (10%). The HAB impacted also artisanal fishing in the region (Okolodkov, 2010).

In the Tabasco region HAB events are described as being cyclic (Mier y Terán-Suárez, et al., 2006), but it wasn't until April of 2002 when the first phase of the contingency program was activated. This consisted in alerting the Comité Estatal del Programa Mexicano de Sanidad de Moluscos Bivalvos (State Committee of the Mexican Sanitary Program for Bivalve Molluscs) and to launch a pre-ban on the species destiny to human consumption. By 2005 a ban was decreed for the first time along with a contingency phase that limited production, marketing, and consumption of bivalve mollusks in the state coasts. Only one intoxication case occurred (Borbolla-Sala, et al., 2006) and, in both cases, the culprit was identified as *Karenia brevis.* Again in 2007 a ban was decreed due to a HAB onset caused by several dinoflagellate species: *Prorocentrum sp., Prorocentrum gracile* and *Pyrodinium bahamense var. bahamense.* No human intoxications or deaths were reported either, as in the 2011 recorded HAB, also by *K. brevis* for which no sanitary ban was established.

Likewise, in 2001, in the coast of the State of Yucatán the death of around 70-90 tons of marine species was recorded, including fish, crustaceans, and mollusks, many of commercial importance. It was determined that the most likely cause was bronchial occlusion and depleted oxygen concentrations due to the proliferation of the diatom species *Nitzchia longissima* and *N. closterium* (Cofepris, 2004). According to the newspapers and data from the Health Services of Yucatan, impacts due to decrease in sales, marketing and consumption of sea products represented an excess loss of 2,250,000 pesos. Afterwards, during the July-August 2003 period the occurrence of a HAB paralyzed 50% of the riverine fleet causing losses of approximately 50 million pesos in the fishing industry of Yucatan (Merino-Virgilio, et al., 2014).

MEXICAN PACIFIC

Off the coast of the Baja California Peninsula bathed by the Eastern Pacific Ocean a HAB event was detected in the coastal lagoon known as Ensenada de La Paz (BCS) during September, 2000. The implicated toxic species was identified as *Cochlodinium polykrikoides*. The proliferation extended to the vicinity of shrimp and fish farming ponds, causing the death of 27 snappers (Pagrus pagrus Linnaeus 1758) inside the ponds (Gárate-Lizárraga, et al., 2000). A similar event occurred again in the same area during the September-November period in 2001, that caused the death of 180 farm fish which showed evidence of gill damage, mainly mucus. The second event was diagnosed as being caused by eutrofization due to anthropic activities, i.e., water discharge from the culture ponds (Gárate-Lizárraga, et al., 2004c).

During August, 2007 a HAB caused by *Akashiwo sanguinea* occurred in the area of Punta Abreojos-La Bocana, BCS. A sample was sent to the Centro de Investigaciones Biológicas del Noroeste (Cibnor), and results were officially issued 12 hs. later stating that it pose no risk due to the absence of toxins affecting humans (Gómez-Tagle, 2007). Notwithstanding, by the middle of September preliminary data indicated the death of approximately 100,000 lobsters (40-45 metric tons) found on the beach, mostly pregnant females. Such event represented an economic loss between 15 and 20 million Mexican pesos. Moreover, approximately 2 tons of abalone y and three oyster harvests were lost, adding up to 3,200,000 pesos in total losses (Gárate-Lizárraga, et al., 2007a).

During January, 2015 a HAB by *Gymnodinium catenatum* (Dinophyceae) occurred in the northern part of the Gulf of California. As a consequence, harvest and marketing of the geoduck *Panopea globosa* were banned for several months due to the accumulation of PST in the tissues of the clam, which required 210 days to lower toxin concentration under 800 μg STX eq kg^{-1}. The desintoxication rate for *P. globosa* was measured for the first time at 4.3% day^{-1}, that deemed this mollusc as a slow depuring species (Medina-Elizalde,, et al., 2018).

Off the coast of Baja California, the northern state of the peninsula a “chocolate colored” HAB of the dinoflagellate *Ceratium furca* was formed during September, 2002, within the region of Puerto Escondido, 10 kms. from a blue fin tuna farm (*Thunnus orientalis)*. The sudden changes in wind direction promoted the invasion of the tuna enclosures and in less than 48 hours caused an economic damage estimated between $ 12 and 15 million pesos due to the death of over 500 tons of marine product, attributed to high levels of ionized ammonia that provoked excessive mucus secretion in the gills of the fish (Orellana-Cepeda, et al., 2004).

Elsewhere, towards the southern part of the country, a HAB occurred in 2000 off Bahía de Banderas, Jalisco-Nayarit, which covered an extension of 63 km of coast. This was coupled with a massive mortality of 13 species of fish stranded on the beach, caused by bronchial obstruction due to excess mucus production. Affected species included *Apterichtus equatorialis* (equatorial eel), *Letharchus rosenblatii* (sailfin snake-eel), other from the *Clupeidae* (sardines) and *Haemulidae* (snapper) families (Cortés-Lara, et al., 2004).

Although Cofepris houses HAB reports for the coasts of the State of Jalisco, since 2003, the earliest that could be accessed was from 2007. From then until 2017, a total of 11 HAB have been recorded. The one that occurred in 2012 extended over Bahía Banderas, Nuevo Vallarta and Guayabitos, Nayarit, up to Vallarta, Jalisco, the culprit being *C. polykrikoides*, that caused the death of 5 tons of fish. A later event (2014) off Bahía Manzanilla, Puerto Vallarta, Jalisco, implied blooms of the diatoms (*Melosira* spp.) and dinoflagellates (*Dinophyisis caudata*) which didn't require a ban, albeit 3,151 kg of oysters (*Crassostrea sp.*), 7,100 kg of chocolate clam (*Megapitaria squalida*, G.B. Sowerby I, 1835) and 4,150 kg of mule leg clam (*Anadara formosa* G.B. Sowerby I, 1833) had to be destroyed.

In the case of the State of Colima, the first HAB report by Cofepris dates to 2007 for Bahía de Manzanillo, on blooms by *Gymnodinium mikimotoii* and *Gymnodinium sp.* This time a ban was enforced and 3.2 tons of oysters (*Crassostrea* sp.) were disposed of; also, 1.5 tons of dead fish were accounted for. Since that event and up to 2017, there have been 21 HAB sightings, none of which is coupled to human intoxications.

Further south along the Mexican Pacific, on the coast of Guerrero, Cofepris reported 13 HAB events from 2003 to 2017, 61% of which were caused by *Gymnodinium catenatum* and 30% by *Pyrodinium bahamense*. Although no economic impacts were reported Gárate-Lizárraga, et al. (2012a) observed that toxicity in samples of violet oyster (*Chama coralloides* Reeve, 1846) from a HAB in 2010, surpassed the concentration limits allowed for human consumption (up to 894.56 ug STX eq $100g^{-1}$), with abundances between 1,000 and 606,000 cél/L of *P. bahamense var. compresumm.*

Finally, in the coasts of the State of Oaxaca, 12 to 214 day bans were enforced from 1989 to 2014, corresponding to14 HAB events of paralyzing toxin producing species (Alonso-Rodríguez, et al., 2015). One HAB in 1989 extended from Guatemala to Chiapas and Oaxaca. In the later, state fisheries economy was affected because the extraction, marketing and consumption of shellfish (oysters and clams) were prohibited for a span of 75 days, with estimated losses adding up to half a million dollars (Cortés-Altamirano, et al., 1993).

THE HEALTH IMPACT ISSUE

Concerning health impacts, Van Dolah, et al. (2000) mention that the reported effects of algal toxins generally appear as swift acute intoxications, while the effects to episodic or chronic exposures to (low levels of) such toxins are scarcely documented, since the affected persons may not report the incidents, or may be misdiagnosed. Thus, Suárez-Isla and Guzmán-Méndez (1998) estimated that globally 2,000 cases of these types of intoxications in humans had been reported since the last two decades with a correspondent 15% death toll. Cofepris in Mexico had records for 411 intoxicated persons and 21 deceased due to consumption of shellfish contaminated with HAB toxins between 1979 and 2012.

In general, one of the most frequent types of HAB intoxications is known as "paralytic shellfish poisoning" (PSP) because it implicates a saxitoxin and/or analogues which interfere with the regular function of the sodium+/voltage pump and blocking nerve impulses. This brings about different degrees of paralysis that range from a mild paresthesia in face, lips, mouth and tongue, to serious respiratory muscle paralysis, a consequent respiratory insufficiency, and death (Guerrero Marín, et al., 2013). Symptoms appear around 30 minutes and 3.3 hours after consuming shellfish (Reyes Chávez, 2012). The main producers worldwide of these toxins are dinoflagellates of the genus Alexandrium. The degree of toxicity varies according to the mixture of the *saxitoxin* (STX) derivatives, whose composition differs with the particular species. It is worth noticing that the shellfish that feed on these dinoflagellates accumulate the toxins without experiencing any harm.

During the last two decades of the past century, an apparent increase in the number of recorded intoxications by PSP has been proposed (FAO, 2005), and maximum historical toxicities have been recorded resorting to mouse assays in order to pinpoint high toxicity and feasible latitudinal patterns. Because different bivalves species show significant differences (up to 100 fold) in ability to accumulate PSP toxins in their tissues, those that rapidly attain high levels of toxins such as mussels (*Mytilus edulis Linnaeus* 1758) are adequate candidates to be used as sentinel species for emitting early PSP alerts . Currently, programs for monitoring PSP that rely on *M. edulis* as toxins sentinels are practiced worldwide (Bricelj & Shumway, 1998).

WORLDWIDE INTOXICATION BY PSP

PSP intoxication records comprise worldwide documented cases. For North America, the first ever recorded case of human intoxication due to seafood consumption dates back to 1793 on the Western coast of the USA (Vancouver, 1798). The next one is not reported until 1799 when the first PSP related HAB occurred in the coasts of Alaska. Then on, the next case was in 1903 in California, one of the states with higher number of HAB related incidents of paralyzing intoxications due to shellfish consumption. For this state, in the 1903 to 1980 period over 500 cases and 32 deceases are accounted for, attributed to intake of mussels and oysters. Albeit, there are only two recorded cases implying oysters, the first one in 1962, when four persons were intoxicated, while the later one included 61 individuals with no deceases. However, there were also 36 persons intoxicated and one death due to consumption of mussels and another because of scallop viscera consumption (Conte, 1984).

In 1927, a massive intoxication event occurred in San Francisco, California, that caused the death of several persons. Sommer, et al. 1927 (in Saldate-Castañeda, 1991) related the coincidence of the dinoflagellate *Gonyaulax catenella* to intoxications due to consumption of mussels. This event gave way to the first mouse assay for detecting the toxin. By 1980 it was known that PSP occurred mainly in temperate regions of the USA Western coasts, and onsets were localized during in May and October, whilst in the East coast they occurred between July and September. Most PSP victims due to shellfish consumption were tourists and hikers that gathered shellfish for their own pleasure, while commercially harvested shellfish have been rarely implicated (Bryan, 1980).

In Canada, 106 records of PSP incidents exist from 1880 to 1995, with 538 individual cases and 32 deceases. Most poisonings (211) occurred at the Saint Lawrence Estuary (Todd, 1977).

According to the most recent reviews on the subject, in Latin America around 1,410 persons have been intoxicated by PSP, including 94 deaths from 1970 to 2016. The main culprit has been *Pyrodinium bahamense,* responsible in 819 cases, followed by *Alexandrium spp.* (350 cases) and *G. catenatum* (241 cases) (Band-Schmidt, et al., 2019). Similar figures are also reported by Sunesen, et al. (2020) from 1970 to 2019.

In Chile, between 1972 and 2002, 437 cases of PSP intoxications, including 27 deaths (Buschmann, 2005). The first one happened at Bahía Bell, Region of Magallanes, which gained notice due to 3 deceases in the regional hospital in October 1972. The correspondent investigation from the Instituto de La Patagonia identified toxins that although harmless to shellfish resulted fatal for humans. Related, the XII Zona de Salud confirmed that no bacteriological contamination was present in "cholgas" (*Aulacomya atra* Molina, 1782), and that heavy metals were also absent, particularly copper and arsenic. Autopsies revealed that the deceased had burst lungs, and that the shellfish had not been digested, indicating a swift and direct action on nervous system and other vital organs such the heart, which confirm the presence of neurotoxins that affected mainly the central nervous system.

In Argentina, the first recorded cases of intoxication date back to 1980, but did not receive attention until 1984-1985, when 18 cases of PSP made the news, due to ingestion of mussels (Vecchio, et al., 1986). The first symptoms experienced by victims included parethesia, and perioral and tongue numbness. Five patients suffered respiratory insufficiency and 3 died.

In Europe, the first onsets of PSP have been scientifically dealt with since 1689. However, the one that gained most notice occurred in Wilhelmshaven, Germany in 1885 (Ministerio de Sanidad y Seguridad, 1978). It was associated to the ingestion of mussels, and studied by the renowned pathologist Virchow during 1885 –1886, naming it mitylotoxism (Mira Gutiérrez, 2005). Much later (1976) mussels (*Mytilus edulis*) caused food poisoning in Spain and in the countries that imported the product from there (Germany, France, Switzerland and Italy) resulting in 120 personas affected, albeit no death were recorded (FAO, 2005).

Finally, in Korea the first incident concerning PSP was recorded in 1984 implicating the food poisoning of a family of six with one death due to the ingestion of mussels, and a second incident derived from the dismantling the hull of a ship, when workers ate mussels resulting in 25 intoxications with 2 deaths (Park, et al., 2013).

PSP INCIDENTS IN MÉXICO

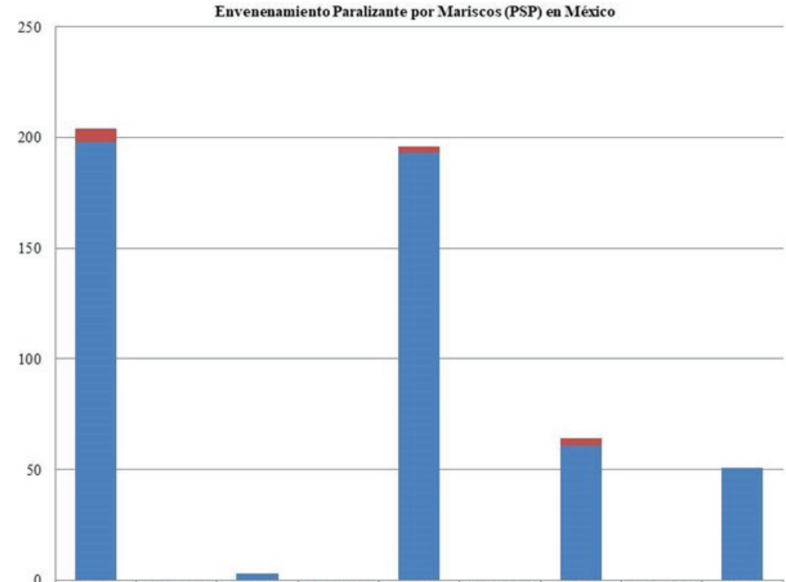
As far as incidents of PSP in México, the most notorious HAB which prompted formal research on this phenomenon occurred in Mazatlan bay, Sinaloa in 1979, when 19 people were intoxicated by eating seafood. There were 3 deceases (De la Garza-Aguilar, 1983) and the culprits were identified as dinoflagellates of the species *Gymnodinium catenatum* (Mee, et al., 1986). A later event occurred in 1988 by the same species and in the same locality, affecting only 10 persons with no fatalities (Cortés-Altamirano y Núñez-Pasten, 1992). Two other HAB events recorded by Ramírez-Camarena, et al. (1999) in Mazatlán occurred, one in spring and the other in autumn. These were also caused by *G. catenatum.* The highest cell density measured in these cases was 5,000,000 cell/L, but in neither event were the concentrations of accumulated toxins in oysters above the maximum limit permitted for human consumption ($80g^{-1}$ y $100g^{-1}$). Even more, the highest cell densities were found far from the oyster beds. Moreover, further south in Salina Cruz and Huatulco, Oaxaca in 1989, 99 cases of PSP were reported, including 3 fatalities. The performed water analyses yielded high densities of *G. catenatum* and *Alexandrium (Gonyaulax) catenella.* Consequent control regulations implied total ban on bivalve mollusk fishing and alerting the population to avoid their consumption (Sáldate Castañeda, et al., 1991).

By 2010 there was an incident involving the intoxication of 12 people that had consumed clams, both cooked and raw, containing a concentration of PSP toxins of 2541μg STX eq 100 g^{-1}, although according to the analyses performed on phytoplancton samples. These were attributed to *P. bahamense var. compressum* (Gárate-Lizárraga, et al., 2010). More recently, Alonso-Rodríguez, et al. (2015) detected paralyzing toxin levels above the established limit permitted for human consumption in scallops (*Striostrea prismática*), gathered in 2009-2010 at Santiago Astata and Puerto Escondido, Oaxaca. Although no intoxications were reported during the study period, afterwards the Cofepris informed that the HAB at La Colorada (Municipality of Santiago Astata), Bahía La Ventosa (Salina Cruz) and Playa Punta Colorada (San Pedro Mixtepec), Oaxaca, resulted in 23 intoxicated persons, prompting a sanitary ban of 214 days. Overall, from 1989 a 2014, 139 intoxications and 9 deaths have been recorded (Alonso-Rodríguez, et al., 2015). Likewise, in 2010 the Cofepris reported 16 intoxicated people on the coast of Guerrero due to a HAB of *P. bahamense var. compressum.* Regulatory measures consisted on establishing a sanitary ban for violet oyster (*Chama coralloides*), plus monitoring phytoplankton.

In Chiapas, 99 intoxications occurred during 1989 with 3 deaths related to proliferation of *P. bahamense var. compressum.* This was repeated 3 years later (1992) but only 2 intoxications occurred. Again, a ban on extraction and consumption of bivalves was enforced. However, on October 2001 intoxication of 50 people and 2 deceases occurred, followed by a HAB with 11 intoxications and one death in December of the same year . This prompted a 6 month duration ban. Four months after the event and consequences the federal government published the Emergent Mexican Official Norm NOM-EM SSA 2001 in the *Diario Oficial de la Federación* (DOF) on 24 december, 2001 for the protection of population exposed to contaminated shellfish (Cofepris, 2004).

CONCLUDING REMARKS

According to the above, and on the basis of the recovered information, we intended to determine if a tendency could be observed on the intoxication incidents records due to HAB in México. On a first conclusive observation, regarding HAB related PSP, there were no reports issued for several years, including Chiapas and Oaxaca for which the most important events have been recorded. In general, reports for the Mexican region are inconsistent, i.e., heterogeneous and incomplete, without any pattern (Fig. 1).



	1989	1990-1991	1992	1993-1994	1995	1995-2000	2001	2002-2009	2010
DEFUNCIONES	6	0	0	0	3	0	3	0	0
INTOXICADOS	198	0	3	0	193	0	61	0	51

FIGURE 1. Recorded cases of paralytic shellfish poisoning (PSP) due to consumption of seafood in Mexico from 1989 a 2010.

WORLDWIDE CIGUATERA POISONING

Firstly, according with the Health Department of Puerto Rico this is a type of food poisoning by ciguatoxins (CTXs) that happens when somebody eats fish caught nearby coral reefs that contain in their tissues toxins produced by dinoflagellates *Gambierdiscus toxicus*. Moreover, other dinoflagellate species are known to cause this type of toxins, e.gr., species of *Prorocentrum*, *Ostreopsis,* and *Coolia* (Almazán Becerril, 2000, in Hernández-Becerril & Almazán Becerril, 2003) and of *Fukuyoa* (Boucaud-Maitre, et al., 2018). In general, this type of intoxication is caused by consumption of carnivorous, tropical and subtropical species that have accumulated ciguatera toxin along the food-chain (FAO, 2005). Notwithstanding, it is impossible to determine at plain sight if a fish is contaminated, inasmuch it doesn't show any symptoms, nor color or odor changes. All in all, ciguatera is deemed an important issue concerning health and resource management for tropical areas, mainly due to their unpredictable erratic temporal-spatial distribution.

Eating fish contaminated with this type of toxins continues to pose a risk for people in general, albeit higher for inhabitants of tropical islands who depend strongly on the marine resources for food and economic trade (Lewis, 1986a). According to Randall (1958) the importance of ciguatera goes beyond the mere medical treatment of patients suffering by the ingestion of contaminated fish, since there is also the marketing prohibition on non contaminated fish and its consumption by people and domestic animals as precautionary measure. Moreover, reef sections known to harbor poisonous fish are avoided during fishing, while areas free of toxic fish are subject to overexploitation. CTXs produced by *G. toxicus* are concentrated in the en gonads, liver, and brain of carnivorous fish. Heavier fish usually contain higher quantities of toxins (Martínez-Orozco & Cruz-Quintero, 2013). However, even when toxin levels may be low, they easily increase to high risk concentration levels after a dinoflagellate proliferation (Bagnis, 1986, in Lehane & Lewis, 2000).

The first symptoms of CTX poisoning may appear within a time span of 30 hours after the toxin ingestion, with a modal time range of 1 to 6 hours (Halstead, 1964). These are mainly gastrointestinal, including colics, vomiting, and aqueous diarrhea. In some cases, numbness and parethesia of the lips, tongue and throat. Paresthesia may further extend to arms and legs (Barkin, 1974, in Hughes, 1976). Other symptoms are metallic taste, mouth dryness, temporal blindness, headache, anxiety, dizziness, coldness, fever, profuse sweating, low pulse (Halstead, 1964), with various neurological symptoms appearing with some delay. In certain cases numbness of the hands has appeared during the cleaning of the fish, thus suggesting that CTX are able to penetrate the skin and mucose membranes. Also identified are transitory brain dysfunctions, fatigue, muscular, articular and dental pain, as well as mood disturbance with depression and anxiety in 50% of the cases (Martínez-Orozco & Cruz-Quintero, 2013). Symptoms depend on the quantity of toxin ingestion, the geographical origin of the ingested fish and its size, plus the particular characteristics of the victim that renders her/him more or less susceptible to the toxins.

In most cases in which the death of a person is reported, the presence of CTX is not verified in an autopsy. It is taken for granted on the basis of clinical symptomatology and information provided by the patient, and in the occasion the suspected food is available it is analyzed. Hamilton, et al. (2010) reported a liver autopsy of a human corpse and ciguatoxins were detected, and it was estimated that at least 10% of the ingested toxin remains in 1.75 kg of human liver for six days after exposure. With this, it is assumed that people that eat fish on a frequent basis may be accumulating toxins, which may explain why some get sick and others don't, or why in certain cases symptoms last from months to years.

Comprising the ciguatera incidents in a worldwide perspective, the first intoxication of this kind occurred in the Western Indies (Antilles and Bahamas) in 1555 and was attributed to the ingestion of seafood locally known as "cigua" (Diogène 1992, in Lechuga-Devéze & Sierra-Beltrán 1995). In 1774, it was reported as an epidemic by the Ship Captain James Cook in the South Pacific (Cook 1777, in Ricourt Regús, 2000). Afterwards, Randall (1958) launched the hypothesis on the origin of the toxin that are briefly shown below (verbatim):

> Fish turn poisonous due to a factor in the environment. If all fish of the same species were toxic wherever they are, either continuously or seasonally, then it would be expected that the toxin be endogenous. However, because fish in a restricted area are toxic while other of the same species and similar size from nearby areas are not, then the toxin must originate in the environment.
> Fish toxicity is associated to its food supply.
> The basic poisonous organism is benthic.
> Because strictly herbivorous fish and those that feed on detritus are poisonous, the toxic agent is likely an alga, a fungus, protozoan, or bacteria.
> Out of the green algae, cyanophytes seem to be the most likely source of ciguatera toxin.
> The most poisonous fish are the large predatory species, especially those that feed on other fish.
> Organisms that produce ciguatera toxin could be the first to grow in new or nude cultures of tropical seas following a normal ecological succession.

Much later, experiments carried out by Yasumoto, et al. (1977) with detritus gathered at the Gambier Islands of the French Polynesia showed evidence of identical toxins related to ciguatoxin and maitotoxin. While their proportions and those of the dinoflagellate *Diplopsalis* sp., were closely correlated, thus concluding that that *Diplosalis* sp., could be the precursor for ciguatera. Later, these dinoflagellates were described by Adachi and Fukuyo (1979) who determined it as *Gambierdiscus toxicus*.

For the United States of America during the 1970-1978 period, fish were reported as being implicated in approximately 7.4 % of diseases related to food-poisoning, mainly ciguatera ciguatera. Between 1978 and 1987 a total of 791 cases of ciguatera poisoning were reported which affected mainly residents and visitors of Florida, Hawaii, Puerto Rico, the Virgin Islands, Guam, and the Marshall Islands (Anderson, et al. 2000). As a consequence, the marketing of certain fish species with a history of causing this disease was banned in several islands, inasmuch the usual cooking procedures (in an oven, boiling, frying), nor salting or drying, offset ciguatoxin activity (Bryan, 1980).

On the other hand, during September 1955 to February 1974, Russell (1975) treated 32 cases of intoxication by ciguatera, where most were consulted through the phone inasmuch the patients resided elsewhere: Massachusetts (2), Nueva York (2), Washington, DC (3), Florida (3), Louisiana (1), Texas (2), Hawaii (1) and México (4). Three of the patients treated by Russell experienced, within the initial 48 hs. after the intoxication, paresthesia, nausea and vomiting, abdominal pain, diarrhea, muscular weakness, lack of coordination, and disturbance of sensory sensibility (perception) felt as tingling or numbing, particularly in legs. Others showed sinus bradycardia, hypotension, and deep and shallow hypoactive reflexes. Also, dizziness, weakness and myalgia were experienced. All patients were administered atropin (0~5 mg every 4 hs.) intravenously by continuous drip of multiple electrolyte solution. Atropin seemed to have an effect on the symptoms and on the gastrointestinal and cardiovascular signs. Nauseas and abdominal pain diminished and vomiting stopped. Blood pressure normalized or recovered almost to normal levels, and sinus rhythm was restored. However, 10 cases did not show improvement 3 to 14 days after the intoxication with the atropine treatment, but they did get better on a high protein diet, intravenous administration of vitamin B, and oral intake of calcium gluconate and vitamin C.

Concerning the insular Caribbean states, according to Celis and Mancera Pineda (2015) the incidence per capita of ciguatera intoxications recorded for the 1980-2010 period added up to 10,710 documented cases in 18 countries. These were reported by the Centro Epidemiológico de El Caribe that estimated an annual incidence rate of 42/100000. Also, the comparison of two separate periods (1980-1990 and 2000-2010) an increase in the annual incidence of recorded cases was noted, i.e., from 34.2 to 45.2 /100,000 countrywide basis and of 2.13 to 6.37/100,000 on a yearly basis.

Clinical observations made between 1964-1977 on 3009 patients from several groups of islands of the South Pacific showed that they generally exhibited neurological symptoms, such as numbing and tingling in hands, cold things felt hot to the touch, they experienced vertigo and equilibrium difficulty. Besides, they commonly showed pathological gastrointestinal alterations such as diarrhea, abdominal pain, nausea and vomiting (Bagnis, et al. 1979). Overall, the annual incidence of ciguatera poisoning recorded for the South Pacific from 1973 to 1983 was 97/100,000. The highest was for the French Polynesia with a total 8,461 cases and an average of 769.18, followed by New Caledonia with 3,024 intoxications and an average of 274.9. Cook Islands had the lowest number of cases with only 3 cases, one in 1980 and two in 1981. These incidence reports represent only 20% of the real amount of cases, which would be 500/100,000. Another note is that small islands where people strongly depend on marine resources are highly impacted. For example, Tokelau is an island with a surface of 10 km^2 with around 1600 inhabitants for which the number of intoxications registered has increased. In 1981 there were 3 cases, a year later 17, and by 1983 it had gone up to 73 (Lewis, 1986b). The study by Skinner, et al. (2011) indicated that the incidence of ciguatera for the South Pacific increased up to 60% for the 1998 to 2008 period, in spite of the variability among states, i.e., the Fiji islands reported a total 13,255 cases, the French Polynesia 8,534, while in New Caledonia the number of intoxications decreased compared to the numbers reported by Lewis (1986), with only 239 cases. In contrast, in the Cook Islands there was an increase, from 3 in 1973-1983 to 2,687. In 7 of the 18 studied states the inhabitants changed their diet as a consequence of ciguatera, along with management measures that included closure of fishing areas. All these may be deemed socio-economic impact *sensu stricto*, although they imply adjustments rather than direct loses.

In the Guadalupe Archipelago (French Western Indies) 234 cases of intoxications were recorded for the 2013–2016 period, with an annual average incidence of 1.47/10,000 (IC 95%), i.e., five times higher than the one recorded (0.3/10,000) for the 1996–2006 period. The main food source responsible for the observed poisoning were fish of the Carangidae and Lutjanidae families. Up to 93.9% of the patients experienced gastrointestinal ailments, 76.0% neurological disturbances (mainly paresthesia, disesthesia and pruritus) and 40.3% exhibited cardiovascular anomalies (bradycardia and/or hypotension). Likewise, a high frequency (61.4%) of hypothermia (<36.5°C) was observed (Boucaud-Maitre, et al. 2018). Elsewhere, in Manakara (east coast) of the Island of Madagascar, Habermehl, et al. (1994) recorded the first onset of ciguatera due to shark consumption, which resulted in close to 500 victims including 20% mortality.

CIGUATERA POISONING INCIDENTS IN MÉXICO

The first records of ciguatera incidents for México date back to 1862 (Halstead, 1967; in Núñez-Vázquez, et al., 2019), although reliable documented cases come later. De Haro, et al. (1997) mentioned a case of food poisoning involving 30 persons that ingested barracuda fish in a restaurant at Isla Mujeres. Even if the intoxication was not properly diagnosed, the consulting medical personnel prescribed antidiarrheic medicine before the patients boarded flight to their home country. Eventually, those patients attended the Centro de Envenenamiento at Marseille, Spain on day 5 for a clinical evaluation of their symptoms. On the basis of the determined scores they were treated with 20% manitol according to Bagnis, et al. (1979).

In another report, Arcila-Herrera, et al. (1998) described 10 ciguatera intoxications in the Yucatán Peninsula due also to ingestion of barracuda, mainly in Isla Mujeres, Quintana Roo. Symptoms appeared between 20 minutes and 12 hs. after eating the fish, with initial digestive disturbances, mainly diarrhea. Then, hipersensibility to cold in all patients. Two out of three male victims that had sexual intercourse experienced pain during ejaculation and dyspareunia, and one of five females experienced hyperesthesia of the nipples. One more report for this region was issued by Farstad and Chow (2001) in which they described the intoxication of a middle age couple due to intoxication with barracuda in Cancún.

Overall, for the State of Yucatán a total of 32 cases of intoxication were reported between 1996 and 2004, in which 96% were caused by barracuda ingestion (Chávez-Peón, 1997; Quiñones-Vega, 2000, in Núñez Vázquez, et al. 2008; Keynan & Pottesman, 2004). Likewise, recently Núñez Vázquez, et al. (2019) accessed a report issued by the Secretaría de Salud in which another 26 cases were detected for Mérida and 6 for Kanasin. Whilst, for Quintana Roo 48 cases were reported in Isla Mujeres, 20 in Cozumel, 12 in Cancún, 5 in Puerto Ventura, 32 in Playa del Carmen, and 4 in Tulum (table 1, at the end of this article) .

In Baja California Sur (BCS), northwestern México an onset of ciguatera occurred in 1984, due to consumption of contaminated fish that resulted in 200 intoxicated persons. After analyzing several species of fish, toxins were detected in specimens of snapper, *Lutjanus* sp. (Parrilla-Cerillo, et al. 1993). Besides, the intoxication of 25 persons by ciguatera in 1992 in San Diego, California, was caused by fish caught at Rocas Alijos, BCS. Symptoms include nausea, vomiting, dizziness, and neurological disorders (Barton, et al. 1995). While in 1993, seven crew members of the tuna boat "Tungui" experienced the same symptoms, also for the consumption of fish from Rocas Alijos, which lasted more than 15 days. The presence of ciguatoxins was confirmed (Lechuga-Devéze & Sierra-Beltrán, 1995).

Likewise, nearby La Paz, BCS, between 1993 and 1997, fishermen reported 5 intoxications after eating fish liver of the Serranidae species, grouper, and snapper (Lutjanidae) at isla El Pardito and Punta San Evaristo (Núñez-Vázquez, et al., 1998; in Núñez Vázquez, et al., 2019). Later (2004), another 3 cases were recorded for Punta Abreojos, BCS (Núñez-Vázquez, et al., 2009 in Núñez-Vázquez, et al., 2019).

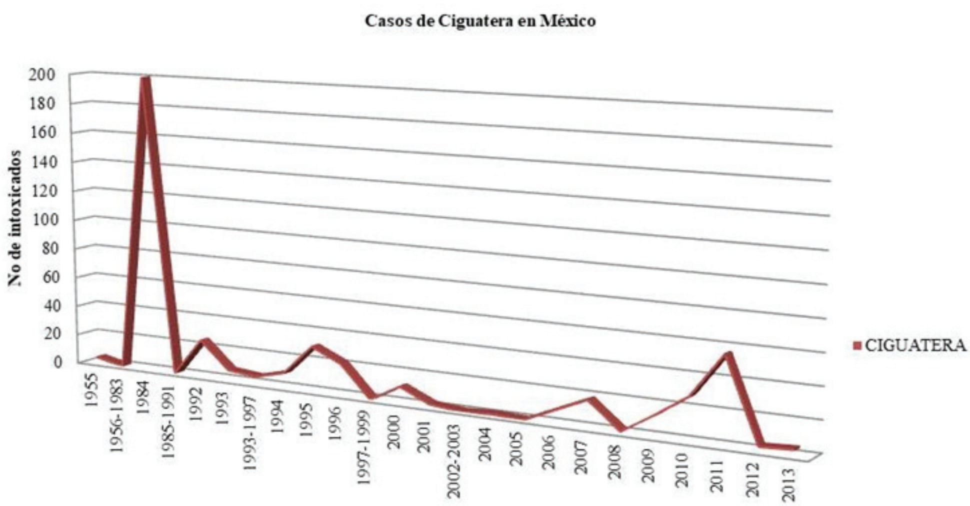


FIGURE 2. Cases of ciguatera poisoning recorded in Mexico from 1955 to 2013, i.e. intoxications due to ingestion of fish (mainly barracuda) contaminated with ciguatoxins.

AMNESIC SHELLFISH POISONING (ASP)

This is yet another form of intoxication due to HAB caused by domoic acid (DA), an excitatory compound of the so-called neuroexcitants or excitotoxins that interfere with neurotransmision mechanisms and cause neuron harm and cellular death. In humans such harm is associated with short term memory loss and sometimes death (Ortegón-Aznar, et al. 2011). The first outbreak of food poisoning caused by DA was detected in 1987 and was due to the ingestion of blue mussels (*Mytilus edulis*) cultivated at Prince Edward Island, Canada, resulting in the intoxication of 107 persons, with three deceases. The more common symptoms were vomiting (in 76% of the patients), abdominal cramps (50%), diarrhea (42%), cephalea (43%) and short term memory loss (25%) (Perl, et al. 1990). The culprit was identified by Bates, et al. (1989) during an outbreak of DA intoxication when observing a HAB in which the diatom *Nitzschia pungens* f. *multiseries* predominated, where a positive correlation was found between the number of cells of this species and the concentration of DA in the plankton, thus concluding that these diatoms were the primary source of the DA found in the toxic mussels. In 1988 they confirmed their hypothesis by analyzing a monospecific proliferation of *N. pungens*, in which they detected the DA found in plankton and in mussels. Afterwards, in 1991, another case of intoxication with DA was recorded involving 24 persons that ingested razor clams (*Siliqua patula*) from the coasts of Oregon and Washington, USA (Kizer, 1994).

By the end of 2004, the French net for phytoplankton monitoring detected DA in concentrations above the allowed limits by the EU, i.e., 20 μg DA/g of tissue, in scallops (*Pecten maximus*) at the Sena Bay. The gathering sites for seafood were closed for several months due to the slow clearing of the scallops.

DIARRHEIC SHELLFISH POISONING (DSP)

Another form of intoxication related to HAB is diarrheic poisoning due to consumption of mollusks (DSP) caused by various toxins including the most potent one okadaic acid (fatty acid). This toxin provokes an inhibition of phosphatase proteins present in the cells of the intestinal epithelium causing water discharge and thus diarrhea, nausea, vomiting, and abdominal cramps (Ortegón-Aznar, et al. 2011). These symptoms appear between 30 minutes and several hours after eating contaminated seafood, with recovery within the three following days (FAO 2005). According to Sánchez-Bravo, et al. (2016) there are no reports on intoxications by okadaic acid for México, albeit species of *Dinophysis* and *Prorocentrum* commonly occur in the Mexican Pacific (Gárate-Lizárraga 2007a). Moreover, there are reports on sanitary bans for localities on the Western coast of the Baja California Peninsula, particularly in BCS, including: Laguna Guerrero

Negro, Bahía de Todos Santos, Laguna Ojo de Liebre, and the estuary El Coyote, in response to the accumulation of diarrheic type toxins (Sánchez-Bravo, et al. 2016).

REMARKS

Although scientific and non-scientific studies of HAB in México are undoubtedly necessary and reliable, there is no evidence whatsoever that they have contributed to mitigate the assumed socio-economic and health impacts related to HAB. A large part of the published reports record HAB events that provide useful data on locality, species associated to the outbreak, physochemical values, density values of the species causing the HAB and, occasionally, the extension and duration of the event. Plus, monitoring programs have allowed knowing which are the most recurrent toxic species in a certain locality, including the possibility to determine the distribution of several HAB forming taxa (table 3).

In spite of the above, what has partially motivated this essay relies on the fact that in general HAB related studies in México, whether ecological or toxicological, are based on the premise that the relevance of the HAB phenomena revolves around the socio-economic and health impacts they cause. However, there are no available documents, either official or academic, that show with the required precision what the overall economic losses have been. The same thing can be said with respect to the alluded health impacts, as it can be perceived in the compiled information, few reports exist. Moreover, no reports of significant cases of HAB related human intoxications or deaths exist. An explanation for this is likely that medical personnel lacks the basis for diagnosing HAB derived intoxications, inasmuch there is no reference protocol available, besides that these are readily confused with infection related pathologies. This situation calls for express training of the health personnel on how to diagnose intoxication cases due to PSP, ciguatera, amnesic poisoning, and so forth, because no tests have been developed hitherto to confirm them, so conclusions are reached through interviews or physical (medical) diagnosis. Moreover, some publications inform of no cases of intoxication or deaths. When aerosol effects are observed only the symptoms such as irritation of eyes, nose and throat soreness, coughing and respiratory difficulties are recorded, but no numbers of people affected are provided.

Concerning impacts on marine fauna, in most of the revised cases there is no precise quantification of mortality, and are generally mentioned as massive fish death. Some studies provide species or family identification of fish, and approximate total weight in tons, e.g. a HAB event in Tamaulipas in 2015 (García-Mendoza, et al. 2016). On the other hand, in certain studies toxicity was measured in commercial mollusk species, as in

Hernández–Sandoval, et al. (2009) who determined profile and concentration of paralyzing toxins found in bivalve mollusks (*Pinna rugosa, Modiolus capax, Megapitaria squalida, Periglyptia multicostata, Dosina ponderosa* y *Megapitaria aurantiaca*), and it was found that the highest concentrations of paralyzing toxins were 31.14, 37.74 and 25.89 ug STXeq. $100g^{-1}$ in *M. capax, P. rugosa and M. aurantiaca*. They realized that a more detailed knowledge is required on the transformation and depuration of paralyzing toxins in order to achieve basis for adequate fisheries management regarding these type of contingencies.

Taxonomic studies in México related to HAB have focused on detailed description of species recorded for the first time, complemented by estimation of cell densities and measurements of physicochemical variables such as temperature and salinity (table 4). This information allows to know when a toxic or harmful species is newly found and to infer whether it can reappear when similar conditions return and generate a HAB.

Particularly in México toxicological and ecophysiological research has focused on determining toxin profiles of certain species, among them, those of *Gymnodinium catenatum*. Most of these studies observe that toxin characteristics vary according with culture media and isolation techniques of the species. Isolates of *G. catenatum* in México have been acquired from Bahía Concepción and Bahía de La Paz (BCS), Bahía de Mazatlán (Sinaloa), Bahía de Manzanillo (Colima), and Lázaro Cárdenas (Michoacán) (Bustillos, et al. 2011, 2015). Before 2011, techniques for determining toxin profiles could not identify benzoate type toxins (GC1, GC2Y GC3); since then, it has been recorded after a strain isolated from the Gulf of California. Durán-Riveroll, et al. (2013) verified the occurrence of these analogues by confirming the presence of the benzene group in a fraction of a *G. catenatum* strain isolated from the coasts of Manzanillo. In this way, it has to be noted that most of what has been investigated has been focused on understanding the HAB phenomenon, that turns out to be complex or multifactorial. That is, relating the alleged increase in HAB to increase in eutrophization, and the latter to the output of nutrients derived from anthropic activities. HAB have been also related to non-anthropic phenomena such as upwelling, a process that disturbs the ocean floor and suspending cysts of HAB forming dinoflagellates, along with nutrients. Albeit, not enough evidence is at hand to sustain said relation with scientific certainty.

On the other hand, research alternatives for avoiding losses in marine farms are recognized, in particular the predator-prey interactions that imply potential control of dinoflagellate populations. In this way, Palomares-García, et al. (2006) detected (in vitro) a relation between the calanoid copepods *Acartia clausi* population maxima and those of *Gymnodinium catenatum*, with the copepods feeding on the toxic dinoflagellates without being harmed. Likewise, other studies observed that certain taxa that are able to consume *G. catenatum* in situ may experience cellular damage, as in the case of *Noctiluca scintillans* from Bahía de La Paz, Gulf of California (Bustillos-Guzmán, et al. 2013). In this way, research on natural predators could aid in finding a potential biological control strategy on the basis of the HAB forming species that consume and their specific distribution requirements.

More recent reviews on the investigative endeavor concerning HAB in the Mexican region acknowledge the need for generating more scientific knowledge on the risks and consequences of HAB occurrences off Mexican coasts, and that socio-economic impacts of HAB are not considered within the public expenditure of state or national governmental budgets. Moreover, those economic losses in most cases have not yet been assessed (Duran Riverol, et al., 2019). Indeed, studies are scarce even about the causes and consequences of HAB, exhibiting an urgent need for reinforcing both scientific research and monitoring strategies through national and international research programs (Duran Riverol, et al., 2019). These programs should as well be established in the countries with marine industries that lack the monitoring capacities (Sunesen, et al., 2020). Thus, a collaborative effort between public health authorities, fishermen, aquaculturists, and scientists is imperative in order to undertake the challenges that the HAB phenomena pose, both locally and regionally within Latin America and the Caribbean (Duran-Riveroll, et al., 2019).

DISCUSSION

First of all, the above analysis on the various scientific contributions leads to the this questions: Why during most upwelling events HAB do not develop? What other factors intervene in the onset of HAB? These require testing of creative hypotheses. Whilst, evoking the primary question, has research on harmful algal blooms aided in mitigating their economic and health impacts in México? Other questions still arise: Is there really a significant contribution by the scientific endeavor, considering the effort made, for pertinent management or treatments against the contingencies that HAB represent on the economy and health sectors? Does the generated information add to other studies for other parts of the planet? In other words, is there a contribution for constructing proposals for the mitigation of the economic and health impacts caused by HAB?

Direct actions seeking to mitigate health impacts have consisted in the creation of institutions. In 1991, the Laboratorio de Biotoxinas Marinas was erected in Acapulco, Guerrero, under the supervision of FDA (Food and Drug Administration, from the USA) instructors to monitor the HAB formation and paralyzing toxins, which gain certification by 1993 (Gárate-Lizárraga, et al., 2016). Notwithstanding, in 1995 a HAB caused by *Pyrodinium* *bahamense* var. *compressum* in the coast of Guerrero provoked 138 intoxications and two deaths (Orellana-Cepeda, et al. 1998, in Gárate-Lizárraga, et al. 2016). This would indicate that, apparently, there was not an immediate or efficient communication between health officials and researchers studying HAB in order to make the adequate decisions to prevent the intoxication of the population. Likewise, it evidences the disengagement between the scientific community and society at large, characteristic of countries lacking a scientific culture.

More recently, the thematic network for Harmful Algal Blooms (Red-FAN) was created in México to study harmful algae and to detect existing strengths and weaknesses in order to adequately direct the available resources destined to their study (Blanco Pérez, 2016). However, although the available information is unquestionably important, it doesn't permit the objective establishment of new regulations to mitigate the dreaded impacts, inasmuch many of the strategies followed by fisheries have been based empirically and imitate what is practiced in other countries. Current research on marine HAB seems more oriented in knowing the toxins and their analogues that could eventually allow a pharmacognostic application.

Still, scientific studies on HAB carried out in México have focused mainly on determining which species are proliferating and their abundances, along with their distribution, gradually giving way to the interest on the toxicity of the species. Whatever the case, since the studies on HAB began emphasis in that they pose a very important health and economy problem has been made. Even though most if not all investigators agree on this, specific studies on the subject are scarce. Likewise, another unchallenged statement is that the frequency of HAB has increased recently in a secular scale. However, few academics question if there's a real national health or economic problem, or if HAB have really increased in frequency. In some articles deemed scientific, the discussion section relates little to the addressed study problem because they are focused on why the described species is important and its potential harm, either ecological, on human health or socioeconomic. That differs, for example, from the proposal by Davidson, et al. (2021) that focuses directly on the early warning of HAB and biotoxins that affect shellfish and finfish farming, in order to minimize risk to humans and aquaculture businesses in terms of human health and economic impacts. Although the ongoing studies in México will soon allow for similar proposals with their particular idiosyncrasy, the current and actual status of research on this topic has to be recognized first. Otherwise there could be a bias on objectivity which is not permitted within the scientific domain.

Sadly, few members of the scientific community that specialize in HAB research deny the objectivity of the exposed thesis and are content that it doesn't become an eristic issue within the academy, and resort to personal disqualification and even blackmail to prevent its publication, instead of unemotionally and impartially examining it and contributing by acknowledging the reality of our current national scientific status in order to confront it in an appropriate manner. Our thesis here stated is based roughly on the same information used by recent plausible reviews (Band-Schmidt, et al., 2019; Cortés-Altamirano, et al., 2019; Durán Riverol, et al., 2019; Sunesen, et al., 2020) albeit with a different purpose from ours, but much alike between them. We are simply acknowledging the obvious facts surrounding the justification put forward when undertaken HAB related studies in Mexico and Latin America, and observing that they are not logically coupled. Notwithstanding, as it holds, only the opinions of the referees count precluding the onset of eristic dispute within the scientific community. There are different approaches that may be followed when undertaking this kind of thematic and, while these may dissent, they do not exclude each other. There is no unique way to view the problems that nature poses for our understanding, and scientific and philosophical involvement should be open to contemplate those approaches, and not prone to impose through the demerit of peers, expressly when being ask for a critical review, and delivering instead an aggressive disqualification.

Unfortunately, such attitude is not uncommon within the scientific community, as it is well known, detractors of the anthropic global warming (AGW) thesis (to whom we identify with) are constantly demerit and even threatened for expressing their dissents. Some are distinguished scientists, including ex-members of the infamous IPCC that elaborated the imposed proposal which contains questionable scientific logic (*The Great Global Warming Swindle*, readily available in the WWW). The hidden political agenda is related to the fact that the persons responsible for its establishment are two politicians (Al Gore and Margaret Thatcher) who, of course, are never cited in scientific publications. Their money backed impositions did away with decades of scientific theory on planetary climate variation. Most scientists (too many in México) accept such thesis without question and instead they sum to its defense and demerit the interesting research proposals by referring them absurdly to the AGE. Meanwhile, contrary observations that expose the warming models are bypassed (http://www.dailymail.co.uk/news/article-2415191/And-global-COOLING-Return-Arctic-ice-cap-grows-29-year.html).

Will the situation with HAB research be much similar? That is, the fascinating study of these phenomena having to be justified on the basis of sensationalized health and economic impacts, and demeriting the intrinsic interest of ecological theory construction. It thus seems that the so-called "fear instinct" (Rosling, et al., 2019) escalates up to the highest points of our intellectual spheres. Whilst, an objective look at the HAB human health issue forces us to compare numbers of toxin related human affectations. According to the WHO (World Health Organization) data on the internet, in México 700-1400 deaths due to scorpion (*Centruroides* spp.) stinging, around 200 by black widow (*Latrodectens* spp.) bites, more than 1,000 cases of snake bites just in México (*Crotalinae*), and more than 100,000 deceases worldwide. Much more data contrasting these real health and disaster related number are provided by Rosling, et al. (2019). Thus, it seems more like an advertising matter for the "negligible" figures of deaths caused by intoxication due to HAB, if they were not tragic to the directly affected. However, dimensionality does matter. Whilst, the ecological, ecophysiological, toxicological, pharmacognostic, etc., thematic are of utmost importance, and we think researches should stick to them.

PHILOSOPHICAL SUMMARY

The following summary contemplates the alternative philosophical currents versus the attitudes assumed by academics when facing the above dilemmas as shown by Siqueiros-Beltrones (2015). The present essay derives from the *Criticism* required by all scientific (and philosophical) research proposals, provided by as many members of the community as possible, not just designated reviewers. A proposal may be deprived of the essential critical spirit when prejudiced peer reviewing precludes its publication, taking the form of *Calvinism,* i.e., if I don't approve it is wrong and that's what counts (*Cinism*), denying the benefit of the doubt. Why is it wrong? Because such criticism doesn't support the *Utilitarism* behind the accepted trends. This somewhat contradicts the *Romanticism* that underlies scientific research where studies are directed to understand nature on epistemological basis, with the generated knowledge applied afterwards, in agreement with the *Rationalism* behind scientific ethics and the logical structure of a generated theory. Thus, the need for a correspondence between the research problem, the supporting background, and the unavoidable hypothesis stated by the scientific method (Siqueiros-Boltropes, 2015). A distinction is called for when applying specialized techniques to detect HAB toxins in a forensic case and when an original scientific question is posed. Otherwise, there is the risk of *Scientism* clouding the issue. Finally, there are the bases of *Pragmatism* that very much influence the scientific performance, i.e., as long as results are useful or reliable in any sense they are acceptable, no matter if the report title refers to something else, or the objectives were not addressed properly, or a hypothesis, much required within scientific logic, is lacking. Its absence in the reviewed HAB studies is what is being exposed above, and not an intent to demerit the implicated scientific endeavor.

CONCLUSIONS

On the basis of the above analyses, the proposed hypothesis in this review seems to be sustained. Thus, notwithstanding the relevance of scientific studies carried out on HAB in the Mexican coasts, there are no evidences that the laudable efforts by specialists have contributed to mitigate economic or health impacts attributed to HAB events, mainly because they were not intended to, whilst pursuing other objectives. On the one hand, cases of intoxication happen in spite of the preventive measures taken because people do not abide to the indications emitted by the health authorities, as in the aforementioned case in Acapulco. Apparently, a lack of confidence was shown on scientific based regulations most likely due to ignorance of the symptoms related to seafood and fish poisoning, even by medical personnel. On the other hand, under the socio-economic perspective, the reviewed reports do not provide precise data or evidences of the potential impacts on this sector due to HAB events, including the most recent reviews on the subject cited above. This leaves room for vague conjectures, and emphasizes the need for carrying formal studies on the economic impacts in México. That is, formal research to determine how the HAB relate precisely to fisheries, businessmen, restaurants, consumers, and tourism, in terms of costs that allow government officials to justify timely investments on understanding and adequate managing this complex problem as it has been done in certain countries, and acknowledged in several of the cases reviewed above. However, scientific studies should be emphasizing on generation of theory (ecological, ecophysiological, toxicological) without resorting to sensationalist references on health and economic impacts.

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Table 1.- Ciguatera intoxication events due to fish consumption in Mexico (1984–2013). (after Núñez-Vázquez *et al.*, 2019).

Cases (M: F)	Locality (Cases)	Fish taxon	Analisis	Year
200 (n.d.)	La Paz, B.C.S.	*Lutjanus* sp.	MBA	1984
25 (17:4) *	Rocas Alijos, B.C.S.	*Epinephelus labriformis*	MBA and immunoassay	1992
7 (7:0)	Rocas Alijos, B.C.S.	*Epinephelus* sp. *Mycteroperca* sp.	MBA	1993
5 (4:1)	Isla El Pardito (3), Punta San Evaristo (2), B.C.S.	*Mycteroperca prionura* *Lutjanus colorado*	MBA and HPLC	1993–1997
3 (1:3)	Punta Abreojos, B.C.S.	*Epinephelus* sp.	MD	2004
10 (5:5)	Isla Mujeres, Q. Roo	*Sphyraena barracuda*	MD	1994
30 (14:16)	Isla Mujeres, Q. Roo	*S. barracuda*	MD	1995
21 (n.d.)	Mérida (15), Kanasin (6), Yuc.	*S. barracuda*	MD	1996
11 (1:0) *	Progreso, Yuc.	*S. barracuda*	MD	2000
2 (1:1)	Cancún, Q. Roo	*S. barracuda*	MD	2001
1 (0:1)	Yucatan	n.d.	MD	2004
9 (n.d.)	Isla Mujeres, Q. Roo	*S. barracuda*	MD	2006
13 (n.d.)	Cozumel, Q. Roo	*S. barracuda*	MD	2007
5 (n.d.)	Cozumel, Q. Roo	*S. barracuda*	MD	2007
1 (0:1)	México	n.d.	MD	2008
2 (n.d.)	Cozumel, Q. Roo	*S. barracuda*	MD	2009
12 (12:0)	Cozumel, Q. Roo	*S. barracuda*	MD	2009
11 (n.d.)	Mérida, Yuc.	*S. barracuda*	MD, MBA	2010
12 (4:8)	Cancún, Q. Roo	*S. barracuda*	MD	2010
5 (2:3)	Puerto Aventuras, Q. Roo	*S. barracuda*	MD	2010
29 (n.d.)	Playa del Carmen, Q. Roo	*S. barracuda*	MD	2011
27 (14:13)	Isla Mujeres, Q. Roo	*Lutjanus* sp. *S. barracuda*	MD	2011
3 (2:1)	Playa del Carmen, Q. Roo	*S. barracuda*	MD	2012
4 (3:0)	Tulum, Q. Roo	*S. barracuda*	MD	2013
16 (3:9)	Cuba	*Lutjanus* sp.	MD	1986
Total: 464 (90:66)				

Table 2.- Representative reports of HAB occurrences in Mexico and references.

Species	Toxic	Year	Locality	Sample anlyses of bivalves	T°C	Nutrient concentration	Impact	Reference
Polykrikos sp. (5263 × 10_{3} cells/L), *Cochlodinium polykrikoides* (18 × 10_{3} cells/L), *Pyrodinium bahamense* var. *compressum* (410 × 10_{3} cells/L) y *Gymnodinium catenatum* (129 × 10_{3} cells/L).	yes	2010	Bahía de Petacalco to Puerto Vicente, and Costa Grande, Guerrero	Rock oyster (*Crassostrea iridescens* Hanley, 1854)			12 intoxicated persons	Gárate-Lizárraga *et al.*, 2010.
Trichodesmium erythraeum 0.75 y 4.5 × 10_{6} cells/L		2005-2011	Bahía de La Paz		20-30			Gárate-Lizárraga & Muciño-Márquez. 2012
Cochlodinium polykrikoides (360 x 10^3 a 7,05 x 10^6 cells/L)		2000	Ensenada de La Paz		29-31	0.165- 0.897 µM $NO_2 + NO_3$, 0.16-3.25 µM PO_4 and 1.0-35.36 µM SiO_4.	180 dead fish in culture tanks	
Cochlodinium polykrikoides (276 x 10^3 cells/L a 980-1425x 10^3 cells/L)		2012	Bahia de La Paz, Golfo de California		29-30			Gárate-Lizárraga, 2013
Scrippsiella (15.9 × 10^6 - 249 × 106 cells/L)		1998	Playa Eréndida, Bahía de La Paz, BCS		29.7 a 33.2	Total nitrogen (0.2–11.50 µM), PO_4 (4.14 µM) Oxygen 5,66 and 10.17 mg / l	No harm on cultured shrimp was noted	Gárate-Lizárraga *et al.*, 2012b.
Lingulodinium polyedrum (6X10^6 cells/L)					26.96		YTX producer	Pérez-Cruz *et al.*, 2015
Amphidinium carterae 28.2 a 64.8 × 103 cells/L		2011			20		Icthyotoxic and producer of hemolytic substances	Gárate-Lizarraga, 2012
Pyrodinium bahamense var. *compressum* < 1000 and max. 194000 cells/L	yes	2010	Costa Chica, Guerrero	rock oyster 46.24 and 788.85 µg STXeq 100 g^{-1}. Betwen 52.2 and 440.88 µg STXeq 100 g^{-1}.	30.5		No human intoxications recorded. Fast response from Acapulco public health authority	Gárate-Lizarraga *et al.*, 2013a
Noctiluca scintillans (613 × 103 cells/L; Fig. 6), *Gymnodinium catenatum* (197 cells/L; Fig. 5), and diatoms *Guinardia delicatula* (83 × 103 cells/L).					27 and 26.3.	0.27–0.7 µM PO_4 1.04–2.2 µM NH_4, 2.9–6 µM NO_2	No reports of impact on health, economy or fauna were issued	Gárate-Lizárraga, *et al.*, 2013b
Gonyaulax spinifera. 401 to 1342 × 103 cells/L	Yes, YTX	2012	Ensenada de La Paz, Gulf of California		20		No observed impact	Gárate-Lizárraga *et al.*, 2014
Levanderina fissa (163 a 265 × **10**3 cells/L) *Polykrikos hartmannii* (16 - 33 × 103 cells/L)					29.5 -31			Gárate-Lizárraga, 2014 b

Pseudo-nitzschia spp. (2.4 × 106 cells/L), *Thalassiosira eccentrica* (2.3 × 106 cells/L) and *Chaetoceros* spp. (9.65 x 105 cells/L).	Domoic acid Ichthyo-toxic	2006	Bahia de La Paz, Gulf of California	Chocolate clam *Megapitaria squalida* (0.55 µg g–1 domoic acid, and white clam *Dosinia ponderosa* (0.06 µg g–1 domoic acid)	Increase from 19.0 to 27.0	Inorganic nitrogen 1.0 ± 0.6 µM and $Si(OH)_4$ 15.5 ± 8.0 µM.	Dead fish by suffocation	López-Cortés *et al*., 2015b

Table 3.- Distribution of main toxic HAB causing species in Mexican coasts, a
references.

Species	Distribution	Reference
	Paralytic toxins (PSP)	
	Mexican Caribbean and Yucatan	
	San Felipe, Dzilam and Progreso	Barón-Campis *et al.*, 2
Alexandrium spp.	Costa Norte, Yucatan	
	North Pacific and Gulf of California	
	San Felipe-Puertecitos,	COFEPRIS
	Mexicali, Baja California.	COFEPRIS
	Bahía de Ohuira, Sinaloa	
	South Pacific	
	Tonalá and Puerto Madero, Chiapas.	COFEPRIS
	South Pacific	
Alexandrium minutum	Salina Cruz and Salinas del Marques, Tehuantepec, Oaxaca.	COFEPRIS
	North Pacific and Gulf of California	
	San Felipe-Puertecitos, Mexicali,	COFEPRIS
	Baja California	COFEPRIS
	San Felipe and High Gulf of California,	COFEPRIS
	Mexicali, BC	Band-Schmidt *et* al., 2
	Bahía de San Quintin, Laguna de	Band-Schmidt *et* al., 2
	Guerrero Negro, BCS.	Band-Schmidt *et* al., 2
	Puerto Libertad	COFEPRIS, Band-Schm
	Bahía Kun Kaak	*al.*, 2010*
	Bahía de Los Angeles	COFEPRIS
	Bahía de la Paz, BCS,	Band-Schmidt *et al.*, 2
	El Tecolote to El Burro.	Band-Schmidt *et al.*, 2
Gymnodinium catenatum	Bahía Concepción	COFEPRIS
	East coast of BC	Band-Schmidt *et al.*, 2
	Bahía Magdalena-Almejas	COFEPRIS
	Bahía Kino, Sonora	COFEPRIS
	Golfo de Santa Clara, Estero Morua,	COFEPRIS
	La Cinita, Bahía Salina, Bahía San	COFEPRIS
	Jorge to San Francisquito, Sonora.	Band-Schmidt *et al.*, 2
	Bahía de Mazatlan and Estero Urias,	and COFEPRIS
	Sinaloa;	Band-Schmidt *et al.*, 2
	Monumento al Pescador to	Band-Schmidt *et al.*, 2
	El Faro and Playa Norte, Bahia de	Band-Schmidt *et al.*, 2
	Mazatlan, Sinaloa.	Band-Schmidt *et al.*, 2
	Mazatlán, Sinaloa.	

	Bahía Altata Norte and Bahía Ensenada	*al.,* 2010*
	Pabellones,	
	Navolato, Sinaloa	Band-Schmidt *et al.,* 2
	Santa María- La Reforma Angostura,	COFEPRIS
	Sinaloa	COFEPRIS
	Pto. Vallarta, Jalisco,	COFEPRIS
	Nuevo Vallarta, Nayarit.	COFEPRIS
	Bahia de Matachen	Band-Schmidt *et al.,* 2
	Bahías de Manzanillo and Santiago,	
	Colima.	
	Bahía de Manzanillo, Colima.	
	San Blas and Puerto Vallarta	
	Puerto Vallarta, Jalisco	
	El Malecón, Puerto Vallarta, Jalisco.	
	Hotel Sheraton, Puerto Vallarta, Jalisco	
	Bahía de Perula, Jalisco.	
	Bahía Banderas	
	South Pacific	
	Lázaro Cardenas, Michoacán	COFEPRIS
	Bahia de Acapulco, Guerrero	COFEPRIS, Band-Schn
	Costa Chica, Bahía de Acapulco and	*al.,* 2010*
	Costa Grande, Guerrero.	COFEPRIS
	Salina Cruz and Salinas del Marques,	COFEPRIS
	Tehuantepec, Oaxaca.	COFEPRIS
	Bahia Sta. Cruz, Playa Tangolunda,	Band-Schmidt *et al.,* 2
	Playa Cacaluta, Playa el Organo, Pta.	Band-Schmidt *et al.,* 2
	Colorada, Oaxaca	Band-Schmidt *et al.,* 2
	Puerto Escondido a Huatulco	Band-Schmidt *et al.,* 2
	Laguna Corralero Alotengo, Oaxaca	Band-Schmidt *et al.,* 2
	Salina Cruz to Chiapas	COFEPRIS
	Golfo de Tehuantepec	
	Costas de Salina Cruz	
	Municipios de Tapachula Pijijiapan,	
	Mazatan and Tonala Chiapas	
	North Pacific and Gulf of California	
Gymnodinium mikimotoii	Bahía de Manzanillo, Colima	COFEPRIS
	North Pacific (and Gulf of California)	
	Bahía de Santiago, Colima	COFEPRIS
Pyrodinium bahamense		
	South Pacific	
	Costa Chica, Bahia de Acapulco,	COFEPRIS
	La Colorada, Santiago Astata,	COFEPRIS
	Bahía La Ventosa, Salina Cruz	COFEPRIS
	and Playa Punta Colorada,	COFEPRIS
	San Pedro Mixtepec, Oaxaca.	

	Tapachula, Chiapas	
	North Pacific and Gulf of California	
	Rincón de Ballenas, BC	COFEPRIS
Pyrodinium bahamense var. *compressum*	Magdalena-Almejas to Gulf of Tehuantepec, and Bahia de La Paz	COFEPRIS
	South Pacific	
	Oaxaca, Chiapas, Guerrero and Michoacán	Band-Schmidt *et al.*, 2011*
	Costa de Guerrero.	COFEPRIS
	Bahía de Acapulco Costa Chica	COFEPRIS
	and Costa Grande, Guerrero	COFEPRIS
	Bahía de Huatulco, Oaxaca	COFEPRIS
	Salina Cruz and Salinas del Marques,	COFEPRIS
	Oaxaca	COFEPRIS
	La Colorada, Santiago Astata,Oaxaca	COFEPRIS
	Oaxaca: Santa Maria Huatulco, San	COFEPRIS
	Pedro Pochutla, Santa Maria Tonameca, Santa María Colotepec, San Pedro Mixtepec, Santiago, Pinotepa Nacional and Villa de Tututepec, Melchor Ocampo, Suiate, Tapachula and Mazatan, Chiapas	COFEPRIS
	Gulf of Mexico	
		COFEPRIS
	Mexican Caribbean	COFEPRIS
Pyrodinium bahamense	**North Pacific and Gulf of California**	
	Southern Gulf of California	COFEPRIS
	South Pacific	
	Michoacan	COFEPRIS
	Coasts of Guerrero	COFEPRIS
	Gulf of Tehuantepec, Oaxaca	COFEPRIS
	Ácido Domoico	
	Mexican Caribbean	
	Dzilam de Bravo and San Felipe, Yucatan.	COFEPRIS
	North Pacific and Gulf of California	
	Rincón de Ballenas, Baja California	COFEPRIS
	Estero Coyote, Localidad de Punta	COFEPRIS
Pseudo-nitzschia spp.	Abreojos, BC.	COFEPRIS
	North of Bahía de La Paz: El cayo,	COFEPRIS
	Punta Estero, Boca del estero,	COFEPRIS
	El Pardito Isla Sur, Francisquito	COFEPRIS
	and El Portugues, BCS	Gárate-Lizárrag
	Punta Abreojos, Estero Coyote, BCS	*et al.*, 2016b*
	Frente a Bahía Magdalena, BCS.	

	Quimixto, Los Arcos, Paredon, and	
	Colorado, Malecon Hotels Sheraton	
	Velas en Puerto Vallarta, Jalisco.	
	South Pacific	
	Tapachula and Puerto Madero,	COFEPRIS
	Pijijiapan, Mazatan, and	COFEPRIS
	Tonala, Chiapas, Tapachula, Chiapas	
Pseudo-nitzschia / Thalassiosira	**North Pacific and Gulf of California**	
	Bahía de La Paz, BCS	COFEPRIS
Pseudo-nitzschia seriata *Pseudo-nitzschia pungens**	Bahia Ballenas*	COFEPRIS
	Mexican Caribbean	
	Puerto de Dzilam, Yucatan	COFEPRIS
	North Pacific and Gulf of California	
Pseudo-nitzschia delicatissima	San Ignacio, BCS	Gárate-Lizárraga *et c*
	Brevetoxin (NSP)	
	Gulf of Mexico	
	Tamaulipas, Veracruz and Tabasco	Band-Schmidt *et al*
Karenia brevis	San Fernando, Tamaulipas.	COFEPRIS
	Playa Bagdad, Matamoros, Tamaulipas	COFEPRIS
	and Panuco and Tuxpan, Veracruz.	COFEPRIS
	Complejo Lagunar Carmen-Machona	COFEPRIS
	Pajonal and Laguna de Mecoacáan, and Centla, Tabasco	COFEPRIS
	Miarmar, Pico de Oro, Centla, Tabasco	
	Mexican Caribbean	
	Puerto de Dzilam, Yucatan	Band-Schmidt *et al*
	Yucatan	COFEPRIS
Chatonella spp.	**North Pacific and Gulf of California**	
	Bahía de La Paz, BCS	Band-Schmidt *et al*
	Bahía de Kun Kaak, Sonora; Sinaloa	Band-Schmidt *et al*
	Okadaic acid	
	Gulf of Mexico	
	Complejo Lagunar Carmen-Machona, Tabasco	COFEPRIS
Prorocentrum sp.	**North Pacific; Gulf of California**	
	Rincón de Ballenas, Bahia Todos	COFEPRIS
	Santos, Baja California	COFEPRIS
	Bahía de San Quintin, Laguna	COFEPRIS
	Guerrero Negro	COFEPRIS
	Estero el Coyote and Estero el Cardon, BCS	
	Bahías de Manzanillo and Santiago, Colima	

	Gulf of Mexico	
Prorocentrum gracile	Complejo Lagunar Carmen-Machona, Tabasco	COFEPRIS
	Mexican Caribbean	
Prorocentrum lima	Puerto de Dzilam, Yucatan	COFEPRIS
	North Pacific and Gulf of California	
	El Pardito, BCS	Band-Schmidt *et al*
	North Pacific and Gulf of California	
Prorocentrum micans	Estero el Coyote, Pta. Abreojos, BCS	COFEPRIS
	Estero la Bocana, Mulege, BCS	COFEPRIS
	Bahías de Manzanillo and Santiago, Colima	COFEPRIS
	North Pacific and Gulf of California	
Dipnophysis spp.	Bahía de San Quintin, Laguna de Guerrero Negro, BC.	COFEPRIS
		COFEPRIS
	Rincon de Ballenas, Bahia Todos Santos, Baja California.	COFEPRIS
		COFEPRIS
	Bahías de Manzanillo, Colima	COFEPRIS
	Bahía de Perula, Jalisco.	
	Palo María, Puerto Vallarta, Jalisco	
	North Pacific and Gulf of California	
Dipnophysis caudata.	Manzanillo and Santiago, Colima	COFEPRIS
	Bahía la Manzanilla, Puerto Vallarta and Tehuamixtle, Jalisco.	COFEPRIS
	South Pacific	
	Bahía Sta. Cruz, Playa Tangolunda, Playa Cacaluta, Playa el Organo, Pta. Colorada, Oaxaca	COFEPRIS
	Ciguateras	
	Mexican Caribbean	
Gambierdiscus toxicus	Cozumel, Q. Roo	Núñez-Vázquez *et*
	Parque El Garrafón,	Núñez-Vázquez *et*
	Isla Mujeres Club Med., Cancun,	Núñez-Vázquez *et*
	Pat O'Brien's, Cancun, Q. Roo	Núñez-Vázquez *et*
	Cozumel, Q. Roo	Núñez-Vázquez *et*
	Mexican Caribbean	
Gambierdiscus caribaeus	Cancun, Q. Roo	Núñez-Vázquez *et*
Gambierdiscus carpenteri	**Mexican Caribbean** Cancun, Q. Roo	Núñez-Vázquez *et*
Gambierdiscus carolinianus	**Mexican Caribbean** Cancun, Q. Roo	Núñez-Vázquez *et*

Modified after: Barón-Campis *et al.*, 2014*; Band-Shmidt *et al.*, 2010**; Band-Shmi 2011***; Gárate-Lizárraga *et al.*, 2016b; Núñez-Vázquez *et al.*, 2019.

Table 4.- First records of HAB causing dinoflagellates in Mexican coasts, and references

Species	Toxic	Year	Locality	T°C	Salinity	Reference
Cochlodinium catenatum (10 841 000 cell/L)	Yes, ichthyotoxic	2004	Bahia de Banderas	25-32	33-35 ups,	Cortés-Lara *et al*., 2004
Pro*rocentrum mexicanum* (3 135 200 cell/L)	Yes	1997	Bahia de La Paz	24.5		Gárate-Lizárraga y Martínez-López, 1997
Mesodinium rubrum (64,000 – 1 000 000 cell/L)		2002	Bahía de Banderas			Cortés-Lara, 2002
Peridinium quinquecorne (2.5 x 10^6 cell/L)		2002	Veracruz	26.3	34 ups	Barón-Campis *et al*., 2005
Polykrikos kofoidii		2007	Magdalena-Almejas			Gárate-Lizárraga *et al*., 2007a
Cochlodinium catenatum (10 841 000 cell/L)	ichthyotoxic	2004	Bahia de Banderas	25-32	33-35 ups	Cortés-Lara *et al*., 2004
Prorocentrum mexicanum (3 135 200 cell/L)	Yes	1997	Bahia de La Paz	24.5		Gárate-Lizárraga y Martínez-López, 1997
Mesodinium rubrum (64,000 – 1 000 000 cell/L)		2002	Bahía de Banderas			Cortés-Lara, 2002
Peridinium quinquecorne (2.5 x 106 cell/L)		2002	Veracruz	26.3	34 ups	Barón-Campis *et al*., 2005
Polykrikos kofoidii		2007	Magdalena-Almejas			Gárate-Lizárraga *et al*., 2007a
Nematodinium armatum, *Dinophysis odiosa*, *Metaphalacroma skogsbergii*, *Amphidoma caudata*, *Amphidoma* sp., *Protoperidinium turbinatum*						
Rhizosolenia debyana (2,576,000 - 3,684,000 cell/L)				26		Gárate Lizárraga *et al.* ,2003
Protoperidinium ovatum			Laguna de Tamiahua, Veracruz			Figueroa-Torres; Weiss-Martínez, 1999
Gyrodinium instriatum (796 y 2120 × 103 cell/L)			Bahia de Acapulco, Guerrero	24.4	33.13	Gárate-Lizárraga *et al*., 2013
Amoebophrya ceratii (200 000 cell/L)			Bahia de La Paz	26		Gárate-Lizárraga *et al*., 2006
Spatulodinium pseudonoctiluca			Bahia de Los Angeles; Loreto; Bahía de Mazatlan, Gulf of California; Bahia de Acapulco, Guerrero; Salina Cruz, Oaxaca, Mexican Pacific			Gárate-Lizárraga, 2011
Trichodesmium thiebautii		2010	Bahia de la Paz			Gárate-Lizárraga, & Muciño-Márquez, 2012.

Amphidiniopsis hirsuta, Amphidiniopsis sp.*, Amylax buxus, Cochlodinium pulchellum, Cochlodinium virescens, Durinskia* cf. *baltica, Gyrodinium* sp.*, Thecadinium* sp., *Prorocentrum minimum* var. *triangulatum*	*Prorocentrum minimum*, neurotoxins and hepathotoxins	2011	Bahia de la Paz	20		Gárate Lizárraga, 2012
Gyrodinium instriatum 796 y 2120 × 103 *cell*/L.	Harmful	2012	Bahia de Acapulco Guerrero	24.4 - 33.13	33.13	Gárate-Lizárraga, *et al*., 2013b
Gonyaulax hyalina, Gonyaulax birostris and *Gonyaulax fusiformis; Gonyaulax cochlea* and *Lepidodinium chlorophorum; Pterosperma* sp., *Arcuatasigma challengeriense*		2012	Gulf of California	20	35.5	Gárate-Lizárraga, *et al*., 2014
Amylax triacantha		2016-2013	Bahia de Los Ángeles, Bahía San Lucas, Loreto, Bahia de Acapulco and Salina Cruz, Oaxaca	21-25		Gárate-Lizárraga, 2014a
Amylax triacantha var. *buxus*			Cuenca Alfonso, Bahía de Los Ángeles, Bahia San Lucas and Salina Cruz.	21-25		Gárate-Lizárraga, 2014a
Ankistrodinium semilunatum and *Sclerodinium calyptroglyphe,* *Pronoctiluca acuta,* *Prorocentrum robustum*			Mexican Pacific Gulf of California Bahia de La Paz.	29.5- 31	34.4-34.82.	Gárate-Lizárraga, 2014b.