

# Seafood and Shellfish Poisoning: A Review

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**Abstract:** Seafood and shellfish poisoning is a consequence of ingestion of poisonous seafood contaminated with marine biotoxins. Marine biotoxins are secreted by phytoplanktons, which often manifest themselves as unaesthetic mushy growth on the surface of water bodies commonly referred to as harmful algal blooms (HABs). HABs are essential food sources for crustaceans such as shrimps, crabs and lobsters and molluscs such as clams, mussels, scallops, oysters and octopus. This review has given an explicit and current account on the types, mode of action, symptoms, diagnosis and detection of toxins. Additionally, a comprehensive account on the significant economy and health impact due to prevalence of HABs has been provided. The review exposes the need of improvement in detection and monitoring techniques of the toxins.

**Keywords:** Seafood, Shellfish, Poisoning, Marine biotoxins, Harmful algal blooms

## Introduction

Sea food and shellfish poisoning in humans is caused by marine toxins majorly produced by phytoplankton, namely dinoflagellates and diatoms. Due to the high nutritional value of shellfish and seafoods, including high levels of polyunsaturated fatty acids (PUFAs), especially omega-3 fatty acid, they are considered as superfoods (Furey et al., 2010). Harmful algal blooms abbreviated as HABs are a result of proliferation of algae which is directly associated with the presence of marine biotoxins (Nicolas et al., 2017). The biotoxins secreted internally by phytoplanktons are ingested by smaller and bigger fishes. The phenomena of bioaccumulation is observed in the marine food chain (Hess, 2010; Gerssen et al., 2009). Concentration of toxin reaches maximum on accumulation in humans. The toxins have been classified on the basis of the symptoms observed – Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), Neurotoxic Shellfish Poisoning (NSP) and Amnesiac Shellfish Poisoning (ASP) (Ciminiello and Fattorusso, 2006; Watkins et al., 2008). The type of toxin present and carrier fish forms basis of another classification- Ciguatera Poisoning, Scombroid (Histamine) Poisoning, Pufferfish poisoning. Other toxins include azaspiracids (AZA), platytoxin (PLTX) and cyclic amines. Marine biotoxins are resistant to heat and processing methods. Several detection and monitoring methods have been developed for analysis of the toxins (Daguer et al., 2018). Although toxic algal blooms are entirely natural occurrences that have toxic algal Bloom's, in a strict sense. Throughout the documented history, both on a global scale (Hallegraeff, 1993) and within the Australasian region (Hallegraeff, 1992), the public health and economic impacts of such events seem to have increased in frequency, severity and geographical spread over the past two decades. Since the mid-1980s, the Australian seafood industry and, since 1993, the New Zealand seafood industry have become aware of the possible hazards of algal biotoxin contamination of cultured and wild shellfish. There have been occasional reports of shellfish poisoning historically; Captain Vancouver reported one fatal incident that occurred in British Columbia in 1793 and the earliest scientific reference to shellfish poisoning appeared in 1851 (Chevallier A., 1851). Shellfish consumption prohibitions are found in many cultures, and this, along with religious beliefs, has restricted the position of shellfish as a potential source of food. Mouse bioassay (MBA) is used worldwide as per AOAC guidelines but alternative techniques are being developed to majorly combat the ethical issues presented by MBA.

## Paralytic Shellfish Poisoning

It is considered the most harmful and widely distributed toxin with a highly frequent occurrence worldwide, from north-eastern American and western European coast to tropical Malaysian and north-eastern Asian coast (Kwon et al., 2020). Earliest record dates back to 1793 and was followed by mussels ingestion (Ansdell, 2019). *Alexandrium spp.* (*A. fundyense*, *A. tamarense*, *A. catenella*, *A. minutum*, *A. ostenfeldii*, *A. angustitubulatum*) *Gymnodinium spp.* (*G. catenatum*), and *Pyrodinium spp.* (*P. bahamense var compressum*) are the algal species majorly responsible for the poisoning incidents (Huang et al., 2020). *Alexandrium spp.* is the major causative species in the dinoflagellate genera (Anderson et al., 2012). This class of toxin consists of more than 20 derivatives, each differing in toxicity factor. It can be classified into 4 types on the basis of R4 molecular structure (Pomati et al., 2004), namely,

1. Carbamate toxin: saxitoxin (STX), gonyautoxins (GTX1&4, GTX2&3) and neosaxitoxin (NEO).
2. N-sulfocarbamoyltoxin: gonyautoxins (GTX5) and di-sulfated (C1&C2) toxins.
3. Decarbamoyltoxin: decarbamoyl-saxitoxin (dcSTX) and decarbamoyl-gonyautoxins (dcGTX1&4, dcGTX2&3)
4. Deoxy-decarbomylated-gonyau-toxin

Saxitoxin is the most harmful and potent toxin of all (Pomati et al., 2004). Mouse LD50 is 3-10 mcg/kg. US/EU regulatory limit has been specified as 800 mcg/kg. (Ching et al., 2015; Manila bulletin, 2013). In a study, a link between the interspecific competition between diatoms and dinoflagellates and the PSP outbreak was established (Kwon et al., 2020). The areas of severe PSP outbreak were enriched with organic nutrients with relatively low saline content than the areas of weak PSP outbreak. Past records indicate a higher occurrence of PSP above 30° north and below 30° south but there has been a recent increase in El Salvador, Guatemala, Singapore, Thailand, India, etc. (Ansdell, 2019).

### Mode of action

Saxotoxin, a tetrahydropurine is composed of two guanidinium fused in a azaketel linkage (Baden and Trainer, 1993). This guanidinium acts as a substitute of sodium ion, blocking the passing of ion through the voltage dependent channel during generation of action potential. As a result, generation of impulse is stopped in skeletal muscles and peripheral nerves (Llewellyn, 2006; Baden and Trainer, 1993) Neutral pH promotes optimum growth of the toxin (Hille, 1968; Narahashi et al., 1969). Na<sup>+</sup> is only affected in case of application at outer nerve membrane (Baden, 1983).

### Clinical Symptoms

Signs and symptoms of PSP occur within 30-60 mins of consuming toxic shellfish but are often delayed for 3 hours or more. Initial symptoms include paresthesias of face, lips, tongue and later spreads to the arms and legs. Affected person may complain of tingling and numbness of the extremities, progressing to muscular incoordination, light headedness or respiratory distress causing death within 12 hours of eating toxic shellfish. Other symptoms may include headache, increased salivation, nausea, vomiting, and diarrhoea (Chand, 2009). Hypertension could also be a vital finding. Severe cases are usually related to ingestion of enormous toxin dosage and clinical symptoms, such as ataxia, dysphagia, rapid pain and anuria (Hallegraef, 1993). It is possible that children could also be more sensitive to PSP toxin than adults. Additionally, the access to emergency medical services in acute cases is crucial to prognosis. Prognosis seems to be good in case of patients who survive for past 12 hours. Patients usually recover within a week but may occasionally be prolonged for several weeks.

### Diagnosis and detection

Diagnosis is based on observation of clinical symptoms, i.e. acute gastrointestinal and neurological symptoms (Chand, 2009). Mouse bioassay is the official method of detecting and analysing the toxin in many countries including Europe and the US. Ethical issues, false positives, time consuming procedure and cost concerns have paved the way for development of alternative screening and detection methods (Kawatsu et al., 2014). Advances in liquid chromatography, such as LC-MS method using HILIC is a highly sensitive and selective technique but a long analysis duration and matrix associated problems make it unsuitable for routine monitoring (Dell'Aversano et al., 2005; Huang et al., 2020). Liu et al. (2020) developed a GCB-SPE and HILUC-HRMS method which was proved to be a reliable, sensitive and accurate method of determining the presence of extracellular PSP toxins in the culture medium of marine dinoflagellates. An ELISA system was developed by Kawatsu et al. (2014) suitable for screening before MBA testing as well as monitoring. The high startup cost was identified as a barrier. Another screening method involving a qualitative indication of PSP toxin presence in shellfish was explored by Turrel et al. (2007). The anti-body based Jellet Rapid Test helped eliminating PSP negative shellfish before proceeding to quantitative method of MBA analysis. HPLC method is not suitable for screening as it is expensive and time consuming but can be used as a substitute to MBA for confirmatory analysis (Kawatsu et al., 2014).

### Diarrhetic Shellfish Poisoning

*Dinophysis spp.* (*Dinophysis fortii*, *Dinophysis acuminata*, *Dinophysis caudate*, *Dinophysis acuta* and *Dinophysis rotundata*) and *Procentrum spp.* blooms are responsible for occurrence of diarrhetic shellfish poisoning (Liu et al., 2011; Chand, 2009). The poisoning can be attributed to a group of toxins derived from okadaic acid, namely dinophysistoxin-1 (DTX1), dinophysistoxin-2 (DTX2) and derived fatty acid acyl esters collectively referred to as DTX3 (Li et al., 2012). Although, pectenotoxins (PTX) and yessotoxins (YTX) were also detected in DSP China outbreak (2011) samples analysed by (Li et al., 2012). YTX mainly targets heart, pancrea, liver and brain cells (Dominguez et al., 2010). PTX is hepatotoxic in nature (Daguer et al., 2018). Frequency of DSP was observed to be more than PSP in an investigation conducted on Chinese shellfish, though the level of toxin was low (Zhou et al., 1999). EU has established a regulatory limit of 160 mcg OA equivalent/kg (Li et al., 2012). 12 mouse units in the minimum concentration of toxin capable of causing diseases in humans (Chand, 2009). LD50 in mice has been reported to be 192 mcg/kg (Tachibana et al., 1982).

### Mode of action

It acts by inhibiting protein phosphatase 1 and phosphatase 2A and phosphorylation stimulation in proteins responsible for controlling sodium secretion by the cells of intestine, resulting in disruption of duodenal paracellular permeability (Chand, 2009; Chevallier et al., 2015; Gerssen, 2010). Increased epithelial permeability results in hyperphosphorylation of kinases and rupture of F-actin. Tissue integrity is also impaired when desosomes are affected by toxin (Vale and Botana, 2008; Tripuraneni et al., 1997; Okada et al., 2000). These hypotheses show a combined effect of inducing diarrhoea. Okadaic acid induces contractions in aorta of rabbit, umbilical arteries smooth muscles of humans (Shibata et al., 1982). It has also been observed in guinea pig's cardiac myocytes that it significantly increases the L-type inward calcium flow (Chand, 2009). Another probable cause of diarrhoea has been identified which involves a neuropeptide Y (Louzao et al., 2015). A confirmed mode of action has not been identified yet. Yessotoxin action can be attributed to four mechanisms – cAMP cellular level modulations, calcium modulation between different compartments of cells, apoptosis and altered protein structure (EFSA, 2008).

### Clinical Symptoms

DSP is characterized by canal symptoms including nausea, abdominal pain, vomiting, and diarrhoea. Symptoms develop within 3 hours after consuming contaminated shellfish and thereby persist for several days (Halstead BW, 1998). Sometimes, headaches and fever may also occur and are usually associated with dehydration. Usually, clinical symptoms of contaminated shellfish are mistaken for those of bacterial gastric infections and the problem may be much more widespread than imagined. In contrast to PSP, no human fatalities have been reported and patients usually recover within 3-4 days (Lee JS et al., 1997). Thus, DSP is considered self-limiting

and non- life threatening (Suganuma et al., 1998). However, a number of toxins concerned may act as abdomen neoplasm promoters and therefore, manufacture chronic issues in shellfish consumers (Lee JS et al., 1997).

### Diagnosis and detection

Japan uses MBA using intraperitoneal toxin extract injections (Chand, 2009). LC-MS/MS and HPLC has been used in detection and analysis of DSP. Though HPLC is used for monitoring in Sweden but the high cost and time-consuming nature necessitates innovation in the field of monitoring programs for lipophilic toxins (Lee et al., 1989; Li et al., 2012). An alternative to MBA is also required in order to avoid false positives (Li et al., 2012).

### Neurotoxic Shellfish Poisoning

Molluscs are contaminated by a class of cyclic polyether toxins called brevetoxins (Baden et al., 2005). Brevetoxins are heat stable toxins produced by dinoflagellate *Karenia brevis* and *Gymnodinium breve* (Abraham et al., 2008). Death of *G. breve* produces neurotoxins (Baden et al., 1995). This species is also responsible for the red tides which is fatal to marine animals and sea birds (Nicholas et al., 2017). Its earliest mention dates back to 1844, Florida west coast (Andsell, 2019). Its symptoms portray an uncanny resemblance to ciguatera poisoning and PSP (Andsell, 2019). Hemolytic and neurotoxin together compose brevetoxin (Poli et al., 1986). Backbone structure forms the basis of classification (Abraham et al., 2008). PbTx-2 is majorly produced followed by PbTx-1 and PbTx-3 (Chand, 2009). These toxins are passed out of human body through urinary disposal. Metabolites of the toxin were detected in the urine with BTX-3 showing highest LC-MS/MS sensitivity and selectivity (Abraham et al., 2008). This proves the potential of BTX-3 as a biomarker of NSP. Mouse LD50 of brevetoxin is 0.20 mg/kg (Chand, 2009). No fatalities have been reported till now. NSP is geographically restricted to east coast of Florida, the Caribbean, Gulf of Mexico and New Zealand, though there are chances of future occurrence in other parts of the world (Stommel et al., 2004, Andsell, 2019).

### Mode of action

Polycyclic ethers that bind to and depolarize nerve and muscle, opening Na<sup>+</sup> channels which leads to the increase in Na<sup>+</sup> influx into the cell (Baden and Trainer, 1993). Site 5 of alpha-subunit Na<sup>+</sup> channels is activated by the toxin resulting in inhibition of neuromuscular transmission due to the blockage of ion conduction created at neuromuscular junction (Ramsdell, 2008; Munday, 2017). This leads to paralysis of limbs and respiratory issues. This can be reversed by tetrodotoxin and saxitoxin (Baden and Trainer, 1993).

### Clinical Symptoms

NSP is characterized by channel symptoms as well as diarrhoea and vomiting. Some neurologic symptoms include tingling and symptoms of lips, tongue, and throat, muscular aches and dizziness. Moreover, eye and nasal membrane irritation may occur, caused chiefly by exposure to sea-spray aerosols and by direct contact with hepatotoxic algal blooms while swimming (Fleming and Baden, 1999). Symptom onset after ingestion, ranges from quarter-hour to 18 hours and therefore, the period of toxicity ranges from 1-72 hours (usually 24 hours). Symptoms such as tremor, dysphagia, motor weakness, bradycardia, decreased reflexes, and mydriasis may also occur.

### Diagnosis and detection

It is majorly based on clinical symptoms. MBA, antibody immunoassay and ELISA have been used to detect and analyse the toxin (Chand, 2009). These toxins are difficult to detect. A confirmatory method has been designed by Abraham et al. (2008) which structurally characterizes the metabolites of brevetoxin excreted through urine by LC-MS/MS. There is a need for development of simple and rapid confirmatory tests for this toxin.

### Amnesiac Shellfish Poisoning

*Pseudonitzschia spp.* (*P. Multiseries*, *P. Australis* and *P. pungens*) and *Nitzschia pungens* produces a heat stable toxin called domoic acid (Andsell, 2019). Its presence has also been detected in *Chondria armata* and *Alsidium corallium* (Fattorusso and Piattelli, 1980). In 1987, over 100 people in Canada were affected after consumption of mussels harvested off Prince Edward Island (Perl et al., 1990). Four fatalities were reported. This was followed by death of pelicans and cormorants of Monterey Bay, California and detection of toxin in Dungeness crabs and razor clams of Oregon and Washington coasts in the year 1991 (Chand, 2009). The species and toxin are found in Gulf of Mexico and in East coast shellfish respectively. Domoic acid potency in animals is 3 times more than kainic acid and 30-100 times more than glutamic acid (Chand, 2009).

### Mode of action

Neuronal depolarization is caused by Na<sup>+</sup> influx, K<sup>+</sup> efflux, increased levels of Calcium in cells and decreased synthesis of ATP as a result of alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid and kainic acid receptors activation caused by binding of domoic acid, in brain (Berman and Murray, 1997; Munday, 2017). This also results in development of reactive oxygen and nitrogen species which have been identified as the causative agents of neuronal damage observed on ingestion of the toxin (Munday, 2017). Hippocampus necrosis, brain lesions and amygdala has been reported in humans ASP cases (Teitelbaum et al., 2004).

### Clinical Symptoms

Gastroenteritis, accompanied by headache and short-term memory loss, confusions, hallucinations and disorientation are some common symptoms (Todd, 1993). Acute gastro-intestinal and neurological symptoms include vomiting, extreme diarrhoea,

abdominal cramps, ophthalmoplegia, motor and sensory motor neuropathy. Some patients have experienced cognitive long term dysfunction. Four deaths occurred, all in patients older than 70 years of age (Teitelbaum et al., 1990).

### Diagnosis and detection

Presence of domoic acid in shellfish can be confirmed by MBA, LC-MS, HPLC and ELISA techniques (Lawrence et al., 1989).

### Ciguatera Poisoning

Dinoflagellate *Gambierdiscus toxicus* and *Fukuyoa spp.* has been identified as the species responsible for ciguatera poisoning (Ansdell, 2019; Chinain et al., 2020). They grow on marine algae which feeds on dead coral reef and detritus (Rains and Parsons, 2015; Yong et al., 2018). Ciguatoxin, scaritoxin and maitotoxin are highly heat stable, lipid soluble and practically indestructible in nature (Ansdell, 2019). Earliest documentation of this poisoning dates back to 1601 in Mauritius (Chinain et al., 2020). Concentration of these toxins is maximum in GI tract, liver, head and roe (Ansdell, 2019). The part and amount of fish consumed, and previous exposure to toxin are the major factors influencing severity of the poisoning. Toxin accumulation and immune sensitization as a result of previous exposure seems to increase severity of poisoning in the next episode of poisoning (Ansdell, 2019). It is majorly concentrated between latitudes 35° north and 35° south (Ansdell, 2019). Caribbean Sea, Indian and Pacific Ocean, western Gulf of Mexico, Canary Islands and the eastern Mediterranean Sea are the high risk areas (Chinain et al., 2020; Ansdell, 2019). It is the most common marine poisoning with case count reaching upto 50,000-5,00,000 annually. Both carnivorous fishes such as snapper, baracuda, grouper, jack and herbivorous fishes such as parrotfish and surgeonfish are responsible (Ansdell, 2019). Certain marine invertebrates have also been detected with CTX (Rongo and van Woesik, 2011; Mak et al., 2013; Díaz-Asencio et al., 2019a; Kintzing and Butler, 2014). Mouse LD50 is 0.45 mcg/kg (Tachibana, 1980). The shortage of certified standards for ciguatoxins is a very important obstacle for implementation of legal regulations.

### Mode of action

Action is similar to brevetoxins, where binding of CTX takes place at site 5 of sodium channels resulting in blockage of neuromuscular transmission (Nicholson and Lewis, 2006; Lewis et al., 1993). The blockage is due to increased internal Na<sup>+</sup> concentrations. This is facilitated by continuous opening of and inability to close Na<sup>+</sup> channels during subsequent depolarization (Baden and Trainer, 1993). The ciguatoxin replaces Ca<sup>+</sup> at receptor sites responsible for Na<sup>+</sup> permeability control (Miller et al., 1984).

### Clinical Symptoms

There have been reports of a wide variety of symptoms, including symptoms of deep fatigue, sweating, chills, arthralgia, myalgia, along with a metallic taste in the mouth. There is normally an acute gastro-intestinal disorder, accompanied by the signs of neurology. There may be cardiovascular signs including an irregular pulse and low blood pressure. The onset of symptoms normally occurs within 1-3 hours on consumption of contaminated fish, but may occur within 15-30 minutes or may be delayed for upto 30 hours (Ansdell, 2019). Within 1-4 weeks, most of the symptoms resolve on their own. Some neurologic symptoms can linger for months in extreme cases and may recur for years.

### Diagnosis and detection

Diagnosis is based on clinical symptoms. ELISA, and radioimmunoassays are used for detection purposes. Rapid test kits are not commercially available (Ansdell, 2019).

### Scombroid (Histamine) Poisoning

Scombroid poisoning administers itself as a severe allergic response. High levels of histidine in fish is converted to histamine by bacteria, including *Morganella morganii*, *Klebsiella pneumoniae*, *Escherichia coli*, *Aerobacter aerogenes*, and *Plesiomonas shigelloides*, optimally at 20-30°C as a result of improper refrigeration or freezing after harvest (Ansdell, 2019). The bacteria possess a high histidine decarboxylase activity (Ansdell, 2019). Scombridae family, dark- and red-muscle fishes are the carriers. Mahi-mahi, Bluefin and yellowfin tuna, albacore, saury, mackerel and bonito are some examples (Hungerford, 2010; Feng et al., 2016; Lavon et al., 2005-2007). The toxin cannot be destroyed by cooking, smoking, freezing or canning. Earliest account has been reported by Captain Edmund Fanning in North Atlantic, 1797 (Ansdell, 2019).

### Mode of action

Scombroid symptoms resemble IgE-mediated allergic reaction. The IgE activates the mast cells which in turn react with the allergen to produce mediators which causes the allergic reaction (Ansdell, 2019).

### Clinical Symptoms

The typical symptoms of scombroid poisoning includes flushing, rash, urticaria, palpitations, headache, burning of mouth and throat and dizziness. Gastro-Intestinal symptoms may include abdominal cramps, nausea, vomiting and diarrhoea (Hungerford JM, 2010; Lavon O. et al., 2008). After consuming the infected fish, symptoms begin within 10-90 mins. Imposing rash appears on the neck, face, shoulders and upper back. The rash is a typical form of urticaria but unlike, an allergic reaction there is no healing. The rashes last for 2-5 hours and within 3-36 hours, the other symptoms also vanish.

### Diagnosis and detection

Diagnosis is based on clinical symptoms. Histamine levels in fish are measured by performing confirmatory tests (Ansdell, 2019).

### **Pufferfish Poisoning**

Pufferfish poisoning is a consequence of consumption of tetrodotoxin contaminated fish. It is a water soluble, heat-stable and non-protein toxin which cannot be destroyed by processing (Ansdell, 2019). The bacterial toxin is synthesized by *Actinomyces*, *Alteromonas*, *Aeromonas*, *Pseudomonas*, and *Vibrio spp.* and *Pseudoalteromonas tetraodonis* (Nicolas et al., 2017; Lago et al., 2015; Kaku and Meier, 1995). Pufferfish is the major carrier of this toxin. It is also found in porcupine fish, ocean sunfish, flatworms, starfishes, crabs, molluscs and even in the venom of blue ringed octopus (Ansdell, 2019). Highest concentration of toxin is present in ovaries, intestine, liver and skin. (Ansdell, 2019). Europe has banned the sale of puffer (Nicolas et al., 2017). Pufferfish consumption considered a luxury in Japan since the consumer feels a rush of euphoria and exhilaration on ingestion. Consumption of pufferfish is permitted in Japan and America only if it has been processed and prepared by a professional certified fish cutter. This type of poisoning is mainly restricted to Asia, specifically Japan where 6386 cases were reported with a mortality of 59% between 1886-1963 (Ansdell, 2019). Training, regulations and awareness resulted in a reduction in poisoning cases. Only 1105 cases with 34% mortality were reported between 1967-1976 (Kaku and Meier, 1995). Only few cases have been observed in Europe, South and North America (Cole et al., 2015; Fernandez-Ortega et al., 2010; Silva et al., 2010).

### **Mode of action**

Voltage gated sodium channels are bound by tetrodotoxin at site 1 of alpha-subunit which blocks the Na<sup>+</sup> influx (Narashi, 1988). This prevents generation of action potential and axonal nerve transmission ultimately resulting in respiratory failure and muscle paralysis (Ansdell, 2019).

### **Clinical Symptoms**

The major symptoms of pufferfish poisoning include perioral paresthesias, nausea, dizziness followed by weakness, numbness, ascending paralysis incoordination, thereby leading to respiratory failure and circulatory collapse. The typical onset of symptoms occur within 10 minutes of consumption of contaminated fish or may be delayed for more than 4 hours (Kaku and Meier, 1995). Widespread paralysis, hypotension, bradycardia, and other arrhythmias are found in the most severe cases. Most accidents happen due to breathing failure and occur within the first 6 ppen

### **Diagnosis and detection**

Diagnosis is based on clinical symptoms. LC-MS/MS can be used for analysis and detection of the toxin (Rodriguez, et al., 2018).

### **Economic Impact**

A severe HAB results in business and marine life loss, negatively affects tourism and necessitates fishing restrictions. The added cost of providing medical facility to poisoned citizens and the loss of priceless lives affects the economy. Tourism sector suffers the most in terms of revenue losses (Béchar, 2020). Demand of seafood is thwarted by negative press coverage as discussed by Béchar (2019) where he stated that coastal restaurants may suffer a monthly revenue loss of 2-3% during continuous bloom. Galveston county's marine related industries lost over \$10 million and revenue generated by recreational fishing decreased by \$2 million during the red tide bloom in the year 2000 (Evans and Jones, 2001; Oh and Ditton, 2008). Gulf states were met by a similar fate over a duration of decade, 1994-2004 (Béchar, 2020). New England's fisheries and seafood revenue lost \$2 million in 2005 during a severe HAB (Béchar, 2020). It was estimated that in the year of 2011, oystermen of Calhoun County suffered a loss of \$8000 per boat during each month (Cummins, 2012). According to a study conducted by Béchar (2020) the major reasons behind revenue loss are harvesting and consumption restriction on shellfish and negative coverage of seafood that brings down the demand of unaffected species as well.

### **Health Impact**

A significant global rise in the occurrence of global toxins in seafoods and shellfish have been noted, with many new groups of toxins found in recent years. In recent decades, the effect of ingestion of biotoxins in shellfish on human health has apparently increased (Fleming et al., 2015). There is evidence, although not definitive, suggesting that the rise in HABs is the result of large-scale ecological changes resulting from anthropogenic activities, increased eutrophication, marine transport and aquaculture. A significant proportion of foodborne illnesses are linked to seafood, caused by a number of parasites, viruses and bacteria. The diseases caused by toxin ranges from mild gastroenteritis to the conditions that are life-threatening. Gastrointestinal symptoms such as nausea, vomiting, diarrhoea, gastroenteritis and neurological symptoms such as tingling of hands and thumb, numbness, ascending paralysis, vertigo and many deaths are the usual symptoms of seafood and shellfish poisoning. The frequency and magnitude of occurrence of toxins have been increased, indicating a global risk to public health. Due to the lack of clinical testing methods has contributed to a significant underestimation of the occurrence of human poisonings due to algal toxins, especially because many of the symptoms are similar to viral and bacterial infections. Moreover, only acute poisonings due to algal toxins are recognized and due to prolonged exposure to these toxins, there is very little awareness of the human impacts.

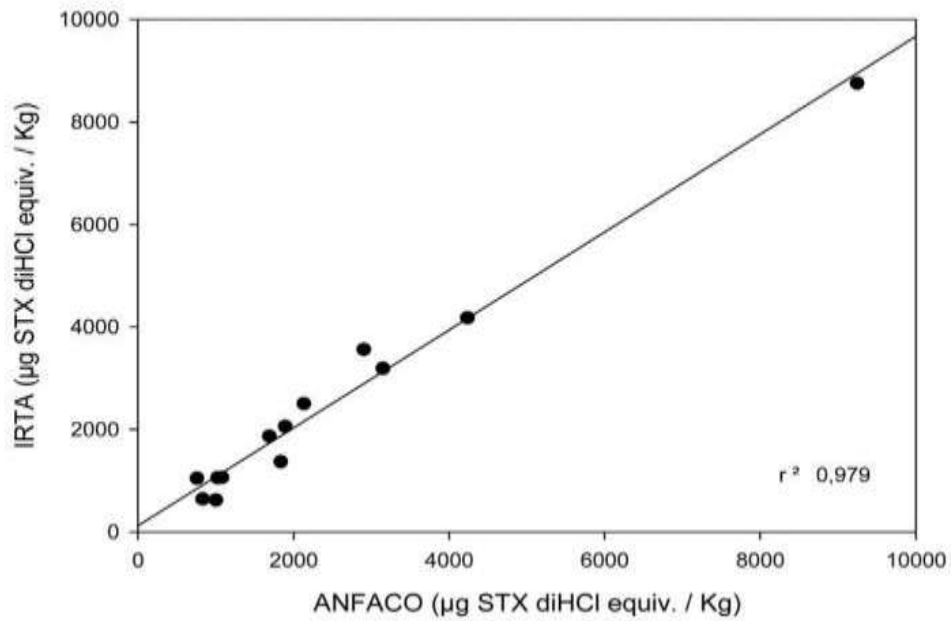


Figure 1: Sigma-plot correlation chart for the total PSP toxicity present in raw bivalves set analyzed by HPLC-FLD (microgram STX diHCL equiv/kg) (n=13) showing a good correlation between results obtained at ANFACO and IRTA laboratories.

Source: Cabado, 2020.

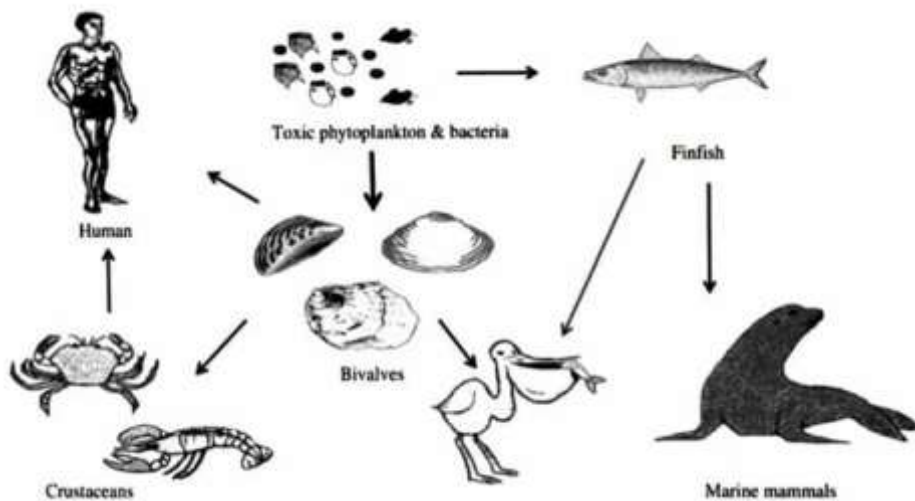


Figure 2: The toxin cycle: Diagram illustrating the interrelationship between harmful algae and shellfish, finfish, birds and mammals. Source: James et al., 2010.

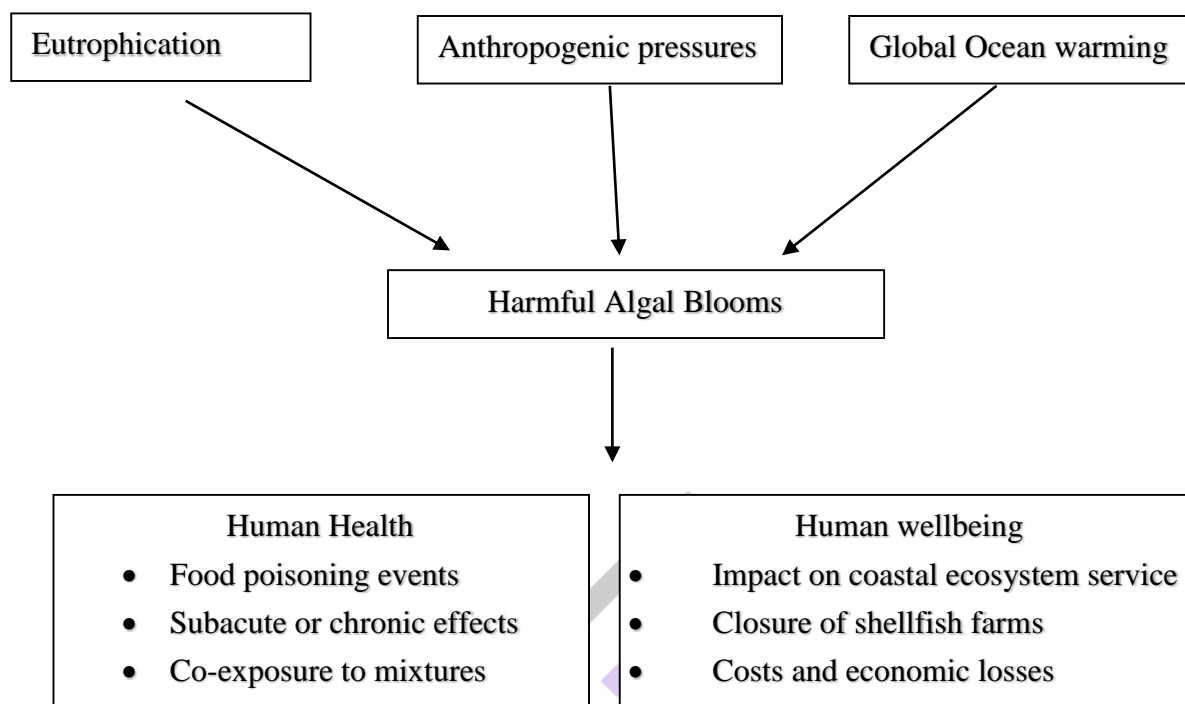


Figure 3: Factors involved in the occurrence of harmful algal blooms and the consequences on human health and well-being.

Source: Berdalet et al., 2015.

### Conclusion

A significant danger to human health is posed by marine biotoxins. The disease can be extremely fatal and serious, life threatening, possibly. Seafood toxins are typically not recognised by the taste, smell, or appearance of infected foods and cannot be eliminated by frying, smoking, freezing, marinating, or brining. There is no reliable cure and care is symptomatic and supportive, with the exception of scombroid (histamine fish poisoning). The mouse bioassay (MBA) is the official tool for the detection of marine biotoxins and demonstrates some limitations due to ethical constraints and inadequate precision. Due to the lack of long-term toxicity research, it has not been possible to assess tolerable daily intakes for any of these marine biotoxins, although an acute reference dose can be calculated. Since these molecules show acute toxicity, they should be considered more suitable. HAB's direct effect on human health is linked to poisoning after ingestion of contaminated fish. As this phenomenon arises from complex interactions, increasing knowledge on human exposure hazards and techniques capable of preventing the occurrence of HAB in seafood must now be understood and strengthened. In an attempt to proactively track the disease at a proactive stage, the crucial problem of educating the medical sector and the general public needs to be tackled as a priority, both nationally and internationally. To encourage greater understanding of the issue, relevant steps and strict laws such as the laws of EU should be taken to enable both early detection of clinical symptoms of toxins. While, it is also important for the industry to carry out quality controls on the finished product in order to ensure that it meets the legal specifications and that the levels of contaminants are safe, this must be done in the same manner as the reference legislation notes. For marine biotoxins, current information on chronic toxicity is very scarce, and further research on the same needs to be performed.

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