Paralytic Shellfish Poisoning: Global Epidemiology, Clinical Manifestations, Management and Emerging Health Challenges – A Narrative Review

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Abstract

Paralytic Shellfish Poisoning (PSP) is a potentially fatal marine toxin-mediated illness resulting from the consumption of seafood contaminated with saxitoxins and related paralytic shellfish toxins. These neurotoxins are primarily produced by harmful algal bloom-forming dinoflagellates of the genera Alexandrium, Gymnodinium, and Pyrodinium, and accumulate in filter-feeding shellfish and other marine organisms. PSP has been reported worldwide and remains an important public health concern, particularly in coastal communities dependent on shellfish harvesting and seafood consumption. Clinical manifestations range from mild perioral paresthesia and gastrointestinal symptoms to severe neuromuscular paralysis and respiratory failure. Diagnosis is largely based on clinical suspicion, exposure history, and laboratory confirmation of toxins in seafood or environmental samples. As no specific antidote is currently available, management remains primarily supportive, with early airway protection and mechanical ventilation being critical in severe cases. The increasing frequency of harmful algal blooms, climate change, expanding seafood trade, and the emergence of novel toxin analogues have contributed to renewed global interest in PSP. This narrative review summarizes the historical background, epidemiology, toxin classification, pathophysiology, clinical manifestations, diagnosis, management, prevention strategies, and emerging public health challenges associated with PSP. Improved surveillance, rapid diagnostic techniques, and multidisciplinary public health interventions are essential to reduce the burden of this potentially life-threatening intoxication. Future directions include artificial intelligence–based outbreak prediction, rapid biomarker-driven diagnostics, investigation of chronic low-dose neurotoxicity, and development of targeted antidotal therapies for saxitoxin poisoning. Future advances may include environmental DNA surveillance, toxin-neutralizing nanotechnology, microbiome-based detoxification, synthetic biology approaches to reduce toxin bioaccumulation, and wearable neurophysiological monitoring systems, potentially transforming PSP prevention, early diagnosis, and therapeutic intervention

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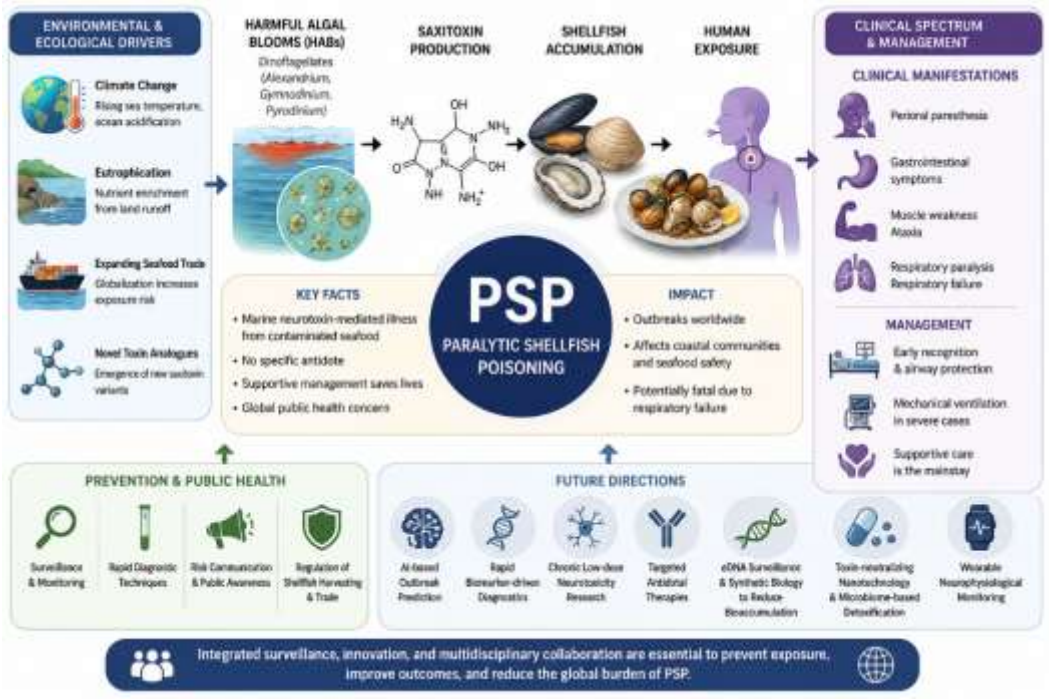

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Introduction

Marine biotoxins represent an important group of naturally occurring toxins that pose significant threats to human health, marine ecosystems, and global food security. Among the various seafood-borne intoxications, Paralytic Shellfish Poisoning (PSP) is recognized as one of the most severe and potentially fatal neurotoxic syndromes. PSP results from the ingestion of shellfish and other marine organisms contaminated with saxitoxins and related paralytic shellfish toxins (PSTs), a diverse family of potent neurotoxins produced primarily by marine dinoflagellates. Owing to their ability to rapidly induce neuromuscular paralysis and respiratory failure, these toxins have attracted considerable attention from clinicians, toxicologists, environmental scientists, and public health authorities.

The principal toxin-producing organisms associated with PSP belong to the dinoflagellate genera Alexandrium, Gymnodinium, and Pyrodinium. Under favorable environmental conditions, these microorganisms can proliferate extensively and form harmful algal blooms (HABs), commonly referred to as “red tides.” During such blooms, large quantities of saxitoxins are released into the marine environment and subsequently accumulated by filter-feeding shellfish including mussels, oysters, clams, scallops, and cockles. Importantly, shellfish contaminated with saxitoxins usually appear normal in appearance, taste, and odor, making toxin exposure difficult to recognize without laboratory testing. Human intoxication occurs following consumption of contaminated seafood, often leading to outbreaks involving multiple individuals.

Paralytic Shellfish Poisoning has been reported from virtually every inhabited continent and is considered a global public health concern. Endemic regions include the coastal waters of North and South America, Southeast Asia, Japan, Australia, New Zealand, and parts of Europe. In recent years, increasing reports from previously unaffected regions have highlighted the expanding geographical distribution of toxin-producing algae. This expansion has been attributed to several factors, including rising sea surface temperatures, oceanographic changes, eutrophication, coastal development, and globalization of seafood trade. Consequently, PSP is increasingly viewed not only as a food safety issue but also as an emerging environmental health challenge associated with climate change.

The toxic effects of saxitoxins arise primarily through blockade of voltage-gated sodium channels in neuronal and muscle membranes. By preventing sodium influx, these toxins inhibit action potential generation and propagation, resulting in sensory disturbances, muscle weakness, paralysis, and, in severe cases, respiratory arrest. Clinical manifestations may appear within minutes to hours after toxin ingestion and can range from mild perioral paresthesia to life-threatening ventilatory failure. Despite decades of research, no specific antidote is currently available, and management remains largely supportive, emphasizing early recognition and prompt respiratory support when necessary.

Although significant advances have been made in shellfish monitoring programs and toxin detection methods, PSP continues to present diagnostic, therapeutic, and public health challenges. Underreporting, limited awareness among healthcare professionals, inadequate surveillance systems in certain regions, and the emergence of novel toxin analogues complicate accurate assessment of the disease burden. [1-7]Furthermore, the increasing frequency of harmful algal blooms worldwide has renewed interest in understanding the epidemiology, clinical characteristics, and prevention strategies associated with PSP.

This narrative review aims to provide a comprehensive overview of Paralytic Shellfish Poisoning, including its epidemiology, toxin classification, pathophysiology, clinical manifestations, diagnosis, management, prevention strategies, and emerging public health concerns. By summarizing current evidence, this review seeks to enhance awareness among clinicians, researchers, and public health professionals regarding this important marine toxin-mediated disease.

Methodology

This narrative review was undertaken to provide a comprehensive overview of Paralytic Shellfish Poisoning (PSP), including its epidemiology, toxin classification, pathophysiology, clinical manifestations, diagnosis, management, and emerging public health concerns. A structured literature search was conducted using PubMed, Scopus, and Google Scholar databases for articles published up to June 2026.

The search strategy employed a combination of Medical Subject Headings (MeSH) terms and free-text keywords including “Paralytic Shellfish Poisoning”, “PSP”, “saxitoxin”, “paralytic shellfish toxins”, “marine neurotoxins”, “harmful algal blooms”, “shellfish poisoning”, “seafood-borne intoxication”, “marine biotoxins”, and “public health”. Boolean operators (AND, OR) were used to refine the search and maximize retrieval of relevant literature.

Eligible publications included original research articles, epidemiological studies, review articles, case reports, surveillance reports, and official publications from recognized public health and environmental agencies. Articles published in English and focusing on human poisoning, toxin-producing organisms, environmental determinants, diagnosis, treatment, prevention, and public health implications of PSP were included. Studies dealing exclusively with unrelated marine toxins, non-human toxicological experiments without clinical relevance, or publications lacking sufficient scientific information were excluded.

Particular emphasis was placed on recent literature published within the last decade to incorporate current evidence regarding climate change, harmful algal blooms, advances in toxin detection, and emerging epidemiological trends. Landmark historical studies and classic reports describing the discovery, toxicology, and clinical presentation of PSP were also reviewed to provide historical context.

Additional references were identified through manual screening of reference lists from relevant articles and review papers. Information extracted from the selected literature was organized into thematic sections addressing global epidemiology, toxin types, pathophysiological mechanisms, clinical manifestations, diagnostic approaches, management strategies, prevention measures, and future public health challenges.
As this study represents a narrative review, formal meta-analysis and quantitative synthesis were not performed. Instead, available evidence was critically summarized and integrated to provide a concise yet comprehensive overview of the current understanding of Paralytic Shellfish Poisoning and its implications for clinicians, toxicologists, environmental scientists, and public health professionals.

Historical Background of Paralytic Shellfish Poisoning
Paralytic Shellfish Poisoning (PSP) is one of the oldest recognized marine toxin-mediated diseases. Indigenous coastal communities in Alaska and the Pacific Northwest were aware of the dangers associated with shellfish consumption long before the condition was scientifically described. Traditional knowledge among Alaska Native populations included warnings against harvesting shellfish during certain seasonal algal bloom events, reflecting centuries of empirical observation of shellfish-associated illness. Historical records suggest that episodes consistent with PSP were recognized in Alaska as early as the late eighteenth century during exploratory voyages along the North Pacific coast.
During the twentieth century, PSP emerged as a major public health concern in several coastal regions worldwide. Recurrent outbreaks were documented in Alaska and British Columbia, where consumption of contaminated mussels and clams resulted in numerous cases of neurological illness and occasional fatalities. Canada subsequently became a leader in marine biotoxin surveillance following multiple shellfish-associated outbreaks. Similar large-scale events were later reported from Chile, where harmful algal blooms caused extensive shellfish contamination and significant economic losses to fisheries and aquaculture industries. In the Asia-Pacific region, major outbreaks were documented in the Philippines and Japan,[8,9] largely associated with blooms of toxin-producing dinoflagellates such as Pyrodinium bahamense and Alexandrium species.
Recognition of the public health importance of PSP led to the gradual development of organized shellfish monitoring programs. Early surveillance relied primarily on observation of algal blooms and animal bioassays. Subsequently, regulatory agencies introduced routine monitoring of shellfish harvesting areas, establishment of maximum permissible toxin limits, and temporary closure of affected fisheries during bloom events. Advances in analytical techniques, including high-performance liquid chromatography (HPLC) and liquid chromatography–mass spectrometry (LC–MS), have significantly improved toxin detection and risk assessment. These developments have contributed substantially to reducing PSP-related mortality in many countries. Nevertheless, increasing harmful algal blooms associated with climate change and expanding global seafood trade continue to pose challenges for surveillance systems and public health authorities worldwide.

Global Epidemiology
Paralytic Shellfish Poisoning (PSP) [10]has been reported from every inhabited continent and remains one of the most widely distributed marine toxin-mediated illnesses. The disease is particularly prevalent in coastal regions where shellfish harvesting and seafood consumption are common. High-incidence areas include Alaska, Canada, Chile, Japan, the Philippines, Australia, New Zealand, and several European countries. Outbreaks are typically associated with harmful algal blooms caused by toxin-producing dinoflagellates such as Alexandrium, Gymnodinium, and Pyrodinium species. Indigenous populations, subsistence fishers, and coastal communities are at increased risk because they frequently consume locally harvested shellfish that may escape routine monitoring. Although improvements in surveillance programs and shellfish monitoring have significantly reduced mortality rates in many countries, underreporting remains a major challenge. The global burden of PSP is therefore likely underestimated. Climate change, rising sea surface temperatures, and expanding harmful algal blooms are expected to further influence the geographic distribution and frequency of PSP outbreaks in the coming decades.
Etiological Agents and Types of Paralytic Shellfish Toxins
PSP is caused by a group of neurotoxic alkaloids collectively termed paralytic shellfish toxins (PSTs). More than fifty toxin analogues have been identified.

Major toxin groups include:
1. Saxitoxin (STX)
2. Neosaxitoxin (NeoSTX)
3. Gonyautoxins (GTX 1–4)
4. Decarbamoyl derivatives
5. N-sulfocarbamoyl toxins

These toxins are produced primarily by dinoflagellates belonging to the genera Alexandrium, Gymnodinium catenatum, and Pyrodinium bahamense. Freshwater cyanobacteria have also been reported to produce saxitoxin-like compounds.[11,12]
Shellfish such as mussels, oysters, clams, scallops, and cockles accumulate toxins through filter feeding. Other marine organisms including crabs, gastropods, puffer fish, and certain finfish may also serve as toxin vectors.

Toxin	Principal Producer	Common Vector	Mechanism
Saxitoxin (STX)	Alexandrium spp.	Mussels, clams, oysters	Sodium channel blockade

Neosaxitoxin	Alexandrium spp.	Shellfish	Sodium channel blockade
Gonyautoxins (GTX)	Alexandrium spp., Gymnodinium catenatum	Shellfish	Sodium channel blockade
Decarbamoyl toxins	Marine dinoflagellates	Shellfish	Sodium channel blockade
Sulfocarbamoyl toxins	Pyrodinium bahamense	Shellfish	Sodium channel blockade

Pathophysiology

Saxitoxins exert their toxic effects by binding to voltage-gated sodium channels located on neuronal and muscle cell membranes. This binding blocks sodium influx and prevents the generation and propagation of action potentials.[13,14]

As a result, neuromuscular transmission becomes impaired, producing sensory abnormalities, muscular weakness, and paralysis. Respiratory muscle involvement can lead to ventilatory failure and death in severe cases.

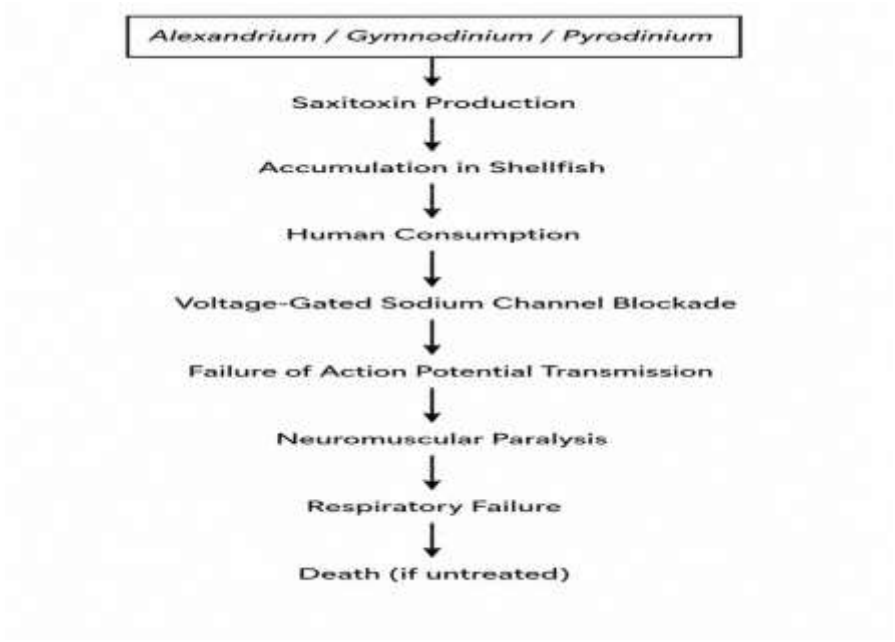
Unlike many foodborne toxins, saxitoxins do not typically cause extensive gastrointestinal injury. Neurological manifestations predominate and often develop rapidly following ingestion.

Clinical Manifestations

Clinical symptoms usually develop within 30 minutes to 4 hours after consumption of contaminated seafood. The severity of illness depends on the toxin concentration ingested, body weight, age, and underlying medical conditions.

In severe intoxication, death may occur within hours if respiratory support is unavailable. Importantly, patients usually remain conscious until late stages because central nervous system depression is not a primary feature.

Severity	Clinical Features	Recommended Management
Mild	Perioral tingling, circumoral numbness, headache, dizziness, nausea, generalized weakness	Observation, symptomatic treatment, oral hydration, and patient education
Moderate	Progressive limb paresthesia, facial numbness, ataxia, dysarthria, muscle weakness, and difficulty walking	Hospital admission, neurological assessment, cardiorespiratory monitoring, and supportive care
Severe	Marked muscle weakness, respiratory distress, hypoxemia, flaccid paralysis, and inability to ambulate	Intensive care unit admission, continuous monitoring, oxygen supplementation, and preparation for airway management
Critical	Respiratory arrest, profound neuromuscular paralysis, and ventilatory failure	Immediate endotracheal intubation, mechanical ventilation, intensive care support, and close hemodynamic monitoring



Diagnosis

Diagnosis is primarily clinical and depends on recognition of characteristic neurological symptoms following recent seafood ingestion.

Key diagnostic components include:

- Detailed dietary history
- Identification of shellfish consumption

• Assessment of symptom onset
• Neurological examination
• Public health notification

Laboratory confirmation may include:

• Detection of saxitoxins in seafood samples
• High-performance liquid chromatography
• Liquid chromatography–mass spectrometry
• Environmental monitoring data

Routine blood investigations are generally nonspecific but may help exclude alternative diagnoses.

Differential Diagnosis

Paralytic shellfish poisoning (PSP) may clinically resemble several acute neurological disorders, including Guillain–Barré syndrome, botulism, tetrodotoxin poisoning, organophosphate toxicity, myasthenic crisis, stroke, and hypokalaemic paralysis. Owing to this overlap in presentation, a thorough clinical evaluation is essential to establish the correct diagnosis.

A detailed history often provides the most valuable diagnostic clue. The rapid onset of neurological symptoms following the consumption of contaminated shellfish or seafood strongly supports the diagnosis of PSP and helps distinguish it from other neuromuscular and toxicological conditions.

Management

Currently, no specific antidote exists for PSP, and treatment is primarily supportive. Management focuses on early recognition of respiratory compromise, maintenance of vital functions, and prevention of secondary complications until the toxin is naturally eliminated from the body.

Initial stabilization should follow the principles of airway, breathing, and circulation (ABC). Close monitoring of respiratory status is critical, as progressive respiratory muscle weakness may necessitate early endotracheal intubation and mechanical ventilation. Pulse oximetry, arterial blood gas analysis, and appropriate hemodynamic monitoring should be undertaken as clinically indicated.

Supportive care remains the cornerstone of treatment and may include oxygen supplementation, intravenous fluid therapy, intensive care monitoring, and ventilatory support in severe cases. Most patients who survive the acute phase recover completely within 24–72 hours, reflecting the reversible nature of toxin-induced neuromuscular dysfunction.[14- 16]

Prevention and Public Health Measures

Prevention remains the most effective approach to reducing the incidence and impact of PSP. Public health strategies focus on minimizing human exposure to toxin-contaminated shellfish through surveillance, regulation, and community awareness programs.[17-18]

Routine monitoring of shellfish harvesting areas, implementation of toxin surveillance systems, temporary closure of contaminated fisheries, and enforcement of seafood safety regulations constitute key preventive measures. The confusion in the diagnosis of dises like GBS still remain. [19]These interventions, together with public education campaigns, have significantly contributed to reducing the occurrence of PSP outbreaks in many regions worldwide**.**

Climate Change and Harmful Algal Blooms

Rising sea surface temperatures, altered ocean currents, and nutrient enrichment have been implicated in the increasing frequency and geographical expansion of harmful algal blooms. These environmental changes facilitate the proliferation of toxin-producing dinoflagellates in regions previously considered unaffected. Several studies have reported northward expansion of Alexandrium species, raising concerns regarding the emergence of PSP in new coastal populations. Consequently, existing surveillance programs may require adaptation to address changing ecological conditions and emerging toxin hotspots. (see figure 1)

Figure 1. Overview of paralytic shellfish poisoning showing the interconnected roles of climate change, harmful algal blooms, saxitoxin exposure, shellfish vectors, neurological toxicity, and public health interventions.

Challenges in Surveillance and Diagnosis
Despite advances in analytical detection methods, PSP remains underreported globally. Many cases present with nonspecific neurological symptoms and may be misdiagnosed as stroke, Guillain–Barré syndrome, or other neurotoxic conditions. Furthermore, subsistence harvesting and informal seafood markets often bypass regulatory monitoring systems. Improved clinician awareness, standardized reporting systems, and rapid toxin detection technologies are required to better define the global burden of PSP and strengthen public health responses.[20]

Global Seafood Trade
International seafood commerce increases the risk of toxin exposure far from the site of toxin production, complicating outbreak investigations.

Underreporting
Many mild cases remain undiagnosed or are mistaken for food poisoning, resulting in underestimation of disease burden.

Novel Toxin Analogues
The discovery of new saxitoxin derivatives raises concerns regarding current monitoring methods and regulatory thresholds.

Expansion Beyond Shellfish
Recent reports suggest toxin accumulation in fish, crustaceans, and marine mammals, broadening the spectrum of potential exposure sources. The expanding geographical distribution of PSP highlights the interconnected nature of environmental, animal, and human health. Future surveillance strategies should adopt a One Health framework integrating marine ecology, seafood safety, climate science, and clinical toxicology.

Future Directions
Despite significant advances in understanding Paralytic Shellfish Poisoning (PSP), several important knowledge gaps remain. Future research should focus on the development of more sensitive, rapid, and cost-effective toxin detection technologies that can facilitate early identification of contaminated seafood and improve public health surveillance. The availability of point-of-care diagnostic tests capable of detecting saxitoxins in biological samples would greatly assist clinicians in establishing an early diagnosis, particularly in remote coastal settings where laboratory facilities may be limited. Furthermore, the increasing frequency and geographical expansion of harmful algal blooms necessitate the development of climate-based predictive models that integrate oceanographic, meteorological, and ecological data to forecast bloom events and guide preventive interventions. Additional studies are required to identify reliable biomarkers of exposure and toxicity that could improve risk assessment and monitoring of affected populations. Although PSP is traditionally considered an acute intoxication, the long-term health consequences of repeated low-dose exposure to saxitoxins remain poorly understood and warrant further investigation. Research into the toxicokinetics, chronic effects, and potential neurological sequelae of prolonged exposure may provide valuable insights into disease burden. Finally, the absence of a specific antidote highlights the need for continued exploration of targeted therapeutic strategies capable of reversing sodium channel blockade and reducing toxin-induced morbidity.[21] Collaborative efforts involving clinicians, toxicologists, environmental scientists, and public health agencies will be essential to address these challenges and strengthen global preparedness against PSP.
The next step is to explore the development of artificial intelligence–based early warning systems that integrate satellite oceanography, meteorological data, and harmful algal bloom surveillance to predict PSP outbreaks in real time. Investigation of circulating biomarkers and metabolomic signatures may facilitate rapid bedside diagnosis and prognostication. Long-term neurocognitive and neuromuscular outcomes following repeated low-dose saxitoxin exposure remain poorly understood and warrant prospective cohort studies. Another promising area is the identification of sodium channel–modulating agents as potential antidotes. Additionally, wastewater-based environmental surveillance and wearable biosensors for high-risk coastal populations could represent innovative approaches to PSP prevention and public health preparedness.

Future research ideas:
- Future preventive strategies may utilize genetically engineered non-toxic microalgae to suppress toxin-producing dinoflagellates and reduce the occurrence of harmful algal blooms.
- Environmental DNA surveillance integrated with autonomous marine monitoring systems may enable early detection of toxin-producing organisms before seafood contamination occurs.
- Toxin-neutralizing nanosponges may emerge as a novel therapeutic approach capable of binding circulating saxitoxins and reducing toxin-induced neuromuscular dysfunction.
- Global marine health observatories combining satellite data, ocean sensors, and predictive analytics may facilitate long-range forecasting of PSP outbreaks.
- CRISPR-based biosensors incorporated into aquaculture ecosystems may provide continuous real-time monitoring of saxitoxin-producing organisms and enhance seafood safety.
- Investigation of the human gut microbiome may identify naturally occurring microbial pathways capable of degrading saxitoxins and mitigating clinical toxicity.
- Synthetic biology approaches may enable the development of shellfish with reduced capacity for saxitoxin bioaccumulation, thereby decreasing the risk of human exposure.

• Wearable neurophysiological monitoring devices may allow early detection of sodium channel dysfunction and facilitate rapid identification of toxin exposure.

Conclusion

Paralytic Shellfish Poisoning remains one of the most important marine toxin-mediated illnesses worldwide, with significant implications for food safety, public health, and coastal economies. The disease results from exposure to saxitoxins produced by harmful algal bloom-forming dinoflagellates and is characterized by rapidly developing neurological manifestations that may progress to respiratory failure and death if not promptly recognized and treated. Although advances in shellfish monitoring programs, toxin detection technologies, and critical care management have substantially reduced mortality rates, PSP continues to occur in many regions and is likely underreported. Growing evidence suggests that climate change, rising sea surface temperatures, and expanding harmful algal blooms may further increase the frequency and geographical distribution of PSP in the coming decades. Early diagnosis, supportive management, and timely respiratory support remain the cornerstones of treatment. Strengthening surveillance systems, improving public awareness, enhancing seafood safety regulations, and developing rapid diagnostic tools are essential for effective prevention and control. Continued research into toxin biology, environmental drivers, biomarkers of exposure, and targeted therapeutic approaches will be crucial for mitigating the future impact of this globally important marine neurotoxic disease.

Declarations

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The authors declare that they have no conflicts of interest related to this manuscript.

Ethical Approval:

As this article is a narrative review of previously published literature, ethical approval was not required.

Informed Consent:

Not applicable.

Data Availability Statement:

No new datasets were generated or analysed during the current study. All information is derived from published literature cited in the manuscript.

Author Contributions:

U. Shobipriya and S. Parthasarathy contributed to the conception, literature review, manuscript preparation, critical revision, and final approval of the manuscript

The authors have used AI tools to create an image sand correct the same – the grammar and language check was done by AI, .

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