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Editorial

Effects of Microalgal Blooms on Aquaculture and Fisheries

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Pigmented planktonic microalgae (phytoplankton) are primary producers that form the basis of marine trophic webs. Phytoplankton blooms are natural phenomena, which sustain bivalves and small pelagic fish production. Over fifty years ago, Reuben Lasker observed that the formation of dense layers of phytoplankton (thin layers) under certain climatic conditions, i.e., 4 days with wind velocities not exceeding 5 m/s, now called a "Lasker event", ensured the success of anchovy (*Engraulis mordax*) recruitment in the Californian upwelling system. However, the same beneficial bloom, under certain circumstances (e.g., an imbalance between growth and grazing), may lead to eutrophication, environmental distress, or even anoxia and mass mortalities of marine fauna, becoming what we know as a high biomass harmful algal blooms (HBHABs). Furthermore, some microalgae produce potent toxins that are transferred through the food web, mainly through filter-feeding bivalves, and cause illnesses such as paralytic (PSP), diarrheic (DSP), amnesic (ASP) and neurotoxic (NSP) shellfish poisoning. These toxin producers, even at low cell concentrations, are filtered and their toxins accumulate in bivalve mollusks, posing a serious threat to public health and shellfish exploitations. More recently, a new toxic syndrome, azaspiracid shellfish poisoning (AZP), has been added to the toxic syndromes list.

In recent decades, the number of HAB reports and their geographic extension have increased dramatically, a fact partly explained by a parallel increment in the exploitation of coastal resources, such as from aquaculture and the tourism industry, and by an exponential growth in the observations carried out in monitoring programs [1,2]. The irrefutable contribution of anthropogenic factors (e.g., agricultural runoff, industrial and domestic waste, and tourism) added to the existing problems for the fisheries and aquaculture sectors [3–6].

Aquaculture and fisheries products are the staple food in the diet and the main source of employment and/or subsistence in coastal populations worldwide. In particular, in developing areas with no alternative sources income, their economic sustainability is of critical importance. The most recent report on the state of word fisheries and aquaculture showed that the global production of aquatic animals had risen to 178 million tons in 2020. In addition to aquatic animals, 36 million tons (wet weight) of algae were produced the same year (Figure 1A). Of the overall production of aquatic animals, 157 million tons (89%), mainly of bivalve mollusks, were used for human consumption [7]. However, these production activities are increasingly affected by the occurrence of a large variety of HAB species and their impacts (Figure 1B). Analyses of the IOC database of HAB events (IOC-HAEDAT) between 1972 and 2022 showed a significant increase in the total number of reports, mainly of paralytic (PSP) and diarrhetic syndromes (DSP), associated with blooms of the genera *Alexandrium* and *Dinophysis*, respectively [8]. Thus, in 2020, a historical maximum number of events were reported worldwide, i.e., 417 reports, 364 (87.3%) of which corresponded to PSP (Figure 1A).

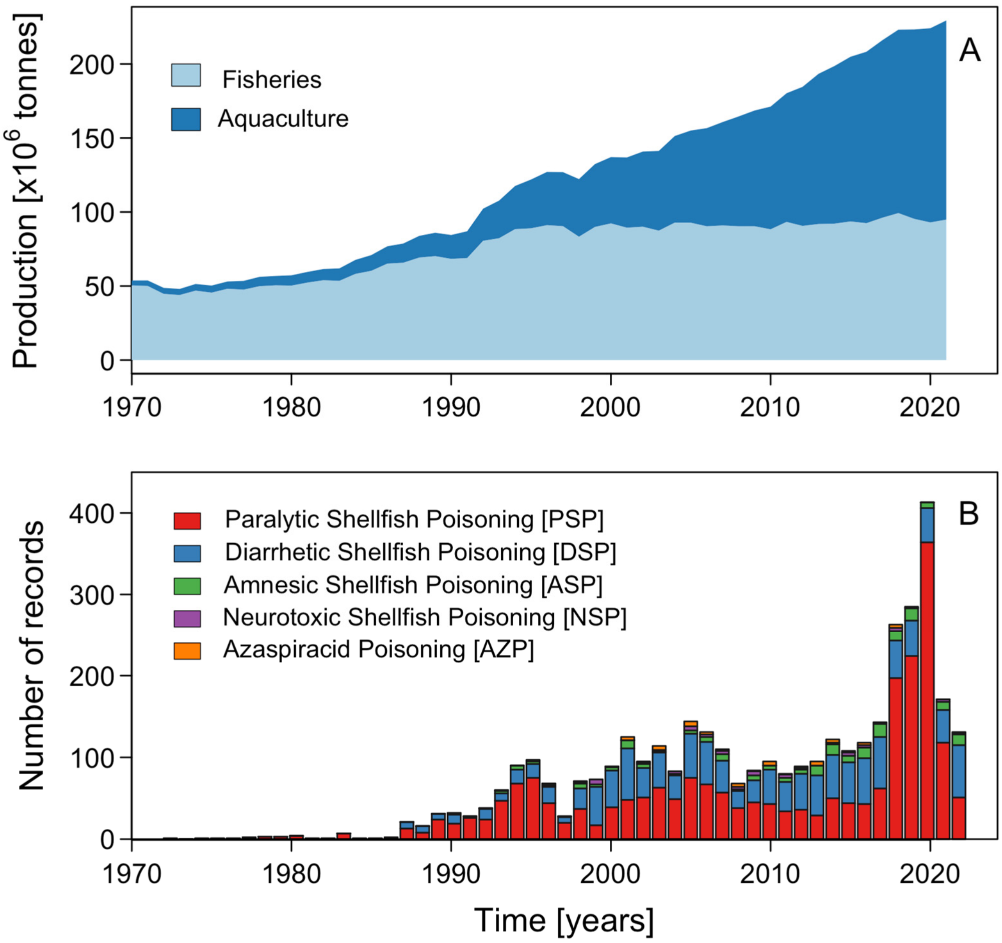

Figure 1. (**A**) World fisheries' catches and aquaculture production, and (**B**) number of global records of the five most common toxic HAB syndromes (PSP, DSP, ASP, NSP and AZP). Data are from FAO (https://www.fao.org) and the IOC HAEDAT (http://haedat.iode.org/).

Understanding the complexity of HAB events requires a multidisciplinary approach. A good example was the international SCOR-IOC GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) program. This program, initiated in 2001, was the umbrella of a long list of projects, working groups and workshops, which led to considerable progress in understanding the mechanisms underlying population dynamics of HABs within an ecological and oceanographic context [9]. Its continuation, the IOC-SCOR GlobalHAB program (www.globalhab.org) initiated in 2016, widened the scope of GEOHAB by incorporating a socioeconomic perspective, including epidemiology, toxicology and evaluation of economic impacts to the aquaculture and tourism industries.

In order to prevent the risks of human exposure to potent marine toxins, many countries have been implementing specific health and safety measures. Mardones et al. [10] estimated that the cost of microalgae and toxin monitoring on the Chilean coast was USD 6.9 million in 2019. This country, the world's second largest producer of cultured blue mussels (*Mytilus chilensis*) and salmon (mainly *Salmo salar* and *Oncorhynchus kisutch*) with 400,000 and 1,000,000 tons per year, respectively, has been severely affected by HABs events in the last decade [11–13]. In summer 2016, a major HAB event in Southern Chile of the fish-killer *Pseudochattonella verruculosa* generated losses of USD 800 million [14]. This event, the world's largest-ever recorded farmed-fish mortality, caused a severe economic and social crisis in the region. Five years later, a bloom of *Heterosigma akashiwo* generated a new massive salmon mortality in Comau Fjord, Chilean Patagonia [15]. During that event, high cell densities (>2 · 10^5 cells mL^{-1}) discolored the sea surface waters with intense brown patches visible to the naked eye (Figure 2).

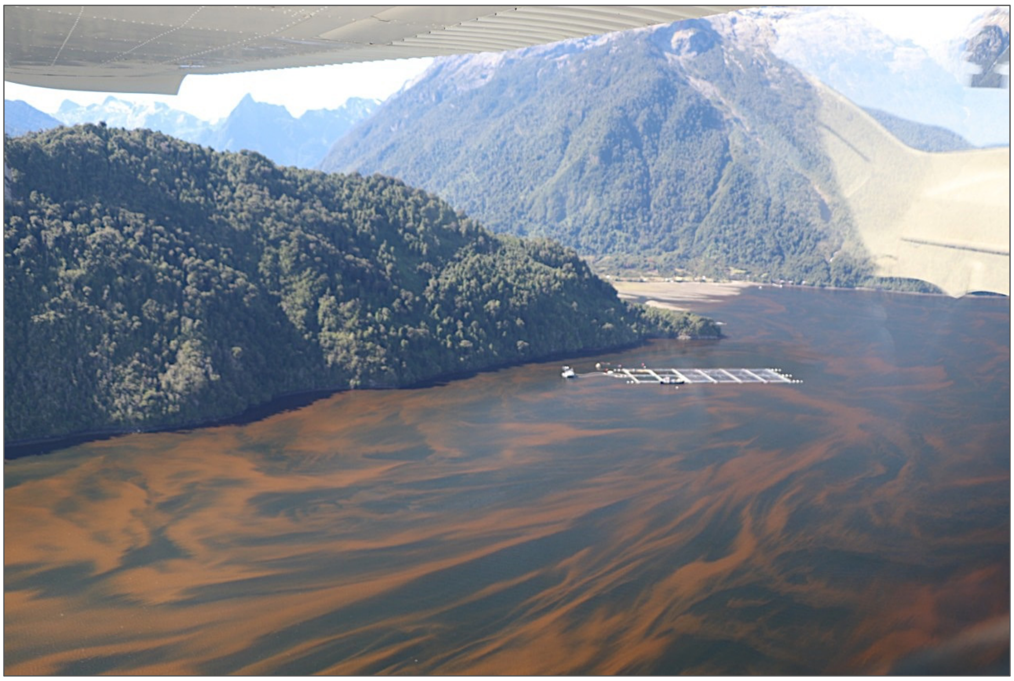

Figure 2. Red tide caused by *Heterosigma akashiwo*. The aerial photo was taken over the Comau Fjord (Chilean Patagonia) in early April 2021. Courtesy of Pamela Urrutia.

The "visible" impacts of HABs, such as massive fish mortalities, extensive shellfish quarantines and human poisonings, are unquestionable and well documented [16]. However, there are important gaps in our knowledge of hidden or cryptic impacts of HAB toxins on marine organisms, which are often attributed without sufficient background knowledge to climatological (e.g., storms and heat waves) and oceanographic conditions (e.g., anoxia and hypoxia) [17] or infectious epidemics [18]. It was widely accepted that shellfish poisoning toxins cause no harm to the vector bivalve mollusks. Nevertheless, some marine biotoxins have been recently associated with massive mortalities, which affected wild invertebrate (bivalves, echinoderms and cephalopods) populations [19–22] and cultivated gastropods [23].

Paralytic shellfish toxins (PST) may cause impairment of adult bivalves by affecting their response mechanisms to physiological (e.g., filtration rates), immunological (e.g., immunocompetence of hemocytes) and behavioral (e.g., burrowing activity) processes [19,24–26]. Similarly, amnesic shellfish toxins (AST) may cause a slow-down of valvar closure and other physiological disturbances, such as, hemolymph acidosis, hypoxia, increased hemocytokine activity and DNA damage [27,28]. In the case of lipophilic toxins (LT) produced by *Dinophysis* species, okadaic acid (OA) causes a decline in filtration rates associated with a cytotoxic effect [29,30], while pectenotoxins (PTXs) induce hypersecretion of mucus and pseudo-phaeces, paralysis, alteration of the digestive gland tissues and reduced escape responses in adult scallops [31]. Other lipophilic toxins, such as YTX and homo-YTX, may cause mass mortalities in the adult stages of different marine organisms at low concentrations (<1 mg eq. YTX kg^{-1}) [20,22,23]. To date, the specific mechanism of action of YTX is not known; however, some studies suggested that YTXs affect the digestive and immune systems [32,33] and cytoskeletal cell components [33,34].

Noxious effects of extracellular toxins on the early life stages of marine organisms have been described in laboratory studies. PST has been associated with decreased swimming activity, larval inactivity, aberrant development, decreased growth, lower settlement rates and mortality in different species, such as scallops, oysters and mussels [35–42]. Domoic acid (ASP toxins) may reduce swimming activity, survival and consequently, the settlement rate in scallops (*Pecten maximus*) [43]. Regarding LTs produced by *Dinophysis*, OA can reduce innate immune responses, hemocyte activity, and larval viability [44–47], while PTX2 produces larval inactivity and rapid mortality [42,48]. Finally, more research is needed to determine the negative effects of other LTs, such as YTX and homo-YTX.

According to some climate predictions, several regions with valuable aquaculture exploitations will be exposed to an increased risk of HAB impacts [12,49]. Current tools for HAB prediction and mitigation lack accuracy, because the response of each HAB species to environmental stressors on multiple scales is species- and site-specific. This Special Issue (SI) seeks to compile contributions with new results aiming to bridge the gaps in our knowledge regarding the visible and hidden impacts of HABs on aquaculture and fisheries.

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