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# Harmful algal blooms and shellfish aquaculture in changing environment

Leila BASTI[*1], Kiyohito NAGAI[*2], Susumu SEGAWA[*3], Yuji TANAKA[*1], Toshiyuki SUZUKI[*4], and Satoshi NAGAI[*4]

**Abstract**: Shellfish aquaculture is mainly carried out in sheltered coastal areas that are affected by several anthropogenic stressors, including eutrophication, pollution, biofouling, invasive species, expanding diseases, and harmful algal blooms. In particular, harmful algal blooms (HAB) have been known to cause fish and shellfish kills; contamination of fish, but mainly shellfish, with potent toxins that cause mild to severe poisonings in humans; and in many cases, alteration of ecosystem functions. In shellfish, notably in bivalve molluscs, in addition to mass mortalities, HAB are known to cause acute to chronic physiological and pathological alterations that lead to impediments to aquaculture farms via reduction of bivalve fitness or following closure of production due to long-term contamination with toxins detrimental to human health.

The frequency, magnitude, duration, and in several cases, the geographic distribution of HAB have been increasing, putting shellfish aquaculture farms under further stress. Several factors have been attributed to such increase in HAB, including climate change. Range expansions of some cosmopolitan HAB species associated with warming ocean temperature have been reported across the North Atlantic and North Pacific. In addition, range expansions of some other cosmopolitan HAB species have been projected across the North Western European Shelf-Baltic Sea system and North East and South East Asia, associated with increased nutrient loads under projected climate change scenario A1B of the IPCC, IPSL-CM4. Warming water temperature driven by climate change is also expected to induce thermodynamic changes in physiological functions of shellfish, with potential shifts in their thermal sensitivity and performance, and it is also expected to alter the responses of bivalves to HAB.

In this mini-review, the effects of HAB and ocean warming – and other climate driven stressors like ocean acidification – on these important cultured shellfish species will be discussed in light of the findings of relevant studies reported in the literature.

**Key words**: harmful algal blooms, shellfish, aquaculture, climate change

## Introduction

Human consumption from aquaculture exceeded that from wild resources for the first time in 2014, and aquaculture has become the fastest growing food production system in the world (FAO, 2014). Despite the expansion of aquaculture activities to offshore production, most of the mariculture activities are still carried out in sheltered coastal areas (Trujillo *et al*., 2012). These areas are subjected to several anthropogenic stressors, including eutrophication, pollution, biofouling, invasive species, expanding

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*1 Department of Ocean Sciences, Tokyo University of Marine Science and Technology, Minato, Tokyo 108-8477, Japan.
*2 K. Mikimoto and Co. Ltd., Osaki Hazako, Hamajima-Cho, Shima, Mie 517-0403, Japan
*3 Department of Aqua Bioscience and Industry, Tokyo University of Agriculture, 196 Yasaka, Abashiri 099-2493, Japan
*4 National Research Institute of Fisheries Science, Fisheries Research and Education Agency, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan
E-mail: lbasti1@kaiyodai.ac.jp

diseases, and harmful algal blooms (HAB) (Rogers and Laffoley, 2011).

HAB pose a significant threat to marine and freshwater ecosystems as they cause a wide range of cascading impacts either via their increased biomass or via the production of potent toxins and bioactive compounds (Burkholder, 1998). These HAB have increased over the past decades with associated increases in their effects on ecosystems and related human activities, including tourism, fishing, and aquaculture (Smayda, 1990; Hallegraeff, 1993; Van Dolah, 2000; Zingone and Enevoldsen, 2000; Allen *et al*., 2006; Matsuyama and Shumway, 2009). In addition, a wide diversity of HAB species causes intoxication of humans following the consumption of seafood products, mainly bivalve molluscs that have accumulated their toxins, leading to closures of shellfish beds and long-term suspension of production in aquaculture farms (Van Dolah, 2000). Several species of HAB have also been known to cause mass mortalities of aquatic organisms and numerous documented deleterious effects on the physiology of cultured shellfish (Landsberg, 2002; Basti *et al*., 2018a).

Coastal areas witnessing expansion of HAB events are also at risk of impacts from climate change-driven forcing, including sea level rise; alteration in nutrients, sediment and salinity regimes; changes in circulation patterns, water residence time and upwelling; frequency and intensity of storms; ocean warming; and ocean acidification (Scavia *et al*., 2002; Caldeira and Wickett, 2005; Harley *et al*., 2006; Domingues *et al*., 2008; Ruckelshaus *et al*., 2013). The impacts of HAB on shellfish aquaculture, mainly bivalve molluscs, and the potential impacts of climate-driven changes on the interactions HAB-shellfish are reviewed.

## Effects of harmful algal blooms on shellfish

HAB affect shellfish aquaculture by causing acute, chronic, and sublethal effects in several species of shellfish (Shumway, 1990; Landsberg, 2002). In shellfish, in addition to mass mortalities, HAB affect the behavior and physiology of several commercially important species. Reduction of filtration, respiration, and valve gaping have been reported in several cultured species, including clams, oysters, mussels, and scallops. Several pathologies in almost all organs of bivalve molluscs have also been shown to be caused by species of HAB, including inflammation, necrosis and atrophy (Shumway and Cucci, 1987; Gainey and Shumway, 1988: Bricelj *et al*., 1996; Basti *et al*., 2009; Basti *et al*., 2011a; Haberkorn *et al*., 2010a; Haberkorn *et al*., 2010b; Hégaret *et al*., 2012). Several pathologies in almost all organs of bivalve molluscs have also been shown to be caused by species of HAB, including inflammation, necrosis and atrophy. Modulation of the immune system, antioxidant system and neuroenzymatic activity, as well as modification of the physiological energetics, can also occur (Hégaret and Wikfors, 2005; Basti *et al*., 2016). The reproduction and the recruitment of shellfish are also affected by several species of HAB, with numerous recruitment failures reported from the field, in addition to several negative effects in gametes, fertilization, embryos and larvae of clams, oysters and scallops (Basti *et al*., 2011b; Basti *et al*., 2013; Basti *et al*., 2015a; Banno *et al*., 2018). In addition, HAB have been shown to affect the susceptibility of shellfish to diseases and, thus, facilitate the expansion of diseases in aquaculture farms (e.g. Da Silva *et al*., 2008; Hégaret *et al*., 2010; reviewed in: Landsberg, 2002; Basti *et al*., 2018a).

## Effects of warming and ocean acidification on shellfish

The effects of climate change on the world ocean are being documented worldwide (IPCC, 2007; Doney *et al*., 2012). Climate-driven changes in the physical and chemical systems of the oceans are inducing changes in the biological systems as well as human uses of ocean resources. Warming water temperature has already been shown to affect the survival, growth, reproduction, health and phenology of marine organisms (Doney *et al*., 2012). Warming could result in changes in the primary production and food web structure and function and, thereafter, changes in life history processes such as spat-fall of shellfish, as well as physiological stresses leading to decreased growth and production (Allison *et al*., 2011). In a literature review, Compton *et al*. (2007) found that warming will have more impacts on the survival, range and productivity of tropical than temperate shellfish species, which might lead to shift in species cultured in aquaculture farms in the future oceans. On the other hand, ocean acidification (OA) has been shown to affect calcifying organisms, including mussels, clams and oysters. Despite the extensive literature on the effects of OA on marine organisms, generalization on the biological effects of OA remains disputable, especially that the mechanisms of sensitivity to long-term exposures to OA are not well understood (Berge *et al*., 2006; Gazeau *et al*., 2007; Cochran *et al*., 2009; Miller *et al*., 2009; Talmage and Gobler, 2010; Allisson *et al*., 2011; Waldbusser *et al*., 2011; Barton *et al*., 2012). There is little information, however, on the effects of both warming and OA on shellfish. For instance, in a short- and long-term laboratory studies, the fertilization and early-life development of Sydney rock oyster were shown to be severely affected by the synergistic effects of warming and OA (Parker *et al*., 2009).

## Impacts of harmful algal blooms and climate change on shellfish aquaculture

Evidence that climate change has been influencing HAB events at a global scale has been accumulating (Moore *et al*., 2008). Climate-driven changes in temperature, irradiance, chemical composition of seawater, nutrients, water stratification, grazing pressures, phytoplankton species, and strain interactions is expected to affect the prevalence and toxicity of HAB (Wells *et al*., 2015). Changes in HAB prevalence and toxicity will affect the responses of shellfish to these global stressors as well as aquaculture activities. For instance, warming water temperature has been shown to affect the metabolism of the most widespread HAB toxin (Paralytic Shellfish Toxins) in commercial oysters from Australia (Farrell *et al*., 2015). Similarly, increased temperatures and OA were shown to increase production of HAB toxins and negative effects in shellfish (Tatters *et al*., 2013; Basti *et al*., 2015b; Basti *et al*., 2018b). These data show that climate-driven warming and OA may increase future risks of HAB effects on shellfish physiology and aquaculture farms.

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Using a global modeling approach, the effects of nutrient loading and climate change on the projected distributions of two genera of harmful algae in coastal ecosystems of three regions of the globe were examined. Range expansions and retractions were found for the two genera suggesting future shifts in the vulnerability of coastal ecosystems to HAB events, increased regional HAB impacts on aquaculture leading to increase in the risks to human health and ecosystem services and associated economic consequences.

(2) Basti L., Endo M., Segawa S., Shumway S. E., Tanaka Y., and Nagai S., 2015: Prevalence and intensity of pathology induced by the toxic dinoflagellate, *Heterocapsa circularisquama*, in the Mediterranean mussel, *Mytilus galloprovincialis*. *Aquat. Toxicol.*, **163**, 37-50.

The study examines the effects of temperature on the pathologies induced by the shellfish-killing harmful alga, *Heterocapsa circularisquama*, in the Mediterranean mussel, *Mytilus galloprovincilias*. The study shows that increased temperature leads to increased prevalence and intensity of pathologies in the mussels in several vital organs, including gills and intestines. The study shows that warming temperature may increase the effects of the harmful alga on mussels even at low cell density, possibly reducing the overall health of the mussels. It also shows that the range expansion of the harmful alga associated with increased winter water temperature may put bivalve aquaculture farms under further risks of mass mortalities and production failure.

(3) Filgueira R., Guyondet T., Comeau L. A., and Tremblay R., 2016: Bivalve aquaculture-environment interactions in the context of climate change. *Glob. Chang. Biol.*, **22**, 3901-3913.

The study examines the interactions between bivalve aquaculture and the environment (bay geomorphic type, freshwater input), in the context of climate change (sea level rise, temperature, precipitation). Based on a factorial deign of 336 scenarios, the modeling showed that temperature is the strongest climate change driver to affect bivalve aquaculture as it can influence their metabolism. Differences in thermal tolerance of the cultured bivalve species would determine "winners" from "losers".

(4) Gobler J. C., Dohrty O. M., Hattenrath-Lehmann T. K., Griffith A. W., Kang Y., and Litaker R. W., 2017: Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. *Proc. Natl. Acad. Sci. USA*, **114**, 4975-4980.

The study models the trends in growth rates and duration of bloom seasons of two species of the most toxic and widespread harmful algal blooms in the North Atlantic and North Pacific oceans using high-resolution SST (sea surface temperature) over the past three decades. Increasing water temperature associated with climate change have expanded the niches of these toxic algae (*Dinophysis acuminata* and *Alexandrium fundeyense*) and might contribute to an expansion of the associated human health threat via the consumption of shellfish contaminated with diarrheic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP).