Harmful algal blooms and shellfish aquaculture in changing environment

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Harmful algal blooms and shellfish aquaculture in changing environment

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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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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.

References

Allen J. I., Anderson D., Burford M., Dyhrman S., Flynn K., Glibert P. M., Granéli E., Heil C., Shellner K., Smayda T., and Zhou M., 2006: Global Ecology and Oceanography of Harmful Algal Blooms, Harmful Algal Blooms in Eutrophic Systems, GEOHAB Report 4IOC and SCOR, Paris and Baltimore, 74pp.

Allison E. H., Badjek M. C., and Meinhold K., 2011: The implications of global climate change for molluscan aquaculture, in "Shellfish Aquaculture and the Environment" (ed. by Shumway S. E.), John Wiley & Sons Ltd, Chichester, pp. 461-490.

Banno K., Oda T., Nagai K., Nagai S., Tanaka Y., and Basti L., 2018: Deleterious effects of harmful dinoflagellates and raphidophytes on egg viability and spermatozoa swimming velocity in the Japanese pearl oyster *Pinctada fucata martensii*. *J. Shellfish Res.*, **37**, 41-48.

Barton A., Hales B., Waldbusser G. G., Langdon C., and Feely R. A., 2012: The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: implications for near-term ocean acidification effects. *Limnol. Oceanogr.*, **57**, 698-710.

Basti L., Nagai K., Shimasaki Y., Oshima Y., Honjo T., and Segawa S., 2009: Effects of the toxic dinoflagellate *Heterocapsa circularisquama* on the valve movement behavior of the Manila clam *Ruditapes philippinarum*. *Aquaculture*, **291**, 41-47.

Basti L., Endo M., and Segawa S., 2011a: Physiological, pathological, and defense alterations in Manila clams (short-neck clams), *Ruditapes philippinarum*, induced by *Heterocapsa circularisquama*. *J. Shellfish Res.*, **30**, 829-844.

Basti L., Go J., Higuchi K., Nagai K., and Segawa S., 2011b: Effects of the toxic dinoflagellate *Heterocapsa circulariquama* on larvae of Pearl oyster *Pinctada fucata martensii* (Dunker, 1873). *J. Shellfish Res.*, **30**, 177-186.

Basti L., Nagai K., Tanaka Y., and Segawa S., 2013: Sensitivity of gametes, fertilization, and embryo development of the Japanese pearl oyster, *Pinctada fucata martensii*, to the harmful dinoflagellate, *Heterocapsa circularisquama*. *Mar. Biol.*, **160**, 211-219.

Basti L., Nagai S., Go J., Okano S., Nagai K., Watanabe R., Suzuki T., and Tanaka Y., 2015a: Differential inimical effects of *Alexandrium* spp. and *Karenia* spp. on cleavage, hatching, and two larval stages of Japanese pearl oyster *Pinctada fucata martensii*. *Harmful Algae*, **43**, 1-12.

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

Basti L., Nagai S., Watanabe S., Oda T., and Tanaka Y., 2016: Neuroenzymatic activity and physiological energetics in Manila clam, Ruditapes philippinarum, during short-term sublethal exposure to harmful alga, Heterocapsa circularisquama. *Aquat. Toxicol*., **176**, 76-87.

Basti L., Hégaret H., and Shumway S. E., 2018a: Harmful algal blooms and shellfish, in "Harmful Algal Blooms: A Compendium Desk Reference" (ed. by Shumway S. E., Burkholder J. M., and Morton S. L.), John Wiley & Sons Ltd, Chichester, pp. 135-190.

Basti L., Suzuki T., Uchida H., Kamiyama T., and Nagai S., 2018b: Thermal acclimation affects growth and lipophilic toxin production in a strain of cosmopolitan harmful alga *Dinophysis acuminata*. *Harmful Algae*, **73**, 119-128.

Berge J. A., Bjerkeng B., Pettersen O., Schaanning M. T., and Øxnevad S., 2006: Effects of increased seawater concentrations of CO_2 on growth of the bivalve *Mytilus edulis* L. *Chemosphere*, **62**, 681-687.

Bricelj V. M., Cembella A. D., Laby D., Shumway S. E., and Cucci T. L., 1996: Comparative physiological and behavioral responses to PSP toxins in two bivalve molluscs, the softshell clam, *Mya arenaria*, and surfclam, *Spisula solidissima*, in "Harmful and Toxic Algal Blooms" (ed. by Yasumoto T., Oshima Y., and Fukuyo Y.), Intergovernmental Oceanographic Commission of UNESCO, Paris, pp. 405-408.

Burkholder J. M., 1998: Implications of harmful marine microalgae and heterotrophic dinoflagellates in management of sustainable marine fisheries. *Ecol. Appli*., **8 (Suppl.)**, S37-S62.

Caldeira K. and Wickett M. E., 2005: Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. *J. Geophys. Res*. **110**. doi:10.1029/2004JC002671

Cochran K., De Yo C., Soto D., and Bahri T., 2009: Climate change implications for fisheries and aquaculture, FAO Fisheries and Aquaculture Technical Paper 530, Rome, 212pp.

Compton T. J., Rijkenberg M. J. A., Drent J., and Piersma T., 2007: Thermal tolerance ranges and climate variability: a comparison between bivalves from differing climates. *J. Exp. Mar. Biol. Ecol*., **352**, 200-211.

Da Silva P.M., Hégaret H., Lambert C, Wikfors G. H., Le Goïc N., Shumway S. E., and Soudant P., 2008: Immunological responses of the Manila clam (*Ruditapes philippinarum*) with varying parasite (*Perkinsus olseni*) burden, during long term exposure to the harmful alga, *Karenia selliformis* and possible interactions. *Toxicon*, **51**, 563-573.

Domingues C. M., Church J. A., White N. J., Gleckler P. J., Wijffels S. E., Barker P. M., and Dunn J. R., 2008: Improved estimates of upper-ocean warming and multi-decadal sea-level rise. *Nature*, **453**, 1090-1093.

Doney S. D., Ruckelshaus M., Duffy J. E., Barry J. P., Chan F., English C. A., Galindo H. M., Grebmeier J. M., Hollowed A. B., Knowlton N., Polovina J., Rabalais N. N., Sydeman W. J., and Talley L. D., 2012: Climate change impacts on marine ecosystems. *Annu. Rev. Mar. Sci*., **4**, 11-37.

FAO, 2014: The State of World Fisheries and Aquaculture - Opportunities and Challenges, FAO, Rome, 223pp.

Farrell H., Seebacher F., O'Connor W., Zammit A., Harwood D. T., and Murray S., 2015: Warmer temperature acclimation impacts metabolism of paralytic shellfish toxins from *Alexandrium minutum* in commercial oysters. *Glob. Chang. Biol*., **21**, 3402-3413.

Gainey L. G. and Shumway S. E., 1988: A compendium of the responses of bivalve molluscs to toxic dinoflagellates. *J. Shellfish Res*., **7**, 623-628.

Gazeau F., Quiblier C., Jansen J. M., Gattuso J. P., Middelburg J. J., and Heip C. H. R., 2007: Impact of elevated CO_2 on shellfish calcification. *Geophys. Res. Lett*., **34**, L07603.

Haberkorn H., Lambert C., Le Goïc N., Guéguen M., Moal J., Palacios E., Lassus P., and Soudant P., 2010a: Effects of *Alexandrium minutum* exposure upon physiological and hematological variables of diploid and triploid oysters, *Crassostrea gigas*. *Aquat. Toxicol.*, **97**, 96-108.

Haberkorn H., Lambert C., Le Goïc N., Moal J., Suquet M., Guéguen M., Sunila I., and Soudant P., 2010b: Effects of *Alexandrium minutum* exposure on nutrition-related processes and reproductive output in oysters *Crassostrea gigas*. *Harmful Algae*, **9**, 427-439.

Hallegraeff G. M., 1993: A review of harmful algal blooms and their apparent global increase. *Phycologia*, **32**, 79-99.

Harley C. D. G., Hughe A. R., Hultgren K. K., Miner B. G., Sorte C. J. B., Thronber C. S., Rodriguez L. F., Tomanek L., and Williams S. L., 2006: The impacts of CC in coastal marine systems. *Ecol. Lett.*, **9**, 228-241.

Hégaret H. and Wikfors G. H., 2005: Time-dependent changes in hemocytes of eastern oysters, *Crassostrea virginica*, and northern bay scallops, *Argopecten irradians irrandians*, exposed to cultured strain of *Prorocentrum minimum*. *Harmful Algae*, **2**, 187-199.

Hégaret H., Smolowitz R. M., Sunila I., Shumway S. E., Alix J., Dixon M., and Wikfors G. H., 2010: Combined effects of parasite, QPX, and the harmful-alga, *Prorocentrum minimum* on northern quahogs, *Merecenaria mercenaria*. *Mar. Environ. Res.*, **69**, 337-344.

Hégaret H., Brokordt K. B., Gaymer C. F., Lohrmann K. B., García C., and Varela D., 2012: Effects of the toxic dinoflagellate *Alexandrium catenella* on histopathogical and escape responses of the Northern scallop *Argopecten purpuratus*. *Harmful Algae,* **18**, 74-83.

IPCC, 2007: Climate Change 2007: Mitigation of Climate Change. Working Group III Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, UNEP, Geneva.

Landsberg J. H., 2002: The effects of harmful algal blooms on aquatic organisms. *Rev. Fish. Sci.*, **10**, 113-390.

Matsuyama Y. and Shumway S. E., 2009: Impacts of harmful algal blooms on shellfisheries aquaculture, in "New Technologies in Aquaculture: Improving Production Efficiency, Quality and Environmental Management" (ed. by Brunell G. and Allan G.), CRC Press, Woodhead Publishing, pp. 580-609.

Miller A. W., Reynolds A. C., Sobrino C., and Riedel G. F., 2009: Shellfish face uncertain future in high CO_2 world: influence of acidification on oyster larvae calcification and growth in estuaries. *PLoS One*, **4**, e5661. doi:10.1371/journal.pone.0005661

Moore S. K., Trainer V. L., Mantua N. J., Parker M. S., Laws E. A., Backer L. C., and Fleming L. E., 2008: Impacts of climate variability and future climate change on harmful algal blooms and human health. *Environ. Health*, **7 (Suppl. 2)**, S4.

Parker L. M., Ross P. M., and O' Connor W. A., 2009: The effect of ocean acidification and temperature on the fertilization and embryonic development of the Sydney rock oyster *Saccostrea glomerata* (Gould 1850). *Glob. Chang. Biol.*, **15**, 2123-2136.

Rogers A. D. and d'A Laffoley D., 2011: International Earth system expert workshop on ocean stresses and impacts, Summary report, IPSO, Oxford, 18pp.

Ruckelshaus M., Doney S. C., Galindo H. M., Barry J. P., Chan F., Duffy J. E., English C. A., Gaines S. D., Grebmeier J. M., Hollowed A. B., Knowlton N., Polovina J., Rabalais N. N., Sydeman W. J., and Talley L. D., 2013: Securing ocean benefits for society in the face of climate change. *Mar. Policy*, **40**, 154-159.

Scavia D., Field J. C., Boesch D. F., Buddemeier R. W., Burkett V., Cayan D. R., Fogarty M., Harwell M. A., Howarth R. W., Mason C., Reed D. J., Royer T. C., Sallenger A. H., and Titus J. G., 2002: Climate change impacts on US coastal and marine ecosystems. *Estuaries*, **25**, 149-164.

Shumway S. E., 1990: A review of the effects of algal blooms on shellfish and aquaculture. *J. World Aquacult. Soc.*, **21**, 65-104.

Shumway S. E. and Cucci T. L., 1987: The effect of the toxic *Protogonyaulax tamarensis* on the feeding and behavior of bivalve molluscs. *Aquat. Toxicol.*, **10**, 9-27.

Smayda T. J., 1990: Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic, in "Toxic Marine phytoplankton: Proceedings of the 4th International Conference on Toxic Marine Phytoplankton" (ed. by Granéli E., Sundström B., Edler L., and Anderson D. M.), Elsevier, New York, pp. 29-40.

Talmage S. C. and Gobler C. J., 2010: Effects of past, present and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. *P. Natl. Acad. Sci. USA*, **107**, 17246-17251.

Tatters A. O., Flewelling L. J., Fu F., Granholm A. G., and Hutchins D. A., 2013: High CO_2 promotes the production of paralytic shellfish poisoning toxins by *Alexandrium catenella* from Southern California waters. *Harmful Algae*, **30**, 37-43.

Trujillo P., Piroddi C., and Jacquet J., 2012: Fish farms at sea: the ground truth from Google Earth. *PLoS One*, **7**, e30546.

Van Dolah F. M., 2000: Marine algal toxins: origin, health effects, and their increased occurrence. *Environ. Health Perspec.*, **108**, 133-141.

Waldbusser G. G., Voigt E. P., Bergschneider H., Green M. A., and Newell R. I. E., 2011: Biocalcification in the Eastern Oyster Crassostrea virginica in relation to long-term trends in Chesapeake Bay pH. *Estuar. Coast.*, **34**, 22-231.

Wells M. L., Trainer V. L., Smayda T. J., Karlson B. S. O., Trick C. G., Kudela R. M., Ishikawa A., Bernard S., Wulff A., Anderson D. M., and Cochlan W. P., 2015: Harmful algal blooms and climate change: Learning from the past and present to forecast the future. *Harmful Algae*, **49**, 68-93.

Zingone A. and Enevoldsen H. O., 2000: The diversity of harmful algal blooms: a challenge for science and management. *Ocean Coast. Manage.*, **43**, 725-748.

Annotated bibliography

(1) Glibert P. M., Allen J. I., Artioli Y., Beusen A., Bouwan L., Harle J., Holmes R., and Holt J., 2014: Vulnerability of coastal ecosystems to changes in harmful algal bloom distribution in response to climate change: projections based on model analysis. *Glob. Chang. Biol.*, **20**, 3845-3858.

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).