# Climate-induced changes and Harmful Algal Blooms in the Mediterranean: perspectives on future scenarios

**Catherine Legrand [1,2] and Raffaella Casotti [3]**

[1] *Alfred Wegener Institute for Polar Research, Bremerhaven, Germany*
[2] *University of Kalmar, Kalmar, Sweden*
[3] *Stazione Zoologica Anton Dohrn, Napoli, Italy*

## Abstract

Climate-induced changes in water temperature, stratification and other physical properties are likely to strongly impact the physiology and behaviour of harmful algae bloom (HAB) species, in terms of occurrence, physiology and toxin production. Although it is impossible to predict and eventually prevent outbreaks of HAB species, based on climate studies, one can expect that features such as increased stratification periods, modified circulation patterns and ocean acidification may affect algal physiology, causing an enhancement of toxin production and amplification through the food web. Apart from toxin production and transfer to final consumers, chemically-mediated interactions among and between species are likely to be modified by the physical environment. In this context, an integrated approach which considers the relationships between different players in the plankton is needed. All this complexity calls for a need of monitoring programmes complemented by suitable experimental approaches to test possible scenarios. In the Mediterranean, coastal areas are already experiencing increased occurrence of HABs, and often "novel" nuisance species are recorded. The improvement of plankton taxonomy skills and/or better monitoring programmes, and the interplay with anthropogenic nutrient inputs also add complexity to the problem. Improving HAB in the Mediterranean calls for integration of basic knowledge of coastal and regional differences with marine policy programmes, and to heighten public awareness of these issues and the potential economic and societal impact.

Recently, the potential impact of climate-induced changes on phytoplankton, and especially on HABs, has raised attention in the scientific community (Riebesell *et al.*, 2000; Edwards and Richardson, 2004; Hays *et al.*, 2005; Dale *et al.*, 2006; Riebesell *et al.*, 2008; Moore *et al.*, 2008). Future research directions to take in this field are often driven by human health concerns due to the potency of some algal toxins that are transferred through the food web. It is widely agreed, climate induced changes will impact phytoplankton physiology, community composition and interactions with the other components of the marine systems. However, we do not really understand the consequences of these modifications since the future dynamics of the physical and chemical environment is not fully predictable, nor are the physiological adaptations of HAB species to these changes known. Here we outline selected potential interactions between climate driven changes and the chemical ecology of HABs, and their potential consequences in the Mediterranean.

Harmful Algal Blooms are a recurrent phenomenon caused by a small fraction of phytoplankton causing a range of negative physiological, environmental and economical effects. Some HAB species, mainly dinoflagellates and diatoms, produce potent toxins, such as paralytic or neurotoxic shellfish poisons, that can be accumulated and transferred through the food web, inducing death or illness in fish and higher animals such as birds and mammals (including humans) (Hallegraeff, 1993). The dynamics of their toxicity is not always clear, as some toxins are toxic only to final consumers (e.g. fish, humans) but apparently are neutrally transferred through intermediate consumers. Additionally, other phytoplankton species produce compounds that are not toxic to humans but negatively impact competitors and grazer reproduction and therefore impact recruitment and population dynamics of fish species of commercial interest (Legrand *et al.*, 2003; Tillmann *et al.*, 2007; Selander *et al.*, 2008). Diatoms in general appear to produce a whole array of different compounds with such effects, directly derived from fatty acid metabolism, in which they are rich (e.g. the diatom *Skeletonema)* (Miralto *et al.*, 1999; Fontana *et al.*, 2007). The same metabolites are shown to have a role as infochemicals, and are involved in signaling adverse conditions within diatom populations (Vardi *et al.*, 2006), act as allelochemicals against competitor algae (Ribalet *et al.*, 2007), or regulate bacterial community composition and metabolism (Ribalet *et al.*, 2008). In general, there is a wealth of secondary metabolites produced by phytoplankton which are involved in the so-called "chemical warfare" that rules interaction among organisms at any level of the pelagic food web (reviewed by Ianora *et al.*, 2006). This field of research is a key to understanding how aquatic ecosystems function, and can also lead to discovery of biotechnologically exploitable molecules.

Other non-toxic HAB species can attain extraordinarily high cell numbers, negatively impacting coastal environments and economies (e.g. *Phaeocystis* in Northern Europe) (see overview by Zingone, this volume). In the Adriatic Sea, a recurrent accumulation of mucilage is apparently due to an imbalance in phosphorus metabolism, which affects bacterial degradation of organic matter from phytoplankton (Pugnetti *et al.*, 2005; Fonda Umani *et al.*, 2007). Mucilage events have also been recently reported in the Black Sea (Aktan *et al.*, 2008). The spreading of marine mucilage has been linked to surface seawater warming (Danovaro *et al.*, 2009).

In the last three or four decades, coastal HABs appear to have increased on a global scale. Several reasons have been suggested: a better knowledge of toxic species, better monitoring and alerting systems, the transport of algal cysts in ballast waters, the development of aquaculture, the stimulating effect of urban and industrial activities and/or atypical climate conditions (Smayda, 1997; Glibert *et al.*, 2005). New approaches and additional data are needed in order to distinguish the effects of climate from other biological and environmental factors driving occurrence of HABs (Wyatt, this volume). The response of HABs to climate changes will highly depend on the ecological and physiological diversity of the species involved and on the time scales.

In the Mediterranean, coastal areas subject to high nutrient discharge are hotspots for algal blooms including HABs, and some of them are at high risk for the possible impact on very delicate ecosystems such as the NW Catalan Sea, the Po river delta, the Nile river delta, and sectors of the Aegean Sea. Recently, the high abundance of dinoflagellates, especially the toxic *Karenia selliformis* in the Gulf of Gabes, Tunisia, has been attributed to increased nitrogen input (Turki *et al.*, 2006; Drira *et al.*, 2008). Additionally, the lack of deep mixing along the coast, and the ultra-oligotrophy of the Gulf of Gabes contributes to its extreme sensitivity to anthropogenic nutrient load. Summer outbreaks of the dinoflagellate *Alexandrium taylorii* are recurrent events in both the central and eastern Mediterranean Sea (Giacobbe *et al.*, 2007). Detrimental to both the tourism industry (water discoloration) and the shallow marine systems (hypoxia), the expansion of this HAB species is linked to high nutrient load.

Climate change triggers an increase in frequency of extreme and dramatic events such as floods, sudden and strong precipitation, and even intense freezing events in wintertime. This climatic variability has an immediate effect on coastal areas where it modulates stratification, general circulation, nutrient availability and also resuspension of sediments, on which some HAB species depend for their spreading. Climatic variability has also an indirect effect on periodic or long-term oceanographic features such as stratification periods or circulation patterns. One of the effects of temperature increase is an enhanced stratification, which will at first select species adapted to low turbulence, high light and to rapid utilization of available nutrients. Increased stratification of the water column, for instance, may favour phytoplankton species such as dinoflagellates, among which many HAB species are present, segregating them in the surface water, favouring blooms and enhancing accumulation. In a second phase, when nutrients are consumed, species able to migrate vertically and access nutrients in deeper layers will be favoured. However, this scenario still needs to be tested. On the other hand, off the coast of Spain, blooms of the HAB dinoflagellate *Gymnodinium catenatum* are driven by the supply of inorganic nutrients through upwelling and wind (Fraga and Bakun, 1990). In case of weakening of the upwelling, blooms of the toxic dinoflagellate could decrease in abundance. However, limiting concentrations of N or P are known to enhance toxin production of some HAB species, thus increasing their negative effects even at low cell concentrations (Graneli and Johansson, 2003; Uronen *et al.*, 2005; Poulton *et al.*, 2005; Adolf *et al.*, 2009). Temperature also has an effect on growth and division of both phytoplankton and their grazers, and this may result in an altered synchrony, inducing encounters between toxic species and predators that were temporally segregated in the past. For example, the seasonal window for growth of the paralytic shellfish toxin (PST) producer *Alexandrium catenella* could increase from about 65 to over 260 days per year following a 4-6°C temperature increase (Moore *et al.*, 2008).

Warmer waters may also increase the geographical range of dangerous benthic species, such as the tropical ciguatera producer *Ostreopsis*, which has now been observed in the Adriatic (see Aligizaki, this volume). Other examples are the pelagophyceaen *Chrysophaeum taylorii* associated with mucilaginous layers found in Sardinia (Luglie *et al.*, 2008), or the toxic dinoflagellate *Gambierdiscus* sp., the range of which is apparently spreading eastwards in the Mediterranean as far as Crete (Aligizaki *et al.*, 2008a). In many cases, doubts arise as to whether such species have never been reported due to lack of occurrence or to lack of observations. For these reasons, long-term time series of plankton observations are necessary to identify new arrivals and signal increased presence of HAB species.

The climate-induced variability in terms of temperature rise and pH lowering will most likely add to the human-induced effects such as continental runoff, fishing, introduced species, exponentially enhancing the impact of HABs. The extent of our knowledge on the ecological effects of ocean acidification is limited (see CIESM, 2008b), and drawing conclusions on the impact of decreasing pH on HABs would be premature. Some studies have tested the positive effect of high pH on growth or toxin production (Hinga, 1994; Hansen *et al.*, 2007). However, different species have different pH optima (Hansen *et al.*, 2007), which calls for changes in phytoplankton composition with decreasing pH (Engel *et al.*, 2008). However, the resilience to slow changes must be taken into consideration, since microalgae may adapt to altered conditions if the time scale of the change is increased. These aspects, and their interactions with temperature rise, are an important field of research that needs to be fostered.

Most research has concentrated on nutrient-phytoplankton interactions under different scenarios of N or P increase, as related to human activities, but there is little information on the synergistic effects of other ecosystem forcing in combination with excess nutrients as induced, for instance, by increased stratification. Future research should also focus on the interactions between HAB species and other components of the ecosystem such as viruses, bacteria, microzooplankton and zooplankton. In fact, it is evident that grazing is involved in control of blooms, but the interplay of mechanical and chemical defense must be further investigated in HABs (e.g. Ribalet *et al.*, 2009). In addition, heterotrophic bacteria often appear to be strongly associated with HAB species and insensitive to their toxins. The understanding of these links and the molecular mechanisms underlying them may lead to increased HAB prediction abilities and eventually bioremediation strategies.

In a scenario where the water column is both warmer and rich in nutrients, algal blooms can potentially last longer and decrease in diversity. However, warmer conditions, and weakening of nutrient upwelling in coastal conditions may produce contradictory responses at the clonal level. Therefore, it becomes crucial to understand the genetic variability of populations and what factors drive selection of a few genotypes within the same potentially toxic species. The link with toxin production is an important field of research, as well as the complex environmental factor interactions underlying the selection. However, ecophysiological experiments seldom include physiological plasticity and genetic strain/population diversity. For the diatom *S. marinoi* in the

Adriatic, it appears that highly genotypically different strains are responsible for blooms in different years, and the link to the observed effect with copepods needs to be established (Casotti and Gohde, pers. comm.). In the North Sea, evidence of the genotypic uniqueness of many clones of the PST producer *Alexandrium tamarense* in mixed plankton assemblages was recently demonstrated (Alpermann *et al.*, 2009). This is a milestone to follow the success of certain phenotypic traits, e.g. toxicity, in ecophysiological experiments or during bloom development.

In conclusion, predicting the impact of climate changes on HABs in the Mediterranean is very challenging because many factors and their combination are involved. Is our society ready to face up to major changes in the extension of HAB events, in the composition of HAB species and toxins, and in the resulting decrease of seafood safety? This calls for increased awareness in both HAB and seafood monitoring programmes, but also to increased attention to the interactions among species and between HAB species and abiotic factors.

**Acknowledgements:** the authors are grateful to the European Commission (IEF-PEOPLE-ALGBACT to CL), the Swedish Research Council Formas (CL) and Stazione Zoologica A. Dohrn (RC) for financial support.