

PROGRAM AND PROCEEDINGS

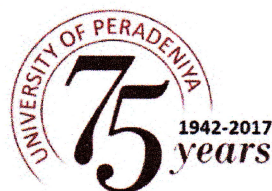
**SHORT COURSE ON EFFECTS OF CLIMATE CHANGE ON
BIODIVERSITY**

(October 27 & 28, 2017)



Jointly Organized by the
**Boards of study in Zoological Sciences and Environmental Science,
Postgraduate Institute of Science (PGIS), University of Peradeniya, Sri Lanka**

In Collaboration with
**The World Academy of Science (TWAS) - Regional Office for Central & South
Asia (ROCASA),
Jawaharlal Nehru Center for Advanced Scientific Research
Bangalore, India**



IMPACT OF CLIMATE CHANGE ON HARMFUL ALGAL BLOOMS (HABS) AND HUMAN HEALTH

M. M. Pathmalal

Professor, Center for Water Quality and Algae Research, Department of Zoology, University of Sri Jayewardenepura.

Introduction

The warming of the global system is unequal and has resulted in unpredicted changes in climate, meaning decadal or longer time scale shifts in overall weather characteristics (Stocker et al. 2013). Global atmospheric concentration of carbon dioxide, methane and nitrous oxides has increased markedly as a result of human activities since 1750. Levels of carbon dioxide have increased from roughly 280 ppmv in pre-industrial times to ~380ppmv at present, mostly due to fossil fuel burning and deforestation (IPCC 2007). The direct and indirect impacts of these increases in greenhouse gas concentrations on the earth will include increasing temperatures, acidification, changes to the density structure which will alter vertical mixing of waters, weakening of upwelling winds, and changes to the timing and volume of freshwater runoff into coastal marine waters, to name a few.

Over the past decade, several studies have suggested possible relationships between climate and the magnitude, frequency, and duration of harmful algal blooms (HABs) (HEED 1998, Dale et al. 2006, Edwards et al. 2006, Manage et al. 2009a; Manage et al. 2010). There is an increasing concern that this shifting environment conditions will cause changes in phytoplankton community structure and composition, including a greater prevalence and geographical spread of harmful algal blooms. Thus, scientists are left mostly to 'informed' speculation about whether future climate may enhance or diminish the frequency, intensity, and distribution of HAB outbreaks. A fundamental challenge to scientists is to identify key indicators and demonstrated relationships that reveal solid evidence of climate-induced changes in harmful algal blooms.

The term 'harmful' has been used to describe blooms of algae that can cause a range of deleterious physiological and environmental effects (Smayda 1997). Some harmful algae (HA) produce potent natural toxins that are bio concentrated by some filter feeding shellfish and finfish, and passed along the food chain causing illness or death if consumed by humans or other organisms. Other HA are non-toxic, but attain high biomass resulting in substantial reductions in biodiversity of the phytoplankton community structure and the amount of light reaching the benthos (Erdner et al. 2008). The decomposition of senescent blooms can lead to serious reductions in dissolved oxygen concentrations as well. Few studies have used comprehensive datasets together with rigorous statistical analyses to confirm linkages between climate and HABs. Even fewer have attempted to include epidemiological information on HAB-related illnesses. Thus, the aim of this presentation is to provide little information of the current state of knowledge of climate impacts on HABs and their known and potential consequences for human health, particularly as it relates to the main current research interest of scientists.

Climate change

The word 'climate' refers to large-scale and low frequency patterns of climate variability, such as the El Niño/Southern Oscillation, as well as anthropogenic climate change. Climate could be described as the average variations of weather over a long

period of time (~30 years) whilst weather is the all-natural phenomena within the atmosphere at a given time (hours to days). The Inter-government Panel on Climate Change (IPCC) in its report (AR5) released in 2016 clearly shows that warming of the climate system is unequivocal (IPCC, 2016). The IPCC confirms that human influence on the climate system is clear and growing, with impacts observed across all continents, freshwater systems and oceans. Many of the observed changes since the 1950s are unprecedented over decades to millennia. According to data humans (95%) are the main cause of current global warming. In addition, the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems, which affect long-lasting changes in all components of the climate system. It was documented that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (IPCC 2016). The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C over the period from 1880 to 2012, when multiple independently produced datasets exist. Since the beginning of the industrial era, oceanic uptake of CO₂ has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1, corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Meanwhile, studies conducted by scientists all over the world have clearly shown that global minimum temperature has increased at a faster rate than that of maximum temperature during the latter of the 20th century resulting in a broad decline in the diurnal temperature range (IPCC 2016).

Climate impact on Harmful Algal Blooms (HABs)

HA species comprise only a small component of the phytoplankton community, and their individual responses to climate variation and change can differ from that of the phytoplankton community as a whole. In the ocean, diatoms from the genus *Pseudo-nitzschia*, dinoflagellates from the genera *Alexandrium*, *Pyrodinium*, and *Gymnodinium*, *Karenia*, *Dinophysis* and *Prorocentrum* and *Gambierdiscus* are the most important HA which cause different poisoning syndromes. In freshwater, the most important HABs are caused by certain species of cyanobacteria (blue green algae) from the genera *Anabaena*, *Microcystis*, *Aphanizomenon* and *Cylindropomopsin* which produce cyclic peptides known as heat stable neuro, hepato and skin irritant microcystins and cylindropomopsin (Kite-Powell et al. 2008, Manage et al. 2009a,b, Manage et al. 2011). In both marine and freshwater systems, for humans and other animals, exposure to HA toxins results from eating contaminated fish or shellfish, drinking contaminated water, inhaling contaminated aerosol, or by contacting contaminated water for recreational activities.

It is generally accepted that HABs are increasing in frequency, intensity, and duration in all aquatic environments on a global scale (Van Dolah et al. 2000, Glibert et al. 2005), and some of this may be due to changes in climate. However, relatively little work has been done to characterize this link, and it is poorly understood (Haines and Patz 2004; Watson et al. 2005) primarily due to difficulty in separating the influence of climate change from other anthropogenic impacts such as eutrophication and ballast water introduction that are known to contribute to the occurrence of some HABs. As time series of monitoring data lengthens, it can be seen quantitatively that climate change impacts on HABs; but presently only a small number of studies are

available. In freshwater, a HAB is most likely to form in warm, still waters with abundant nutrients such as phosphorus and nitrogen. Environmental conditions which are causes for HABs are abundant light, high temperature, high pH levels, stagnant water and excess nutrients. Climate change also might increase the frequency and occurrence of HABs or cause them to be more severe in both freshwater and marine waters. For example, warming temperatures in Lake Erie have contributed to extensive blooms by *Microcystis aeruginosa*, a toxin-producing cyanobacterium that has lasted long into the early winter months. Further, it was found that the climate change is increasing the frequency and severity of blooms due to increases in water and air temperatures, increase in droughts and flooding, changes in salinity, increased amount of CO₂ and sea level rise and coastal upwelling (Figure 1).

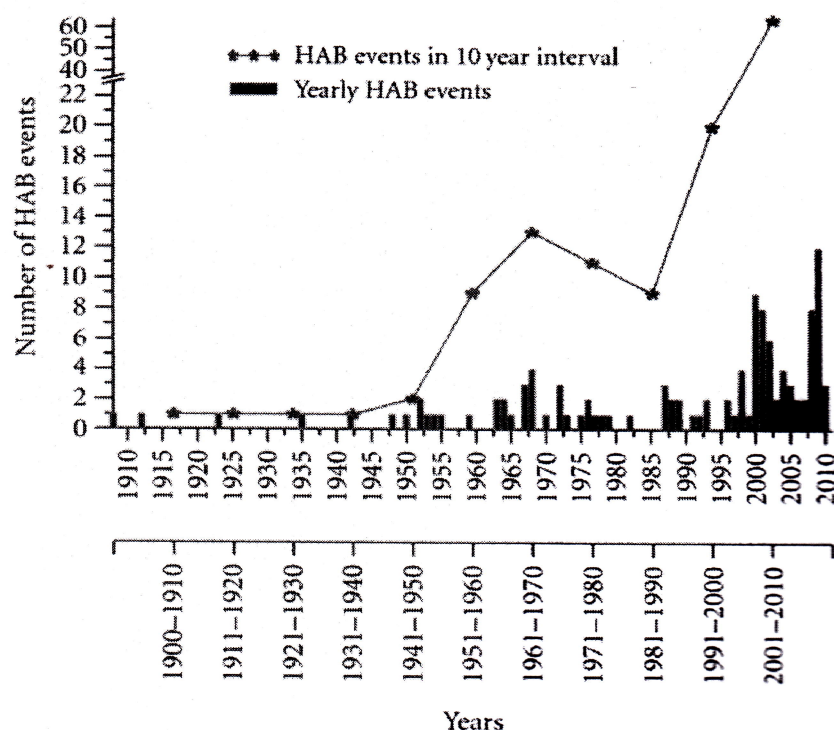


Figure 1: Development of HAB from 1900 to 2010 (NOAA, 2016)

Temperature effects on harmful algal blooms

Temperature is one of the main environmental factors affecting physiological processes in phytoplankton, acting at many different stages of growth and bloom development. It not only is one of the important environmental drivers expected to change with climate, but also is the least contentious, since there already has been measurable warming of the surface mixed layer (Beardalet et al. 2014). Some regions clearly will be affected more by global warming than others, but high latitudes will experience the greatest absolute and relative warming (Stocker et al. 2013). At the same time, increased temperatures may narrow “growth windows” of HAB species in sub-tropical/tropical waters if temperature optima are exceeded. Figure 2 shows HAB types and responsible environmental factors affected by climate change stressors.

		Environmental Factor				
		↑ T°C	↑ Stratification	↑ OA	↑ Cultural Eutroph.	Grazing
HAB Type	Diatoms (e.g., <i>Pseudo-nitzschia</i> spp.)	↑ +	↓ ++	↑ ↓	↓	↑ ↓
	Toxic Flagellates (e.g., <i>Alexandrium</i> , <i>Pyrodinium</i> , <i>Gymnodinium</i>)	↑	↑ ++	↑ ↓	↑	↑ ↓
	Benthic (e.g., <i>Gambierdiscus</i> spp.)	↑ ↓ ++	↑ ++	?	↑	↑ ↓
	Fish Killing (e.g., <i>Heterosigma</i> spp.)	↑	↑ ++	?	↑ +	↑ +
	High Biomass (e.g., mixed spp.)	↑ ↓	↑ ↓	↑ ↓	↑ ++	↑ ↓
	Cyanobacteria (e.g., <i>Nodularia</i> spp.)	↑ +	↑ ++	↑ ↓	↑ ++	?
	Cell Toxicity	?	?	↑ ↓	↑ ↓	↑ ↓

Figure 2: Climate change stressors on HAB. Arrows indicate changes that increase, decrease, or can occur in both directions. Symbols suggest the level of confidence: + (reasonably likely), ++ (more likely) (Stocker et al. 2013)

Temperature is a keystone parameter differentially affecting a range of metabolic processes, and thus is anticipated to have a strong influence on phytoplankton community composition and biomass. While increasing annual temperatures should broaden the windows of some HAB activity it will not affect others or even lessen other harmful algal blooms. It is logical that HAB habitats should expand to higher latitudes, but there is little clear evidence that this has happened and the time series observation systems needed to verify this change are currently lacking. There is little evidence to date that changing temperatures directly affect toxin production in HAB species.

Vertical stratification and Ocean acidification on HABs

Climate change will expand and intensify vertical stratification, particularly at high latitudes. It is clear that vertical stability of the water column is important for multiple HAB species which can flourish under well-stratified conditions (Berdalet et al. 2014), and the emergence of new HAB threats, and expansion of existing HAB organisms, appear to be coincident with global changes in stratification, suggesting that this physical process is a significant contributor.

As a result of climate change atmospheric CO₂ level will increase. Increasing atmospheric CO₂ is being modulated partly by its dissolution into surface seawater, leading to ocean acidification (OA) (Stocker et al. 2013). Although OA is a consequence rather than a proximal effect of climate change, its influence is distributed across all ocean surface waters and so it has a potential impact on development of harmful algal blooms. Scientists have estimated that surface water pH may decrease by 0.3-0.4 units by the end of the century as well.

Status of climate change and HABs in Sri Lanka

According to the Meteorology Department statistics, annual average rainfall of Sri Lanka has decreased over the years and this may be due to climate change induced by global warming. Annual mean air temperature anomalies also have showed a significant trend on increasing air temperatures during the recent few decades in Sri Lanka. The analysis of the meteorological data related to Sri Lanka reveals that there is a clear cut increase in air temperature in some districts of the country (Table 1) and this may directly affect water temperature rises.

Table 1: Increases in air temperature in different districts in Sri Lanka (Source: Meteorology Department 2014)

Location	Gradient (change per year in °C)
Rathnapura	0.0175
Badulla	0.0217
Kandy	0.0185
Nuwara Eliya	0.0146
Colombo	0.0164
Hambanthota	0.0104
Jaffna	0.0180

Algal blooms have been reported in many water bodies in Sri Lanka (Abewickrama 1979, Jayatissa, et al. 2006, Sethunga and Manage 2013). *Microcystis* blooms were found in Beira Lake, Kandy Lake and Kotmale Reservoir (Silva and Samaradiwakara 2005, Silva 2007, Pathmalal and Piyasiri 1995, 1999; Sethunga and Manage 2013). A dinoflagellate species was identified in Rosneath and Dunumadalawa tanks in Kandy and it caused a dysenteric epidemic condition in 2008 (Yatigammana et al. 2011) and coastal waters in Sri Lanka (Senevirathna and Manage 2010). Favorable tropical climatic conditions and anthropogenic nutrient loading and industrial discharges into freshwater bodies and coastal waters promote algal blooms. However, there are only a handful of publications on HABs in Sri Lanka

Implications for human health

Although the adverse health effects from exposure to cyanobacterial toxins have been known for decades or more, very few epidemiologic studies have been done to systematically assess these effects. Probably the most widely studied HA toxins are the brevetoxins associated with Florida red tides. Brevetoxins are a group of polyether toxins that affect sodium channels and can induce broncho-constriction in the mammalian respiratory tract. By contrast, people with asthma are more susceptible to brevetoxins, and may experience both acute and more long-term detriments in pulmonary function (Fleming et al. 2005, 2007). For example, recent work by Stocker et al. (2013) has begun to assess the health effects from recreational exposure to aerosolized microcystins during blooms of *Microcystis aeruginosa* in small lakes. The investigators found very low concentrations of microcystin-LR in the air (0.02 to 0.46 ng m⁻³) and water (2 to 5 µg L⁻¹) when people participated in recreational activities that generated aerosols, such as water skiing or riding personal water craft. Over time, Harmful Algal Bloom related Illness Surveillance System (HABISS) created by the Centers for Disease Control and Prevention (CDC) will be able to be used to assess whether increased contact between HABs and people and animals has a substantial impact on the frequency of HAB-related illnesses in a warmer climate

Present status in research studies in HABs

As a field of research, harmful algal science has progressed to the stage where numerous avenues by which climate change might alter HAB prevalence, distribution, and character can be anticipated. For example, there can be high confidence that, barring improved societal practices in agriculture and other land use policies, climate-driven increases in riverine inflows from human-modified watersheds will increase the prevalence of HAB-induced hypoxia/anoxia. There is an increasing tendency of research on cyanobacteria and harmful algae from 1960 to 2004.

The case for other types of harmful algal blooms, however, remains equivocal because compelling evidence that climate change will enhance the growth of HAB species over the far larger pool of competing non-HAB species is lacking. This shortcoming is partly due to the complexity and multiplicity of phytoplankton community processes such as interspecies competition, and grazing; but it also stems in part from the 'insular' nature of most HAB research, where a species is studied in far more detail than the community of organisms in which it occurs.

Suggestions for HAB and climate change research

There is a strong need to develop some consensus with regard to the 'best' practices for studying the effect of climate change pressures on harmful algal blooms with selected representative model organisms of HAB types for intensified study. Inclusion of co-occurring non-HAB species in longer term HAB laboratory studies by investigating the responses of HAB species to climate change stressors for both fresh and sea water is needed. Currently there is an insufficient understanding about the responses of HAB and non-HAB species under more realistic climate change scenarios, where simultaneous variation of multiple factors such as temperature, salinity, and OA regulate competitive outcomes. Thus, a greater emphasis on multifactorial laboratory experiments is needed. Further, research network investigating the physical science basis of climate change including temperature, precipitation, and sea level change has to be developed form a strong foundation for forecasting the magnitude and character of change by determining how these changes will differentially affect the occurrence and development of phytoplankton functional groups.

References

- Abewickrama, B.A. (1979). The genera of the freshwater algae of Sri Lanka. Parel-UNESCO Man & Biosphere National Committee for Sri Lanka. Special Publication 06. National Science Council Sri Lanka, Colombo, pp 103.
- Beardalet, N., Tarling, G.A., Bakker, D.C.E., Fielding, S. and Feely, R.A. (2014). Dissolution dominating calcification process in polar pteropods close to the point of aragonite under saturation. PLoS ONE 9 (10), Available from: <http://dx.doi.org/10.1371/journal.pone.0109183>.
- Dale B, Edwards, M. and Reid, P.C. (2006). Climate Change and Harmful Algae Blooms. In Ecol Stud Volume 189. Edited by: Granéli E, Turner JT. Heidelberg, Berlin: Springer-Verlag, 367-378.
- Edwards M., Johns D.G., Leterme, S.C., Svendsen, E. and Richardson, A.J. (2006). Regional climate change and harmful algal blooms in the northeast Atlantic. Limnol Oceanogr. 51(2):820-829.
- Erdner D., Dyble, J., Parsons, M.L., Stevens, R.C., Hubbard, K.A., Wrabel, M.L., Moore, S.K., Lefebvre, K.A., Anderson, D.M., Bienfang, P., Bidigare, R.R.,

- Parker, M.S., Moeller, P., Brand, E. and Trainer, V.L. (2008). Centers for Oceans and Human Health: a unified approach to the challenge of harmful algal blooms. *Environ Health*, 7 (Suppl 2), pp 234.
- Fleming, L.E., Kirkpatrick, B., Backer, L.C., Bean, J.A., Wanner, A., Dalpra, D., Tamer, R., Zaias, J., Cheng, Y.S., Pierces, R., Naar, J., Abraham, W. and Baden, D.G. (2005). Initial Evaluation of the Effects of Aerosolized Florida Red Tide Toxins (Brevetoxins) in Persons with Asthma. *Environ Health Perspect.* 113(5):650-657.
- Fleming, L.E., Kirkpatrick, B., Backer, L.C., Bean, J.A., Wanner, A., Reich, A., Zaias, J., Cheng, Y.S., Pierce, R., Naar J., Abraham, W.M. and Baden, D.G. (2007). Aerosolized Red Tide Toxins (Brevetoxins) and Asthma. *Chest*, 131:187-194.
- Glibert, P.M., Anderson, D.M., Gentien, P., Graneli, E. and Sellner, K.G. (2005). The global complex phenomena of harmful algae. *Oceanography*, 18(2):136-147.
- Haines, A. and Patz, J.A. (2004). Health effects of climate change. *JAMA*, 291(1): 99-103.
- HEED: Health Ecological and Economic Dimensions of Global Change Program (1998). Marine Ecosystems: Emerging Diseases as Indicators of Change. Health of the Oceans from Labrador to Venezuela. Year of the Ocean Special Report. NOAAOGP.
- IPCC (2016). Available from: <https://www.ipcc.ch/report/ar5/> (accessed on 22 October 2017)
- IPCC (2007). Summary for Policymakers: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, witzerland.18.
- Jayatissa, L.P, Silva, E.I.L., McElhiney, J. and Lawton, L.A. (2006). Occurrence of toxigenic cyanobacteria blooms in freshwaters of Sri Lanka. *Systematic and Applied Microbiology* 29: 156-164.
- Kite-Powell, H., Fleming, L.E., Backer, L., Faustman, E., Hoagland, P., Tsuchiya, A. and Younglove, L. (2008). Linking the oceans to public health: What is the "human health" in OHH. *Environ Health*; 7, 26-28.
- Lawton, L., Manage, P.M. and Edwards, C. (2011). Novel Bacterial Strains for the Removal of Microcystins from Drinking Water. *Water Science and Technology WST- WSTWS-EM10822R1*, 23-25.
- Manage, P.M. and Piyasiri, S. (1999). Composition, distribution and density of Zooplankton in Randenigala Reservoir, Sri Lanka. *Vidyodaya J. of Sci*, 8: 207-216.
- Manage, P.M, and Piyasiri, S. (1995). The chlorophyll-a content, species composition and population structure of phytoplankton in Randenigala Reservoir in Sri Lanka. *Vidyodaya Journal of Sci.*, 5: 29-41.
- Manage, P.M, Edwards, C., Singh, B. K. and Lawton, L. A. (2009a). Isolation and identification novel microcystin degrading bacteria. *Applied Enviromental Microbiology AEM*. 01928-09.
- Manage, P.M, Edwards, C. and Lawton, L. A. (2009b). Biodegradation of Microcystin LR by natural bacterial population. *Environmental Research in Asia TERRAPUB*, (2009) Vol. 2: 277-285.
- Manage, P.M., Edwards, C. and L. Lawton (2010). "Bacterial degradation of microcystin." *Interdisciplinary Studies on Environmental Chemistry-Biological Responses to Contaminants. TERRAPUB: Tokyo*: 97-104.
- Meteorological Department (2014). Available from: <http://www.meteo.gov.lk/index.php?lang=en> (accessed on 21 October 2017).

- NOAA (2016). Available from: <https://www.ncdc.noaa.gov/sotc/global/201613> (accessed on 21 October 2017).
- Senevirathna, H.M.G.R. and Manage, P.M (2010). Preliminary investigation of red tide producing dinoflagellates in coastal water in Sri Lanka (Thesis)
- Sethunge, S. and Manage, P.M. (2013). "Nuisance algae in water supply projects in Sri Lanka." International Conference on Sustainable Built Environment (ICSBE-2010).pp 32.
- Silva, E.I.L. and Samaradiwakara, S.R.M.S. (2005). Limnology of Kandy Lake before the outbreak of a cyanobacteria bloom in May 1999. III. Phytoplankton composition and succession. Sri Lanka Journal of Aquatic Sciences, 10: 55-71.
- Silva, E.I.L. (2007). Hypertrophic-eutrophic alteration in Kandy Lake, following an outbreak of a *Mycrocystis* bloom. Sri Lanka. J. Aquat. Sci. 12:115- 120.
- Smayda, T.J. (1997). Bloom dynamics: Physiology, behavior, trophic effects. Limnol Oceanogr, 42(5):1132-1136.
- Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgle, P.M., (2013). The physical science basis. In: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 1535-1538.
- Van Dolah, F.M. (2000). Marine Algal Toxins: Origins, Health Effects, and Their Increased Occurrence. Environ Health Perspect, 108 (Suppl. 1):133-141.
- Watson, R.T., Patz, J.A., Gubler, D.J., Parson, E.A. and Vincent, J.H. (2005). Environmental health implications of global climate change. Journal of Environmental Monitoring, 7(9): 834-843.
- Yatigammana, S.K., Ileperuma, O.A. and Perera, M.B.U. (2011). Water pollution due to harmful algal bloom: a preliminary study from two drinking water reservoirs in Kandy, Sri Lanka. J. of Natn. Sci. Foundation Sri Lanka, 39 (1): 91-94.