

# Monitoring algal blooms and associated human health risks at local to global scales

## Overview and potential linkages with ReBALAN:CE

Peter D. Hunter<sup>1</sup>, Andrew N. Tyler<sup>1</sup>, Vagelis Spyrakos<sup>1</sup>, Steve Groom<sup>2</sup>,  
Stephanie Palmer<sup>1,3</sup> and Geoffrey A. Codd<sup>1,4</sup>

<sup>1</sup>*Biological and Environmental Sciences, School of Natural Sciences, University of Stirling, UK*

<sup>2</sup>*Plymouth Marine Laboratory, Plymouth, UK*

<sup>3</sup>*Department of Geography, University of Leicester, UK*

<sup>4</sup>*Division of Molecular Microbiology, College of Life Sciences, University of Dundee, UK*

email: [p.d.hunter@stir.ac.uk](mailto:p.d.hunter@stir.ac.uk)

ReBALAN:CE workshop | University of Stirling | 29-30th August 2013



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# Outline

## Recent and on-going research projects

### 1. Monitoring algal blooms in lakes

#### (a) Earth observation

- NERC GloboLakes, EU FP7 INFORM and MTA KTAMOP

#### (b) Citizen science

- Environment Agency Algal Blooms Pilot Project

### 2. Cyanobacteria, cyanotoxins and human health

- NERC Cyanobacteria, Environment and Human Health (CEHH)
- EU COST Action ES1105 – “CyanoCOST”

# 1a. Monitoring algal blooms in lakes

- Earth observation

# GloboLakes - consortium

GloboLakes (Global Observatory of Lakes Responses to Environmental Change) is a 5-year NERC-funded consortium project

## 1. University of Stirling

Andrew Tyler (PI), Peter Hunter, Vagelis Spyrakos

## 2. Plymouth Marine Laboratory (PML)

Steve Groom, Victor Vicente-Martinez, Gavin Tilstone, Giorgio Dall'Olmo

## 3. University of Reading

Christopher Merchant

## 4. University of Dundee

Mark Cutler, John Rowan, Terry Dawson, Eirini Politi

## 5. Centre for Ecology and Hydrology (CEH)

Stephen Maberly, Laurence Carvalho, Stephen Thackery, Alex Elliott

## 6. University of Glasgow

Claire Miller, Marion Scott, Ruth Haggarty

 Earth observation scientist    Bio-optical oceanographer    Ecosystem modeler  
 Freshwater ecologist    Environmental statistician

# GloboLakes - background

Lakes are under increasing pressure from climate and other drivers of environmental change

- >304 million lakes – important to global biogeochemical cycles (e.g. Bastviken et al. 2011, *Science*)
- Concern over water security (85% of freshwater resource) and provision of ecosystem goods and services
- Global increase in the incidence, magnitude and duration of toxic cyanobacterial blooms
- Very small proportion of lakes globally are routinely monitored (<0.0003%) and standardised approaches are lacking

## Ecosystem goods & services



Water supply

Food



Energy

Flood control



Climate regulators

Recreation



Tourism

Aesthetic & cultural

# GloboLakes – objectives

GloboLakes is investigating the status of lakes globally and their responses to environmental change

## What controls the differential sensitivity of lakes to environmental perturbation?

- Determine spatial and temporal trends and attribute causes of change for 1000 lakes worldwide
- Forecast lake sensitivity to environmental change using ecosystem models
- Use knowledge to inform lake management and policy formation

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### Lakes as sentinels of climate change

Rita Adrian,<sup>a,\*</sup> Catherine M. O'Reilly,<sup>b</sup> Horacio Zagarese,<sup>c</sup> Stephen B. Baines,<sup>d</sup> Dag O. Hessen,<sup>e</sup> Wendel Keller,<sup>f</sup> David M. Livingstone,<sup>g</sup> Ruben Sommaruga,<sup>h</sup> Dietmar Straile,<sup>i</sup> Ellen Van Donk,<sup>j</sup> Gesa A. Weyhenmeyer,<sup>k</sup> and Monika Winder<sup>l</sup>

<sup>a</sup> Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany

<sup>b</sup> Biology Program, Bard College, Annandale, New York

<sup>c</sup> Laboratorio de Ecología y Fotobiología Acuática, Instituto Tecnológico de Chascomús (INTECH), Chascomús Provincia de Buenos Aires, Argentina

<sup>d</sup> Department of Ecology and Evolution, Stony Brook University, Stony Brook, New York

<sup>e</sup> Department of Biology, University of Oslo, Oslo, Norway

<sup>f</sup> Cooperative Freshwater Ecology Unit, Ontario Ministry of the Environment, Laurentian University, Sudbury, Ontario, Canada

<sup>g</sup> Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland

<sup>h</sup> Laboratory of Aquatic Photobiology and Plankton Ecology, Institute of Ecology, University of Innsbruck, Innsbruck, Austria

<sup>i</sup> Limnological Institute, University of Konstanz, Konstanz, Germany

<sup>j</sup> Department of Aquatic Food Webs, Netherlands Institute of Ecology, Centre for Limnology, Nieuwersluis, The Netherlands

<sup>k</sup> Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, and Department of Ecology and Evolution, Uppsala University, Uppsala, Sweden

<sup>l</sup> John Muir Institute of the Environment, Tahoe Environmental Research Center, University of California, Davis, California

#### Abstract

While there is a general sense that lakes can act as sentinels of climate change, their efficacy has not been thoroughly analyzed. We identified the key response variables within a lake that act as indicators of the effects of climate change on both the lake and the catchment. These variables reflect a wide range of physical, chemical, and biological responses to climate. However, the efficacy of the different indicators is affected by regional response to climate change, characteristics of the catchment, and lake mixing regimes. Thus, particular indicators or combinations of indicators are more effective for different lake types and geographic regions. The extraction of climate signals can be further complicated by the influence of other environmental changes, such as eutrophication or acidification, and the equivalent reverse phenomena, in addition to other land-use influences. In many cases, however, confounding factors can be addressed through analytical tools such as detrending or filtering. Lakes are effective sentinels for climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment.

Currently, climate change is considered to be one of the most severe threats to ecosystems around the globe (ACIA 2004; Rosenzweig et al. 2007). Monitoring and understanding the effects of climate change pose challenges because of the multitude of responses within an ecosystem and the spatial variation within the landscape. A substantial body of research demonstrates the sensitivity of lakes to climate and shows that physical, chemical, and biological lake properties respond rapidly to climate-related changes (ACIA 2004; Rosenzweig et al. 2007). Fast turnover times from organismal to ecosystem scales in lakes are prerequisite for detecting such rapid changes. Previous studies have suggested that lakes are good sentinels of global climate change because they are sensitive to environmental changes and can integrate changes in the surrounding landscape and atmosphere (Carpenter et al. 2007; Pham et al. 2008; Williamson et al. 2008). However, a more thorough analysis of the potential for lakes to act as sentinels for the rapid rates of current climate change is lacking.

Studies of lakes provided some of the early indications of the effects of current climate change on ecosystem structure

and function (Schindler et al. 1996a; Magnuson et al. 2000; Verburg et al. 2003) and the consequences for ecosystem services (O'Reilly et al. 2003). Some climate-related signals are highly visible and easily measurable in lakes. For instance, climate-driven fluctuations in water level have been observed on a broad scale in North America (Williamson et al. 2009), and shifts in the timing of ice formation and thawing reflect climate warming at a global scale (Magnuson et al. 2000). Other signals may be more complex and difficult to detect in lakes, but they may be equally sensitive indicators of climate forcing or equally informative regarding effects on ecosystem services. Available long-term historical records and reconstructions from sediment cores have yielded insight into less visible climate-related changes and provided us with an understanding of the mechanisms that give rise to these changes. Paleolimnological records, in particular, have been crucial in developing climate records over recent geologic timescales, allowing us to interpret current climate change and predict its effects (Smol 2008; Leavitt et al. 2009).

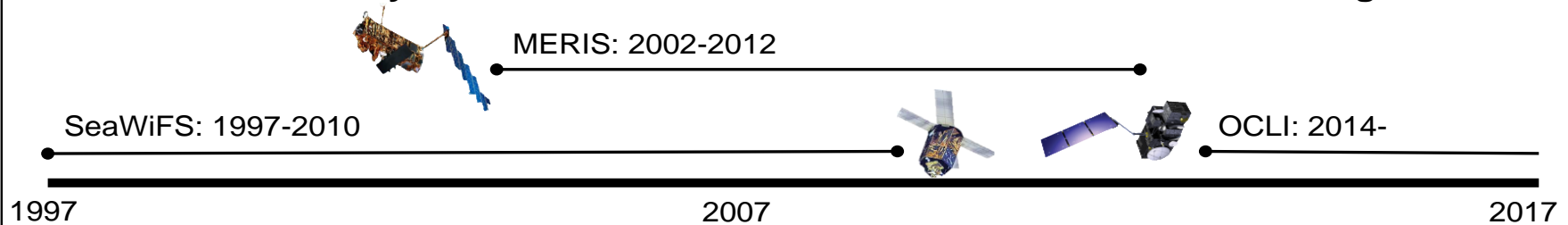
In many ways, lake ecosystems appear to be valid sentinels for current climate change. Lake ecosystems act as sentinels because they provide indicators of climate change either directly or indirectly through the influence of climate

\* Corresponding author: adrian@igb-berlin.de

# GloboLakes – our approach

Satellite-based observatory with near real-time processing for over 1000 of world's largest lakes

## Near-continuous 20-year time series of lake variables from Earth observing satellites

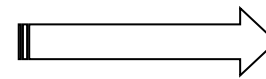


### Core products

- Lake surface water temperature (LSWT)
- Total suspended matter (TSM)
- Coloured dissolved organic matter (CDOM)
- Chlorophyll-a (Chla)
- C-phycoerythrin (CPC)

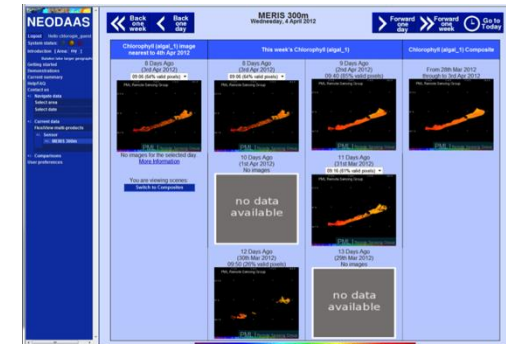
### Secondary products

- Phytoplankton primary productivity
- Lake phenology metrics



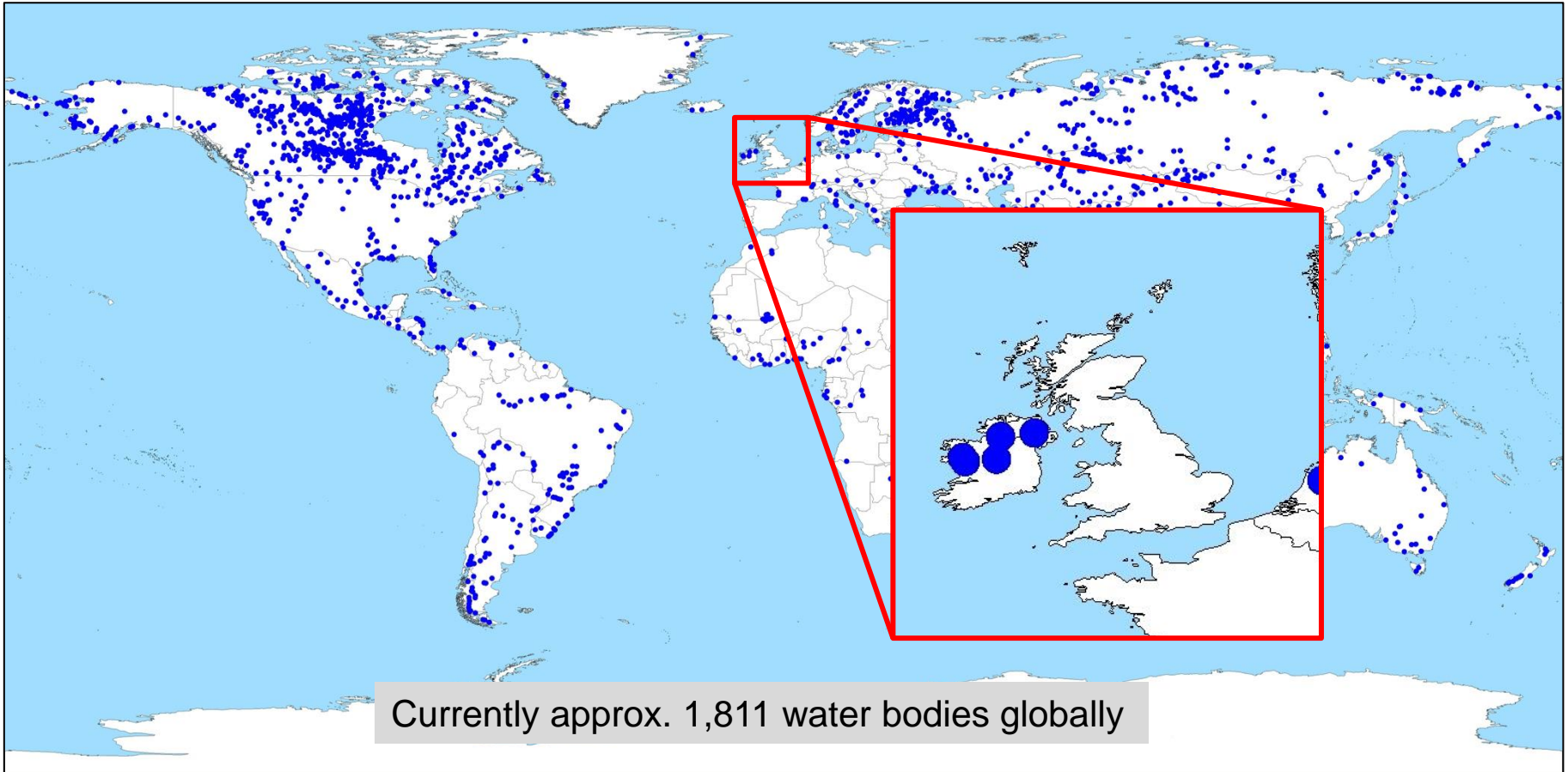
### Web-based GIS portal

OR  
ftp



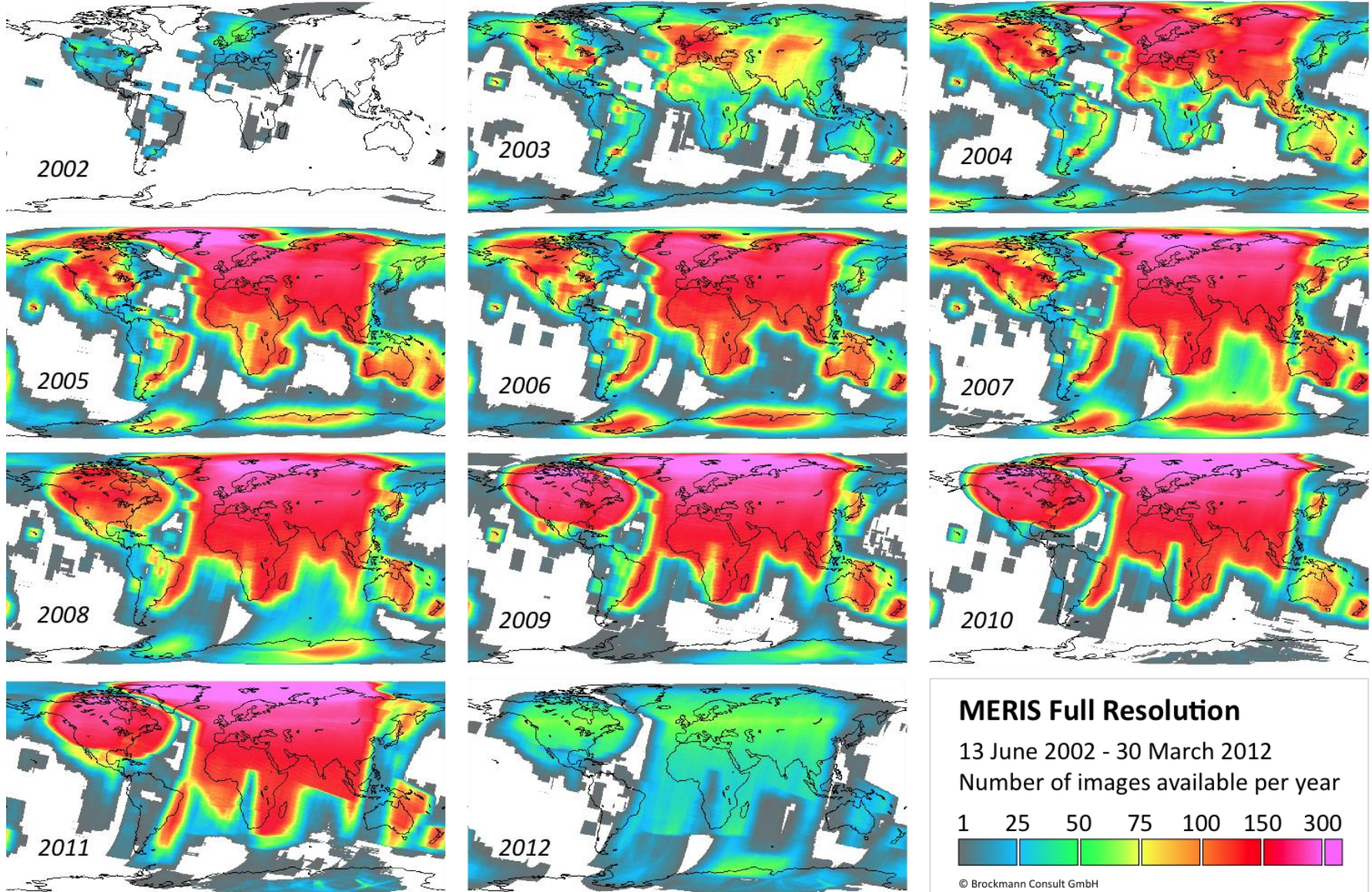
# GloboLakes – target lakes

Satellite-based observatory with near real-time processing for over 1000 of world's largest lakes and reservoirs

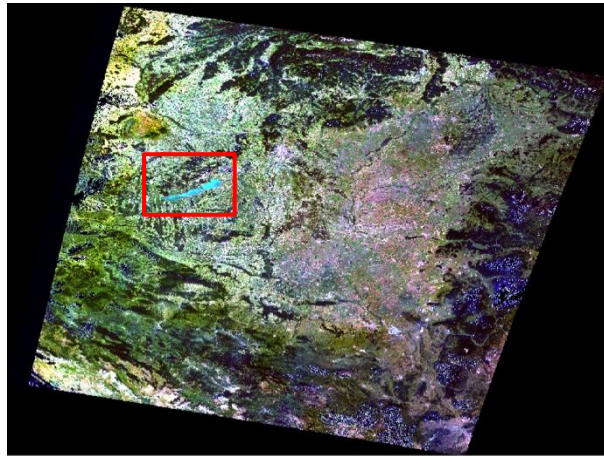




# GloboLakes – example products



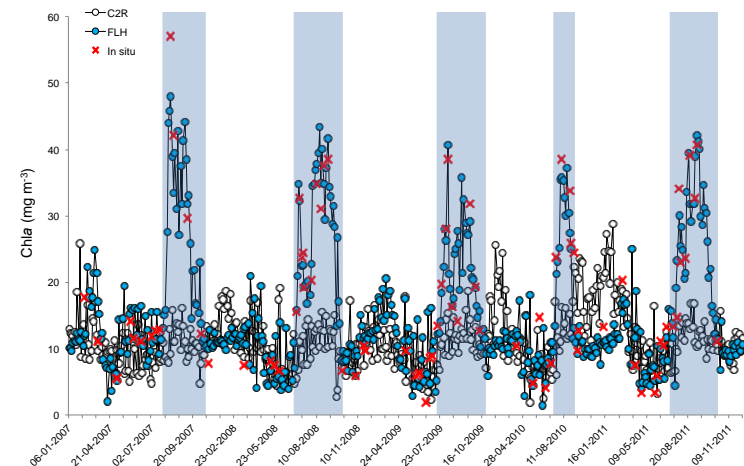
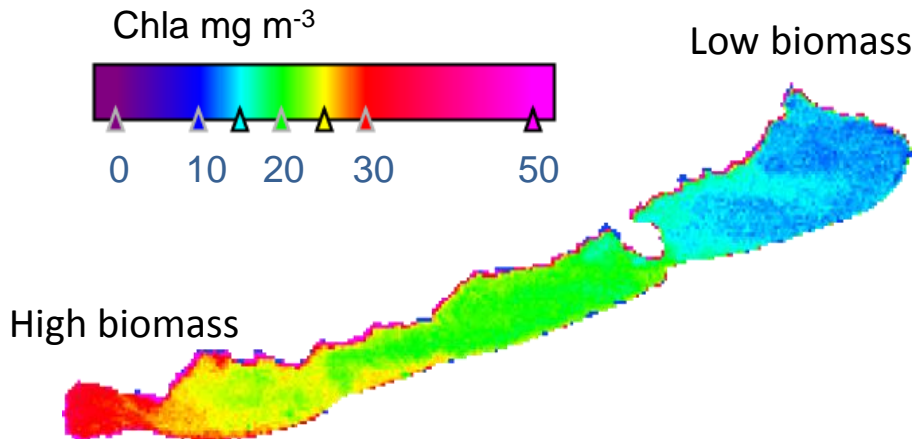
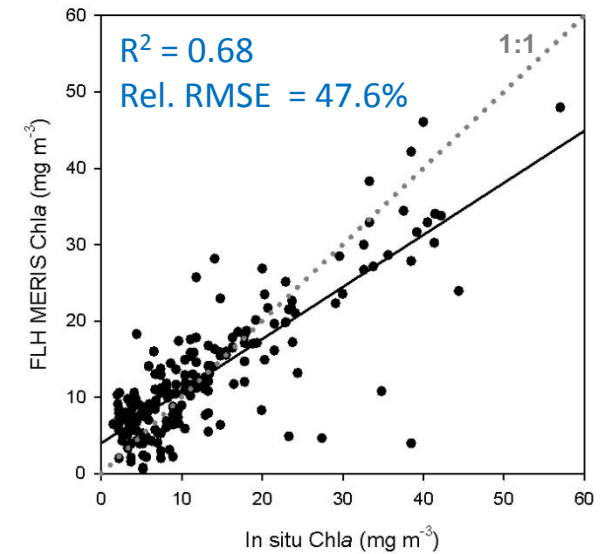
# GloboLakes – example products



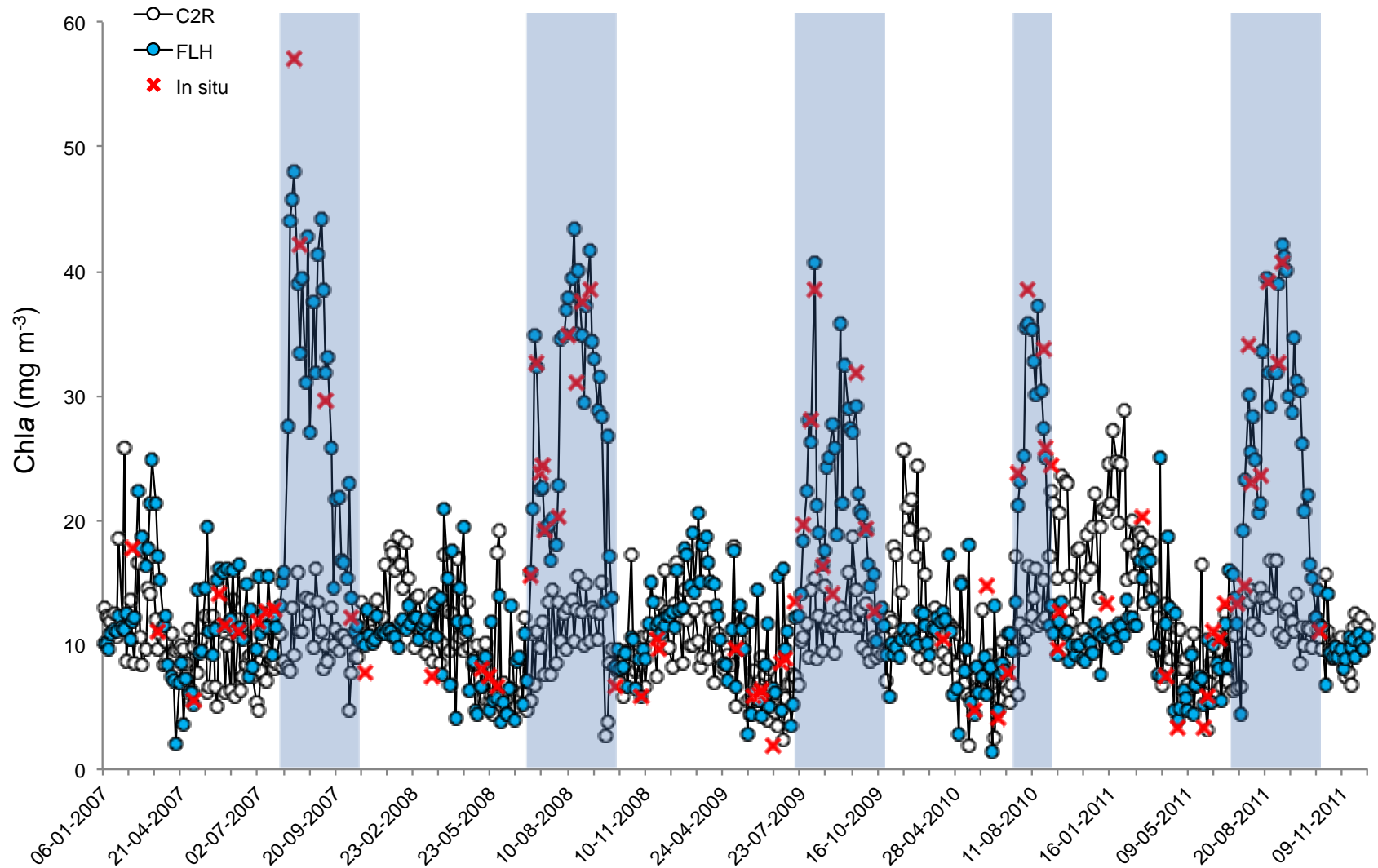
Raw L1b MERIS image



Raw L1b MERIS subset

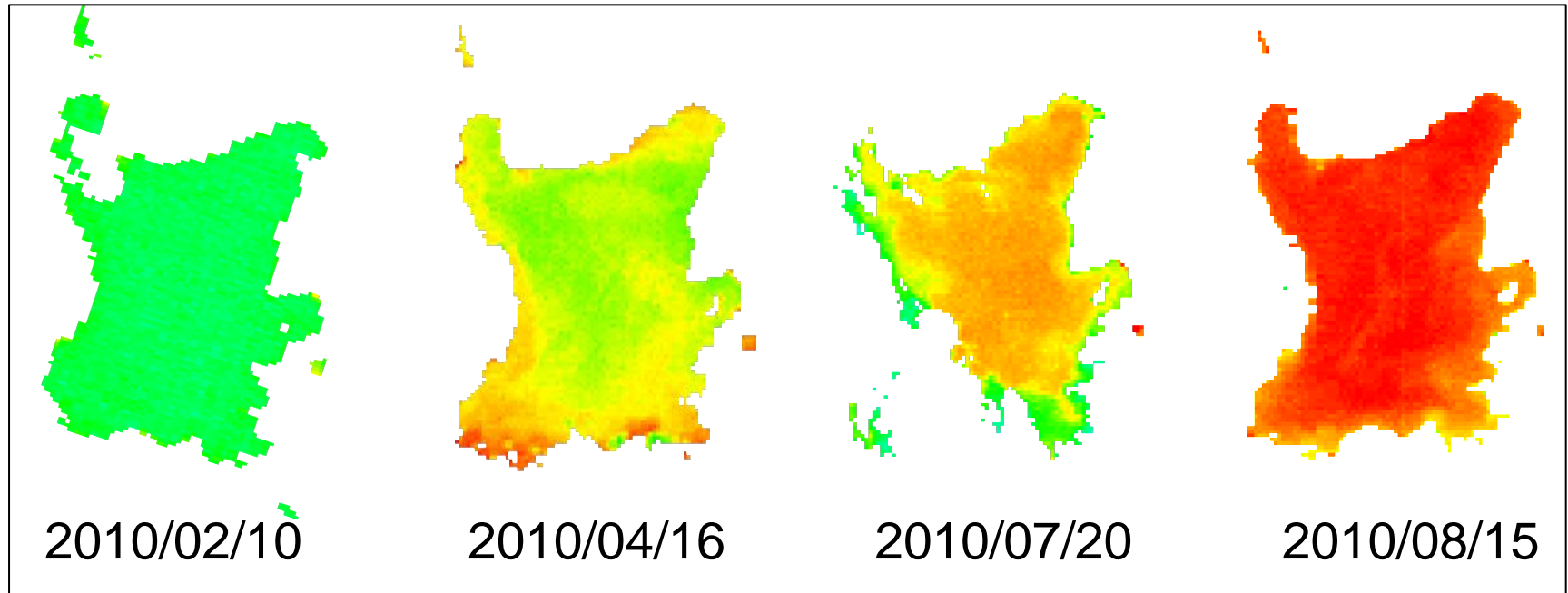


# GloboLakes – example products

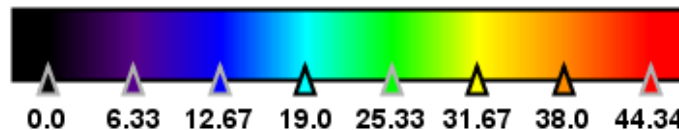


# GloboLakes – example products

Temporal evolution of a cyanobacterial bloom in Lough Neagh during summer 2010

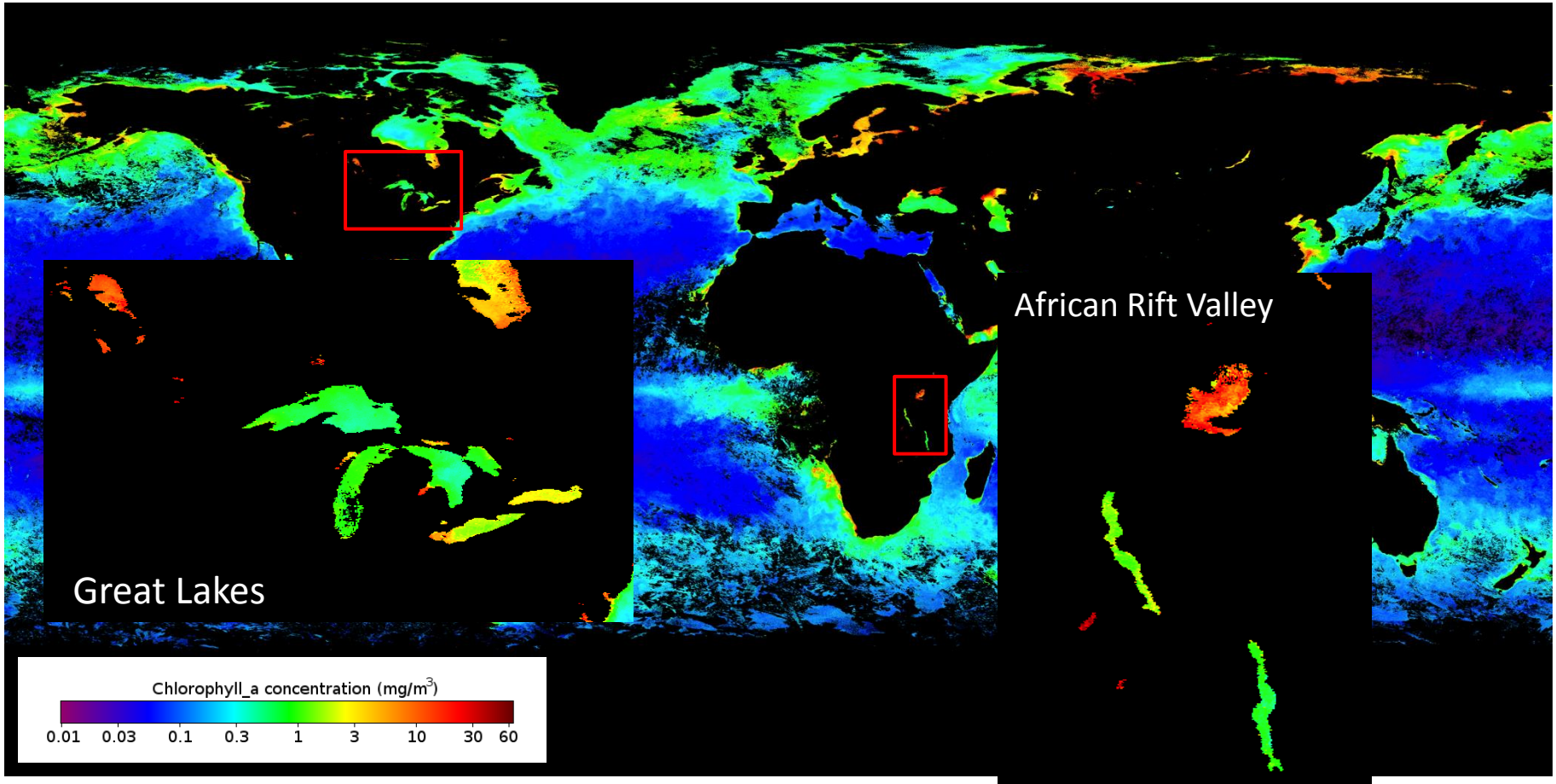


Chl a [ $\text{mg m}^{-3}$ ]

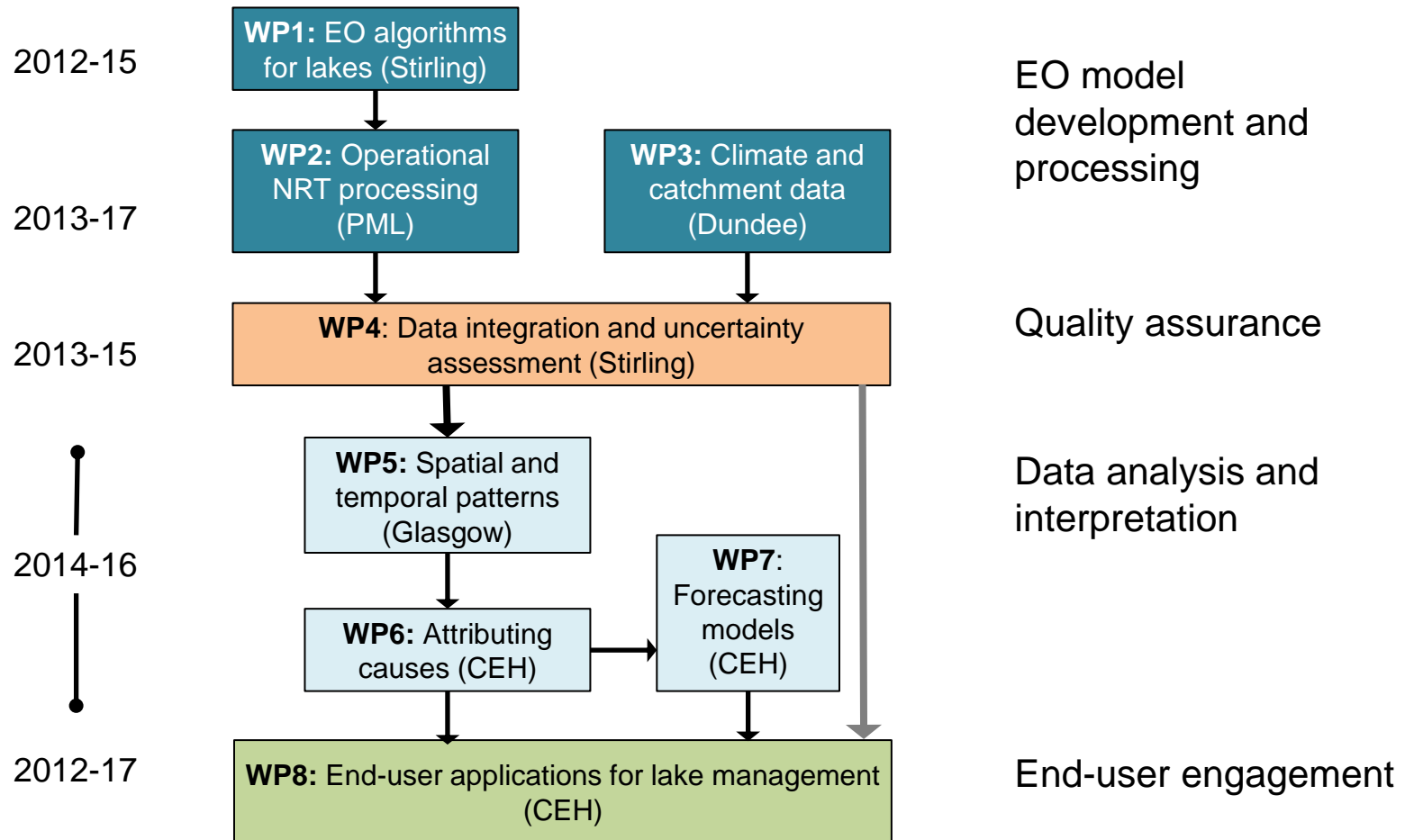


# GloboLakes – example products

Global Chla product (v.-1) – SeaWiFS 4km monthly composite for Aug 1998 (produced by PML for ESA OceanColour-CCI)



# GloboLakes – workpackages



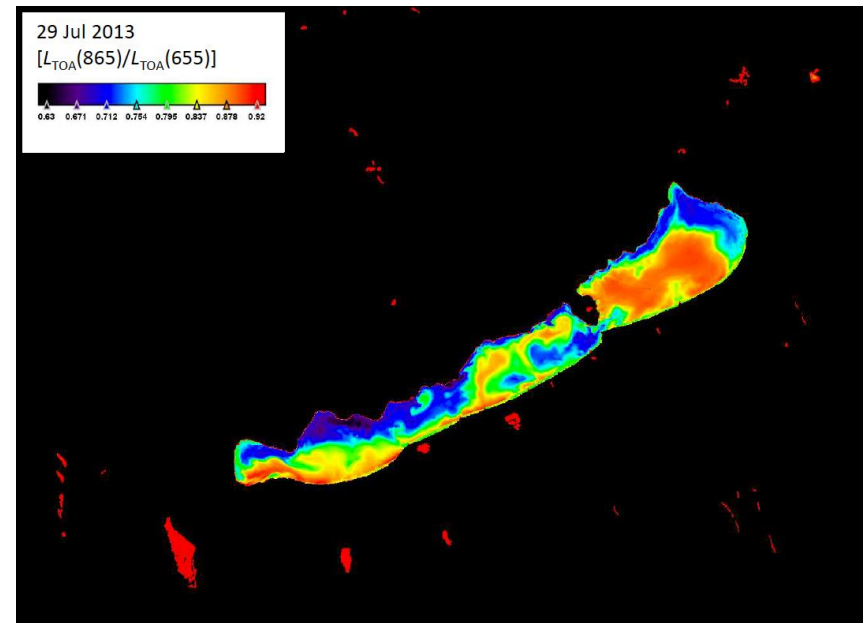
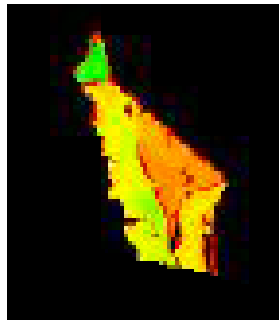
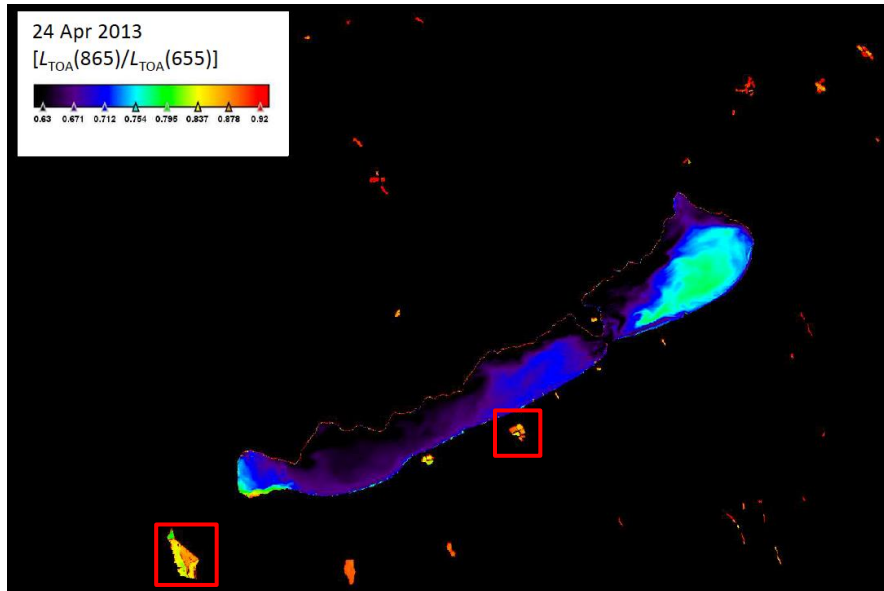
# GloboLakes – wider engagement

Contributions from across the scientific and end-user communities key to success of wider impact

- Currently, more than 25 scientific partners from over 15 nations
  - CSIRO, Australia; CSIR, South Africa; VITO, Belgium
  - Environment Canada; Estonian Marine Institute;
  - EC Joint Research Centre; CNR-IREA, Italy;
  - INTA, Spain; CUNY, USA; Creighton, USA
  - South Florida, USA; Institute of Limnology, Nanjing...
- Several end-user partners including UK environmental regulators (EA, SEPA, NIEA)
- Engagement with UK National Centre for Earth Observation (NCEO), European Environment Agency, ESA and GEO

# KTAMOP – overview

## Sustainability and environmental impact of communities living in Lake Balaton's southern watershed





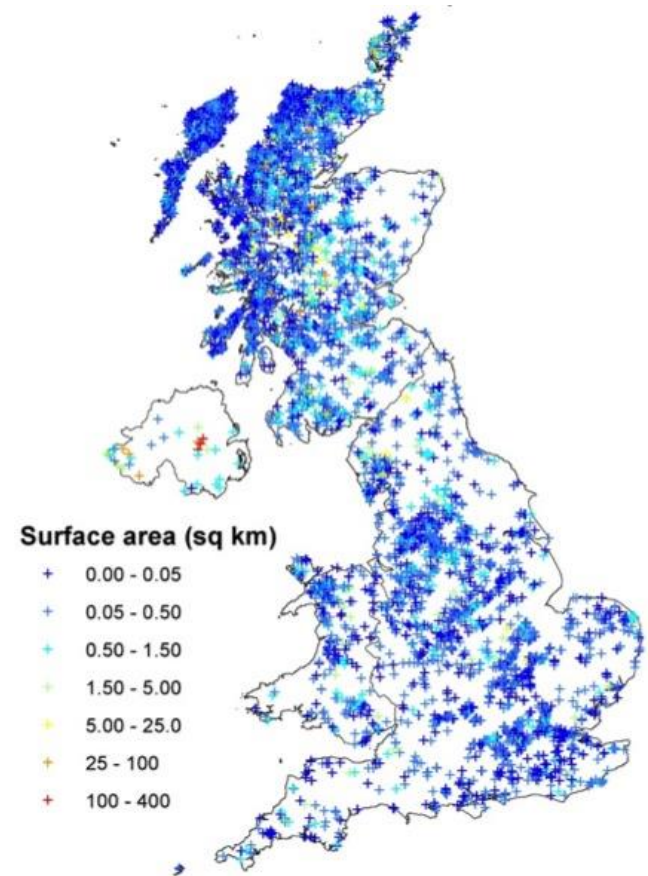
# 1b. Monitoring algal blooms in lakes

- Citizen science

# EA Algal Blooms Project

## Pilot study looking at feasibility of citizen science (and remote sensing) for bloom monitoring in UK

- EA has statutory duty under national and European legislation to monitor water quality monitoring and algal bloom incidents
- 43,738 waterbodies in UK; ~740 WFD lakes; 440 are currently “monitored”
- England & Wales 2006-2010: 11 (Cat-1), 60 (Cat-2) and >300 (Cat-3) cyanobacteria-related incidents (Environment Agency)
- Scotland 2008-2010: 458 reported incidents with 181 exceeding WHO thresholds (cell numbers) (SEPA)
- WFD now requires data on bloom intensity and frequency

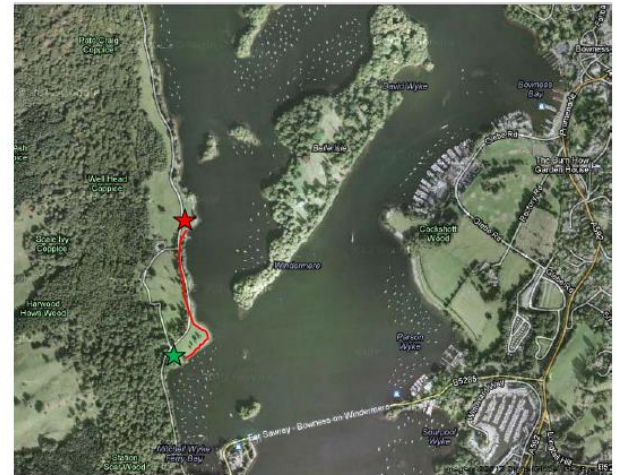


# EA Algal Blooms Project

Pilot study looking at feasibility of citizen science (and remote sensing) for bloom monitoring in UK

- 70 volunteers recruited through Cumbria Wildlife Trust
- Task with monitoring 3 waterbodies (Windermere, Derwent Water and Bassenthwaite) every 2-3 days from 01 Jun to 01 Nov
- Walked shoreline transect, with visual assessment of water appearance (and stick test!)
- If water discoloured by algae or scums visible – samples sent to EA for microscopic inspection
- Comparison against data from conventional monitoring programmes (~weekly)

Map of designated survey area



Red lines indicate areas of shoreline to be walked.

★ Indicates start point. Grid reference – SD 388 959.

★ Indicates finish point. Grid Reference – SD 389 963.

Walked transect at Harrowslack Bay, Windermere

# EA Algal Blooms Project

## Algal Bloom Pilot Project Stick Test Method



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Use this quick identification method to decide if you need to take a sample or not (presence/absence of a bloom).

- Dip the stick into the water up to the marked point, if water depth allows, or as far as it will go if not.
- Look at the colour and opacity of the water against the white stick.
- Lift the stick out and check whether any leaves, filaments or particles adhere to it.
- Go through the four questions on this chart, and take a sample if required.

1. Can you see leaves without the aid of a microscope, in the water or on the stick?

YES - Aquatic higher plants - NO SAMPLE REQUIRED



There are a number of aquatic higher plants that might look like a bloom e.g. Duckweed (*Lemna* sp.), vivid green with smooth-edged leaves, and water fern (*Azolla* sp.), darker greenish-red with wavy-edged leaves in centre of photo.

NO - Go to question 2a

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2a. Can you see strands or filaments without the aid of a microscope, in the water or on the stick?

YES - Filamentous algae, go to question 2b

NO - Go to question 3

2b. Are they attached to the lake bed or stones i.e. not free-floating?

YES - Benthic filamentous algae - NO SAMPLE REQUIRED

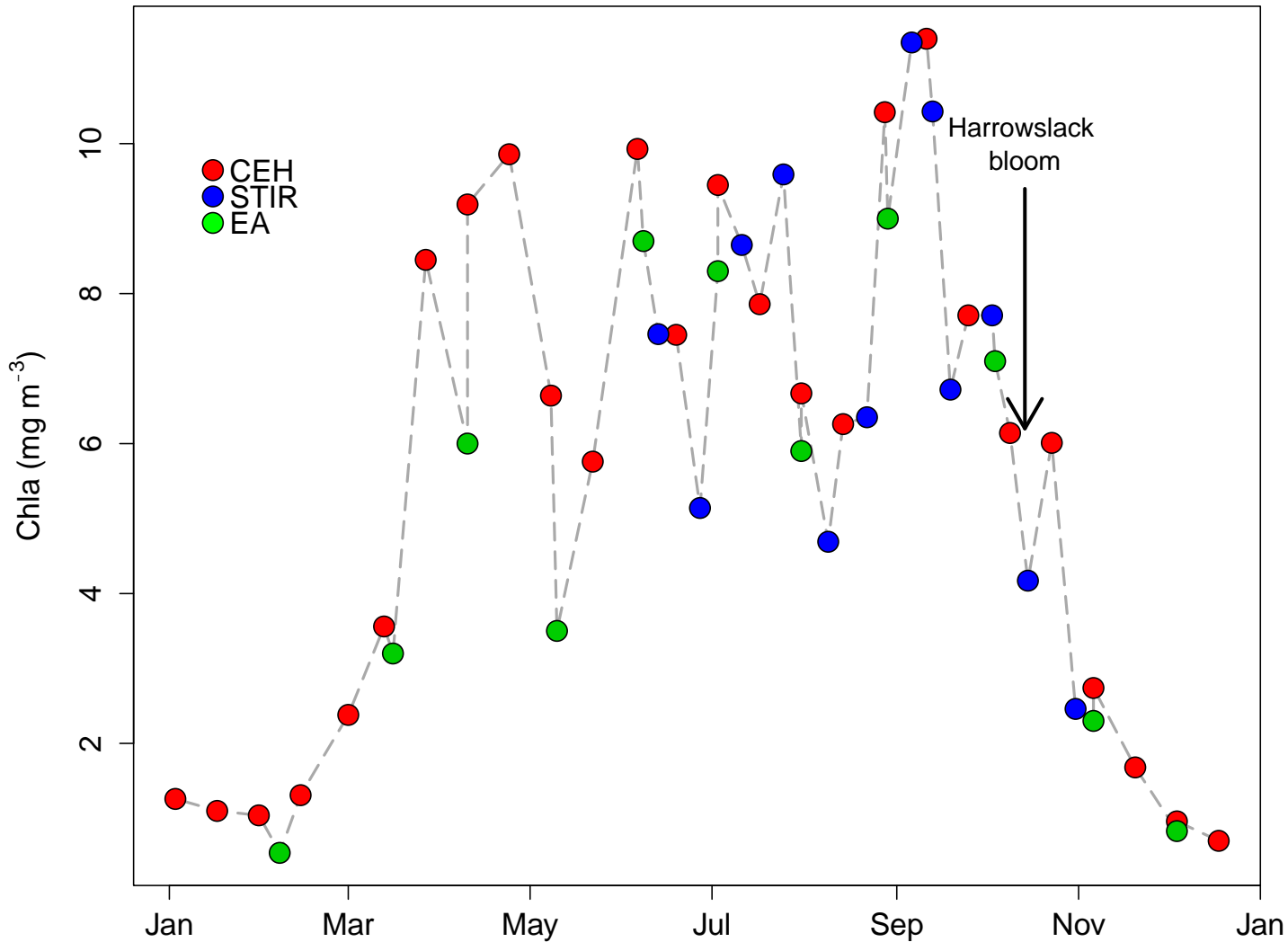


e.g. *Cladophora*, a common benthic filamentous alga.



NO - Free-floating filamentous algae - TAKE SAMPLE

# EA Algal Blooms Project



Comparison of volunteer recorded blooms against in situ monitoring data

## 2. Cyanobacteria, cyanotoxins and human health

# Cyanobacterial toxins

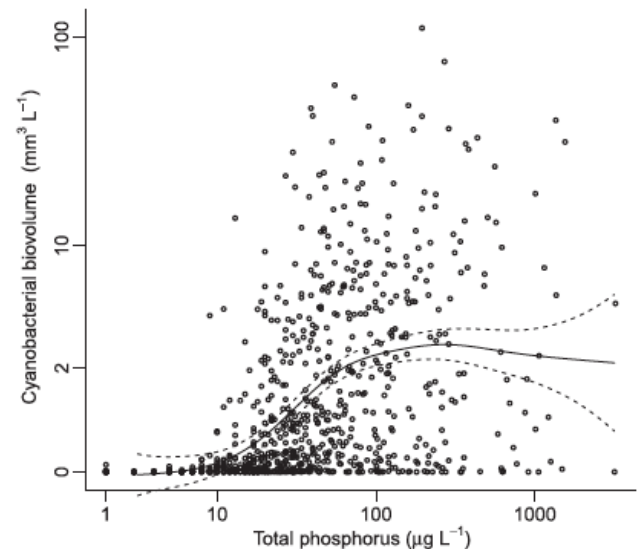
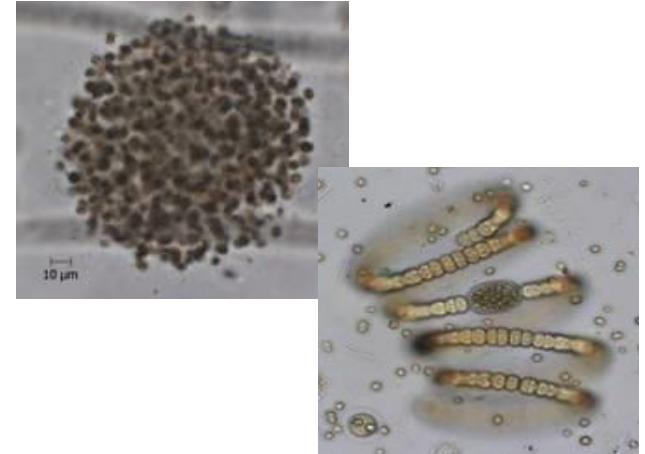
- Mass populations of cyanobacteria (blooms, scums, biofilms) often develop in warm, poorly flushed nutrient-rich waters
- Many species and strains produce potent toxins as secondary metabolites

**Hepatotoxins:** microcystins, nodularins, cylindrospermopsins

**Neurotoxins:** anatoxin-a, homoanatoxin, anatoxin-a(s), saxitoxins, BMAA

**Irritants and allergenic toxins:** aplysiatoxins, lipopolysaccharide (LPS), endotoxins

- Exposure routes: (i) skin contact; (ii) inhalation of spray during recreational activities; (iii) ingestion of **contaminated foodstuffs** or drinking water

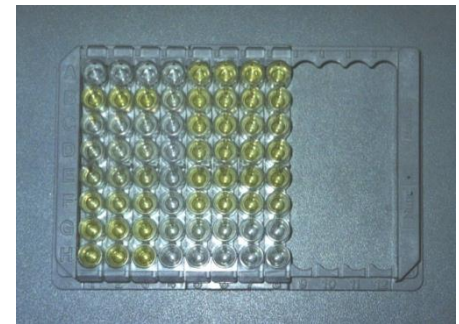


Carvalho et al. (2013) J. Appl. Ecol.

# NERC CEHH project

## Investigating the potential for toxin transfer to crops intended for human consumption

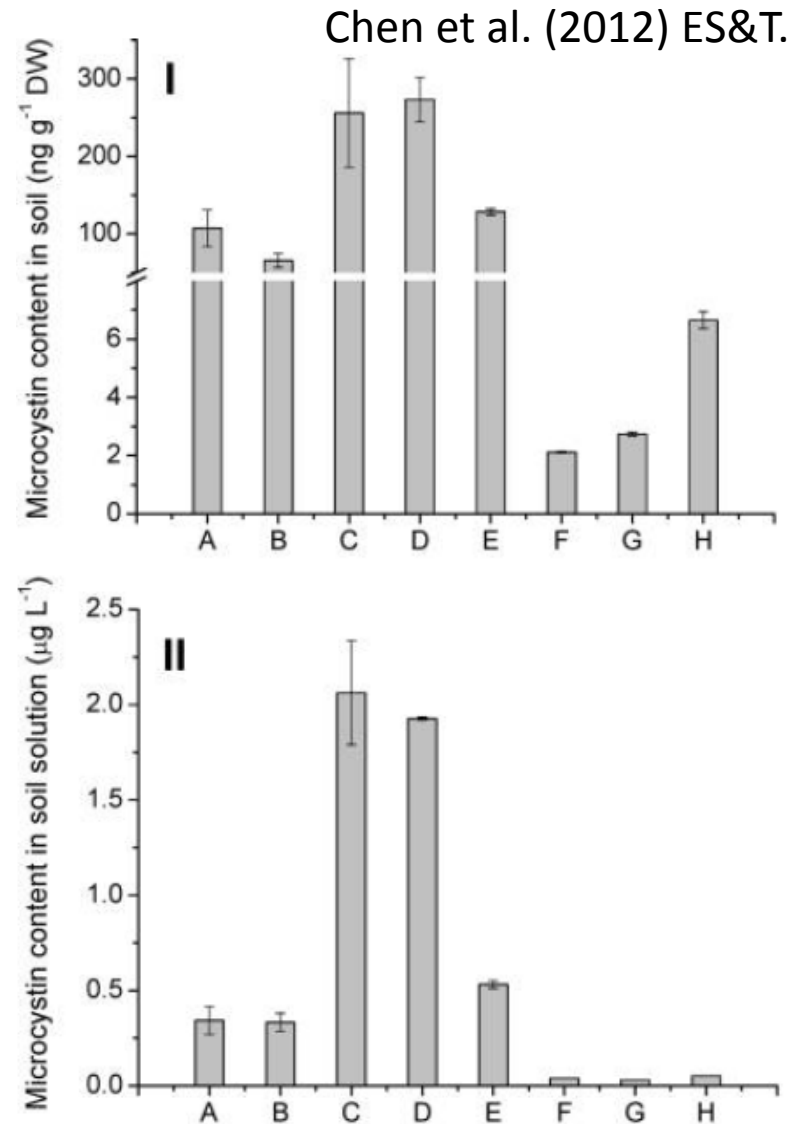
- Potato plants cultivated in greenhouses at SCRI, Dundee under spray irrigation
- Irrigation water spiked with purified microcystins (MC) harvested from cyanobacteria cultures at 0 (water only control), 0.126, 1.26, 12.6 and 126  $\mu\text{g L}^{-1}$  with/without wetting agent
- Potato plants harvested at maturity and at several time steps during growth
- MC in potato tubers, roots and leaves analysed by ELISA (against UoD antibodies) and HPLC-PDA
- MCs were detected by ELISA in the leaves of plants subject to highest dose (approx. 1 ng MC g dry wt<sup>-1</sup> plant tissue)





# Other studies

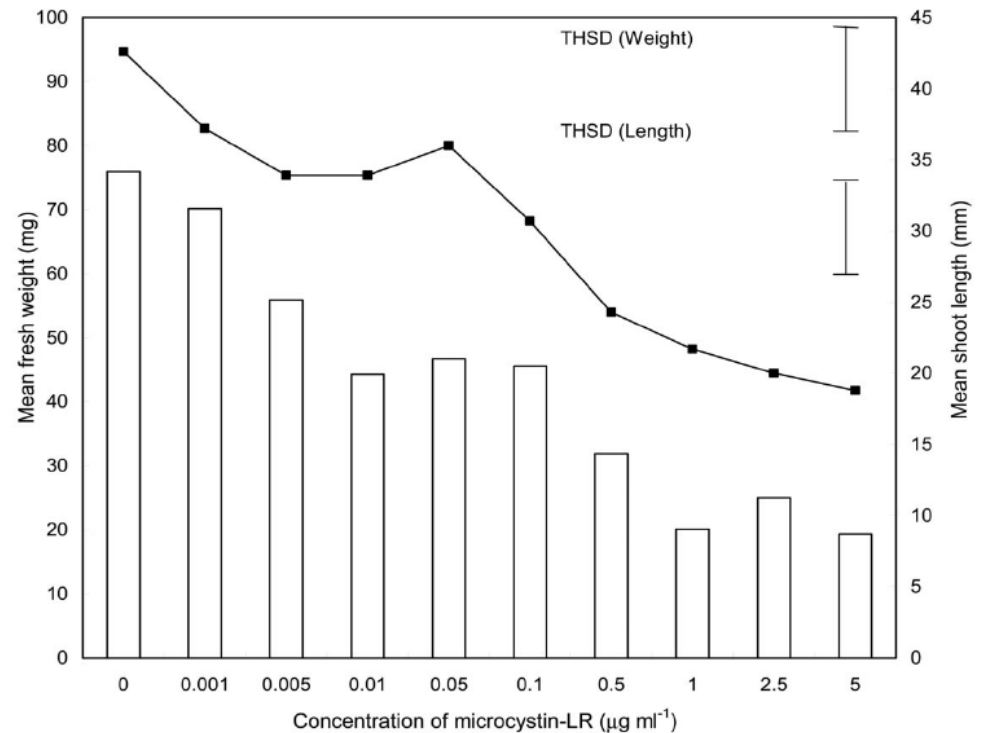
- Half-life of toxins in plant-soil systems varies from a few days to a few months
- Uptake and persistence depends of toxin variant, plant species, microbial community,...
- Vast majority of studies focus on microcystins



# Phytotoxic effects

Several studies have shown cyanotoxins (microcystins) to have phytotoxic effect on agricultural crops

- Tomato, mustard, broccoli, green pea, sugar pea, chick pea, mung bean, French bean, soya bean, alfalfa, lentil, maize, wheat,...



Effect on MC on fresh weight (columns) and length (line) of tomato shoots. McElhiney et al. (2001) Toxicon.

# CyanoCOST

## Cyanobacteria blooms and toxins in water resources: Occurrence, impacts and management

### WP1 Occurrence and monitoring; WP2 Fate, impact and health effects; WP3 Prevention and control measures; WP4 End-user engagement and outreach tools

#### Aquatic Cytox

The **CyanoCOST Action (COST ES 1105)** is consolidating expertise and knowledge of detection and management approaches towards harmful cyanobacteria and their toxins in water resources to ensure best practices in water safety are consistently achievable across all of Europe

**CYANOBACTERIA**, ALSO KNOWN as blue-green algae, are common in surface waters and tend to form blooms in lakes and other freshwater bodies under various environmental and nutrient availability conditions. Exposure through drinking or bathing in cyanobacteria-contaminated waters can seriously affect human and animal health. The toxins they produce may damage the liver, kidneys, or central nervous system, or may cause respiratory or gastrointestinal problems.

Instances of water contamination by cyanobacteria have increased over the last decades and climate change, combined with demographic shifts, make an increase in the prevalence of current toxic cyanobacterial populations highly likely. Moreover, there is evidence that new species are also beginning to invade European waters.

**WATER QUALITY**

The quality of drinking water for human consumption needs to be continuously monitored and controlled. Authorities and water companies, but equally other sources and major water users, such as agriculture and tourism enterprises, also need to ensure the safety of their water. Furthermore, occurrence of extreme algal blooms events that cause serious environmental and human health implications are not uncommon", indicates Professor Peter Chertkov, CYANOCOST member based in the US.

Of the cyanobacteria that threaten health, microcystins are particularly virulent. They are monocyclic heptapeptides produced by several species of cyanobacteria such as *Microcystis*, *Cylindrocapsa*, and *Aphanizomenon* and are found in a large number of variants. "The World Health Organization (WHO) has established a provisional limit of one microgram per litre in drinking water for the most common microcystin, Microcystin-LR, therefore obliging water utilities to apply suitable monitoring plans," Kaloudis explains. While there is a standard international method for determining whether microcystins are present in water samples, there is no established standard for analysing water for other cyanobacteria and cyanotoxins, so harmonised methodology for detecting and dealing with risks to water quality in Europe.

**THE CYANOCOST ACTION**

At Professor Geoffrey Costé of the Action's Steering Committee subsidies, the knowledge gained from the extensive past and current European research in the nature and management of toxic algal blooms is being pooled for the benefit of all European countries. "We hope to extend the benefits of awareness recognition and awareness of the occurrence of cyanobacteria and cyanotoxins, and improve management tools to countries that are best practice for all scales involved. The Action will also address important subject areas such as: (i) proactive and reactive techniques for

**CYANOBACTERIAL BLOOM**

**CHARTING MC-MC-WHEATING, CHADMO, NOVEMBER 2012**

**MICROSCOPIC APPEARANCE OF VARIOUS CYANOBACTERIA**

controlling cyanobacterial blooms; (ii) specific characterisation of cyanobacteria and cyanotoxins in all types of water sources to establish appropriate control measures; (iii) novel and rapid analytical and sensing methods to detect and quantify cyanobacteria and cyanotoxins; and (iv) drinking water treatment processes, including adsorption, membrane filtration, ferrous technologies and advanced oxidation processes for the treatment of cyanotoxins in sources of drinking water supply.

Simple methods for rapid detection of cyanotoxins in the field are also being developed in Europe. The partners are reviewing these to establish which may be suitable for widespread use preferably on-site. This will increase detection capabilities in those European regions that do not have extensive high technology resources.

The consortium is also producing handbooks, journal special issues, and review articles that cover best practices for prevention and control of toxic cyanobacterial blooms, best practices for monitoring and analysis of cyanobacteria, molecular methods based on DNA and that for toxic cyanobacteria, cultivation and molecular identification, and detection methods for other potentially toxic cyanobacteria including cylindrospermopsin, anatoxin-a, BMAA and saxitoxin producers.

The Action will also assemble and produce a comprehensive database of research and researchers dealing with cyanotoxin risk and modify and distribute an existing decision support tool for better management of harmful cyanobacterial blooms. Bialas, Costé, Severin and

**INTELLIGENCE CYANOCOST (COST ACTION ES1105)**

**CYANOBACTERIAL BLOOMS AND TOXINS IN WATER RESOURCES: OCCURRENCE, IMPACTS AND MANAGEMENT**

**OBJECTIVES**

To coordinate and network the ongoing efforts and capabilities across Europe for the risk management of cyanobacteria and cyanotoxins in water, by establishing strong and synergistic collaboration between academia, authorities, industry and citizens.

**PARTNERS**

Steering and Working Group leaders:  
**Dr Triantafyllos Kaloudis (Chair)**, ITOYAP SA, Greece - **Professor Luuk Baaij (Vice Chair)**, RIVM, The Netherlands - **Dr Anastasia Halka (Grant holder)**, NCSL, Demokritos, Greece - **Professor Zorica Stokich (CSM Manager)**, University of Novi Sad, Serbia - **Professor Linda Lawton (WCS)**, Robert Gordon University, Scotland - **Professor Kaarina Stårom (WCI)**, University of Jyväskylä, Finland - **Professor Geoffrey Costé (WCI)**, University of Stirling, UK - **Professor Zorica Stokich (WCI)**, University of Novi Sad, Serbia - **Professor Petrus Vlasveld (WCI)**, University of Amsterdam, The Netherlands - **Dr Anastasia Halka (WCI)**, NCSL, Demokritos, Greece - **Lutz Brehm (WCI)**, University of Bremen, Germany - **Professor Antonia Quesada (WCI)**, Universidad Autónoma de Madrid, Spain

A full list of partners can be found here: [www.cyanocost.eu/Default.aspx?article=News&Action=View&ID=1105&Management](http://www.cyanocost.eu/Default.aspx?article=News&Action=View&ID=1105&Management)

**FUNDING**

CYANOCOST is COST Action ES 1105, funded by the European Cooperation in Science and Technology (COST)

**CONTACT**

**Dr Triantafyllos Kaloudis**  
 Chair of the Steering Committee  
 Athens Water Supply and Sewerage Company - ITOYAP SA  
 Organic Micropollutants Lab - Quality Control  
 Athinas WP, 136 N. Herakli, Greece  
 T: +30 282 274 4058  
 E: kaloudis@itoyp.gr  
[www.cyanocost.com](http://www.cyanocost.com)

**TRIANTAFYLLOS KALOUDIS** is Head of the Organic Micropollutants Laboratory of the Quality Control Division of Athens Water Supply and Sewerage Company (ITOYAP SA). His current research interests include the development of analytical methods for the determination of microcystins in surface and drinking waters, studies of cyanotoxins occurrence in water bodies, and detoxification of water with advanced oxidation processes.

Furthermore, in June this year, the American Chemical Society and the WCAO Action are jointly staging a satellite workshop "Cyanobacteria and cyanotoxins in aquatic environments", during the IACMHS International Conference on Chemistry and the Environment (ICC 2013) in Barcelona. "We aim to open the field up to the scientific community with discussion of the latest information available," concludes Dr Triantafyllos Kaloudis, co-conveners of this event.

## Towards safe waters

Dr Triantafyllos Kaloudis and the CYANOCOST Steering Committee describe their efforts to disseminate knowledge, strategies and tactics for mitigating the growing threat posed by toxic cyanobacteria in European water reservoirs, lakes and fresh water bodies

Firstly, could you offer an introduction to Cyanobacteria and Cyanobacterial Blooms?

Cyanobacteria are photosynthetic microorganisms that are generally distributed in the biosphere and occur naturally in surface waters. Their names are derived from the Greek word "cyanos", meaning blue – they are also called blue-green algae.

They are ancient organisms that are thought to have been present on Earth for more than 3 billion years and it is believed that they played an important role in the formation of the Earth's early atmosphere. They account for up to 30 per cent of the photosynthetic activity of our planet. They are very adaptable and can grow in fresh, brackish and saline waters, in a wide range of temperatures and nutrient environments. Under favourable conditions, cyanobacteria can quickly multiply to form blooms and mats.

What are the main dangers posed by algal blooms and cyanotoxins?

A lot of cyanobacteria species and strains are toxicogenic (able to produce a diverse range of potent toxins as secondary metabolites). Cyanobacterial toxins – more succinctly termed 'cyanotoxins' – fall into three main groups based on their chemical structure: cyclic, peptide, alkaloids and (poly)phenolic acids, while new compounds have recently emerged as possible potential toxins, such as the neocystosin, amino acid BMAA. The problematic microcystins (MCs) are the most widespread cyanotoxins and are often found in lakes and water reservoirs that are used as drinking water sources. MCs are of major concern to public health when water is intended for human consumption. In the last 50-60 years, there have been many reports of human poisoning and

Neotoma deaths caused by drinking water containing cyanotoxins.

Can you expand upon your work to develop a database?

CYANOCOST will develop a Europe-wide rolling database which will act as an extension of UNESCO's TOXIC CYANOBACT. The database will include information about European research in the field (researchers, institutes, expertise, publications, methods, best practices), events (human and animal health incidents, economic and social effects, increased water provision/treatment costs, effects of tourism, national events, etc.), management measures applied or in progress and their evaluation, and national risk management policies and use in Europe and neighbouring states, including guidelines and legislation. CYANOCOST will also disseminate an Improved Decision Support Tool for toxic cyanobacteria and cyanotoxins based on the World Health Organization (WHO) Water Safety Plan concept, which was initially developed in a previous EU project.

Finally, could you offer an overview of the next stages in the project? What is the main focus for the next future?

CYANOCOST is currently in its first year. The main goal for the first two years is the development of handbooks with harmonised methods for the analysis of cyanotoxins, the identification of cyanobacteria with molecular techniques, in-lake prevention measures and water treatment technologies. There is real enthusiasm among participants to contribute to their development and editorial meetings are already planned for the development of the network potential to develop strategic consortia for European and international research projects in the subject area.

# Thank you

**Peter D. Hunter**

Lecturer in Earth Observation

University of Stirling

Biological and Environmental Sciences

**t** +44 1786 466538

**e** [p.d.hunter@stir.ac.uk](mailto:p.d.hunter@stir.ac.uk)

**w** [www.stir.ac.uk](http://www.stir.ac.uk)



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