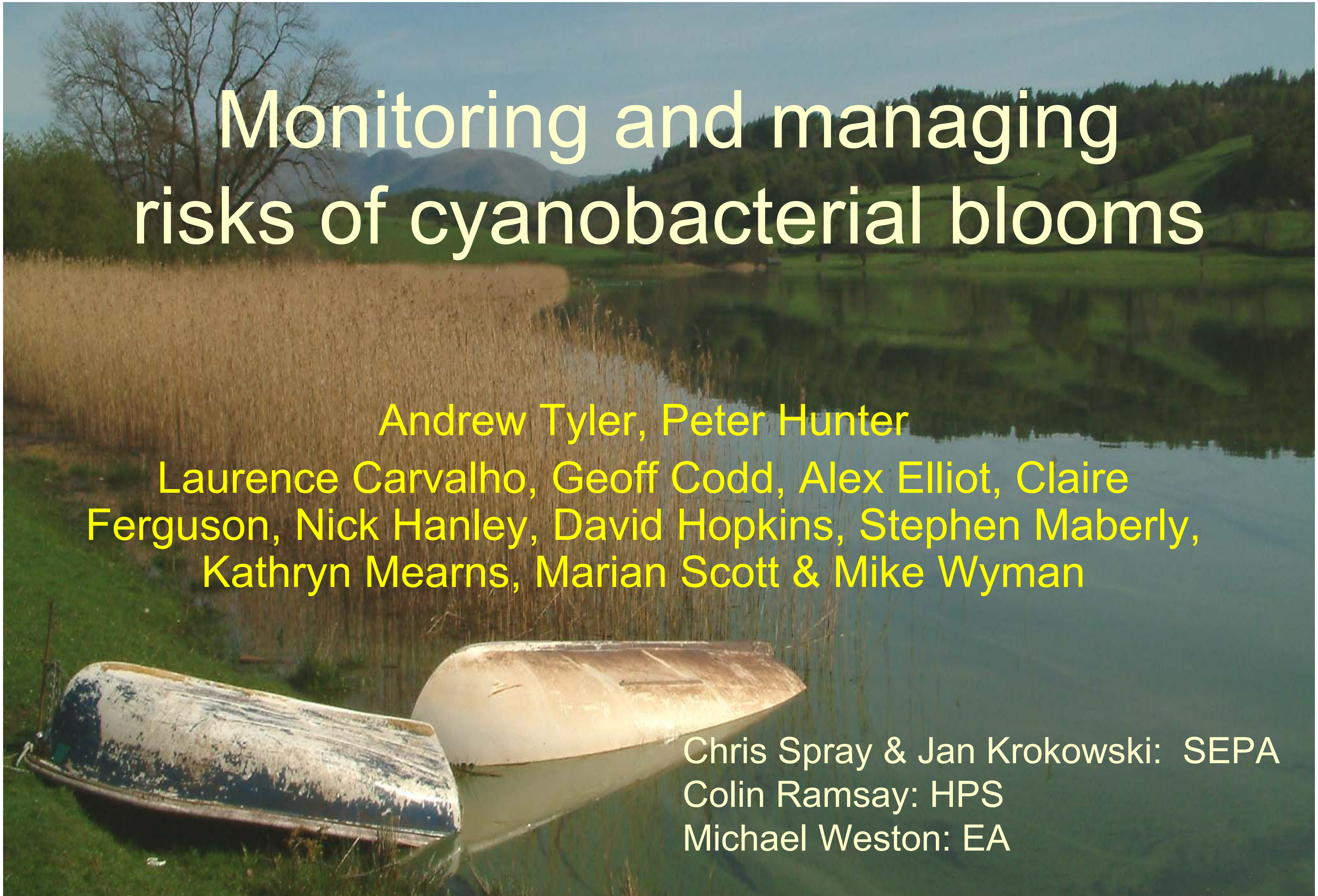


Monitoring and managing risks of cyanobacterial blooms

Andrew Tyler, Peter Hunter

Laurence Carvalho, Geoff Codd, Alex Elliot, Claire Ferguson, Nick Hanley, David Hopkins, Stephen Maberly, Kathryn Mearns, Marian Scott & Mike Wyman

Chris Spray & Jan Krokowski: SEPA
Colin Ramsay: HPS
Michael Weston: EA

NATURAL ENVIRONMENT RESEARCH COUNCIL
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
UNIVERSITY OF STIRLING
UNIVERSITY OF ABERDEEN
CEH Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF DUNDEE
UNIVERSITY of GLASGOW
scri living technology

Outline

- Introduction
- Methodology
  - 4 Tier Risk Assessment Methodology
    - Model Development for Hazard Assessment
    - RS – early warning strategy
    - Cyanotoxin Production
    - Risk and Impact Assessment
- Results
- Summary/Implications

Introduction

- Cyanobacteria are:
  - Gram-negative natural inhabitants of water
  - Toxins constitute one of the most high risk categories of waterborne toxic substances
  - Annual occurrence in water bodies used for:
    - Drinking waters
    - Recreation
    - Fisheries
    - Crop Irrigation

Environment and Health

- Links with illness and mortality - attributed solely or partly to cyanotoxins
- Microcystins (MC)
  - tumour promotion
- Anatoxin-a (ANTX-a)
  - Neuromuscular-blocking alkaloid
- Neurotoxic Amino Acid (beta-methylamino alamine - BMAA)
  - found in Scottish Waters
  - linked with neurodegenerative disease
- WHO & UNESCO recognised the need to improve monitoring of fresh waters

Risk Catagories

cells/ml	μg chl *a* l^{-1} (eq)	MC mg m^{-3} (Planktothrix)	Impact
20,000	10	2-4 (≤ 10)	skin irritation, gastrointestinal upsets
100,000	50	10-20 (≤ 50)	pulmonary & liver damage
Scums	Visible Scums/mats	≥ 1000	serious risk of fatal outcome

Integrating the State of the Art

- Toxin analysis
- DNA & PCR analysis
- Modelling
  - NUPHAR
  - PROTECH
- Remote Sensing – C-PC biomarker
- Economic impact
- Risk Perception
- Food Supply

Tier 1: **Model development for hazard assessment**

Aim

- To understand how cyanobacteria abundances (or hazard) are affected by lake typology and environmental variables.
- To help develop a more proactive strategy for monitoring cyanobacteria risks.

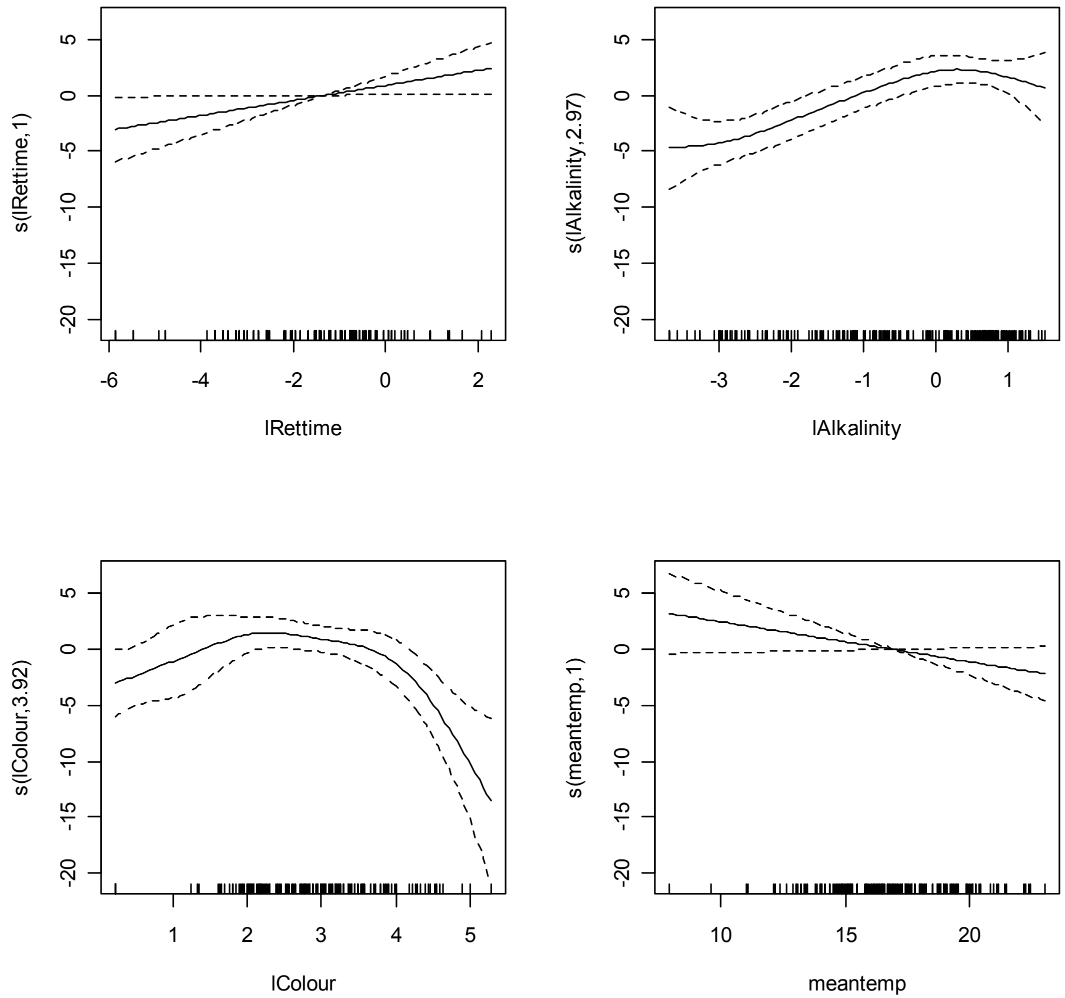
Data

- ~134 UK lakes, samples are from July, Aug and Sept, 2003-2006
- Data Response –
    1. Presence/absence of toxic cyanobactreia
    2. Natural log of cyanobacteria biovolume
    3. Percent cyanobacteria (biovolume relative to all phytoplankton biovolume)
    4. Individual response of the *Anabaena Genus*.
- Explanatory variables – total phosphorus, alkalinity, water colour and temperature, lake altitude and flushing rate.

Statistical models

- Generalised additive models used to fit smooth functions for each explanatory variable.

Response (2) log Cyanobacteria Biovolume



The plots highlight:

- A significant positive relationship with log retention time
- A humped relationship for log alkalinity and log colour
- (Alkalinity and TP highly correlated)
- A negative relationship for mean temp (not significant)

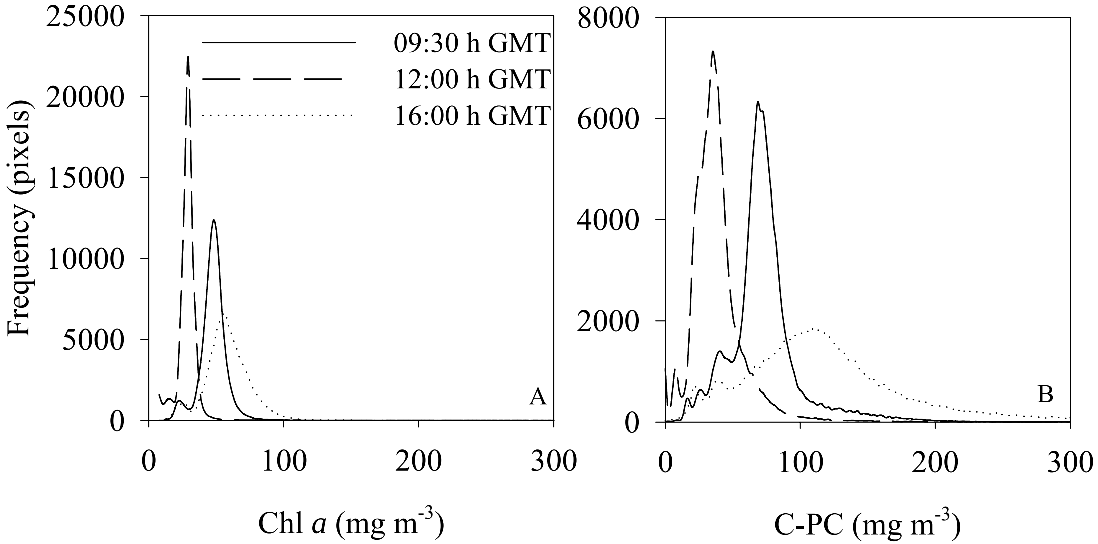
Tier 1: Conclusions

- **Cyanobacteria biovolume** - most appropriate response for hazard assessment, related directly to potential toxin concentrations and WHO guidance levels.
- Bloom forming cyanobacteria abundance generally increase with increasing alkalinity,decrease in lakes of high colour
- The relationships identified are generally supported in studies elsewhere - cyanobacteria favoured by lakes with less flushing (higher retention) because of their relatively slower growth rates.
- Temperature response is not as expected - an artefact of the data, which is only considered over the summer period and zero cyanobacteria biovolumes are identified in some samples over this temperature range.
- The response of the *Anabaena* Genus was most strongly related to total phosphorus.
- The models developed could be used to give a national-scale prediction - targets for monitoring

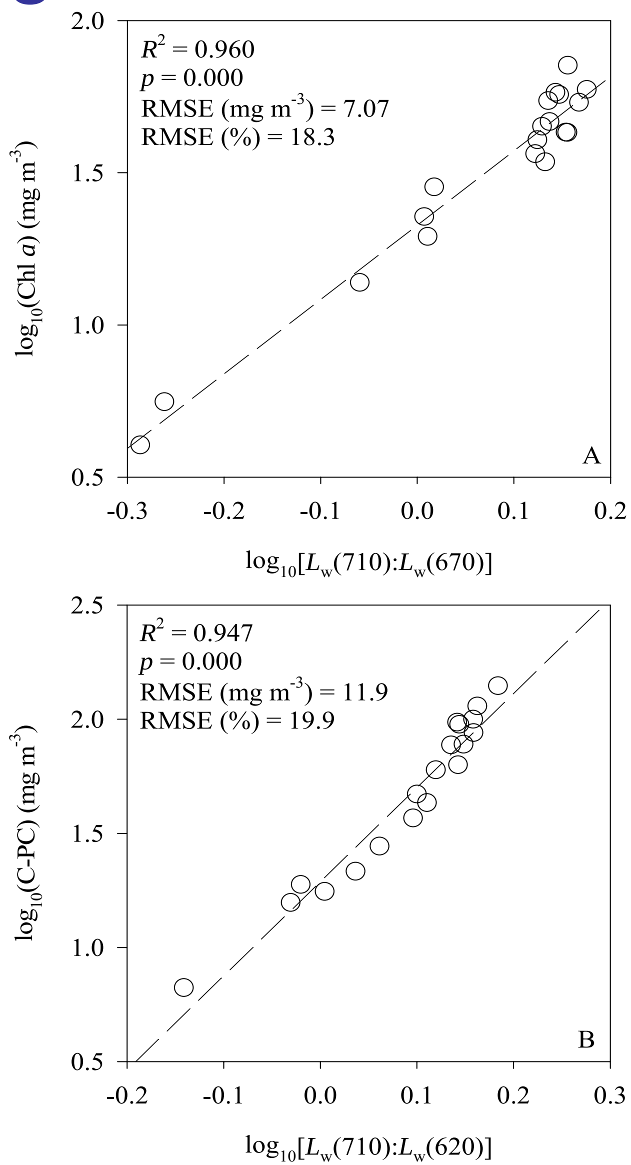
Carvalho *et al.*, in prep

Tier 2: Remote Sensing
(Previous Work)

- Chl-*a* and C-PC calibration for Norfolk Broads data set



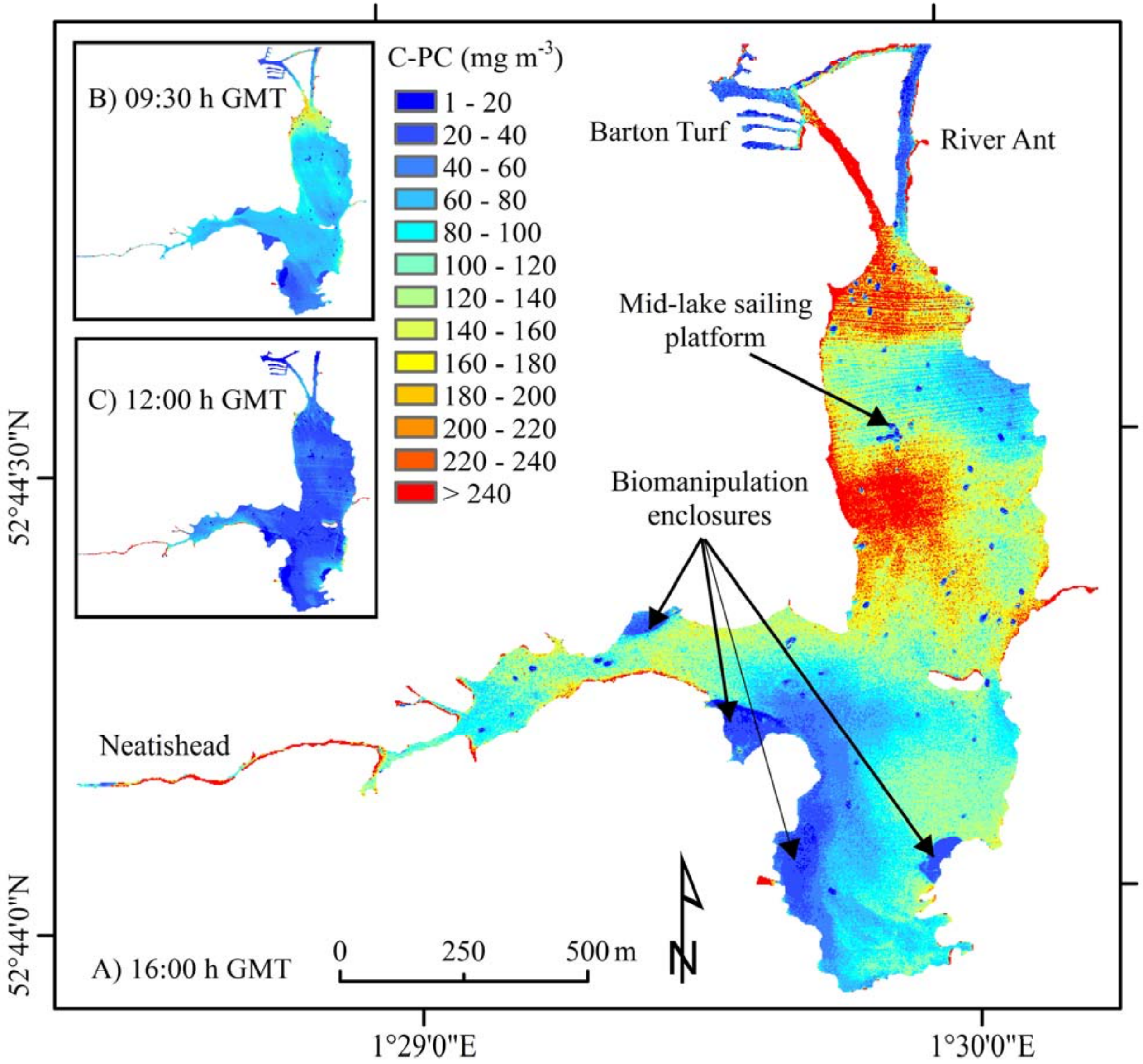
- Histograms showing changes in near-surface pigment concentrations over the CASI time-series



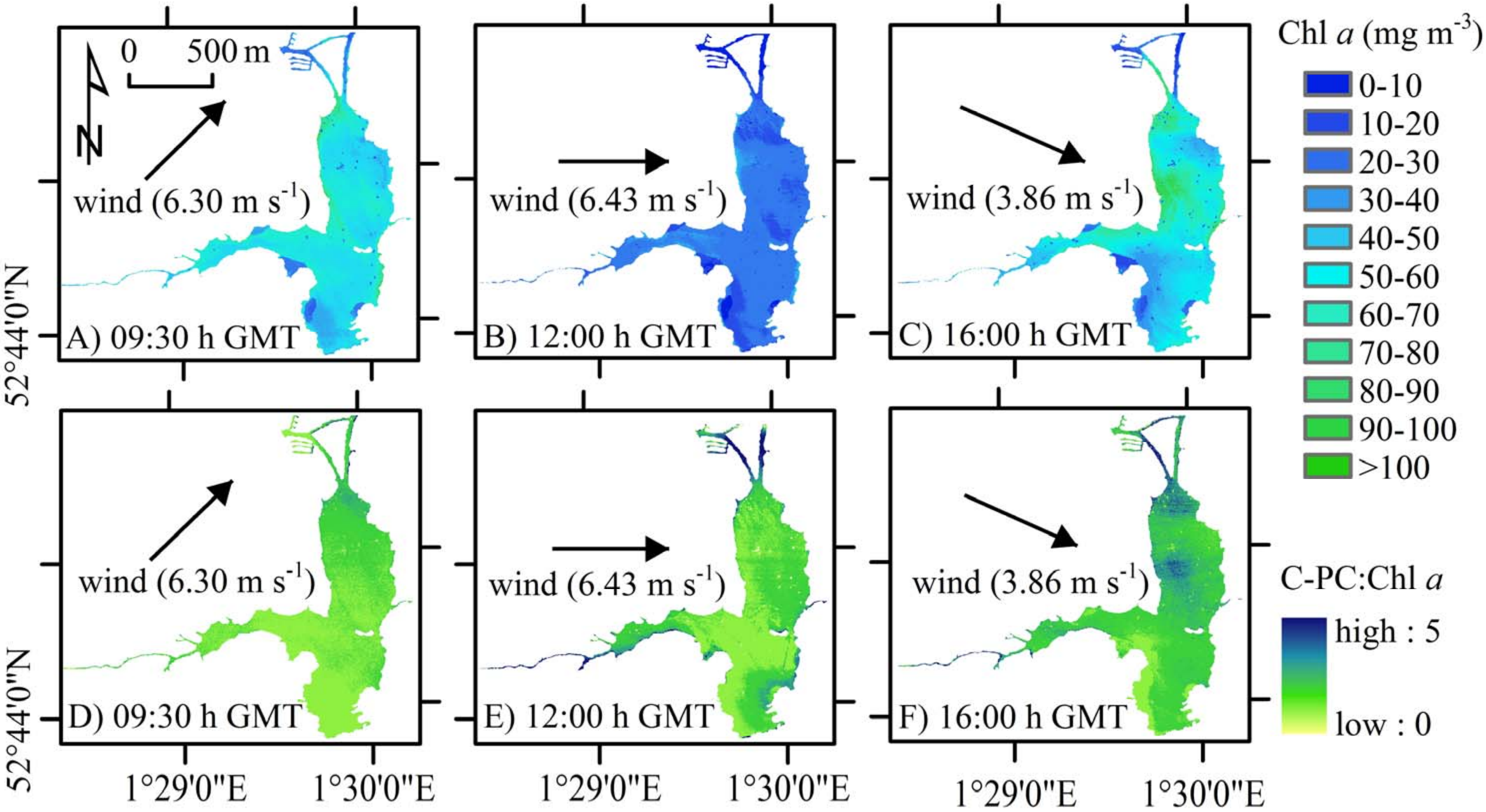
Barton Broad

Microsystis Aueruginosa

29 August 2005
CASI-2



Hunter *et al.*, 2008

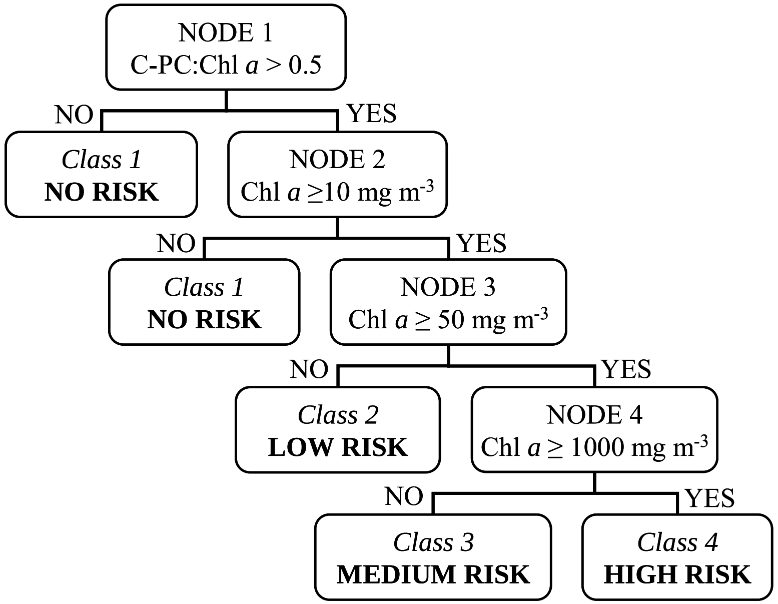


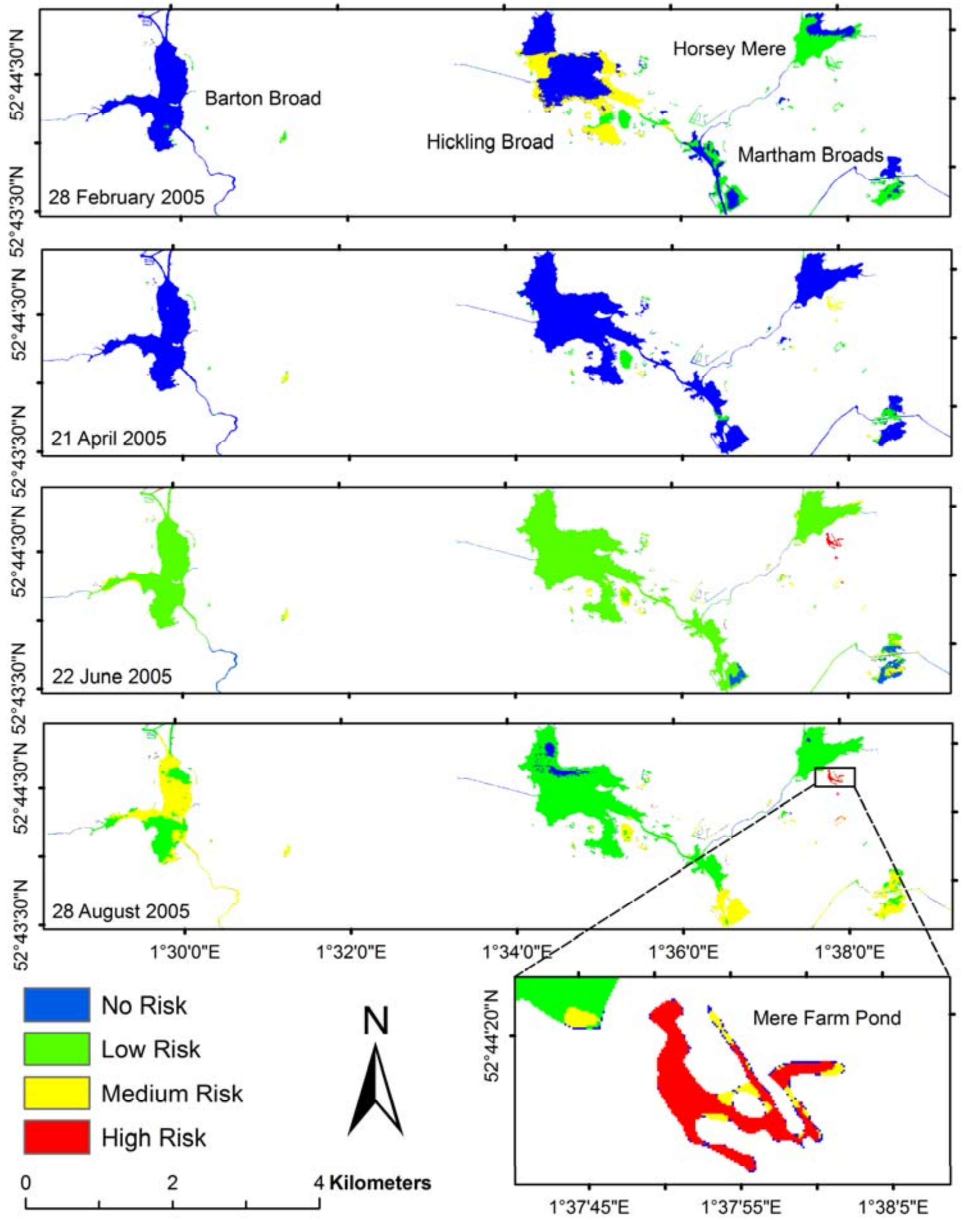
0
500 m
N
wind (6.30 m s-1)
A) 09:30 h GMT
wind (6.43 m s-1)
B) 12:00 h GMT
wind (3.86 m s-1)
C) 16:00 h GMT
wind (6.30 m s-1)
D) 09:30 h GMT
wind (6.43 m s-1)
E) 12:00 h GMT
wind (3.86 m s-1)
F) 16:00 h GMT
52°44'0"N
1°29'0"E
1°30'0"E
Chl a (mg m-3)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
>100
C-PC:Chl a
high : 5
low : 0

Preliminary Risk Assessment

Risk	Guidance level		Potential MC concentrations (mg m^{-3})[a]
	cells (mL^{-1})	Chl *a* (mg m^{-3})	
LOW	20 000	10	2-4 (≤ 10)
MEDIUM	100 000	50	10-20 (≤ 50)
HIGH	Visible scums and mats		≥ 1000

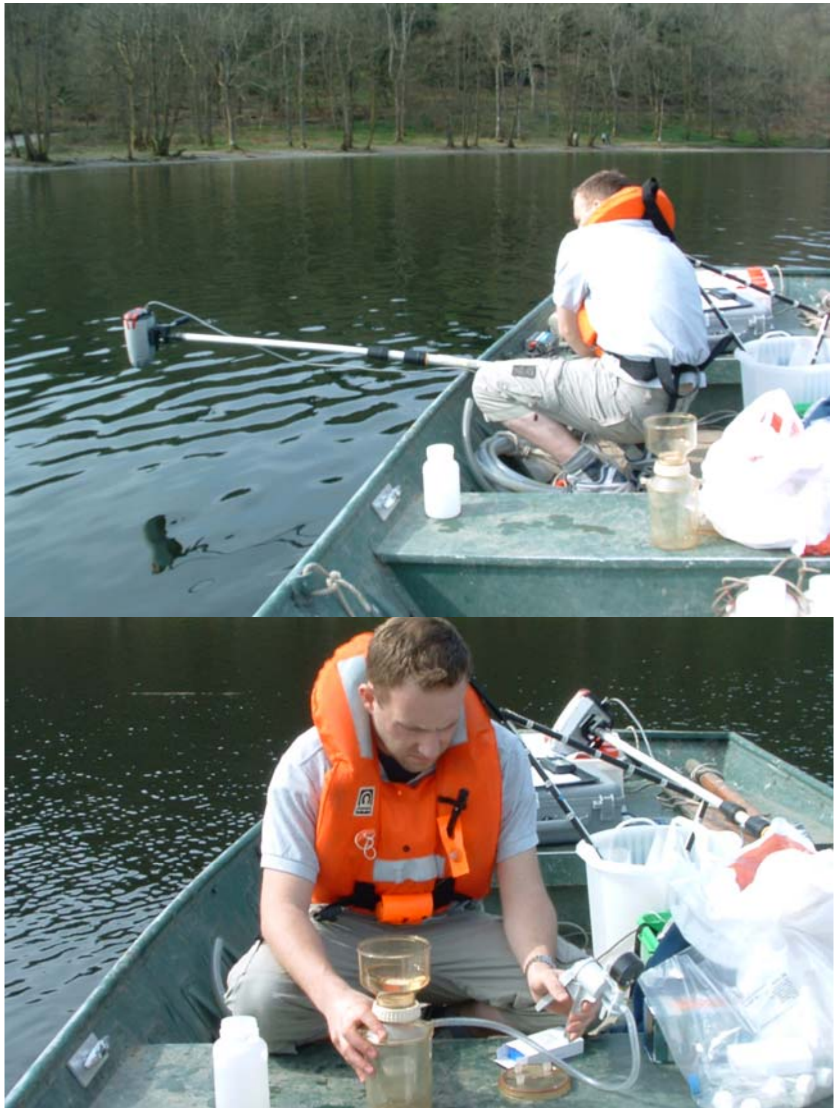
[a]Lower range if *Microcystis* or *Anabaena* dominant, upper limit if *Planktothrix* dominant; based upon an average of 0.2 pg cell^{-1} for *Microcystis* and *Anabaena*





Hunter *et al.*, submitted

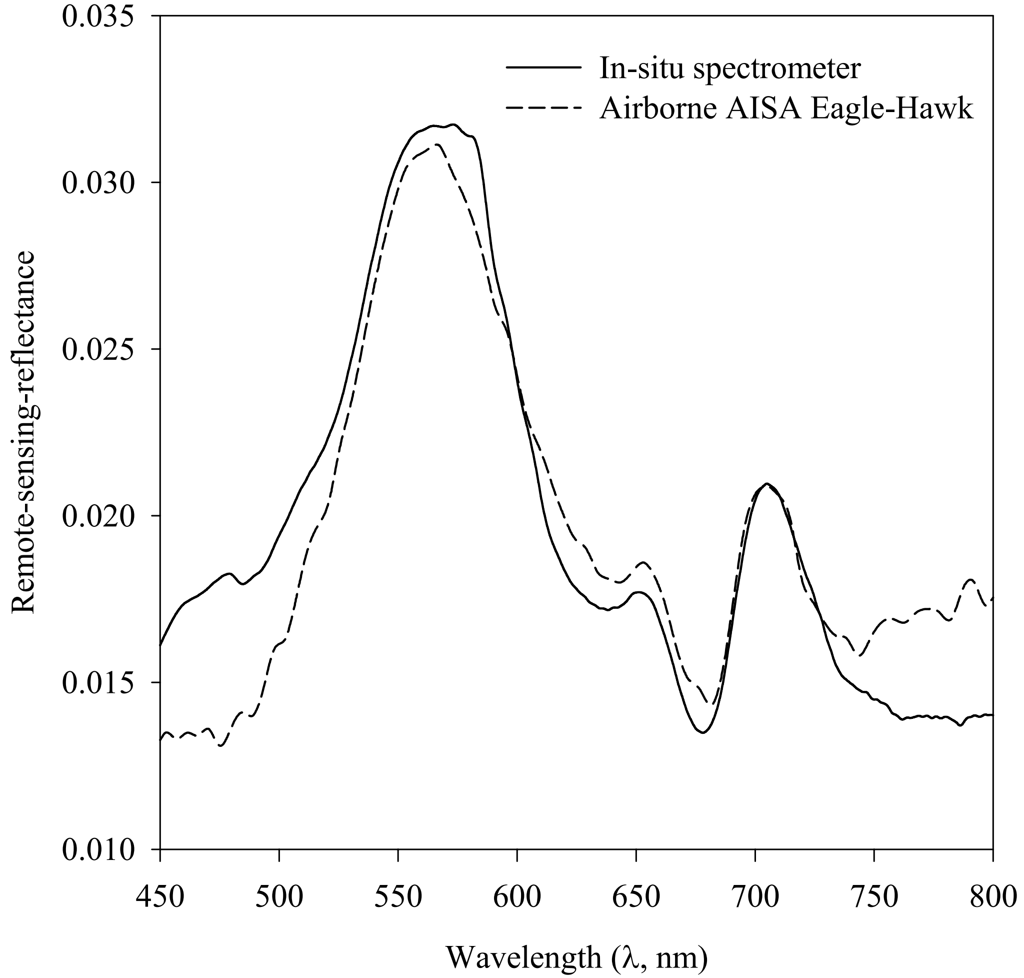
Focus: Loch Leven & Esthwaite Water



- In-situ spectroradiometry
- Same samples used for:
  - Phytoplankton cell counts
  - Cyanotoxin extraction
  - Genomycs analysis (Quantitative RT-PCR and sequence analysis of *mcyA*
  - Pigment analysis (Chl *a,* PC, carotanoids, SPM, CDOM)

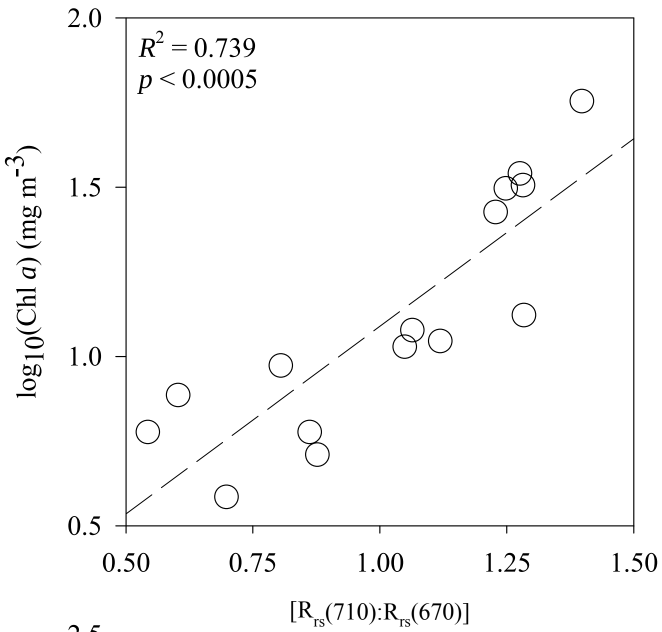
FLAASH atmospheric correction

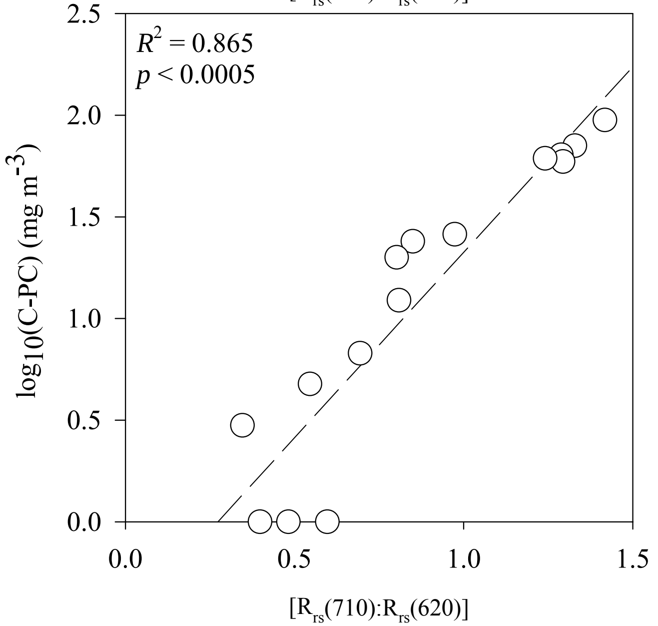
- Uses latest version of the MODTRAN code
- Atmospheric path modelled at 15 cm^{-1} resolution
- Adjacency correction
- Retrieval of aerosol concentrations using the 2 Band (K-T) model
- Plot left shows match-up between Rrs measured in-situ and AISA Eagle-Hawk Rrs following correction using FLAASH (Station 1, Esthwaite Water, 26-Apr-2007)



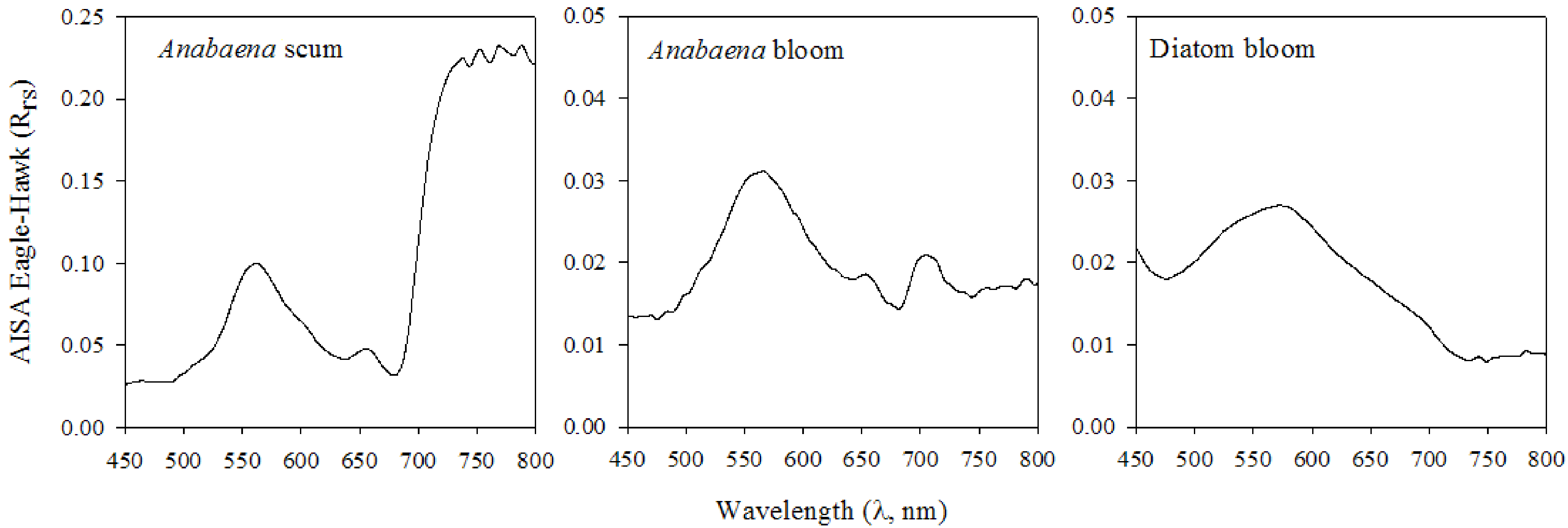
PRELIMINARY Calibration

- Combining atmospherically corrected reflectance from CASI and EAGLE data
- Calibration for Loch Leven and Esthwaite Water for Chl-a and C-PC
- Ratios of remote-sensing-reflectance (R_{rs})



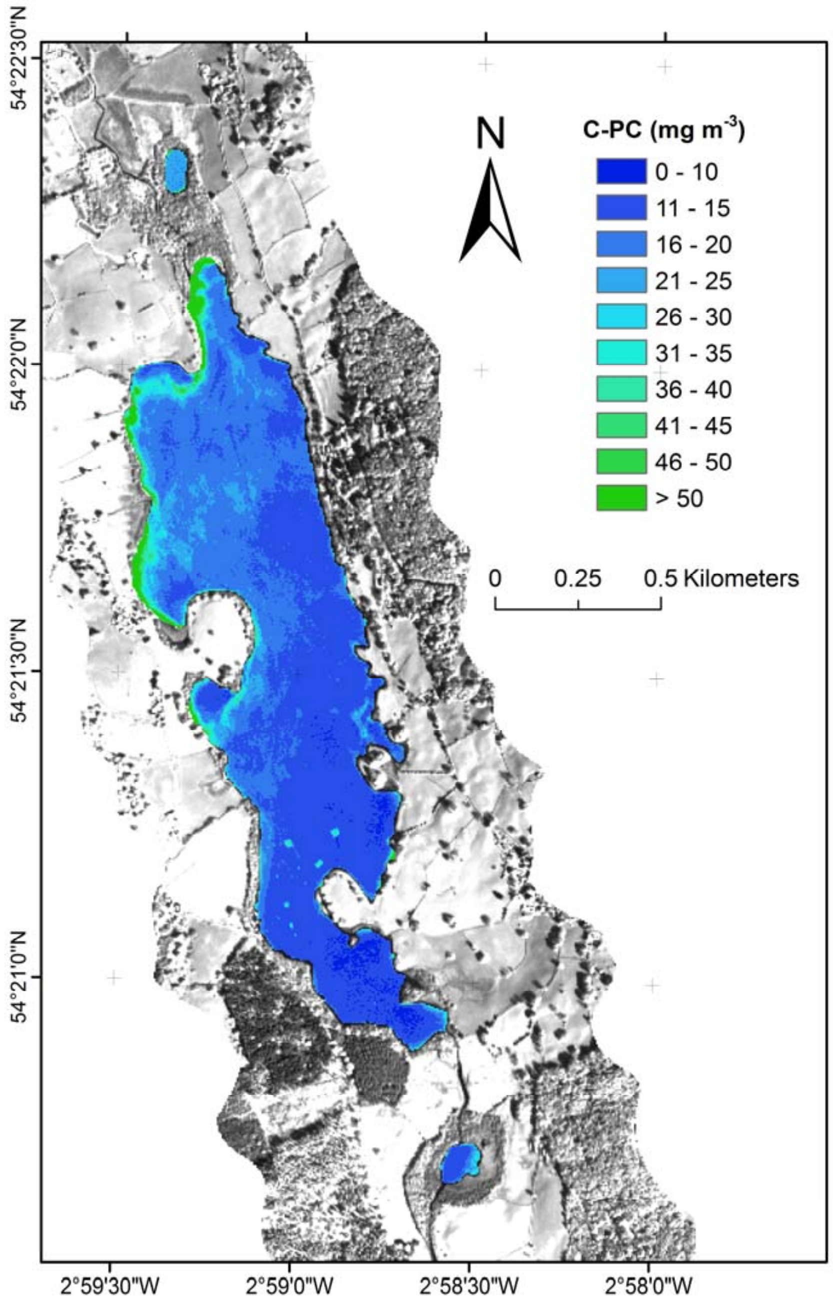


AISA Eagle-Hawk spectra



NATURAL ENVIRONMENT RESEARCH COUNCIL
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
UNIVERSITY OF STIRLING
CEH Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF ABERDEEN
UNIVERSITY OF DUNDEE
UNIVERSITY of GLASGOW
scri living technology

- C-PC in Esthwaite Water during a bloom of *Anabaena* on 26-Apr-2007



NATURAL ENVIRONMENT RESEARCH COUNCIL

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

UNIVERSITY OF STIRLING

UNIVERSITY OF ABERDEEN

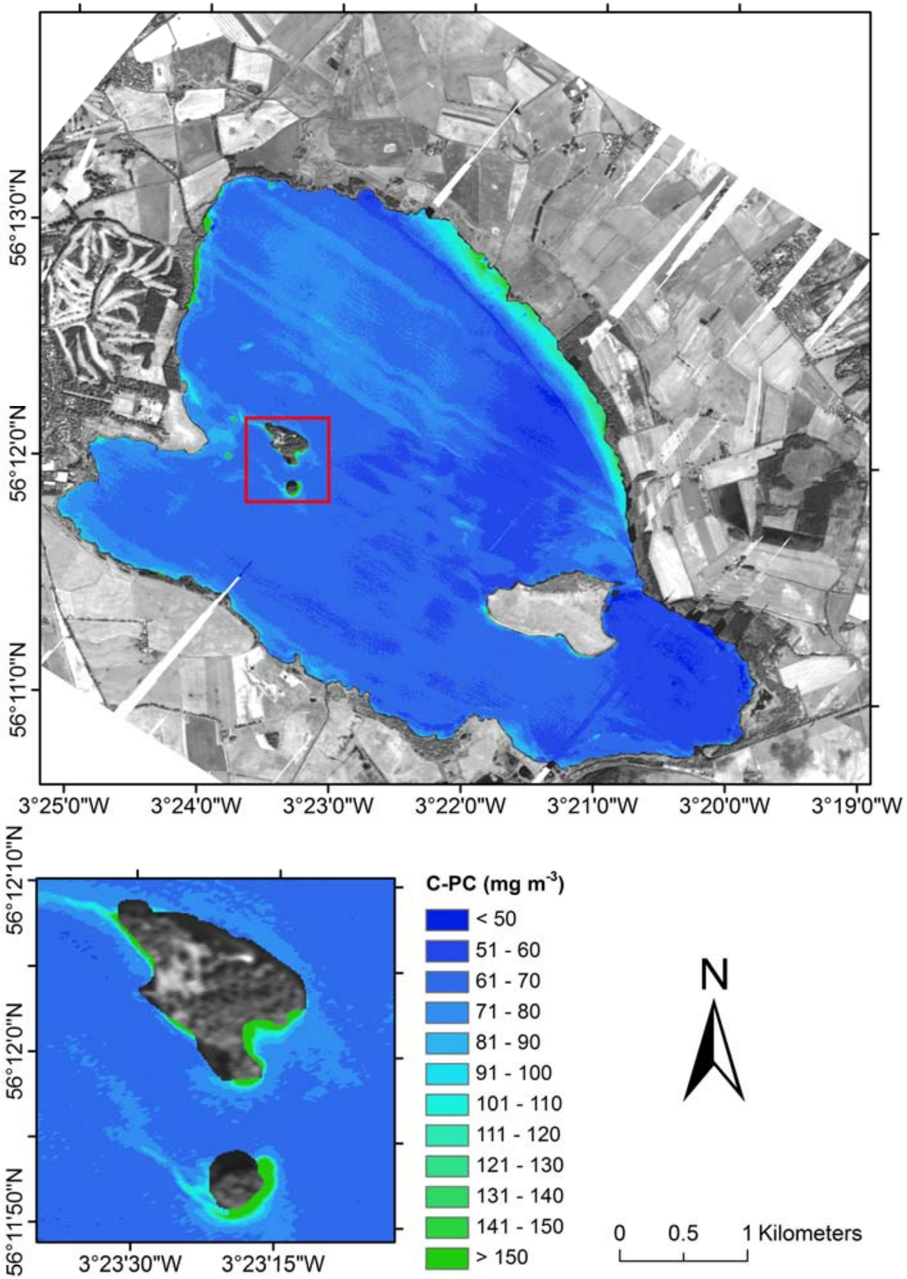
Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF DUNDEE

UNIVERSITY of GLASGOW

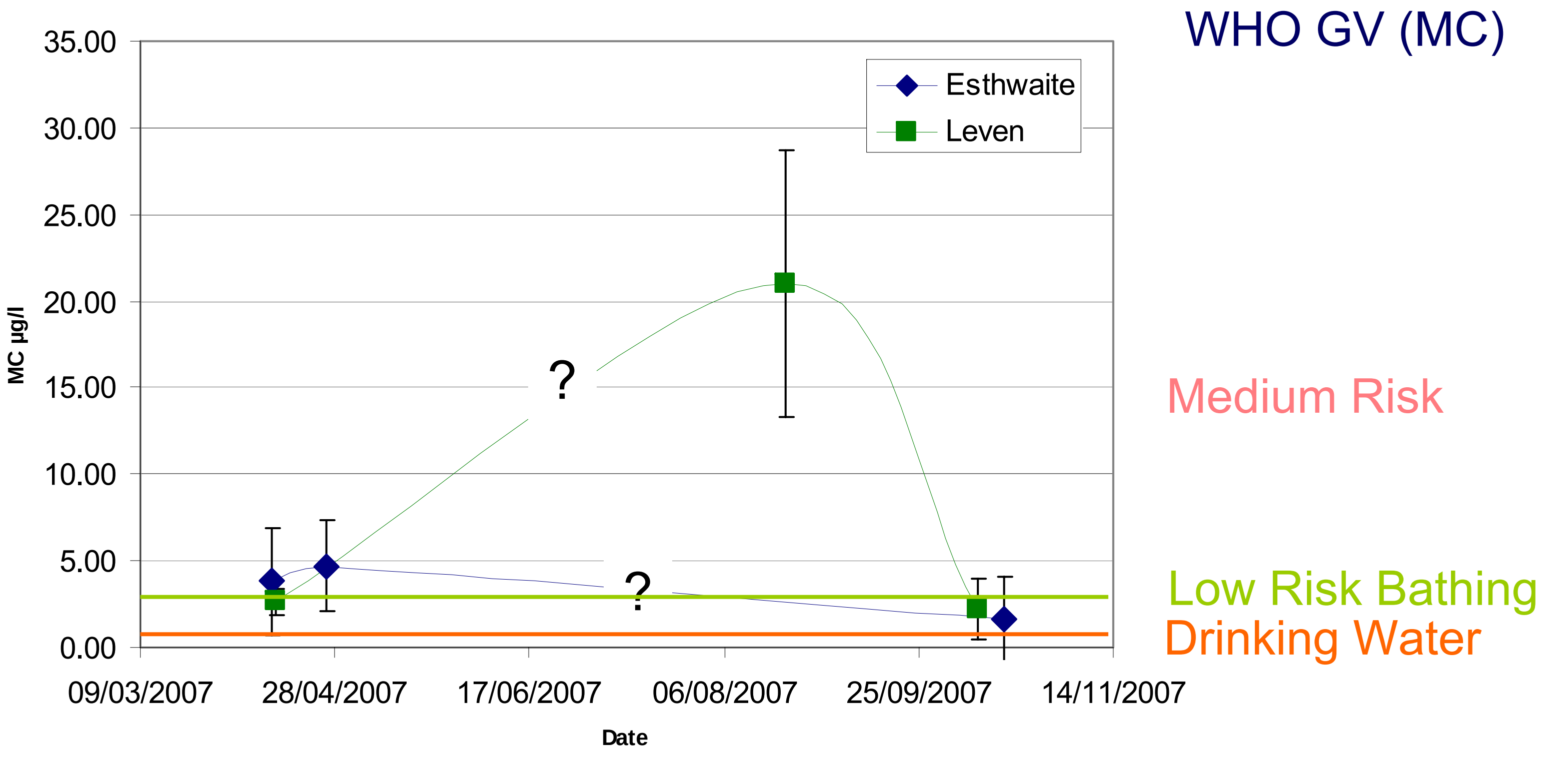
SCRI living technology

- C-PC in Loch Leven during a bloom of *Woronichinia naegeliana* and *Microcystis aeruginosa* on 22-Aug-2007



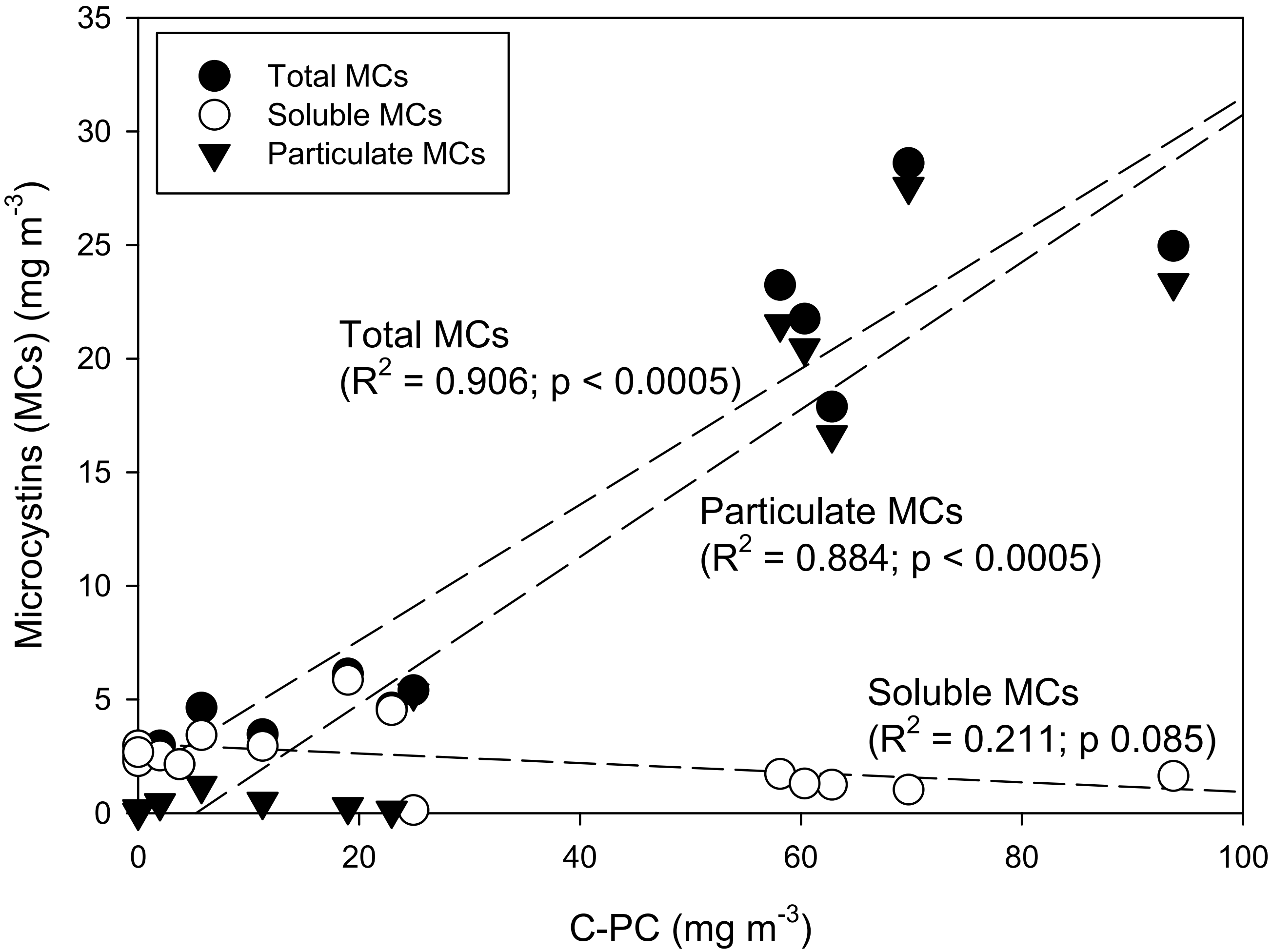
Tier 3: Cyanotoxin Production

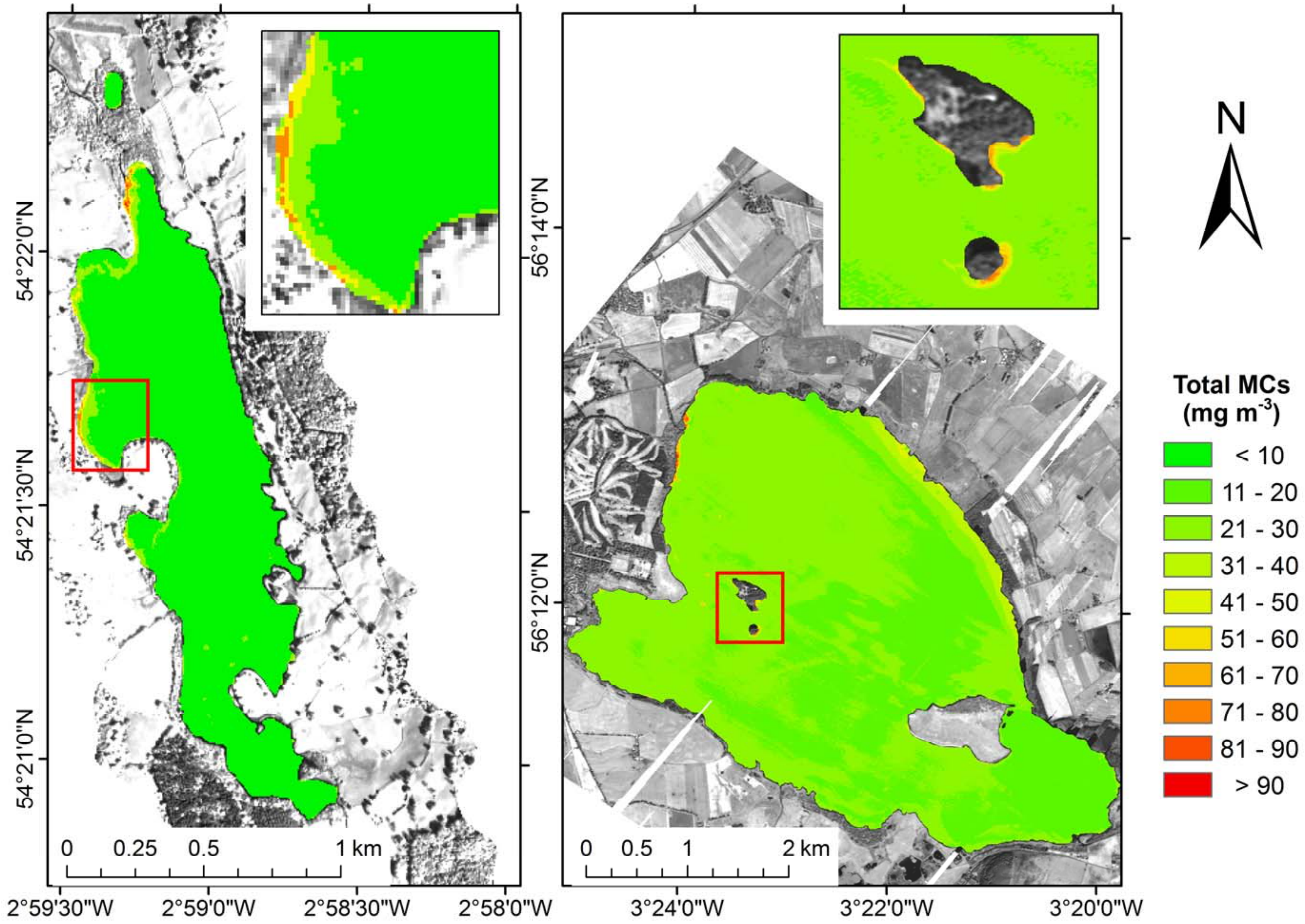
Summary of results



NATURAL ENVIRONMENT RESEARCH COUNCIL
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
UNIVERSITY OF STIRLING
Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF ABERDEEN
UNIVERSITY OF DUNDEE
UNIVERSITY of GLASGOW
SCRI living technology

Relationships with MCs




54°22'0"N
54°21'30"N
54°21'0"N
0 0.25 0.5 1 km
2°59'30"W
2°59'0"W
2°58'30"W
2°58'0"W
56°14'0"N
56°12'0"N
0 0.5 1 2 km
3°24'0"W
3°22'0"W
3°20'0"W
N
Total MCs (mg m^{-3})
< 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
> 90

Risk and Impact Assessment

- Health Assessment
  - At a stage – now ready to review with Colin Ramsay (HPS), Louis Pilotto (UNSW)
- Economic Impact - WTP
- Risk Perception
  - Face to face interviews and workshops
- Risk from Climate Change and Management Influences
- Potential Transfers to Food Supply

Public WTP for cyanobacteria health risk reductions

- Postal questionnaire
  - 370/1400 (26.4% response rate)
- 58.8% of respondents were “concerned” to “very concerned” about cyanobacterial health risks in general
- Most respondents rated WQ in Loch Leven as “Fair” (5-6/10) – but highly variable
- Most respondents rated the current cyanobacterial health risk in Loch Leven as “Low/Moderate” (4-5/10) – but highly variable
- ~ 54.3% of respondents WTP for health risk reductions (protest rate ~ 10%)
- Mean/median WTP/year (mid-point intervals)

  = £25.4/£19.5
- WTP to pay a function of socio-economic factors, attitude to environmental issues and risk perception

Public WTP for cyanobacteria health risk reductions

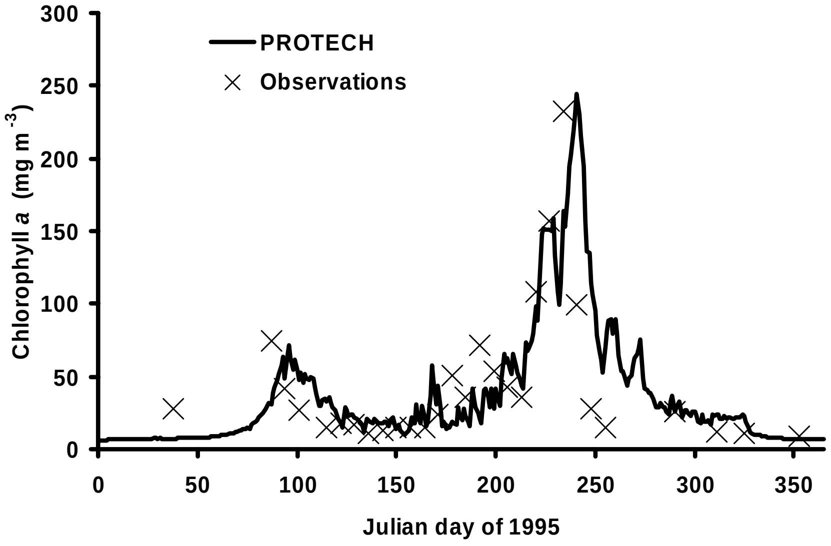
- ~ 150 interviews by shore of Loch Leven
- Main findings to date:
  - Good awareness of past issues in Loch Leven and some awareness of possible human health implications
  - However, risk perception is more often than not informed by these past experiences – not the current water quality status of the loch
  - Moreover, there is a lack of knowledge about what cyanobacteria actually "are" and the specific nature of the ill-health effects that can arise from exposure to their toxins
  - General inability/lack of sufficient knowledge to enable the presence of cyanobacteria in a waterbody to be identified (frequent false negatives and positives)
  - Suggests individuals have an inability to identify and manage risks adequately themselves – a role for regulators

NATURAL ENVIRONMENT RESEARCH COUNCIL
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
UNIVERSITY OF STIRLING
Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF ABERDEEN
UNIVERSITY OF DUNDEE
UNIVERSITY of GLASGOW
SCRI living technology

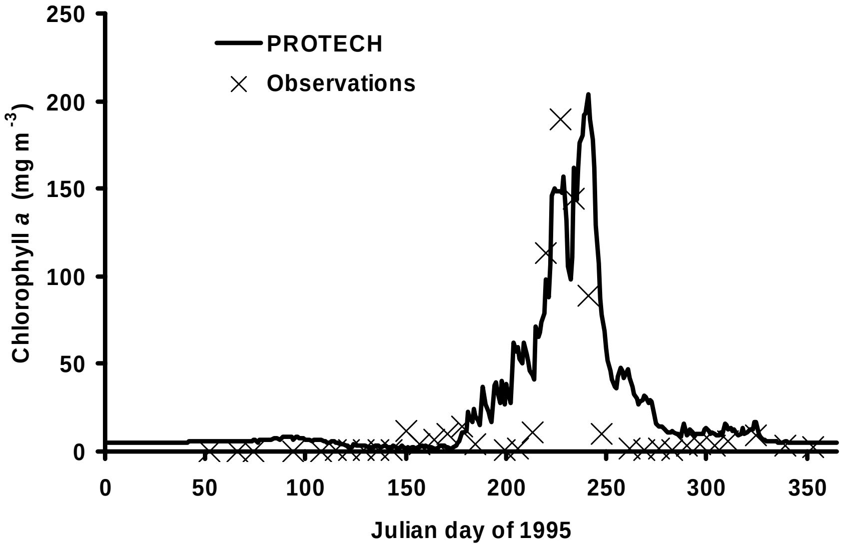
Risk from Climate Change and Management Influences

- PROTECH Modelling of Loch Leven and Esthwaite Water
- Sensitivity of phytoplankton to changes in nutrient loading and water temperature

Loch Leven, 1995: Total Chl *a*



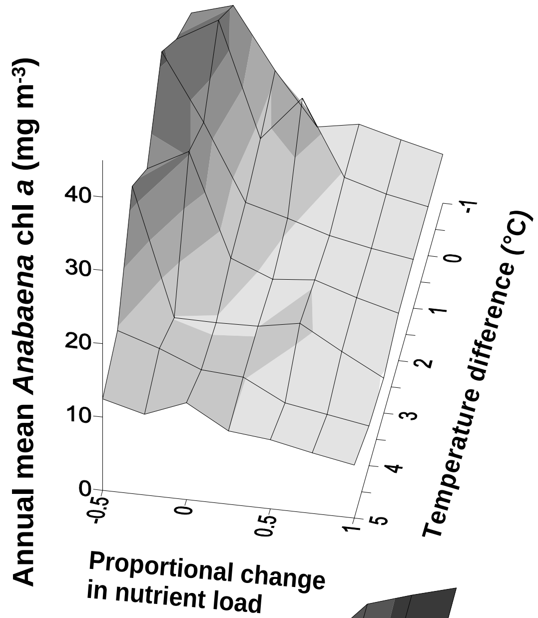
Chl *a* attributable to cyanobacteria

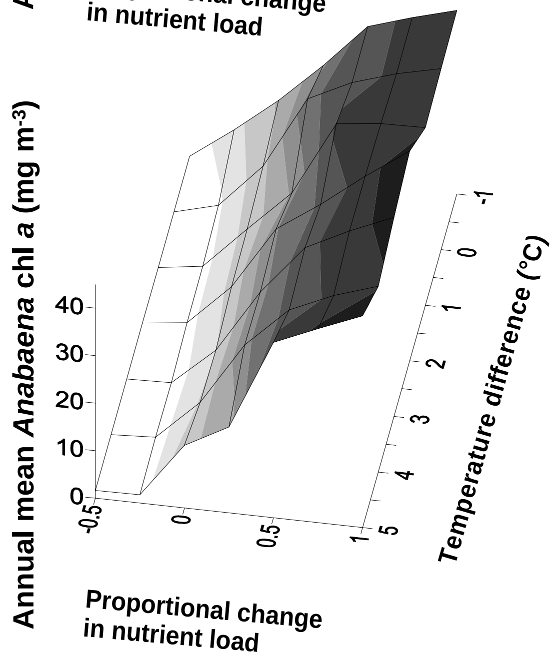


Elliot and May, 2008

Conclusions: Loch Leven

- Small temperature changes had little effect
- Increasing phosphorus only – large change in *Anabeana*
- Changing nitrate load – *Anabeana* increases only under reduced load
- *Anabeana* can exploit P under reduced N conditions
- Model agrees with observations
- Model Repeated for Esthwiate Water





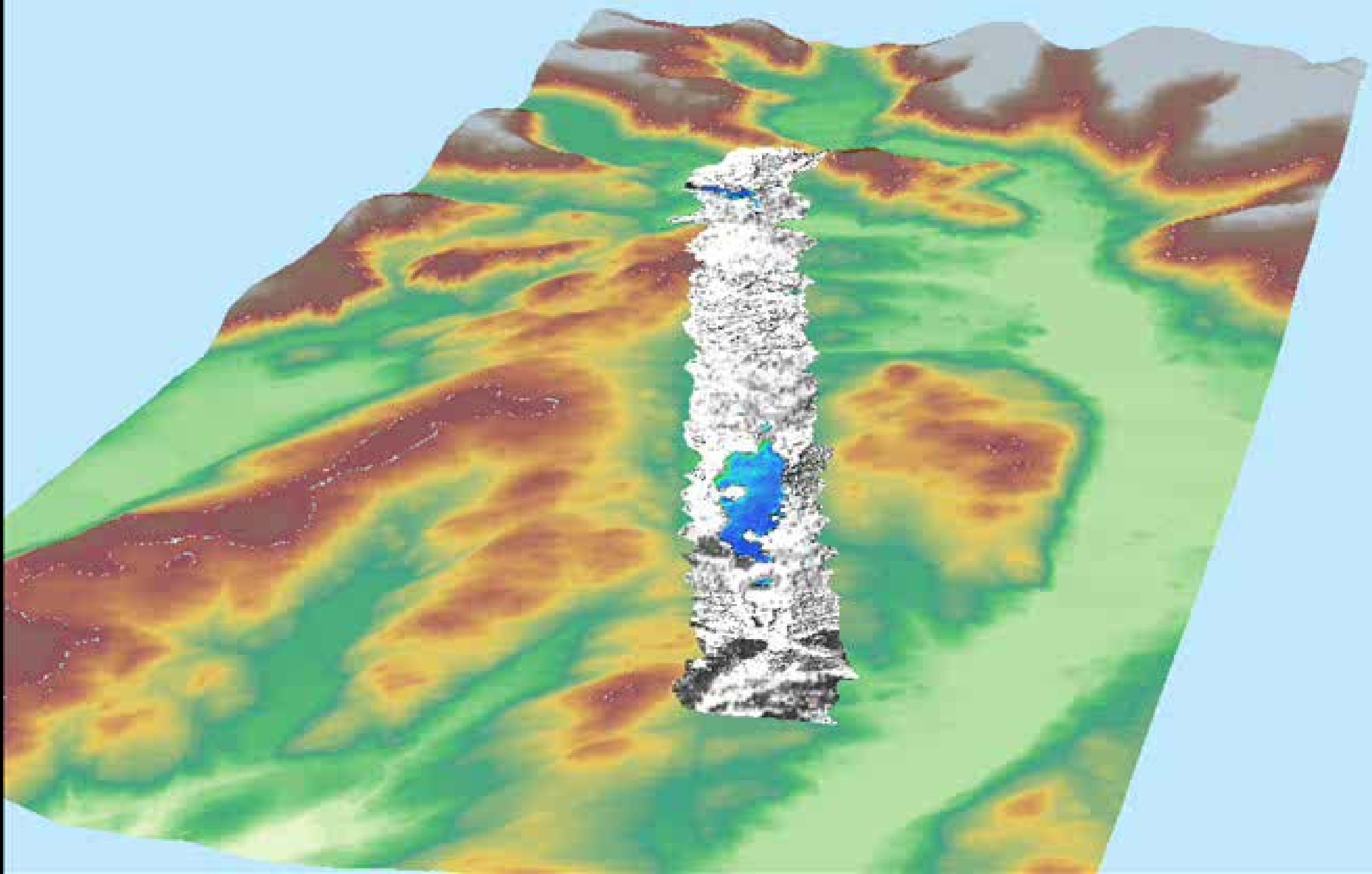
Transfers to Food Supply: Potato Crops

- Replicated greenhouse plant experiment at SCRI
- Simulated spray irrigation from aqueous solution dosed from 0 (control) to 126 µg/l MC
- Leaves harvested during experiment
- Plants were destructively harvested, weighed and samples of the roots, tubers, shoots, leaves & soil were freeze-dried
- Preliminary results from Dundee indicate the presence of microcystins, or products of microcystins, in potato tubers BUT this needs to be confirmed

Summary/Implications

- Significant Environmental & Human Health Hazard
- It is possible to predict water bodies at risk
- RS has the potential of providing important data for risk assessment, but operational implementation requires:
  - Suitable Satellite Platforms:
    - MERIS (300m; current)
    - HyspIRI (<60m;2013-2016)
    - VENUS (10 m, 2011)
  - Rigorous assessment of detection limits
  - Dependency on optical properties (robustness)
- Review of Health implications for study sites and beyond
- *Economic* and *Risk Perception* work ongoing
- Predictive modelling – illustrates the importance of P perhaps over small temperature changes – implications for climate change?
- Possible important implications for food irrigation emerging

ANY QUESTIONS?



NATURAL ENVIRONMENT RESEARCH COUNCIL
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL
UNIVERSITY OF STIRLING
UNIVERSITY of ABERDEEN
Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF DUNDEE
UNIVERSITY of GLASGOW
scri living technology