Remote sensing approaches for detecting and monitoring cyanobacteria blooms in lakes

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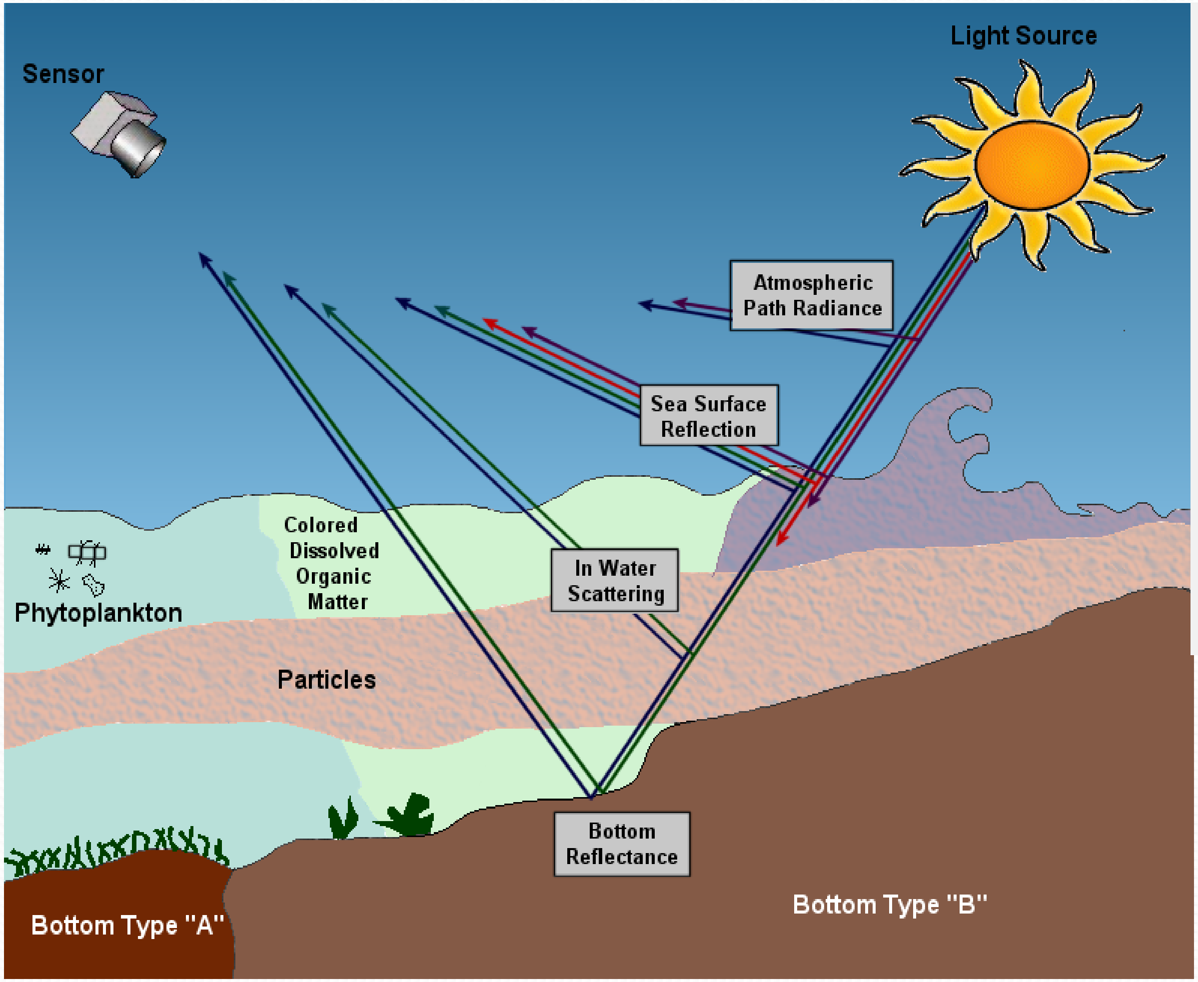
Cyanobacteria Monitoring and Analysis Workshop
USEPA Regional Laboratory
Chelmsford, MA
June 26, 2013

Optical components and pathways of radiance and reflectance in lake waters



Multiple light paths

- ***Scattering due to:***
  - atmosphere
  - aerosols
  - water surface
  - suspended particles
  - bottom
- ***Absorption due to:***
  - atmosphere
  - aerosols
  - suspended particles
  - dissolved matter

What is lake optical color?

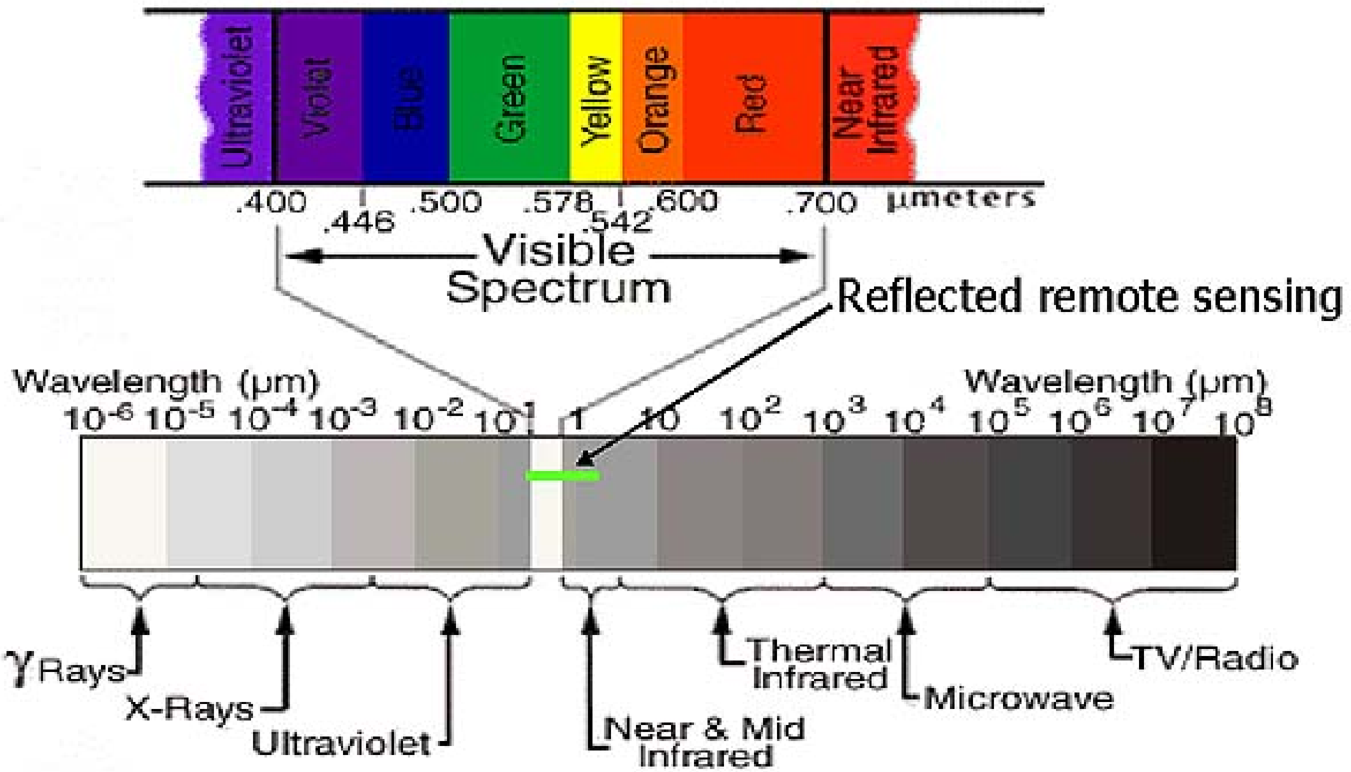


Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.

Definition of Remote Sensing Reflectance

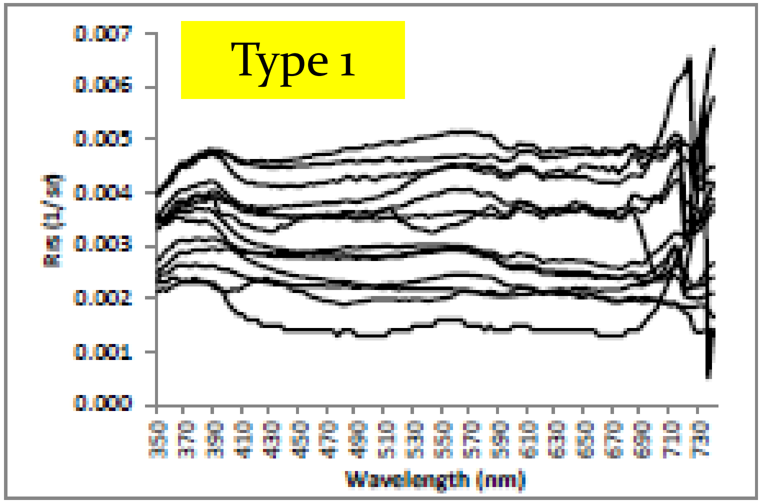
$$R_{rs}(0^+,\lambda) = L_w(0^+,\lambda) / E_s(0^+,\lambda)$$

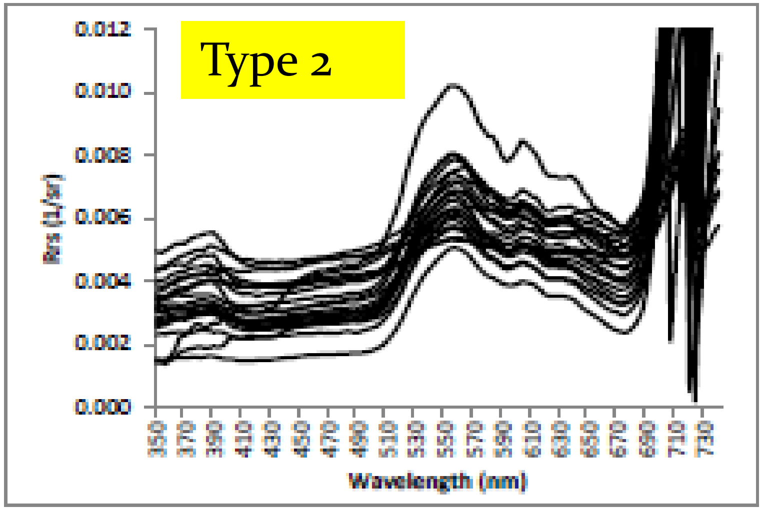
R_{rs} = remote sensing reflectance (1/sr)

$L_w(0^+, \lambda)$ = water leaving radiance measured above the air/water interface ($W\ m^{-2}\ sr^{-1}$),

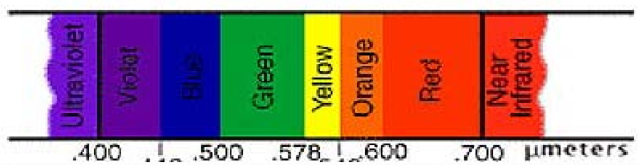
$E_s((0^+, \lambda)$ = downwelling irradiance measured above the air/water interface ($W\ m^{-2}\ sr^{-1}$)

Spectral Character of New England Lakes and Ponds

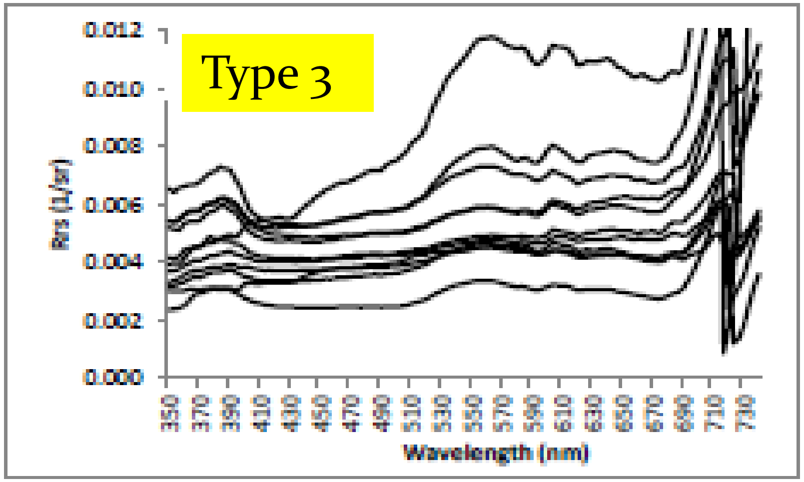




<u>Type 1 spectra</u>
Bright blue, clear lakes low chl *a*, and dominated by CDOM

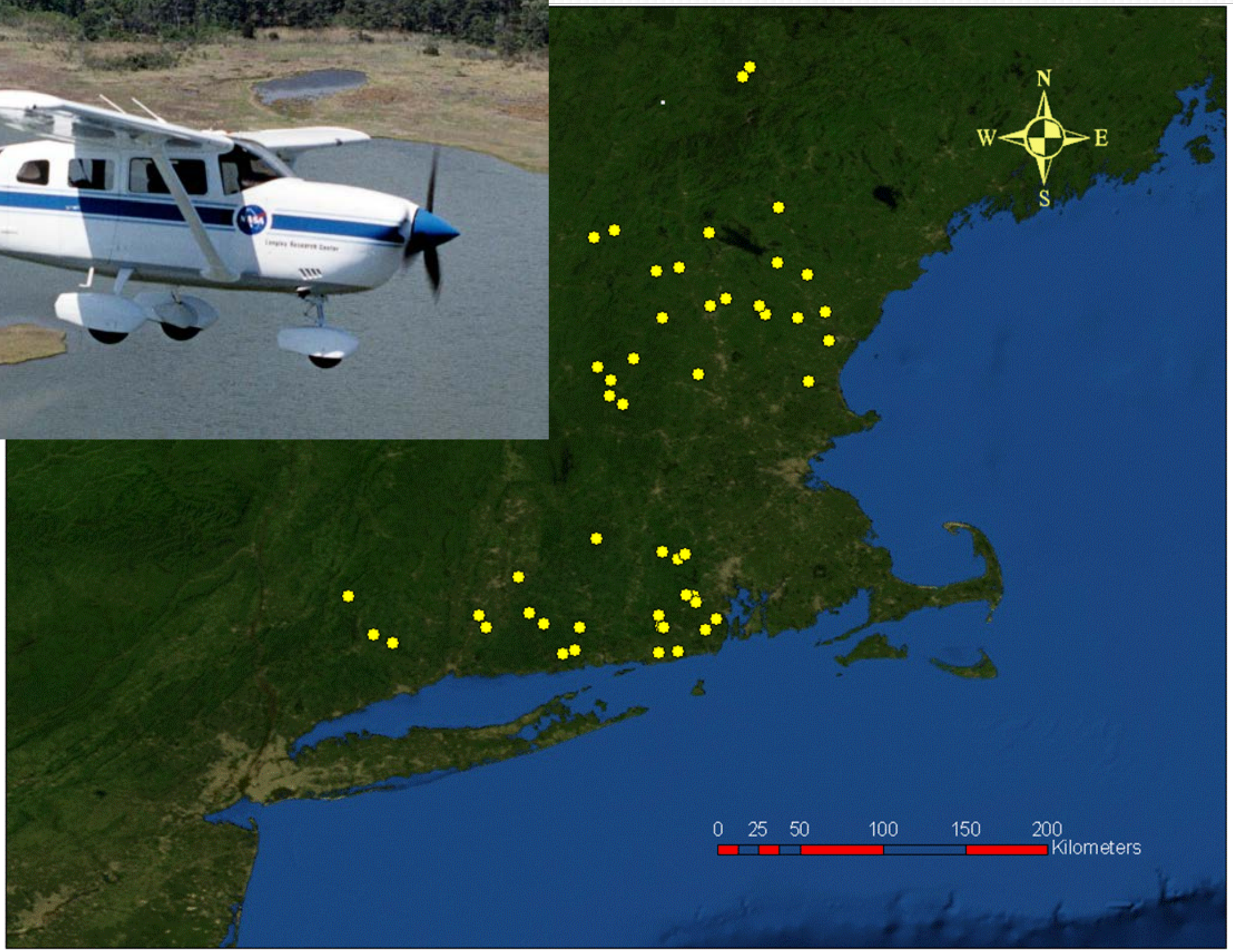


<u>Type 2 spectra</u>
Green lakes with high chl *a* and cyanobacteria present.



<u>Type 3 spectra</u>: similar to Type 2 with lower chl *a* and cyanobacteria

Aircraft monitoring with hyperspectral sensor packages

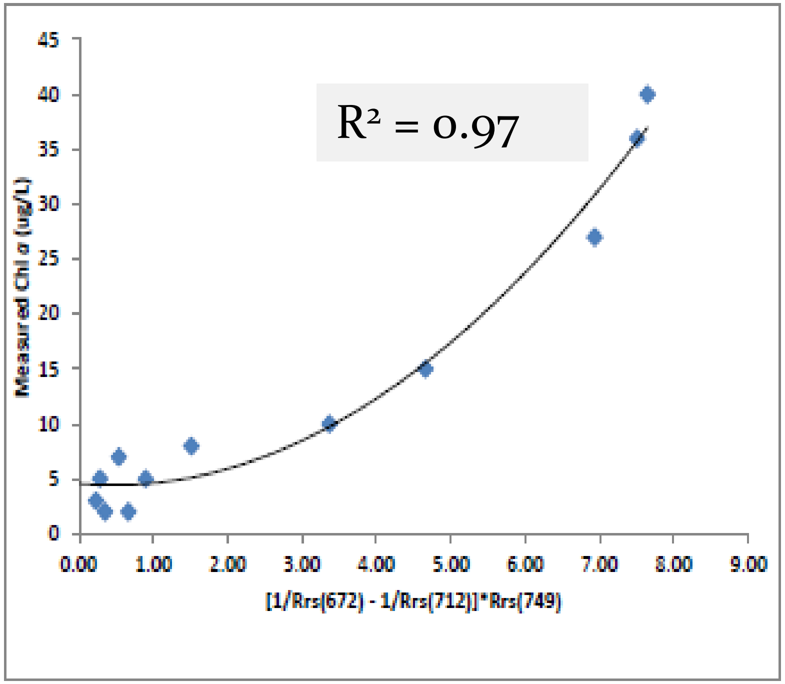


<u>Advantages</u>:
*Better temporal and spatial coverage compared to field sampling.

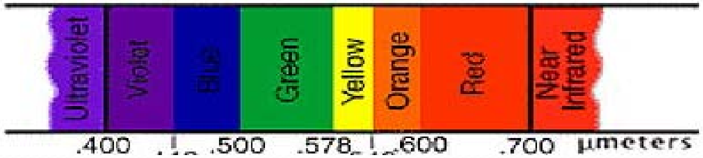
Optimal coverage of small lakes (<10 to >1000 hectares).

Retrieval of phytoplankton biomass [chl *a*] from Red and NIR spectral data (Le et al., 2002; Hunter, 2010)

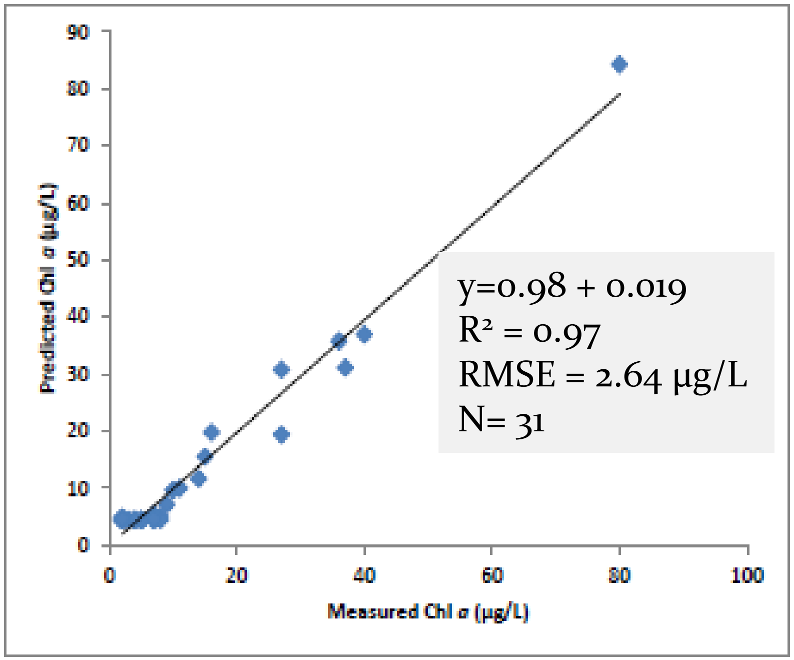
$$\text{pigment concentration} \propto [R_{rs}^{-1}(\lambda_1) - R_{rs}^{-1}(\lambda_2)] \times R_{rs}(\lambda_3)$$



Location	$[R_{rs}^{-1}(672) - R_{rs}^{-1}(712)] \times R_{rs}(749)$	Chl a $_{measured}$ (µg/L)
Canaan Street Lake, NH	0.86	3
Crooked Pond, NH	2.70	10
French Pond, NH	3.59	15
Harvey Lake, NH	2.04	8
Howe Reservoir, NH	1.35	7
Powder Mill Pond, NH	0.74	2
Thorndike Pond, NH	0.84	5
Turtle Pond, NH	6.52	36
Webster Lake, NH	2.10	8
Lake Attitash, Ma	6.63	40
Flat River Reservoir, RI	0.14	2
Beach Pond, RI	0.15	2
Watchaug Pond, RI	1.47	5
Yawgoo Pond, RI	6.05	27



Model Validation



Lake Name	State	Ecoregion	Number of days sampled postflight	Chl a (measured)	Chl a (estimated)
Beseck Lake	CT	NE Coastal Zone	10	7	5
Bigelow Pond	CT	NE Coastal Zone	10	4	4
Gardner Lake	CT	NE Coastal Zone	9	37	31
Hatch Pond	CT	NE Highlands	3	7	4
Lake Lillinonah	CT	NE Coastal Zone	2	9	7
Lake Zoar	CT	NE Coastal Zone	2	27	19
Middle Bolton Lake	CT	NE Coastal Zone	9	7	5
Pickerel Lake	CT	NE Coastal Zone	10	2	5
Pocotopaug Lake	CT	NE Coastal Zone	10	14	12
Powers Lake	CT	NE Coastal Zone	9	80	84
Silver Lake	CT	NE Coastal Zone	1	5	4
Uncas Pond	CT	NE Coastal Zone	9	16	20
Lake Attitash	MA	NE Coastal Zone	0	40	37
Canaan Street Lake	NH	NE Highlands	0	3	4
Crooked Pond	NH	NE Coastal Zone	0	10	10
French Pond	NH	NE Highlands	0	15	16
Harvey Lake	NH	NE Coastal Zone	0	8	5
Howe Reservoir	NH	NE Highlands	0	7	4
Jenness Pond	NH	NE Coastal Zone	0	4	5
Pearly Lake	NH	NE Highlands	0	11	10
Powder Mill Pond	NH	NE Highlands	0	2	4
Thorndike Pond	NH	NE Highlands	0	5	4
Turtle Pond	NH	NE Coastal Zone	0	36	36
Webster Lake	NH	NE Highlands	0	8	5
Beach Pond	RI	NE Coastal Zone	2	2	5
Flat River Reservoir	RI	NE Coastal Zone	2	2	4
Mishnock Lake	RI	NE Coastal Zone	1	2	5
Stump Pond	RI	NE Coastal Zone	2	2	5
Watchaug	RI	NE Coastal Zone	1	5	5
Wincheck Pond	RI	NE Coastal Zone	2	2	5
Yawgoo Pond	RI	NE Coastal Zone	1	27	31

Summary of trophic status for New England lakes based on phytoplankton concentrations

Trophic status	NE Coastal Zone Ecoregion (No. of lakes and ponds surveyed)	NE Highlands Ecoregion	% of total lakes and ponds surveyed
Oligotrophic (Chl *a* < 2 μg/L)	0	0	0
Mesotrophic (Chl *a* > 2 to 7 μg/L)	18	16	69
Eutrophic (Chl *a* > 7to30 μg/L)	5	4	18
Hypereutrophic (Chl *a* > 30 μg/L)	5	1	12

Trophic status definitions from EPA
National Lakes Assessment Program

Summary of biological condition for New England lakes based in chl *a* concentrations

Biological Condition	Ecoregion	Chlorophyll Thresholds	Number of lakes and ponds	% of lakes and ponds surveyed
Good-Fair	NE Coastal Zone	<29 µg/L	23	47
	NE Highlands	<7.6 µg/L	16	33
Fair	NE Coastal Zone	29 to 76 µg/L	4	8
	NE Highlands	7.6 to 13 µg/L	1	2
Fair -Poor	NE Coastal Zone	> 76 µg/L	1	2
	NE Highlands	> 13 µg/L	4	8

Biological condition definitions and chlorophyll thresholds from EPA National Lakes Assessment Program

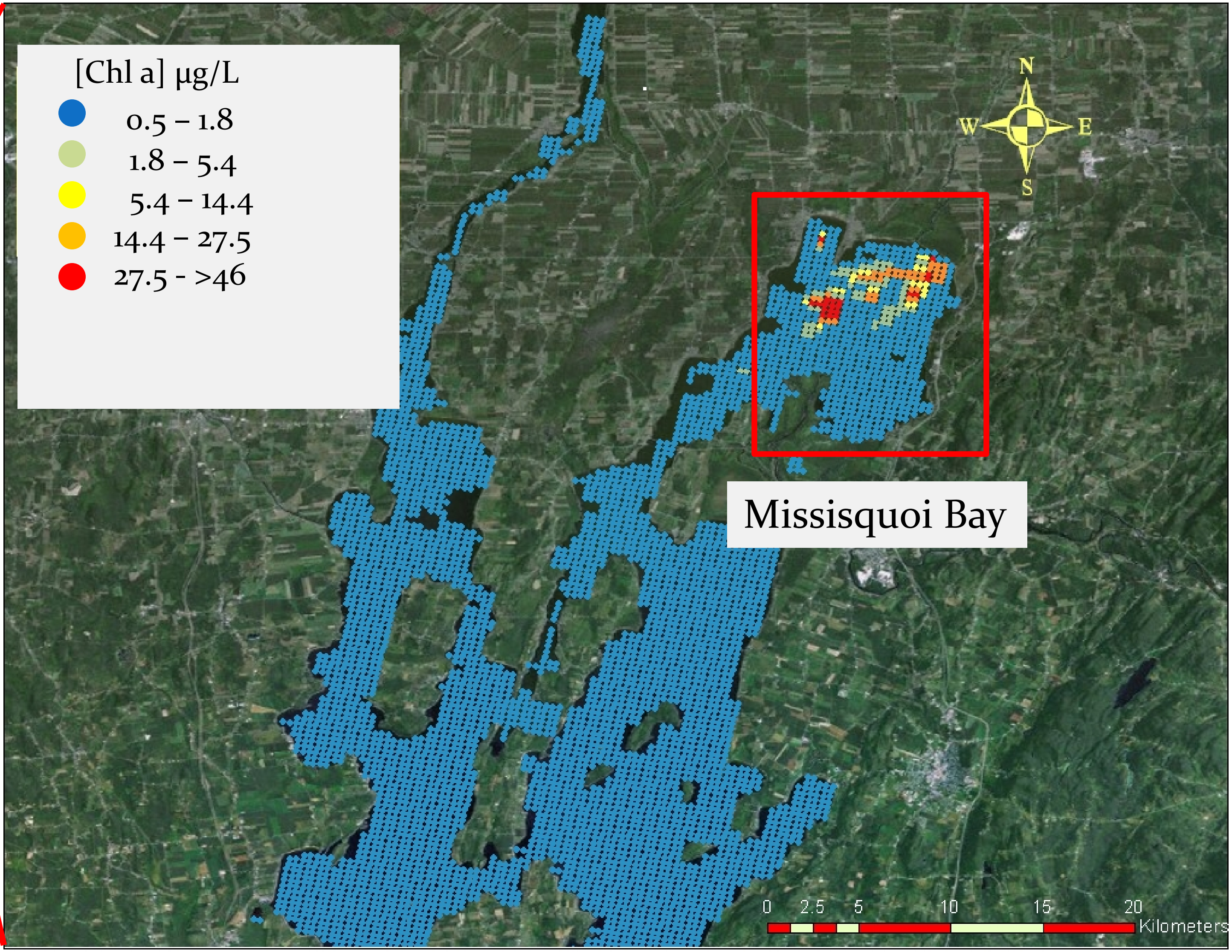
Space-based Lake Color Sensors

SENSOR (spatial resolution)		PLATFORM	AGENCY	Data Distribution Policy	Data Access	Cost to User
HICO 100 m		International Space Station (Sept 2009 –present)	NASA ISS Program	Products distributed online from HICO/OSU web site	Investigator Proposal Required	No cost
MERIS 300/1000 m		ENVISAT (Jan 2002-Apr 2012)	European Space Agency	Free online access of reduced resolution datasets through 'My Earthnet' website Access restrained data sets by submitting a 'My Earthnet' project proposal	Registration required Investigator Proposal required	No cost

<u>Advantage:</u> spatial and temporal coverage for “large” lakes

Phytoplankton distribution and abundance in Lake Champlain: June 4, 2009

Also see: S.M. Wheeler et al. / Journal of Great Lakes Research 38 (2012) 68–75



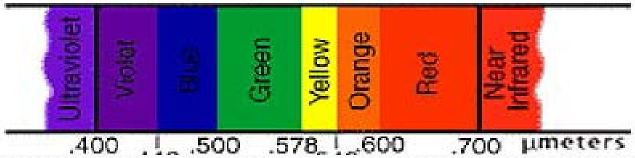
MERIS image courtesy of the European Space Agency

Retrieval of cyanobacterial biomass [C-PC] ***from spectral data*** (Simis et al., 2005; Gons et al., 2005: Hunter et al., 2010)

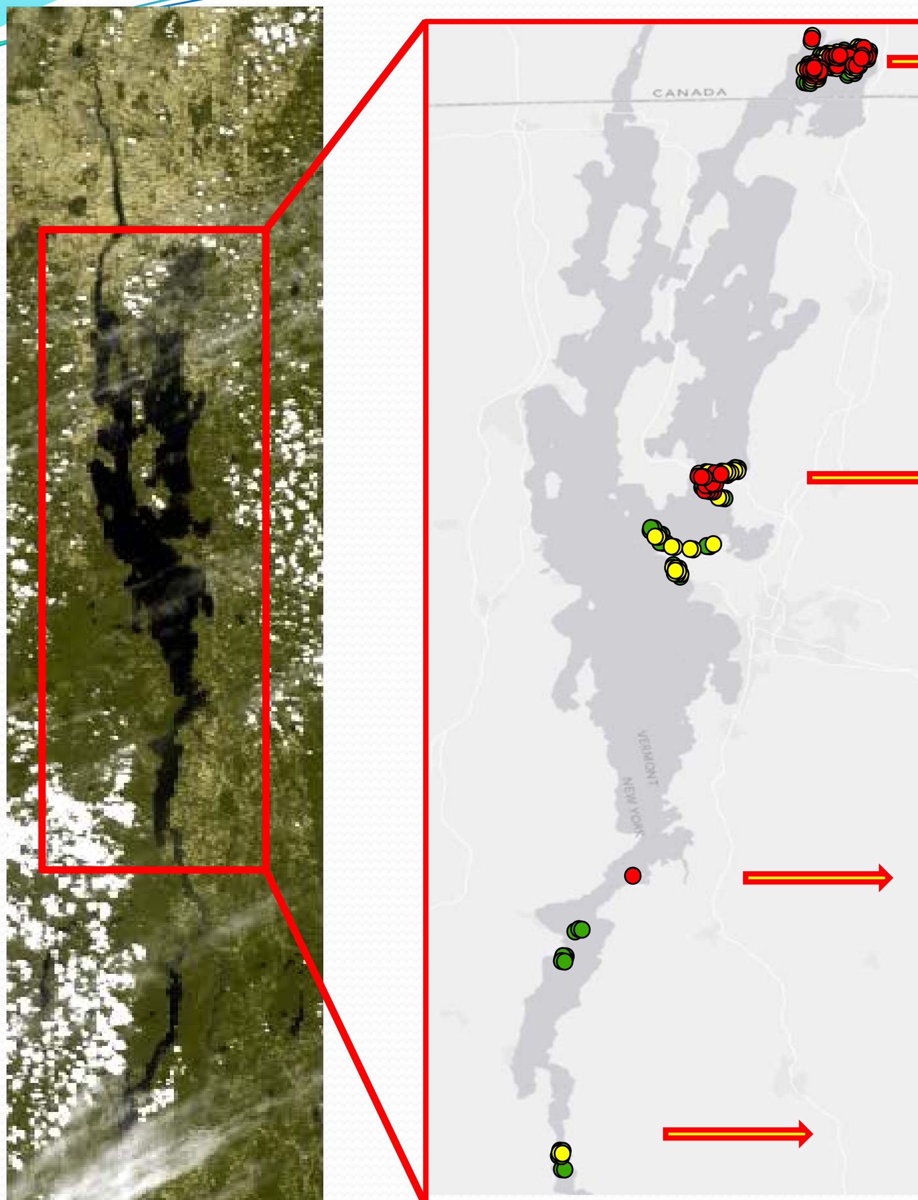
$$[\text{C-PC}]\ (\mu g/L) = a_{\text{C-PC}}(620) / (a_{\text{C-PC}}^{\ *}(620)) \approx 0.007$$

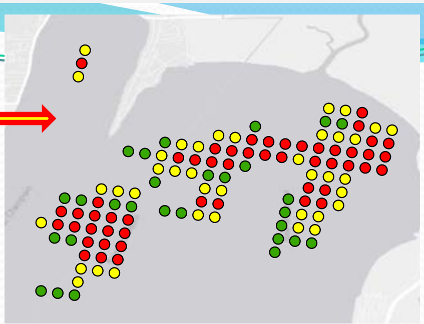
$$a_{\text{C-PC}}(620) = (\{[a_w(709)+b_b\,(779)] \times [R(709)/R(620)]\} - b_b\,(779) - a_w(620) - a_{chl}(665)$$

$a_w(709)$ = water absorption at 709 nm,
$a_w(620)$ = water absorption at 620 nm,
$b_b\,(779)$ = backscatter at 779 nm,
$R(709)$ = reflectance at 709 nm,
$R(620)$ = reflectance at 620 nm,
$a_{chl}(665)$ = chl *a* absorption at 665 nm.

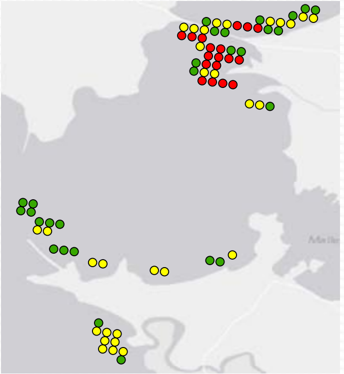


Phycocyanin distribution from MERIS image : June 4, 2009

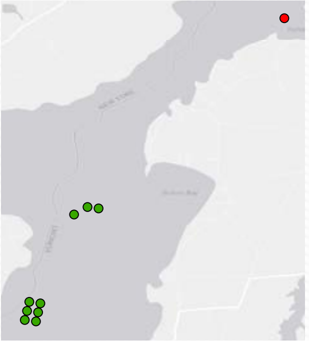




Missisiquoi Bay



Malletts Bay

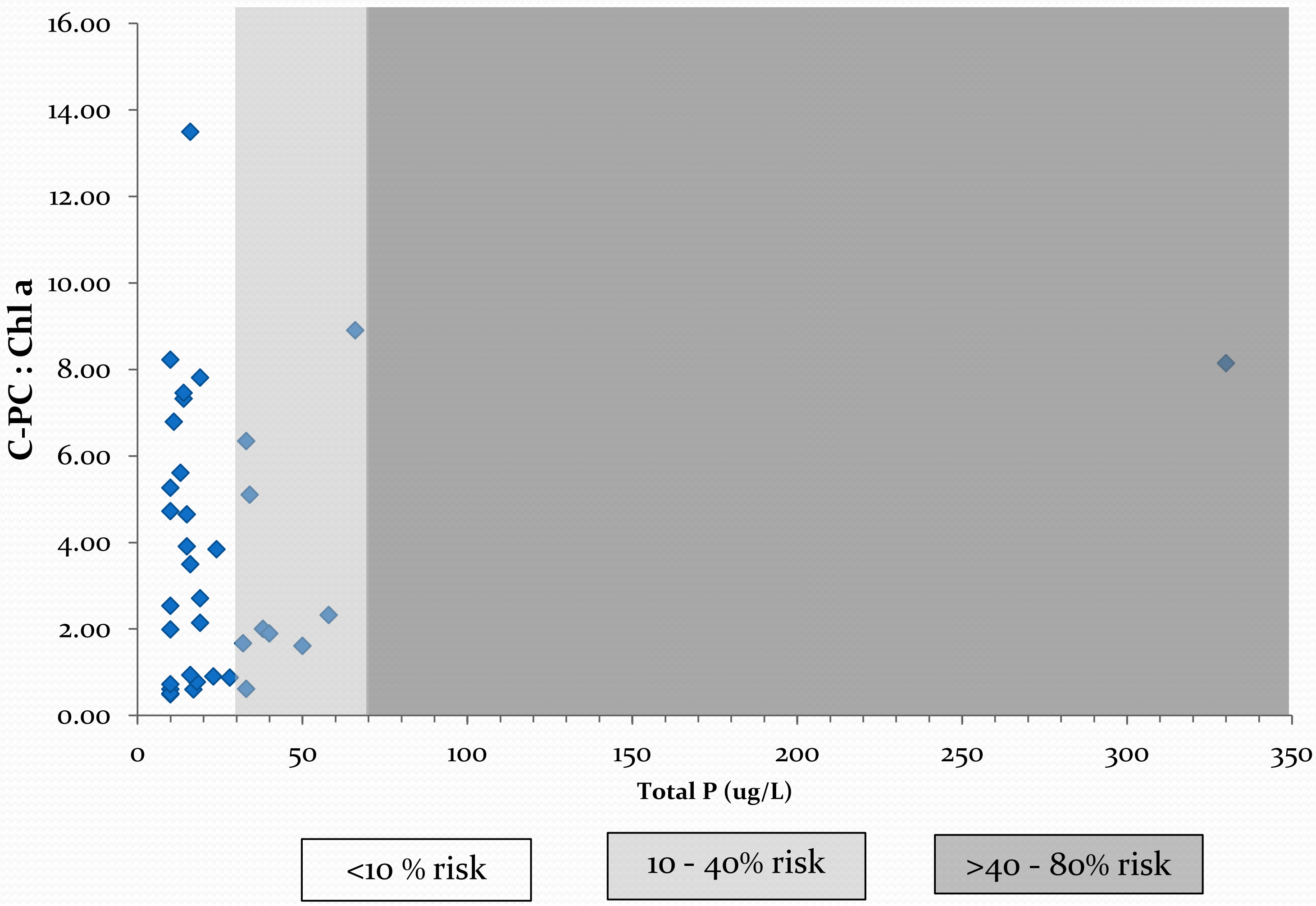


Central Lake Champlain

South Lake Champlain

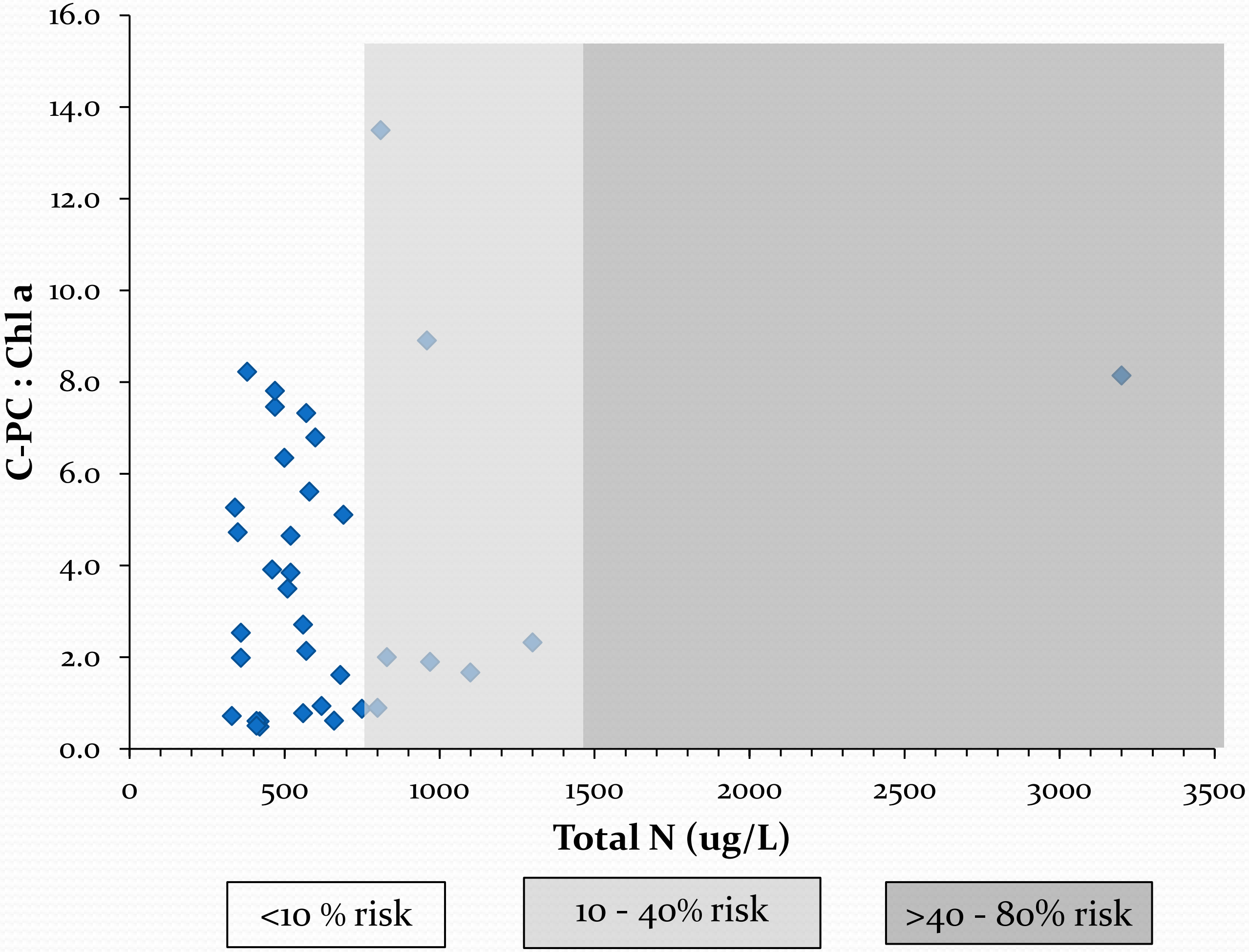
<2 2- 8 >8 ug/L

Relative risk of cyanobacteria dominance for New England lakes and ponds based measured total phosphorus (Total P) concentrations and lake susceptibility to dominance (C-PC:Chl a)



See: Downing, JA, Watson, SB, McCauley, E., 2001. Predicting cyano- bacterial dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences, 58, 1905–1908.

Relative risk of cyanobacteria dominance for New England lakes and ponds based measured total nitrogen (Total N) concentrations and lake susceptibility to dominance (C-PC:Chl a)



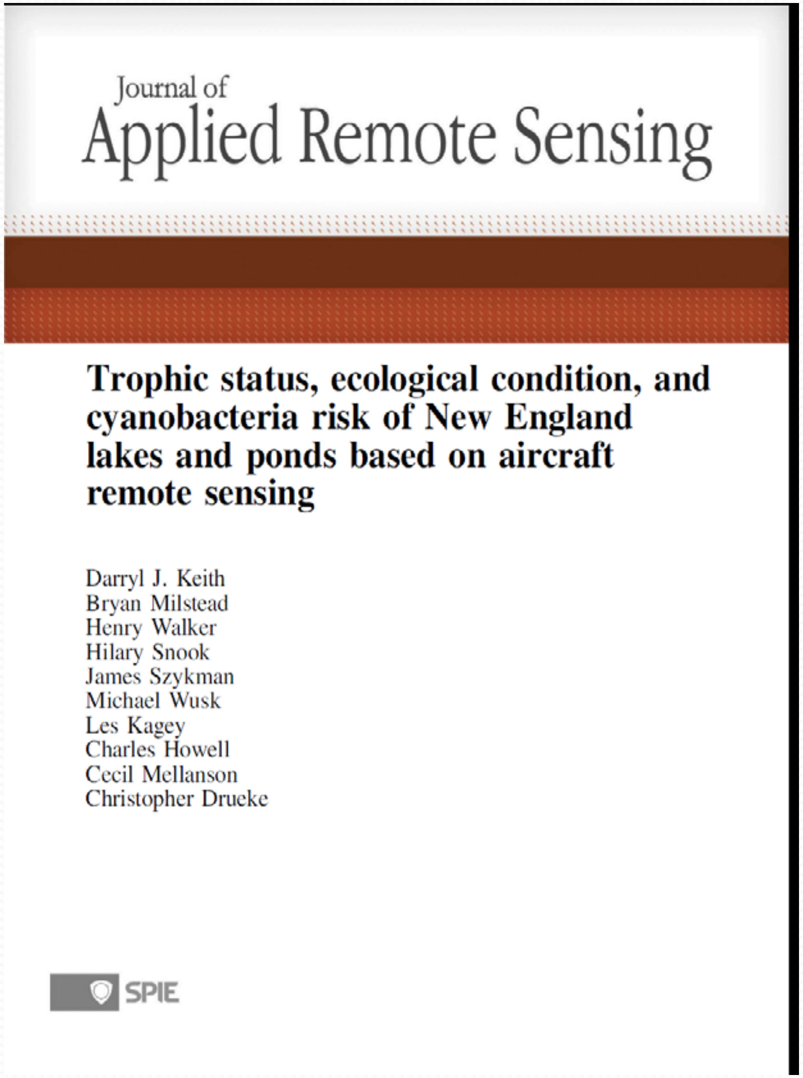
See: Downing, JA, Watson, SB, McCauley, E., 2001. Predicting cyano- bacterial dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences, 58, 1905–1908.

Recreational Suitability of New England Lakes based on Potential Human Health Hazards

Relative Probability* of Acute Health effects	NE Coastal Zone Ecoregion (no. of lakes and ponds)	NE Highlands Ecoregion	Health Effects*
Low *(Chl a < 10 µg/L)*	19	16	Skin irritations, Gastrointestinal illness
Moderate *(Chl a 10-50 µg/L)*	8	5	Long term illness, Skin irritations, Gastrointestinal illness
High *(Chl a 50 -5000 µg/L)*	1	0	Potential for acute poisoning, Long term illness, Skin irritations, Gastrointestinal illness

* from World Health Organization

Questions?



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Trophic status, ecological condition, and cyanobacteria risk of New England lakes and ponds based on aircraft remote sensing

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