
“Eutrofización y biogeoquímica ambiental del fósforo”
Curso de posgrado
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(CURE-UDELAR)
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FACULTAD DE AGRONOMÍA
UPEP
PEDECIBA
MEC-UDELAR
Comienzo 8 de abril 2024. (intensivo/ presencial - distancia)
Info: aguadulceuy@gmail.com

P y eutrofización

Dr. Guillermo Goyenola goyenola@gmail.com 04/2024


¿Por qué
“la eutrofización llega”
en el siglo XX?

Reconstrucción pre/histórica: la aproximación paleolimnológica

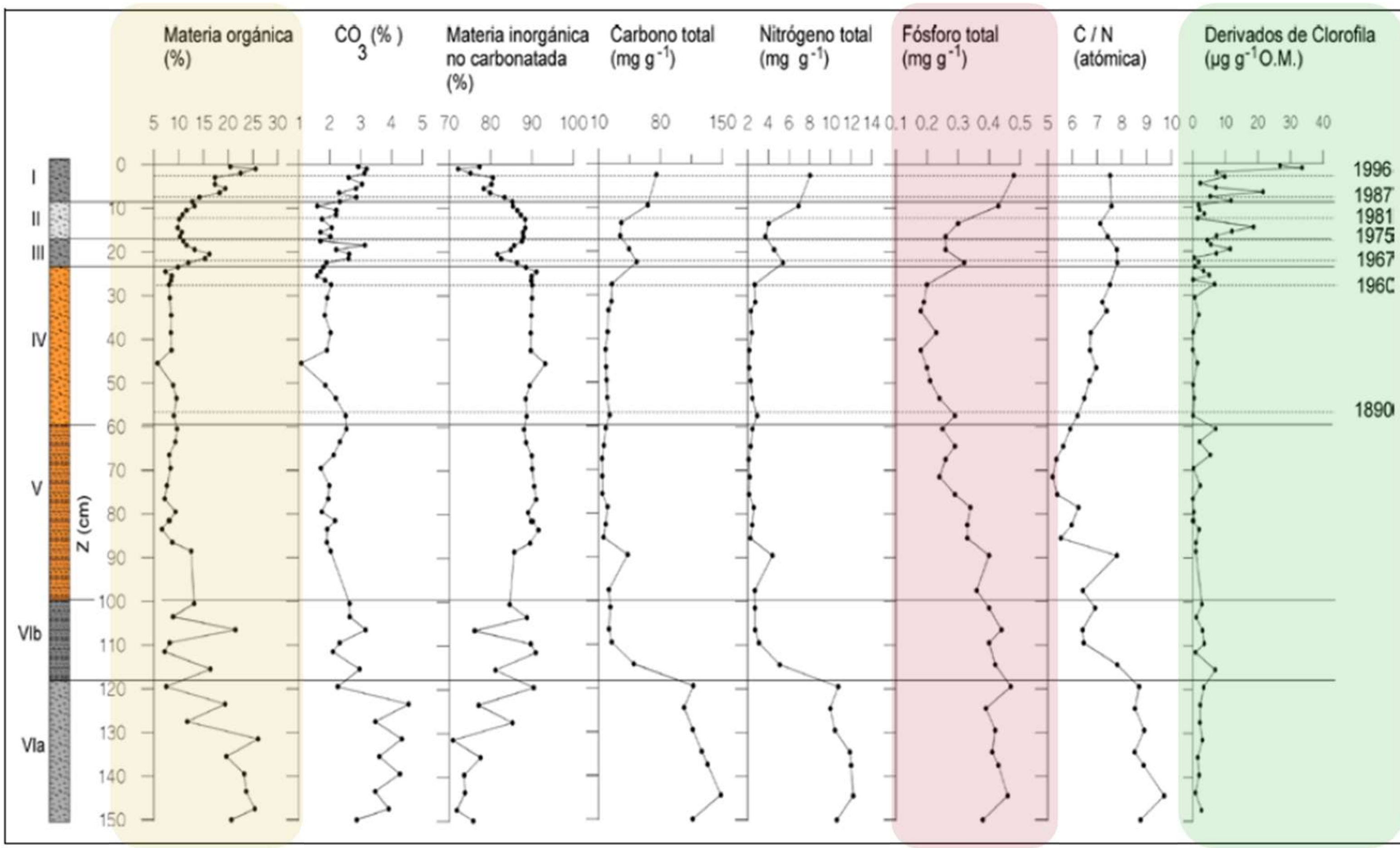
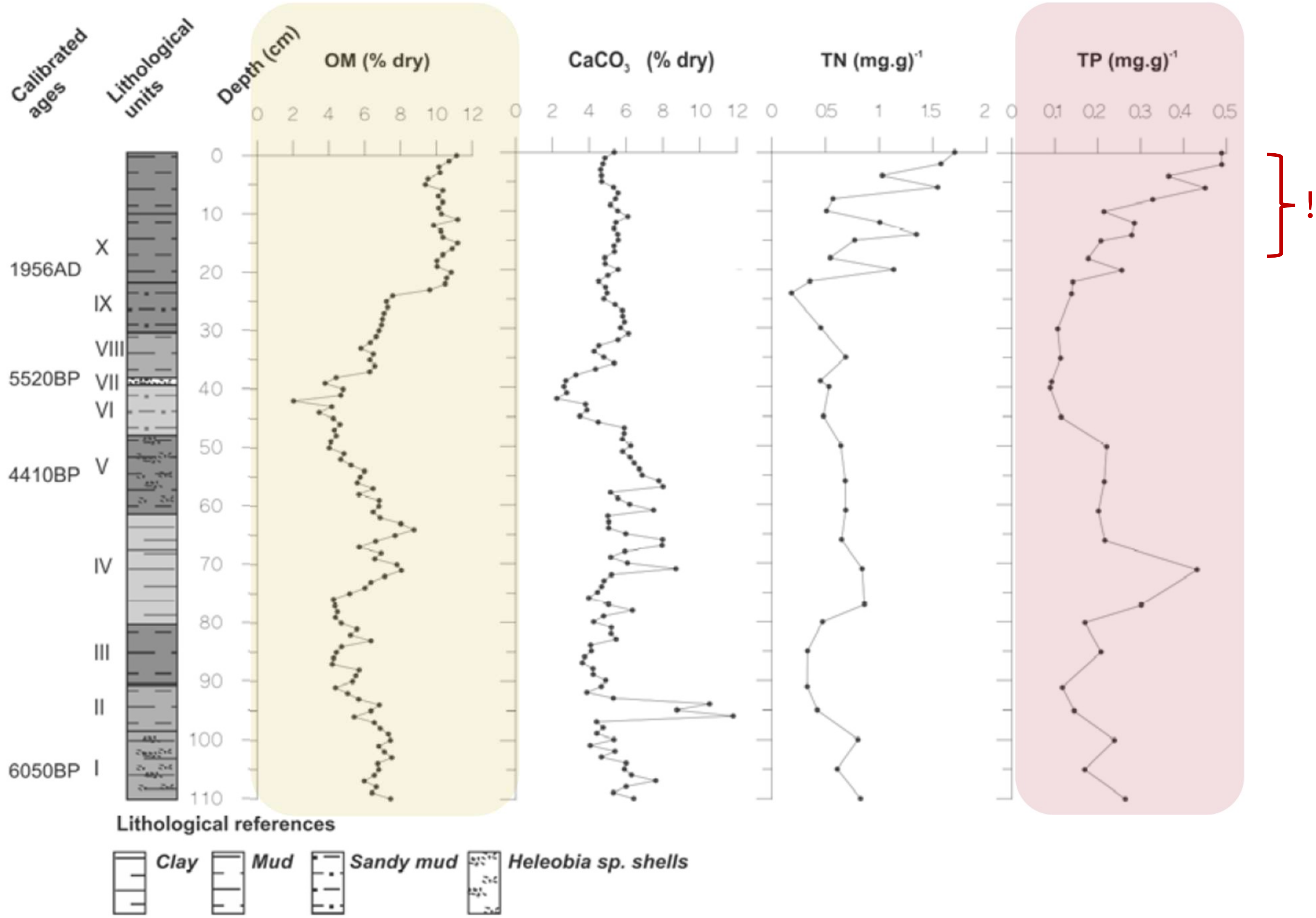


Fig. 39. Distribución vertical de materia orgánica, CO_3, fracción inorgánica no carbonatada, carbono total, nitrógeno total, fósforo total y pigmentos derivados de clorofila, en los 150 cm superficiales del testigo LBL1.

!

Laguna Blanca (Maldonado)

García-Rodríguez, F. (2002). *Estudio paleolimnológico de Lagunas de Rocha, Castillos y Blanca, sudeste del Uruguay. (Tesis Doctorado). PEDECIBA/Ecología - DAAD, Facultad de Ciencias, UDELAR, Montevideo.*



Laguna del Diario (Maldonado)

Inda, H., García-Rodríguez, F., del Puerto, L., Stutz, S., Lopes Figueira, R. C., de Lima Ferreira, P. A., & Mazzeo, N. (2016). Discriminating between natural and human-induced shifts in a shallow coastal lagoon: A multidisciplinary approach. *Anthropocene, 16, 1-15. doi:10.1016/j.ancene.2016.09.003*

Eutrofización antrópica

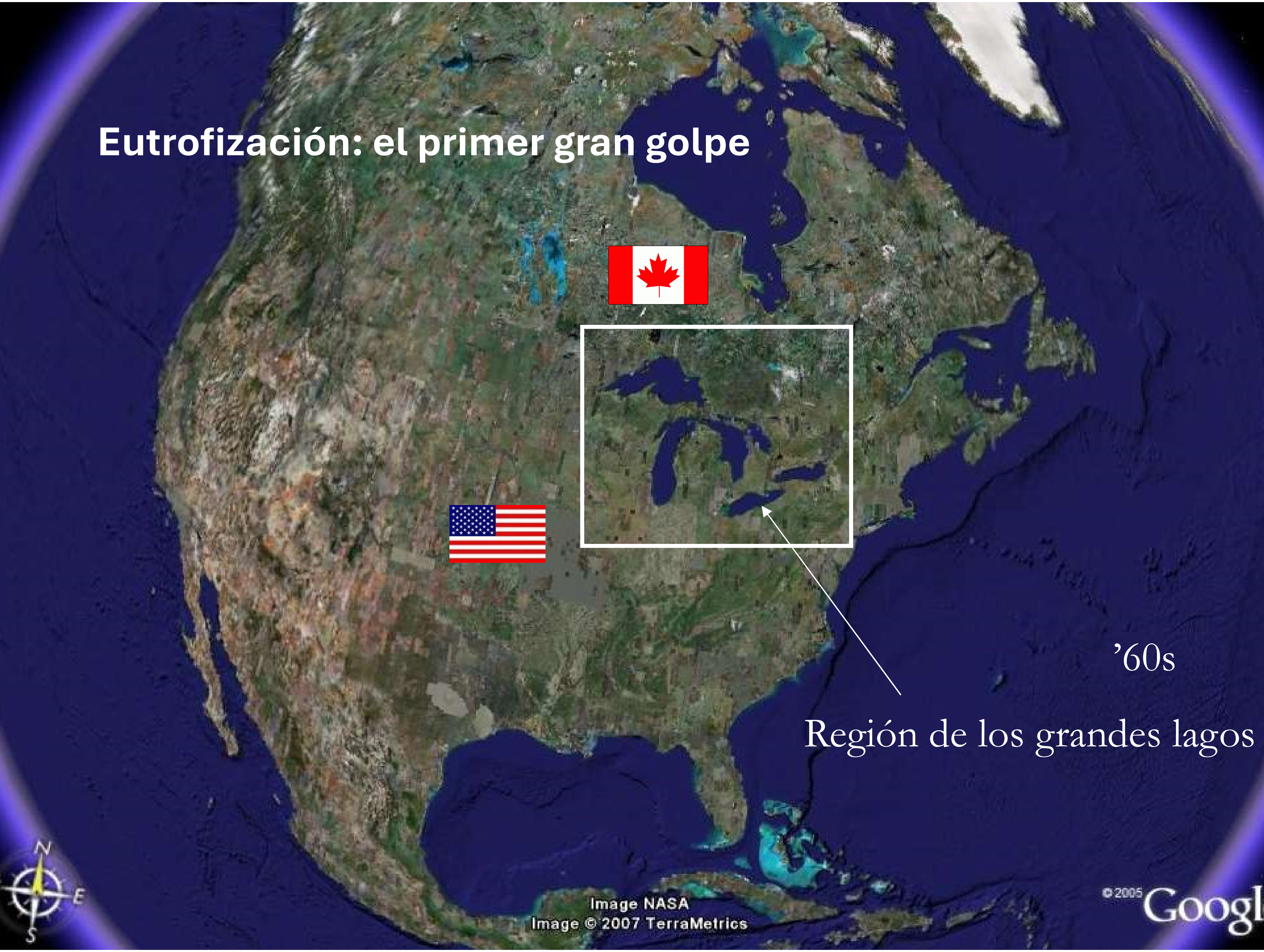
Eutrofización cultural

- Proceso artificial
- Acelerado

"LANDFALL" (2014)

Erik Johansson https://www.erikjo.com/

Eutrofización: el primer gran golpe




Lago Erie
Ottawa
Toronto
Detroit
Chicago
Cleveland, OH
Columbus
FORD
Image NASA
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Image IndianaMap Framework Da
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Secuencia |||||||||| 100%
Alt. ojo 482.62
Googl

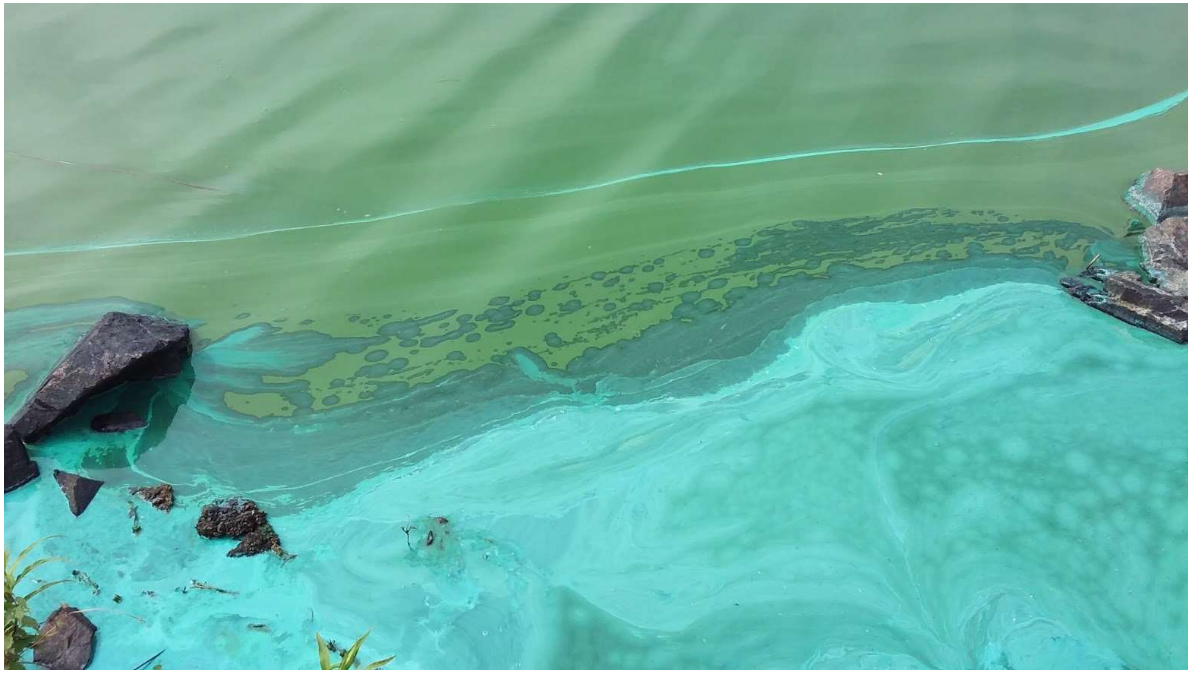
https://glbusinessnetwork.com/wp-content/uploads/2019/07/lake-erie-HAB-Shoreline.jpg

https://environmentaldefence.ca/2022/08/15/lake-erie-algae-bloom-2022/

https://environmentaldefence.ca/2022/08/15/lake-erie-algae-bloom-2022/

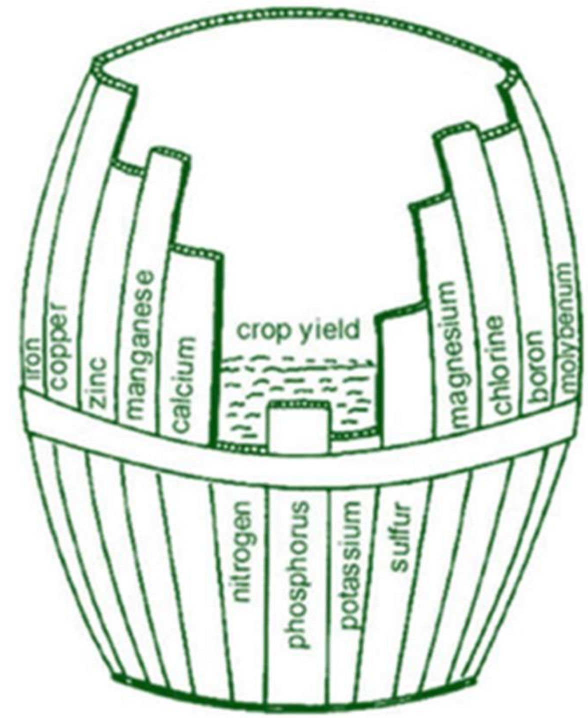
EUTROFIZACIÓN

CAUSA



- Aumento de la carga interna de nutrientes
  - Nutriente limitante?

¿Nutriente limitante?



- aquel que controla la máxima cantidad de biomasa
- el que primero se consume

ESTADO TRÓFICO

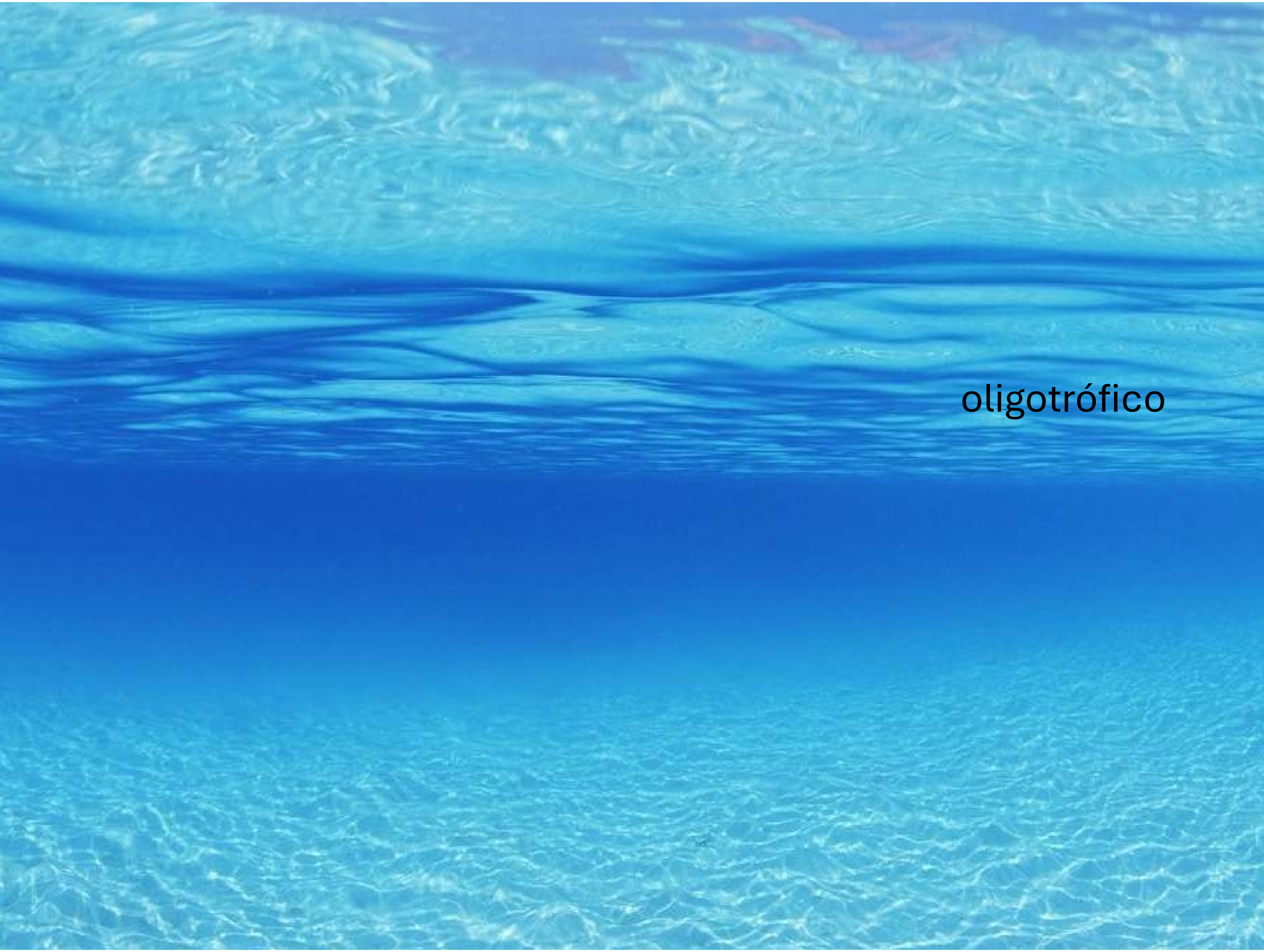
- En líneas generales un sistema acuático puede clasificarse como:
  - **oligotrófico** (pobre en nutrientes)
  - **mesotrófico** (estado intermedio)
  - **eutrófico** (rico en nutrientes)

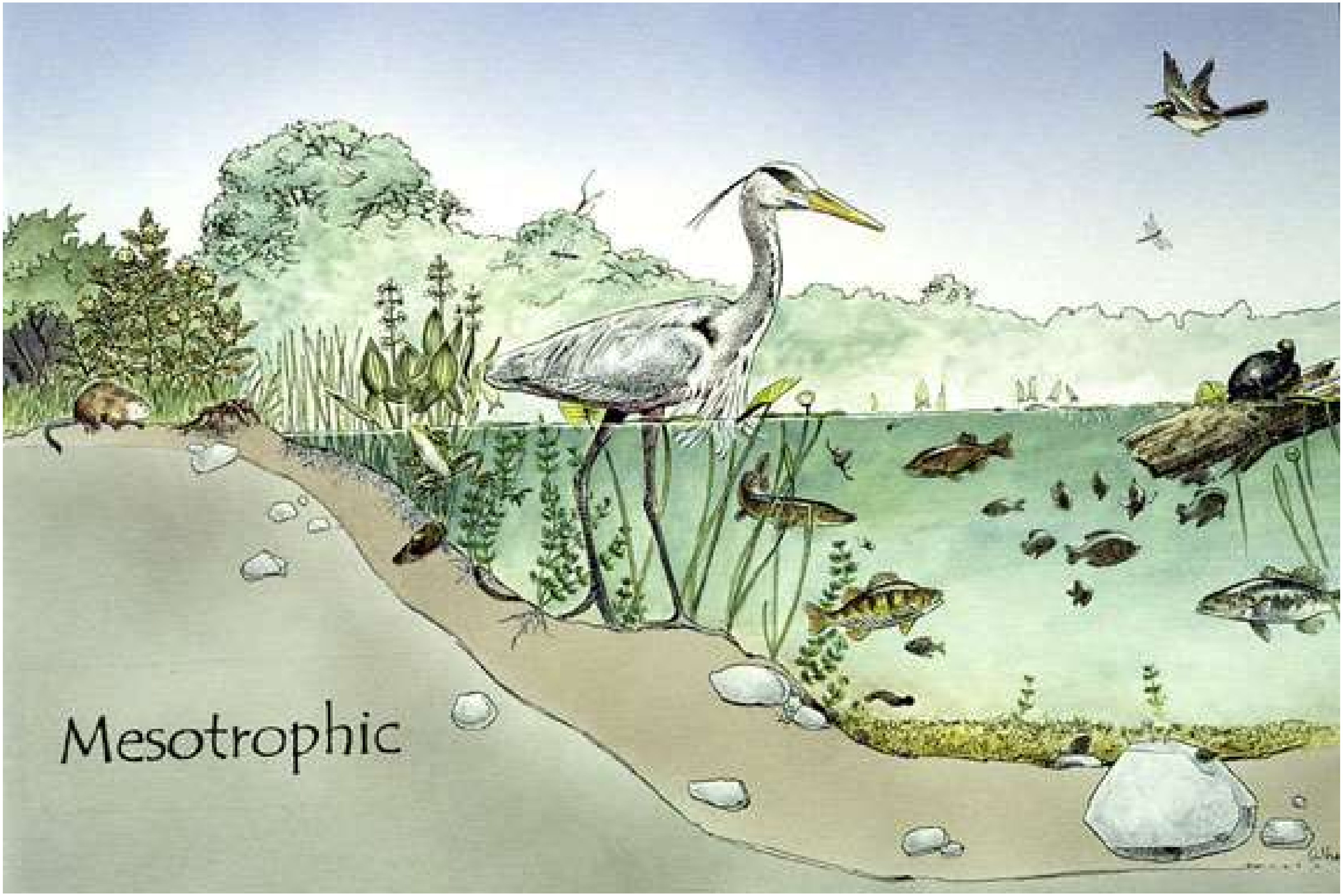
Naumann, E., 1919. Nagra synpunkter angaende limnoplanktos ökologi med särskild hänsyn til fytoplankton. Svensk. Bot. Tidskr. 13, 129-163.


Oligotrophic


oligotrófico


oligotrófico

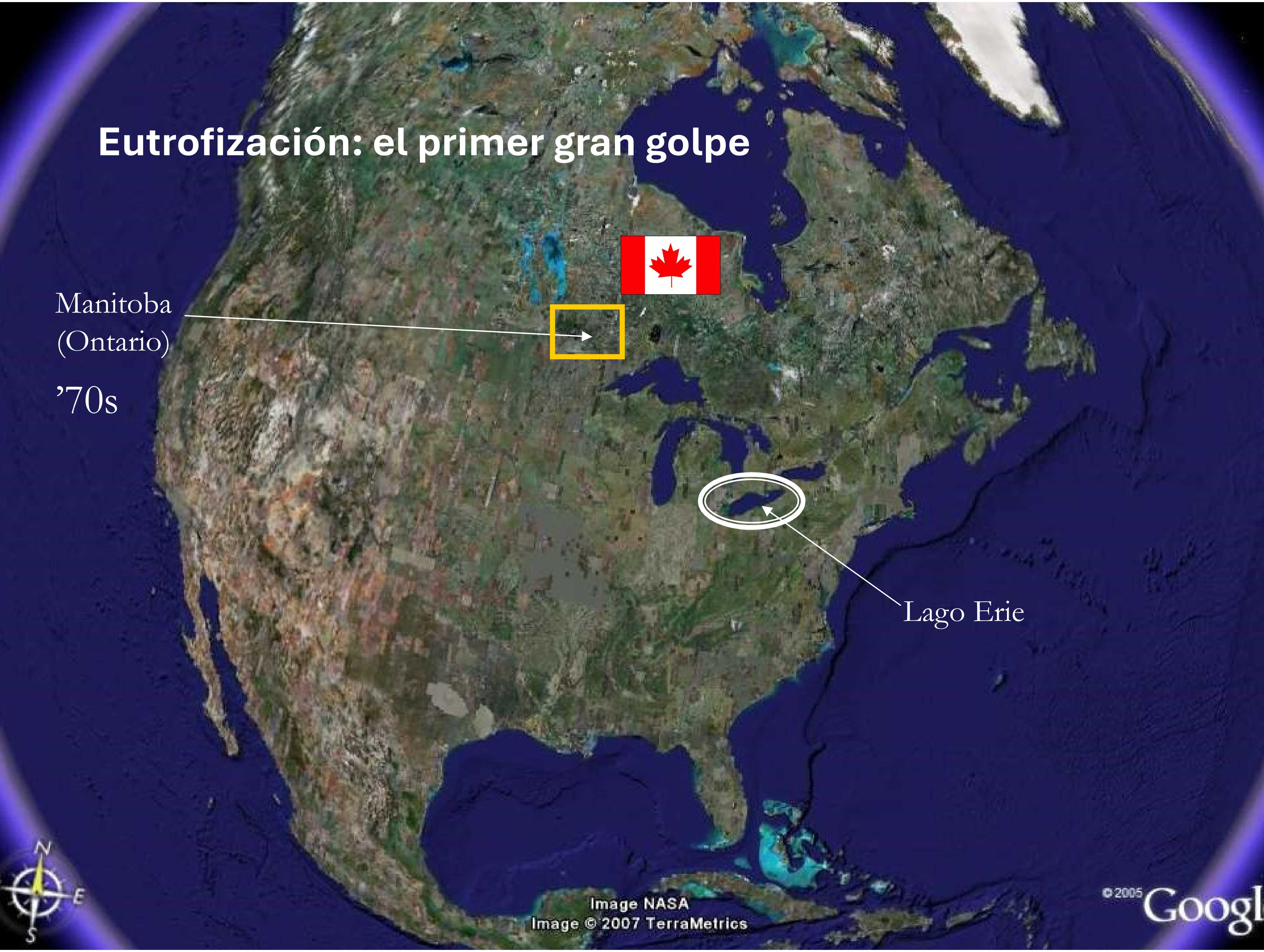

oligotrófico


Mesotrophic


Eutrophic

Lago Rivera
(Montevideo)

Lago Rodó
(Montevideo)


Eutrofización: el primer gran golpe
Manitoba
(Ontario)
’70s
Lago Erie
N
E
S
Image NASA
Image © 2007 TerraMetrics
© 2005 Googl

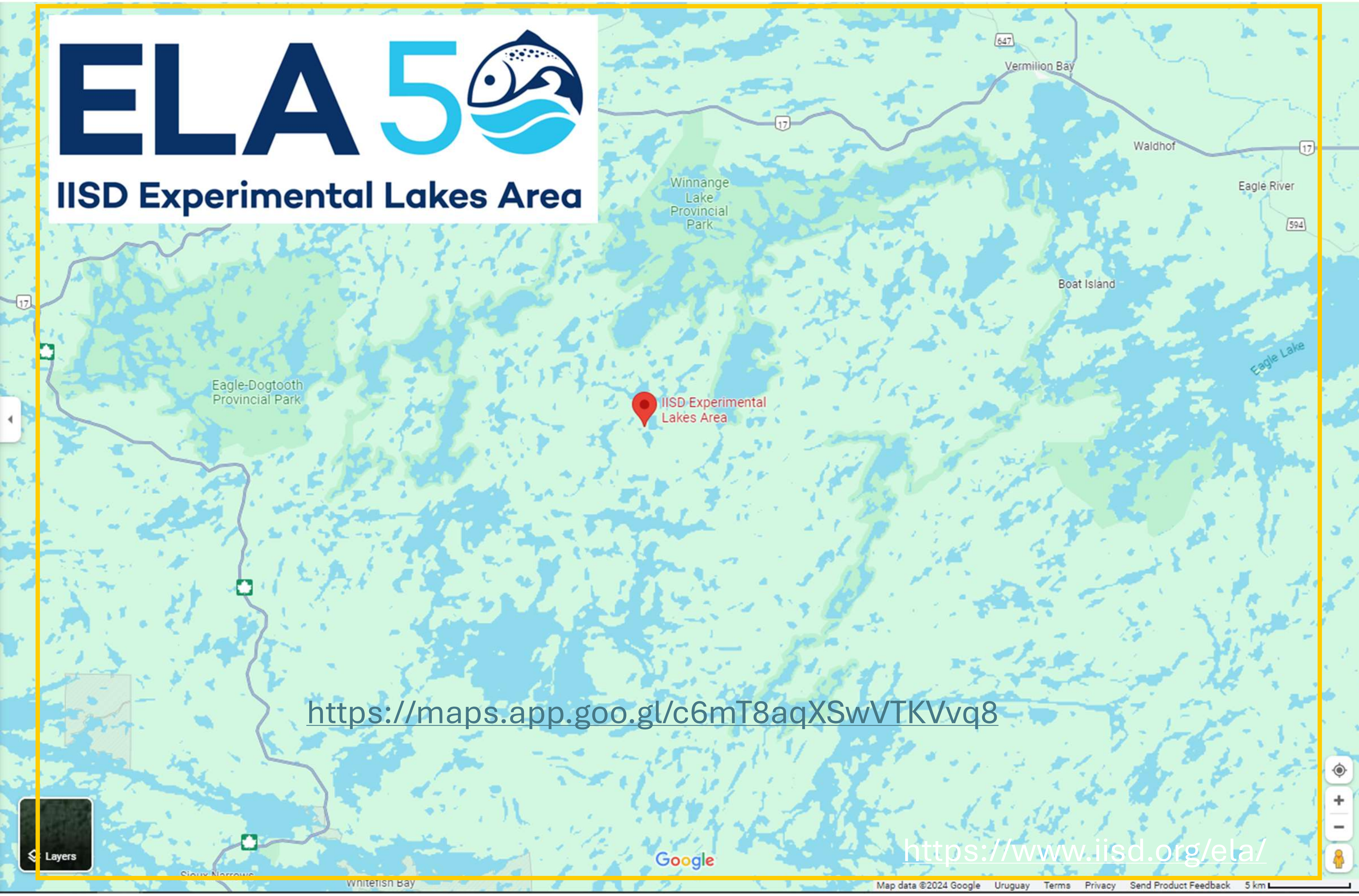
ELA 50

IISD Experimental Lakes Area

https://www.iisd.org/ela/

ELA 50

IISD Experimental Lakes Area



https://maps.app.goo.gl/c6mT8aqXSwVTKVvq8

https://www.iisd.org/ela/


lake 226 - ELA
lake 226 - ELA
N
E
S
Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
©2005
Google

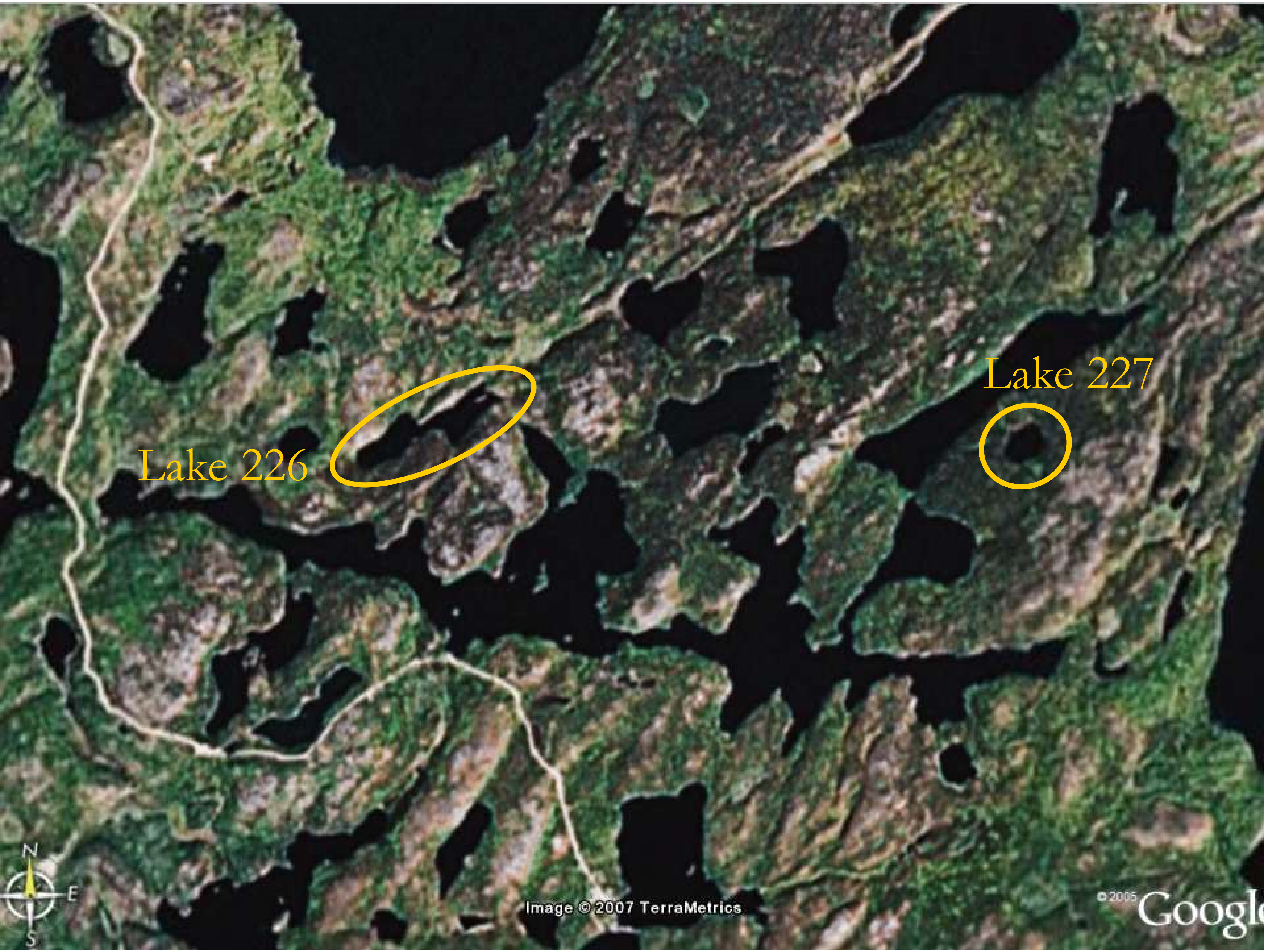

Lake 226
Lake 227
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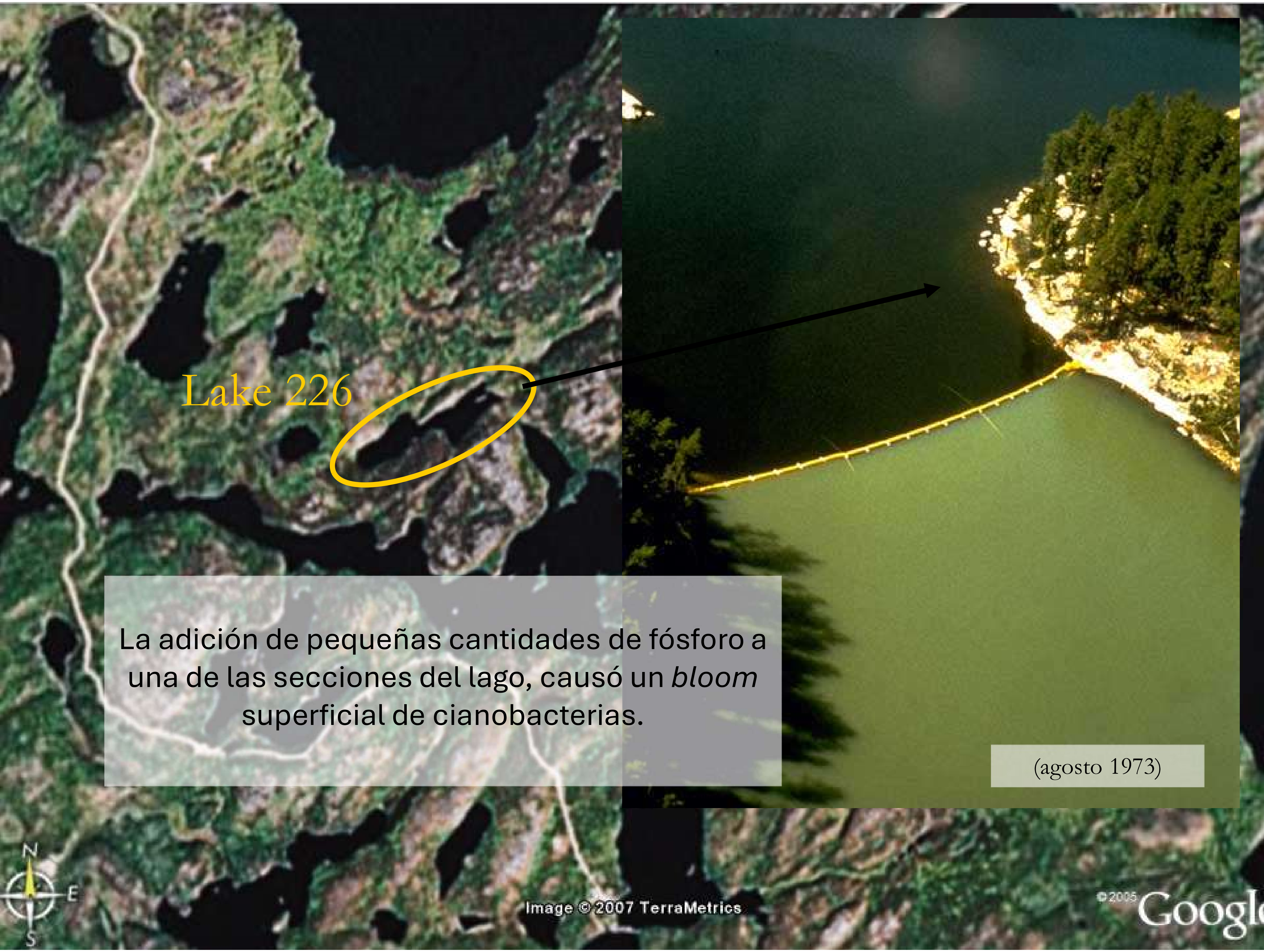
Image © 2007 TerraMetrics
© 2006
Google



La adición de pequeñas cantidades de fósforo a una de las secciones del lago, causó un *bloom* superficial de cianobacterias.

tion spectrophotometer equipped with a flameless mercury cell. Elemental mercury was observed. Also, a liquid trap of cysteine was placed in the flow system immediately before the acid-permanganate trap. This trap was counted along with the acid-permanganate trap and showed no accumulated activity during the course of the experiment. Since the cysteine trap would remove mercury and methylmercuric ions but not elemental mercury from the nitrogen flow, the mercury species trapped by the oxidizing acid-permanganate trap must have been elemental mercury. Further direct measurements of evolved Hg with the atomic absorption spectrophotometer would have required excessively large concentrations of mercury, and the rate of release was so slow that this method of analysis was discontinued.

8. M. Schnitzer and S. V. Khan, *Humic Substances in the Environment* (Dekker, New York, 1972).
9. N. M. Atherton, P. A. Cranwell, A. J. Floyd, R. D. Haworth, *Tetrahedron* 23, 1653 (1967); R. Riffaldi and M. Schnitzer, *Geoderma* 8, 1 (1972); M. V. Cheshire and P. A. Cranwell, *J. Soil Sci.* 23, 424 (1972); B. R. Nagar, N. P. Datta, M. R. Das, M. P. Khakhar, *Indian J. Chem.* 5, 587 (1967).
10. B. R. Nagar, A. Chandrasekhara Rao, N. P. Datta, *Indian J. Chem.* 9, 160 (1971).
11. Supported in part by funds from the Environmental Protection Agency under grant R-800427. We thank P. W. Carr, E. G. Jansen, and E. R. Pomeroy for thoughtful discussions of this work.

10 December 1973; revised 21 January 1974

Eutrophication and Recovery in Experimental Lakes: Implications for Lake Management

Abstract. *Combinations of phosphorus, nitrogen, and carbon were added to several small lakes in northwestern Ontario, Canada, at rates similar to those in many culturally eutrophied lakes. Phosphate and nitrate caused rapid eutrophication. A similar result was obtained with phosphate, ammonia, and sucrose, but recovery was almost immediate when phosphate additions only were discontinued. When two basins of one lake were fertilized with equal amounts of nitrate and sucrose, and phosphorus was also added to one of the basins, the phosphate-enriched basin quickly became highly eutrophic, while the basin receiving only nitrogen and carbon remained at prefertilization conditions. These results, and the high affinity of sediments for phosphorus indicate that rapid abatement of eutrophication may be expected to follow phosphorus control measures.*

Although the U.S.–Canada Water Quality Agreement (*1*) was signed on 15 April 1972, legislation prohibiting the use of phosphorus in detergents and controlling inputs of phosphorus to the St. Lawrence Great Lakes has not been passed by many states (*2*). Much of the foot-dragging on anti-eutrophication laws undoubtedly still results from the controversy and confusion surrounding the debate over the effectiveness of controlling phosphorus in influents to freshwater lakes (*3*). Among the main points debated (often on the basis of inconclusive evidence) have been:

1) Is phosphorus really responsible for eutrophication problems?

2) If sufficient phosphorus is available, can carbon limit the growth of undesirable algae?

3) Is phosphorus removal alone an effective means of overcoming eutrophication problems?

4) Are already culturally eutrophied lakes recoverable? Can this be done by controlling inputs of phosphorus alone?

5) What concentration of phosphorus can be considered safe?

Answers to these questions have been sought in a series of whole-lake experiments conducted in the Experimental Lakes Area of northwestern Ontario. Lakes in the area are set in Precambrian Shield bedrock. Chemically and biologically they are similar to more than 50 percent of the waters draining to the St. Lawrence Great Lakes (*4*).

In an early experiment, phosphate and nitrate were added to lake 227, which has an extremely low content of dissolved inorganic carbon, to see whether shortage of carbon would prevent the eutrophication of such a lake (*5*). The lake was transformed into a teeming, green soup within weeks after nutrient additions were begun. Algal standing crops up to two orders of magnitude greater than those in unfertilized lakes of the area have been observed (*6, 7*). No increase in phosphate concentration was observed, and any added phosphate disappeared in minutes because of uptake by plankton (*8*). Gas-exchange studies revealed that some of the additional carbon required for production of this algal bloom was drawn from the atmosphere, and a comparison of dissolved inorganic carbon concentrations and parameters affecting gas exchange indicated that there was no possibility that shortage of carbon could prevent the eutrophication of the St. Lawrence Great Lakes or any other water body of economic importance (*9*).

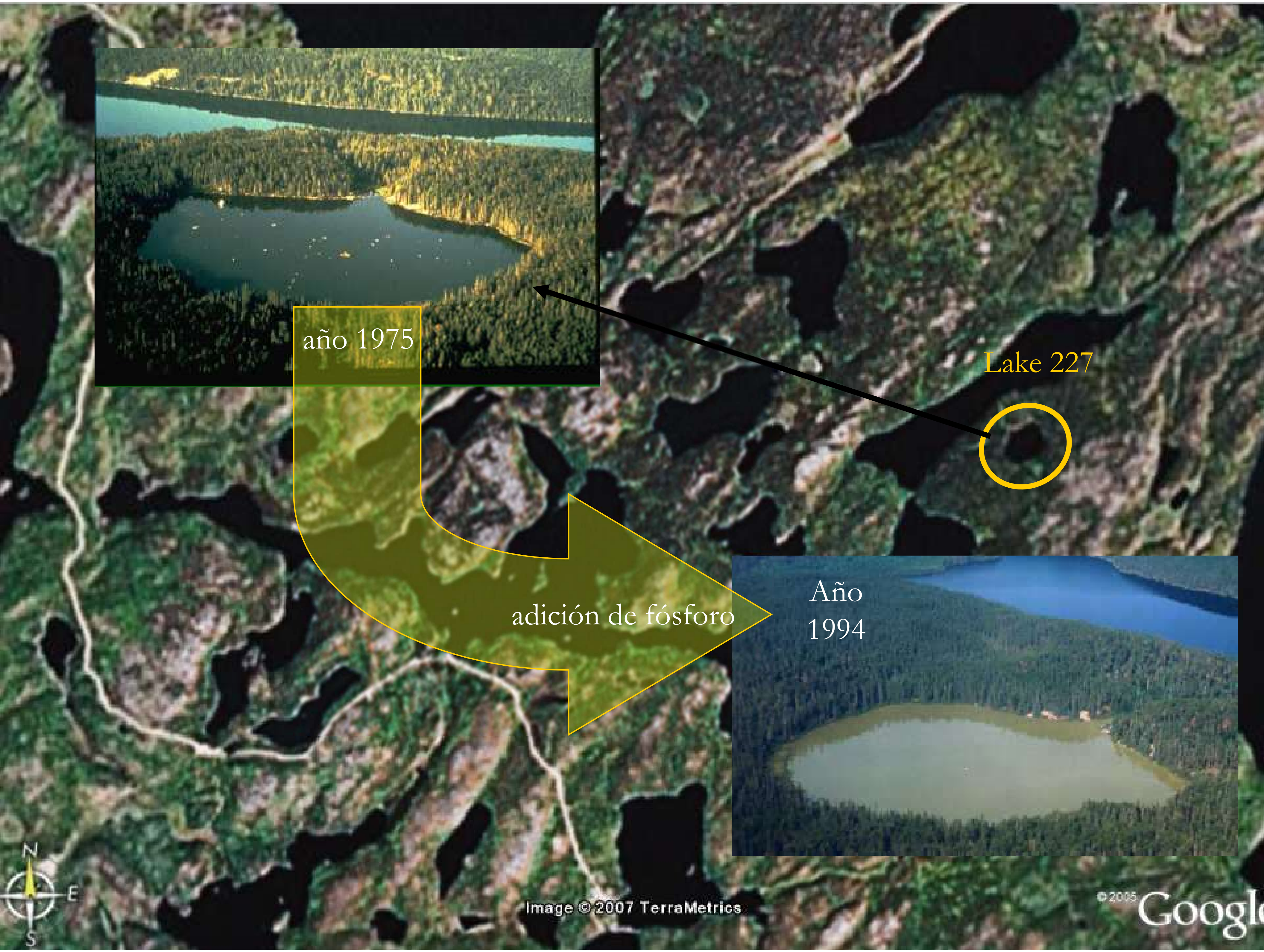
Fig. 1. Lake 226, demonstrating the vital role of phosphorus in eutrophication. The far basin, fertilized with phosphorus, nitrogen, and carbon, was covered by an algal bloom within 2 months. No increases in algae or species changes were observed in the near basin, which received similar quantities of nitrogen and carbon but no phosphorus.

Experiments conducted in smaller enclosures (2 to 3 m^2) in the same lake revealed that if phosphorus was not supplied, algal blooms did not occur (*10*). In order to test the validity of this conclusion on a whole lake, an experiment was begun in 1973 in another small lake, 226. This lake, which has two similar basins separated by a shallow neck (see Fig. 1), was divided into two equal areas by using a sea curtain (60 by 6 m) of vinyl reinforced with nylon (Kepner Plastics, Torrance, California), which was sealed into the sediments and fastened to the bedrock in the narrow section of the lake. Beginning in late May 1973, additions of nitrogen and carbon were made equally to both basins, but phosphorus was added only to the northeast basin of the lake (*11*).

The photograph in Fig. 1 was taken on 4 September 1973, when a bloom of the blue-green alga *Anabaena spiroides* covered that basin receiving phosphorus. Throughout the year, phytoplankton species and standing crops in the basin that received only nitrogen and carbon remained similar to those before fertilization was begun, consisting chiefly of *Tabellaria fenestrata*, *Synedra acus*, and other diatoms. The results indicate the efficacy to be expected from controlling phosphorus content of the influents to such waters as a means of preventing eutrophication.

A common belief is that phosphate, returned from anoxic sediments in

Schindler, D.W., 1974. Eutrophication and Recovery in Experimental Lakes: Implications for Lake Management. Science 184, 897-899.



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Lake 227
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Image © 2007 TerraMetrics
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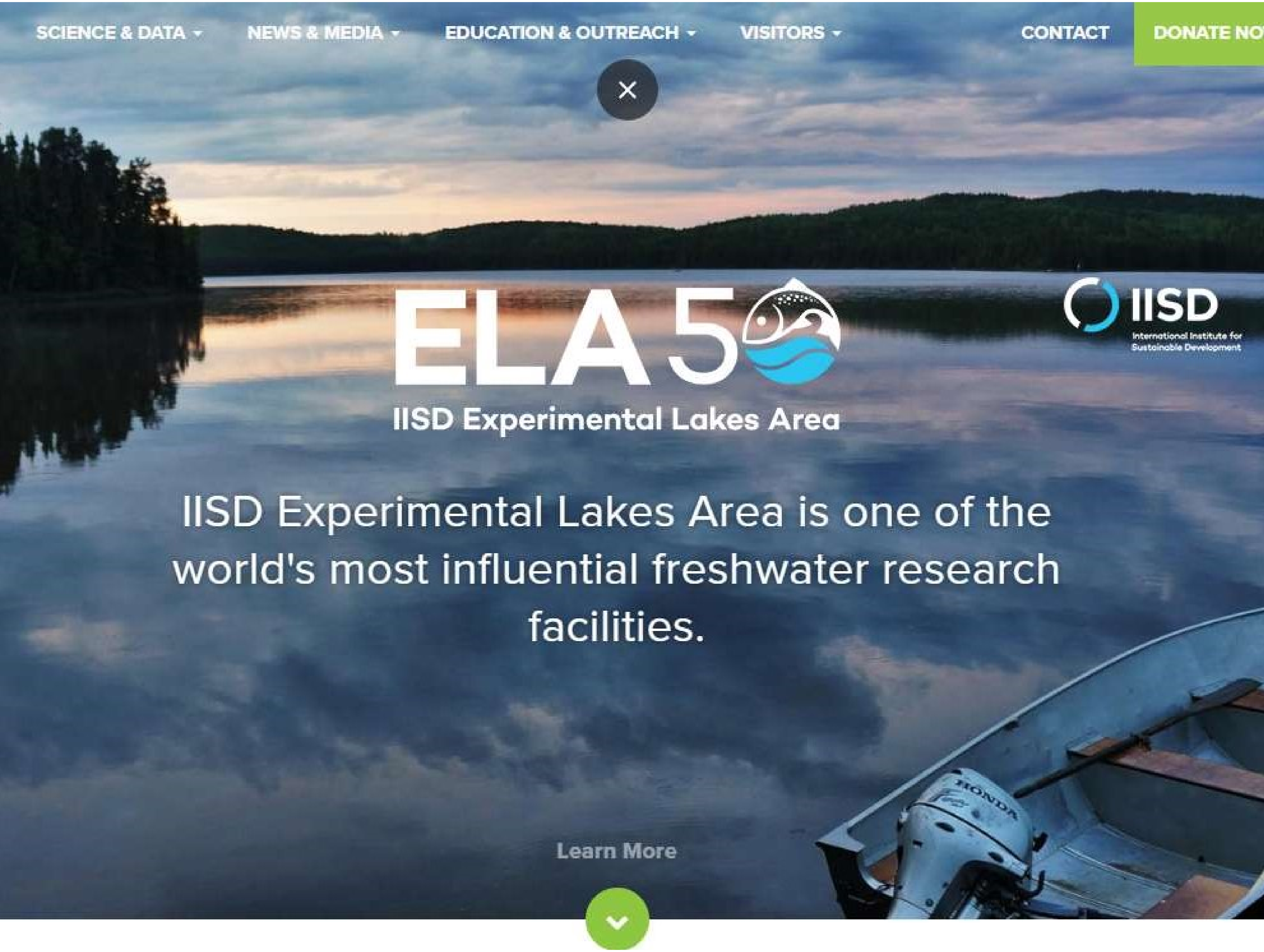
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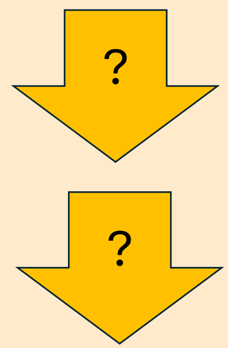
ESTADO TRÓFICO

- **oligotrófico** (pobre en nutrientes)
- **mesotrófico** (estado intermedio)
- **eutrófico** (rico en nutrientes)

CONDICIÓN DE ESTADO



¿PROCESO DE CAMBIO?

Naumann, E., 1919. Nagra synpunkter angaende limnoplanktos ökologi med särskild hänsyn til fytoplankton. Svensk. Bot. Tidskr. 13, 129-163.

ESTADO TRÓFICO

- **oligotrófico** (pobre en nutrientes)
- **mesotrófico** (estado intermedio)
- **eutrófico** (rico en nutrientes)

CONDICIÓN DE ESTADO

EUTROFIZACIÓN

?

?

¿PROCESO DE CAMBIO?

Naumann, E., 1919. Nagra synpunkter angaende limnoplanktos ökologi med särskild hänsyn til fytoplankton. Svensk. Bot. Tidskr. 13, 129-163.

ESTADO TRÓFICO

- **oligotrófico** (pobre en nutrientes)
- **mesotrófico** (estado intermedio)
- **eutrófico** (rico en nutrientes)

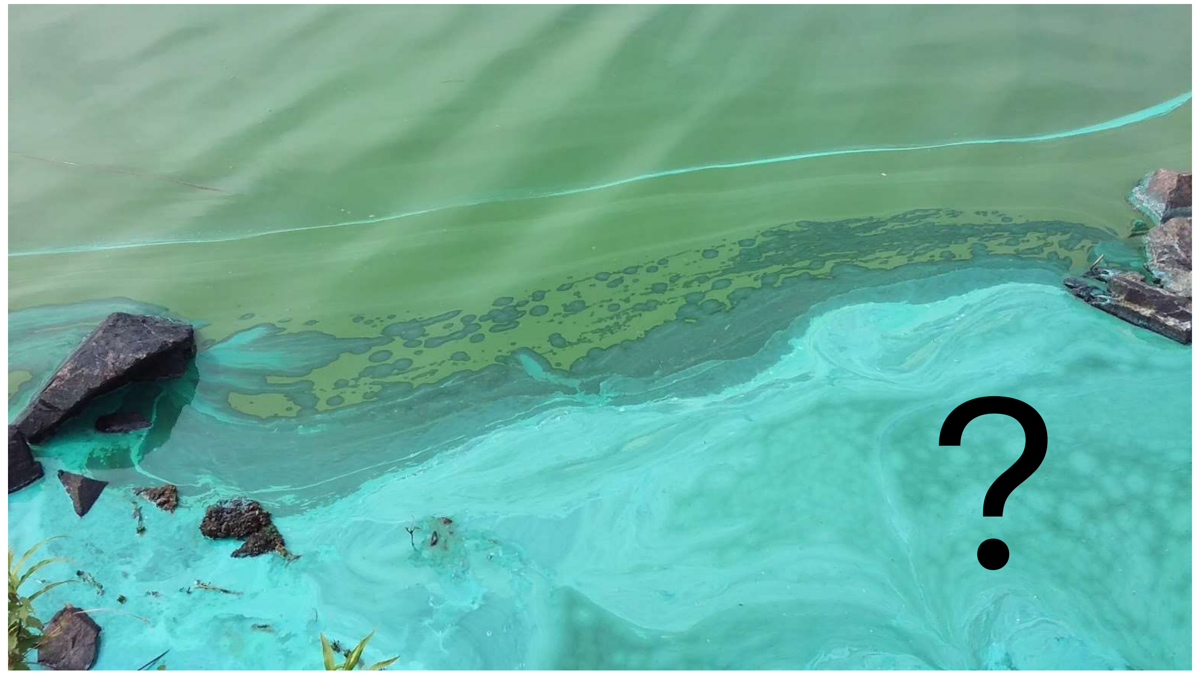
CONDICIÓN DE ESTADO

EUTROFIZACIÓN	OLIGOTROFIZACIÓN
?	?
?	?

¿PROCESO DE CAMBIO?

Naumann, E., 1919. Nagra synpunkter angaende limnoplanktos ökologi med särskild hänsyn til fytoplankton. Svensk. Bot. Tidskr. 13, 129-163.

EUTROFIZACIÓN



CAUSA

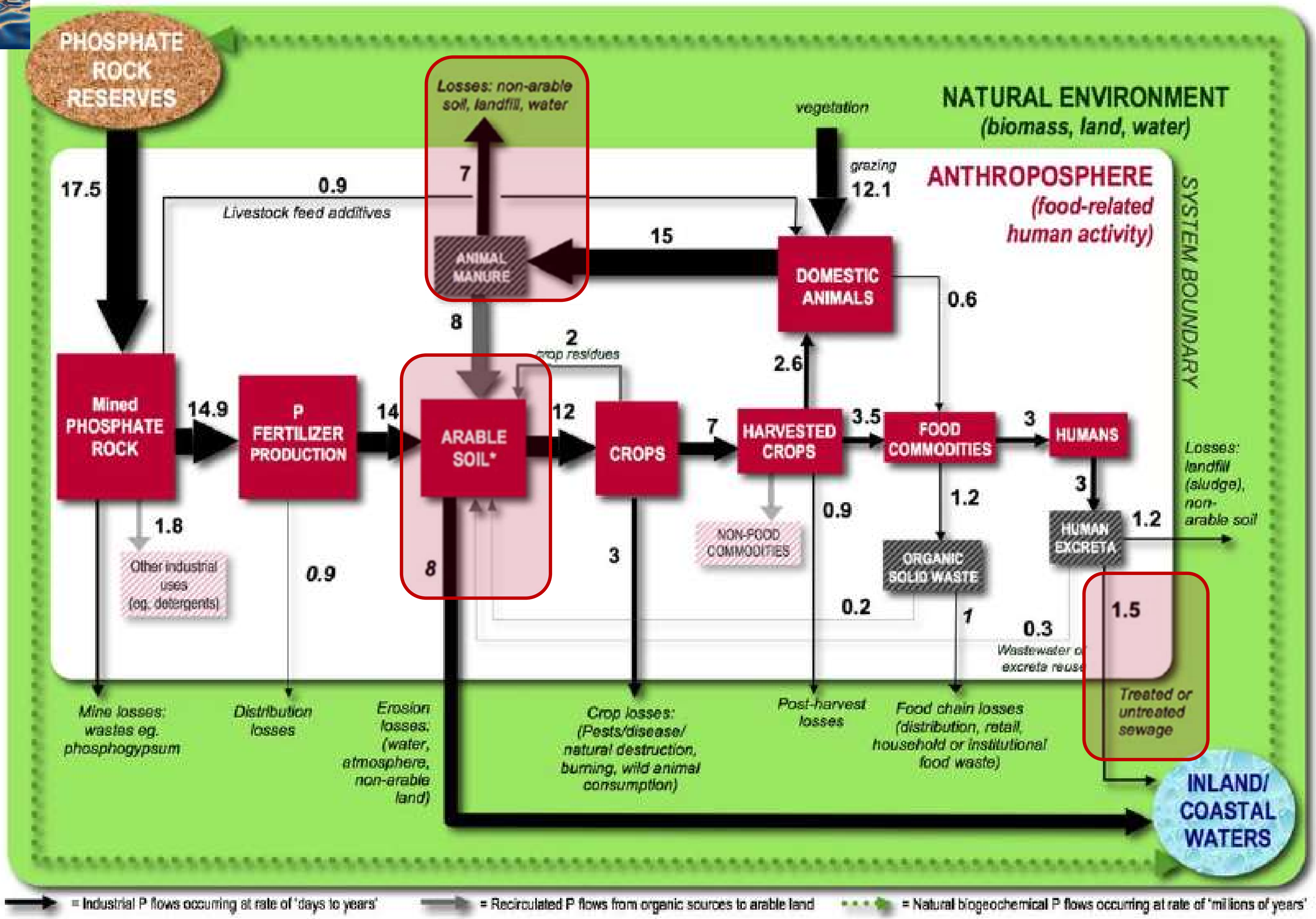
- Aumento de la carga interna de nutrientes
  - Particularmente del nutriente limitante
  - **P**

¿De donde proviene el P?

- En los años 60's-70's, los detergentes poseían un 16% de su peso en fósforo (tripolifosfato sódico como quelante de cationes)
- 1973 Canadá fue el primero en prohibir detergentes con elevados niveles de fósforo (más de un 2,2%).

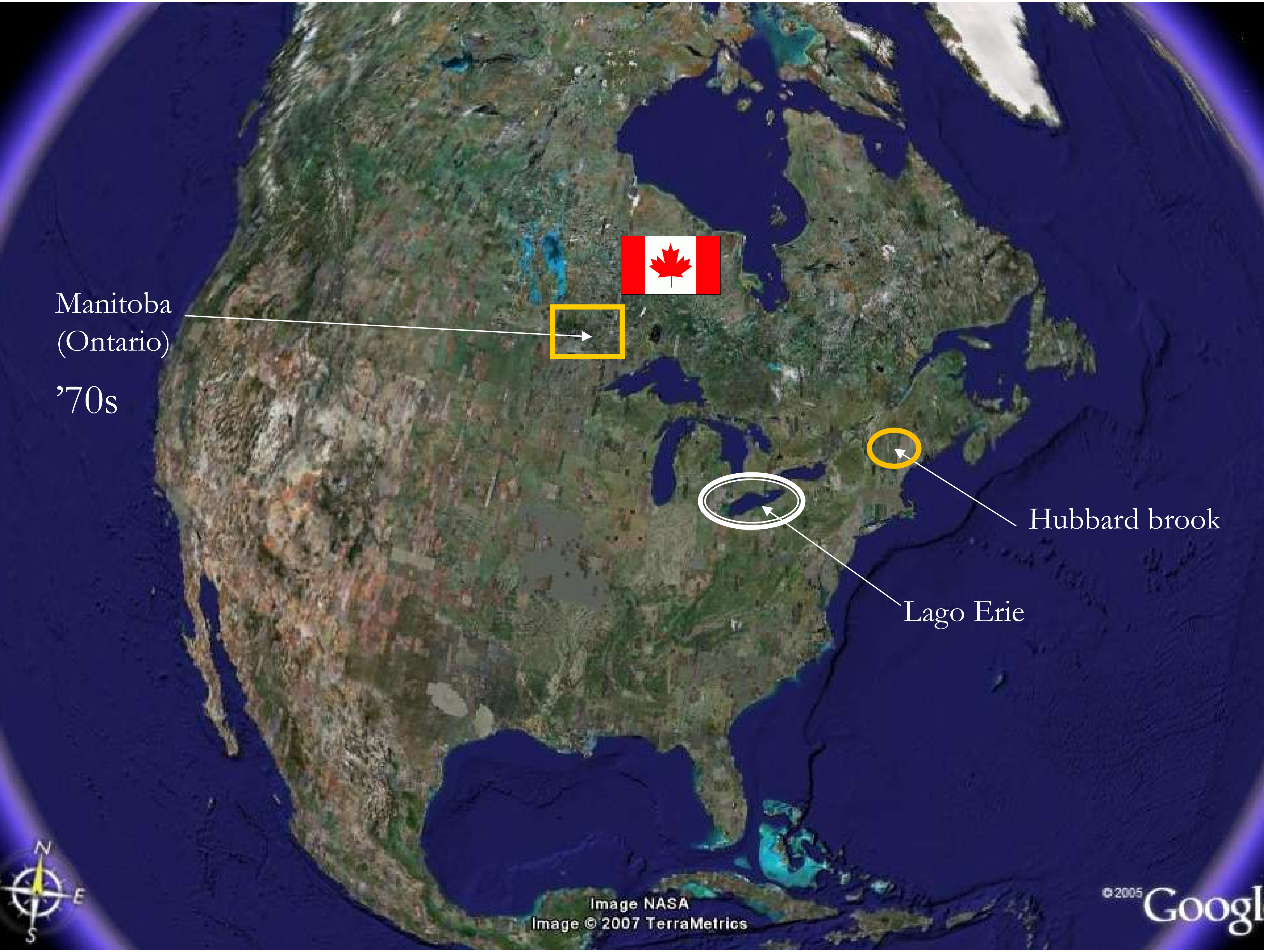
La eterna puja entre la ciudad y el campo...
Fuente puntuales vs fuentes difusas...

1 teragramo = 10^{12} g



* only a fraction of applied mineral P is taken up by crops in a given year, the balance comes from the soil stocks, either from natural soil P, or build up from previous years and decades of fertilizer application

Cordell, D., J. O. Drangert and S. White (2009). "The story of phosphorus: Global food security and food for thought." Global Environmental Change 19: 292-305.

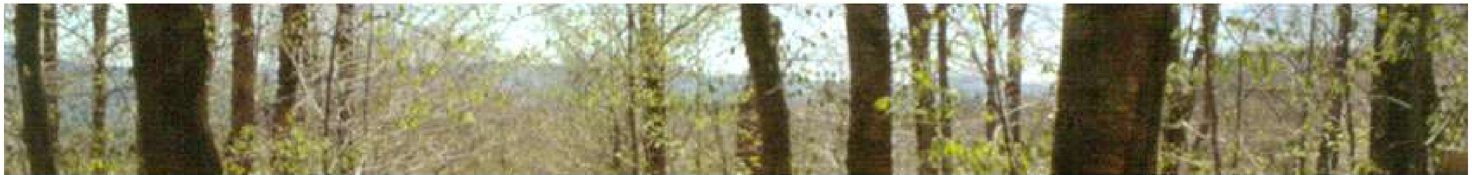

Manitoba
(Ontario)
'70s
Hubbard brook
Lago Erie
N
E
S
Image NASA
Image © 2007 TerraMetrics
© 2005 Googl

HUBBARD BROOK
ECOSYSTEM STUDY

1955 al presente (!)
http://www.hubbardbrook.org/

Hubbard Brook
Ecosystem Study

Operated by the USDA Forest Service since 1955,
and a member of the National Science Foundation's
Long-Term Ecological Research (LTER) Program since 1988.



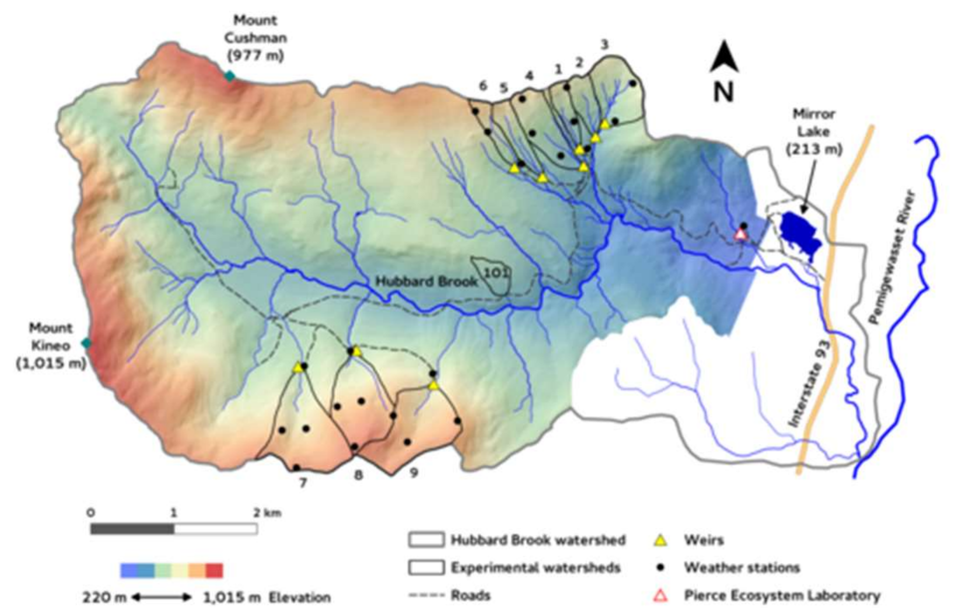
Overview...
- Homepage
- Introduction
- Historical Perspective
- Research Philosophy
- Attributes of HBEF
- Site Description
- Watersheds
- Mirror Lake
- Research Activities
- Facilities
- Site Administration
- Contact Us

For Researchers
Proposals, data sharing, tools...

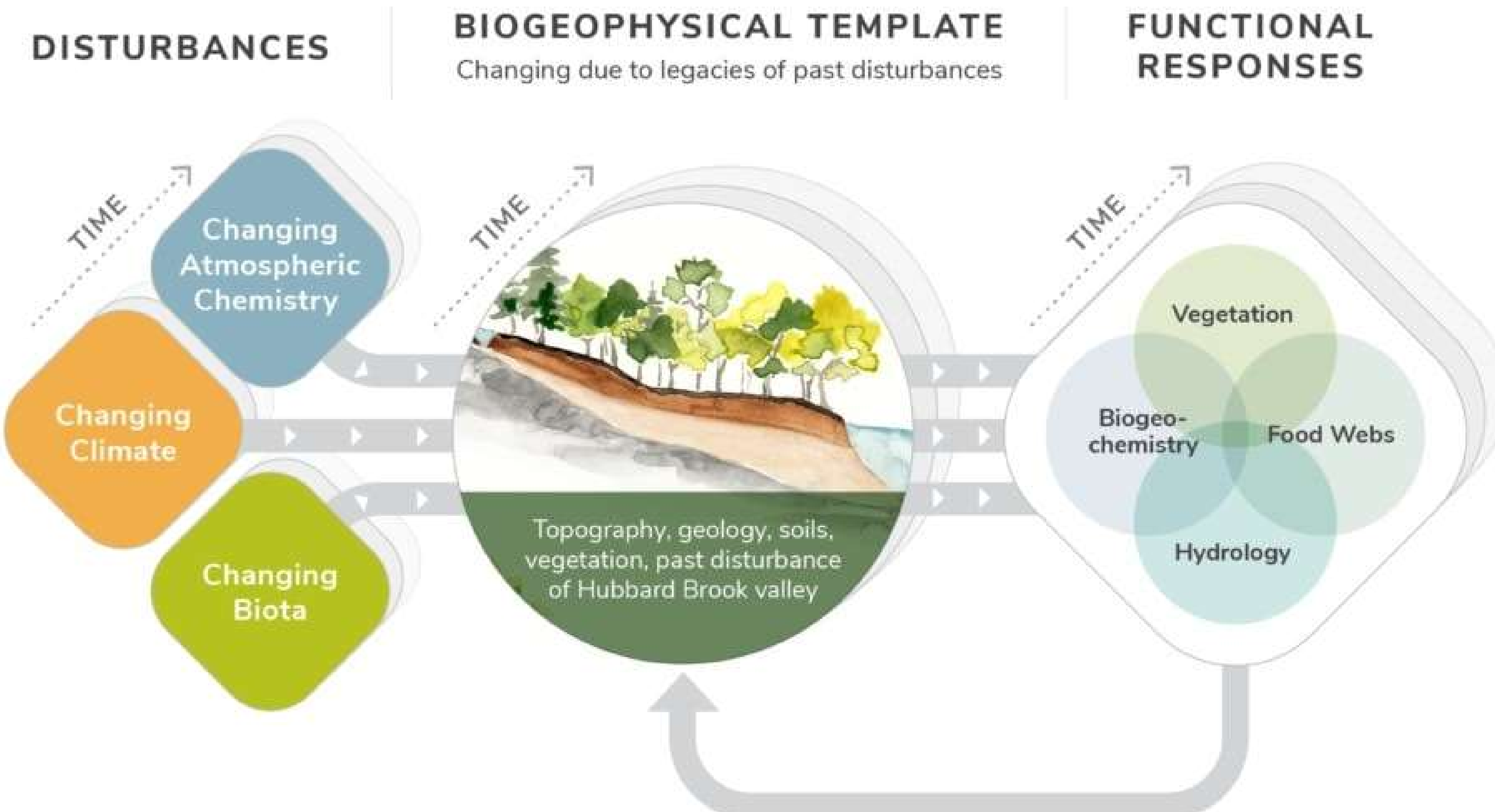
Watersheds

There are nine gaged watersheds at the Hubbard Brook Experimental Forest, four of which have been treated experimentally. A tenth ungaged watershed was also treated. All are shown in the map below.

The table of Hubbard Brook Watersheds provides summary data. Detailed information on each watershed can be found below the table.



http://www.hubbardbrook.org/



https://hubbardbrook.org/conceptual-model/

Nutrient Cycling

Small watersheds can provide invaluable information about terrestrial ecosystems.

F. H. Bormann and G. E. Likens

Life on our planet is dependent upon the cycle of elements in the biosphere. Atmospheric carbon dioxide would be exhausted in a year or so by green plants were not the atmosphere continually recharged by CO_2 generated by respiration and fire (1). Also, it is well known that life requires a continual cycling of nitrogen, oxygen, and water. These cycles include a gaseous phase and have self-regulating feedback mechanisms that make them relatively perfect (2). Any increase in movement along one path is quickly compensated for by adjustments along other paths. Recently, however, concern has been expressed over the possible disruption of the carbon cycle by the burning of fossil fuel (3) and of the nitrogen cycle by the thoughtless introduction of pesticides and other substances into the biosphere (4).

Of no less importance to life are the elements with sedimentary cycles, such as phosphorus, calcium, and magnesium. With these cycles, there is a continual loss from biological systems in response to erosion, with ultimate deposition in the sea. Replacement or return of an element with a sedimentary cycle to terrestrial biological systems is dependent upon such processes as weathering of rocks, additions from volcanic gases, or the biological movement from the sea to the land. Sedimentary cycles are less perfect and more easily disrupted by man than carbon and nitrogen cycles (2). Acceleration of losses or, more specifically, the disruption of local cycling patterns by the activities of man could reduce existing "pools" of an element in local ecosystems, restrict productivity, and consequently limit human populations. For example, many agriculturalists and ecologists believe that man is accelerating losses of phosphorus and that this element will be a critical limiting resource for the functioning of the biosphere (1, 5).

Recognition of the importance of these biogeochemical processes to the welfare of mankind has generated intensive study of such cycles. Among ecologists and foresters working with natural terrestrial ecosystems, this interest has focused on those aspects of biogeochemical cycles that occur within particular ecosystems. Thus, information on the distribution of chemical elements and on rates of uptake, retention, and release in various ecosystems has been accumulating (6). Little has been done to establish the role that weathering and erosion play in these systems.

Yet, the rate of release of nutrients from minerals by weathering, the addition of nutrients by erosion, and the loss of nutrients by erosion are three primary determinants of structure and function in terrestrial ecosystems. Further, with this information it is possible to develop total chemical budgets for ecosystems and to relate these data to the larger biogeochemical cycles.

It is largely because of the complex natural interaction of the hydrologic cycle and nutrient cycles that it has not been possible to establish these relationships. In many ecosystems this interaction almost hopelessly complicates the measurement of weathering or erosion. Under certain conditions, however, these apparent hindrances can be turned to good advantage in an integrated study of biogeochemical cycling in small watershed ecosystems.

It is the function of this article (i) to develop the idea that small watersheds can be used to measure weathering and erosion, (ii) to describe the parameters of watersheds particularly suited for this type of study, and (iii) to discuss the types of nutrient-cycling problems that this model renders susceptible to attack. Finally (iv), the argument is developed that the watershed ecosystem provides an ideal setting for studies of ecosystem dynamics in general.

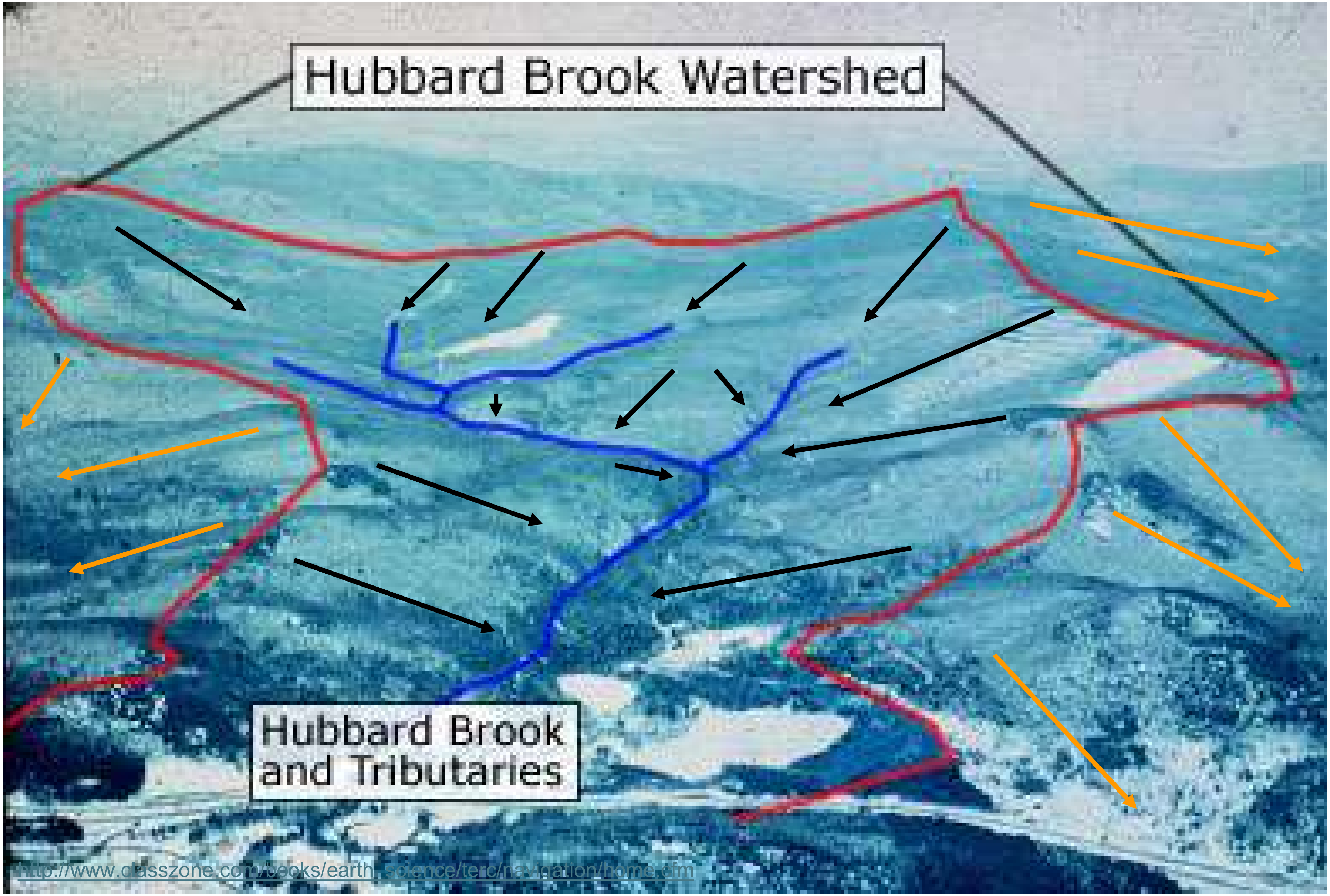
Dr. Bormann is professor of forest ecology, Yale School of Forestry, Yale University, New Haven, Connecticut; Dr. Likens is associate professor, Department of Biological Sciences, Dartmouth College, Hanover, New Hampshire.

cuenca como unidad funcional

Bornman, F.H. & G.E. Likens. 1967 Nutrient cycling. *Science* 155: 424-8.

Science AAAS

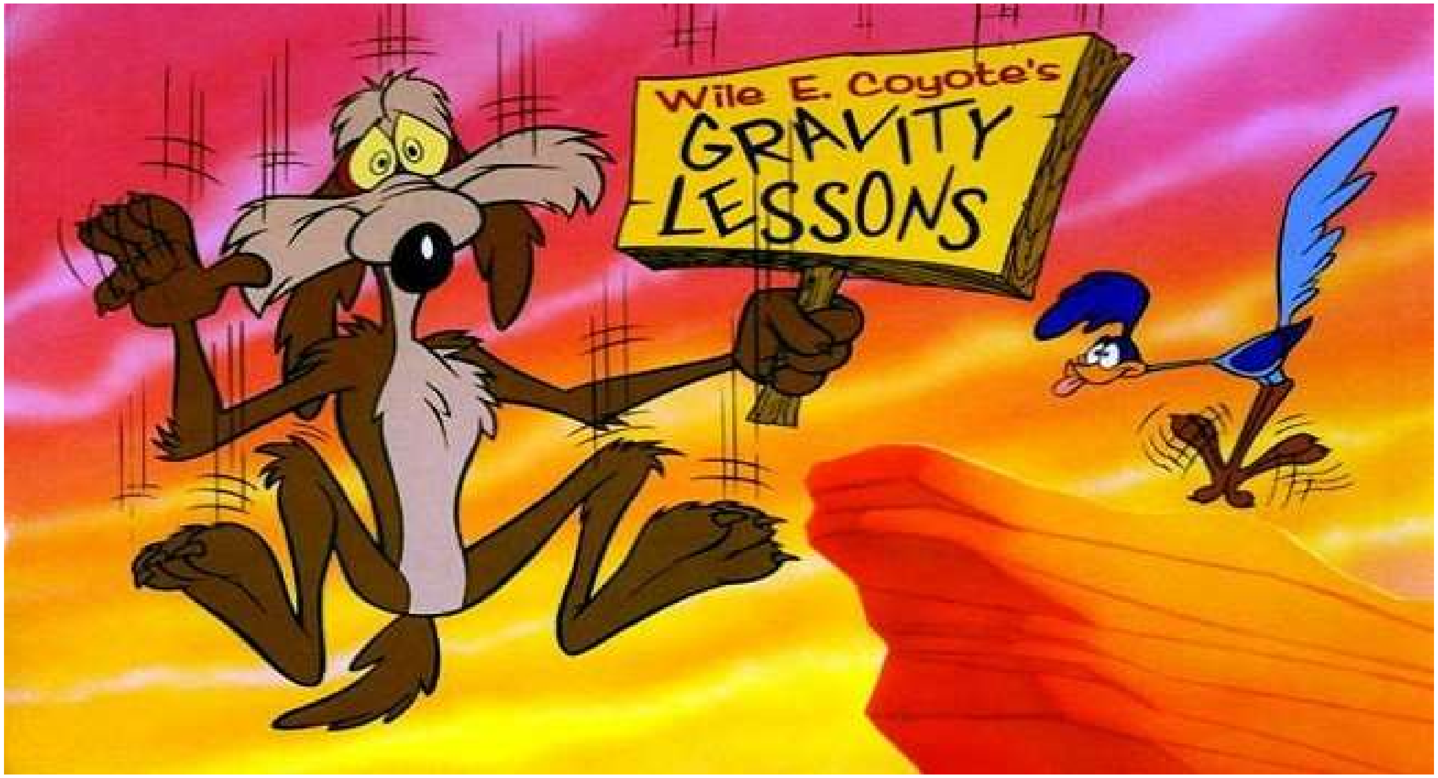
❶ la hidrología define los límites del sistema de una forma natural

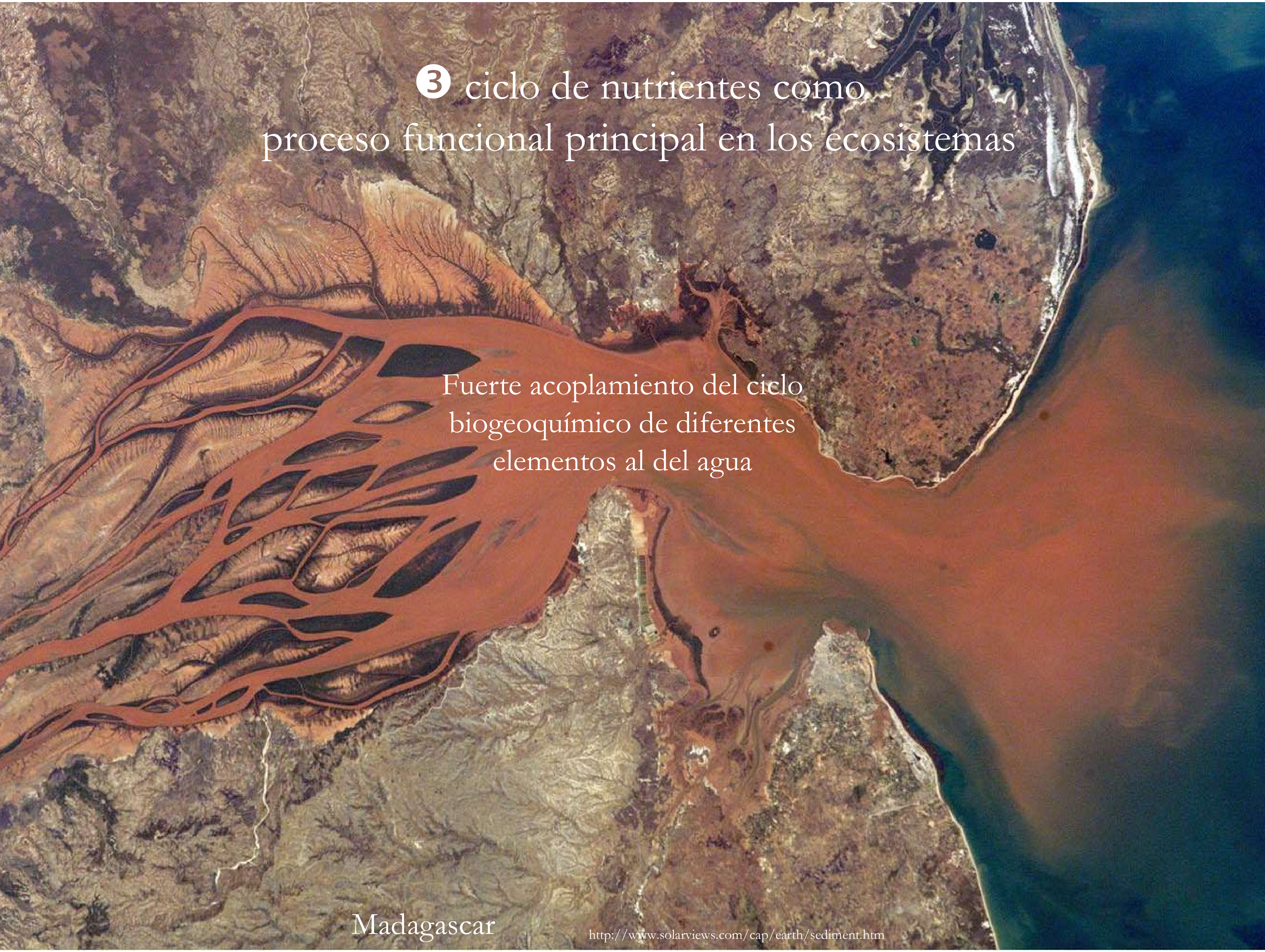


❷ Las actividades en la cuenca van a repercutir, tarde o temprano, directa o indirectamente, aguas abajo.

http://www.hubbardbrook.org/

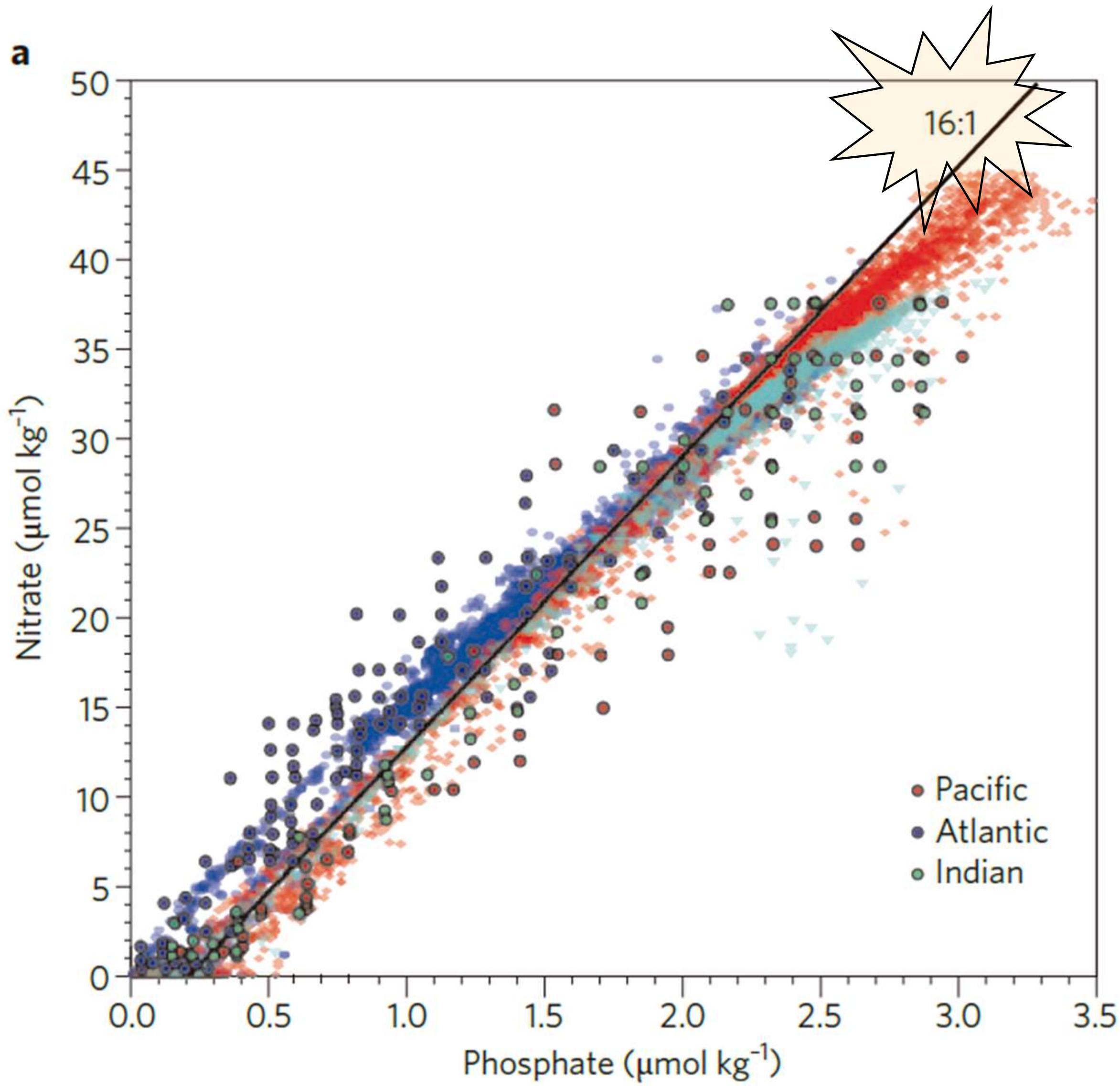
❷ Las actividades en la cuenca van a repercutir, tarde o temprano, directa o indirectamente, aguas abajo.




❸ ciclo de nutrientes como
proceso funcional principal en los ecosistemas
Fuerte acoplamiento del ciclo
biogeoquímico de diferentes
elementos al del agua
Madagascar
http://www.solarviews.com/cap/earth/sediment.htm

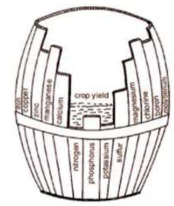
¿Sólo **P**?

Redfield ratio

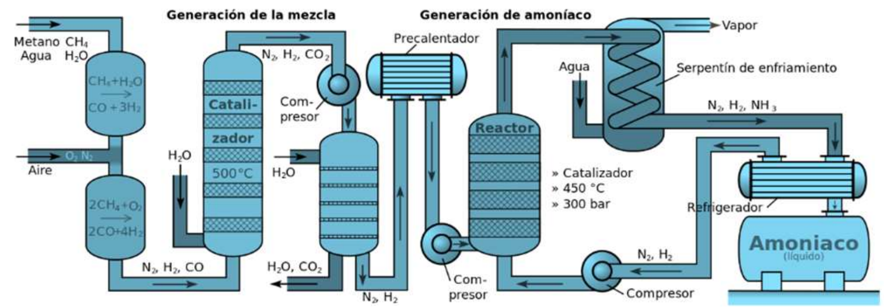


Gruber, N., & Deutsch, C. A. (2014). Redfield's evolving legacy. *Nature Geoscience, 7(12), 853-855. doi:10.1038/ngeo2308*

Humboldt (guano)
1802



1840



Aire deflogisticado
1772

1910

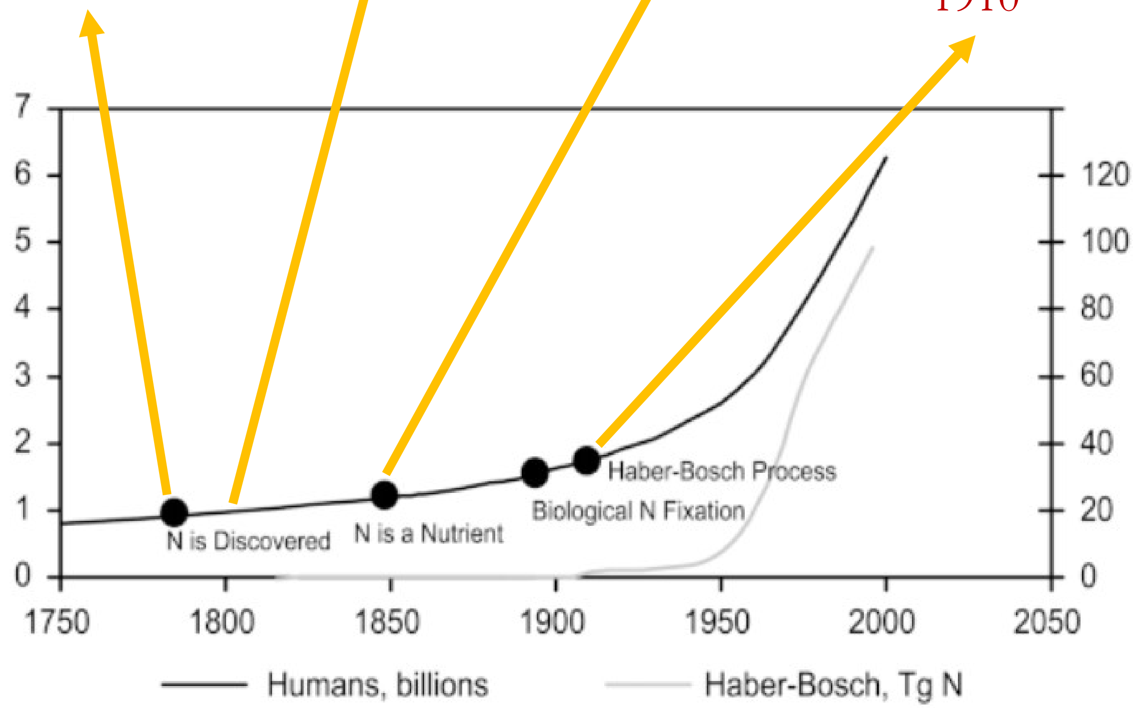


Figure 1. Global population trends (36, 53) with key dates for the discovery of N as an element in the periodic table and its role in various biogeochemical processes. Also shown is an estimate of the annual production of Nr by the Haber-Bosch process.

El proceso Haber produce más de 100 millones de toneladas de fertilizante de nitrógeno al año.
El 8,27% del consumo total de energía mundial en un año se destina a este proceso.

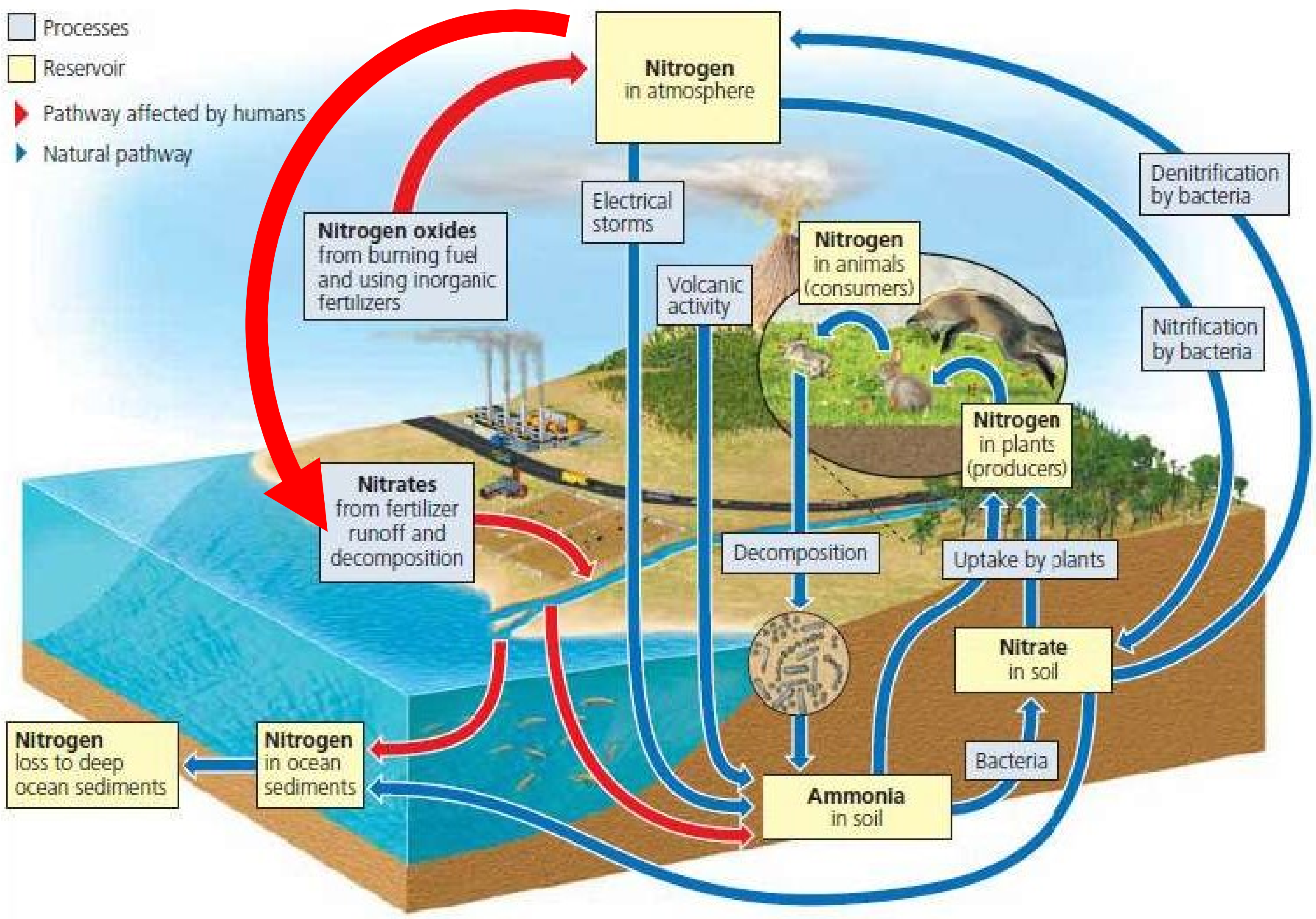
Galloway, J. N. and E. B. Cowling (2002). "Reactive Nitrogen and The World: 200 Years of Change." AMBIO: A Journal of the Human Environment 31(2): 64-71.

Table 2. Examples of human intervention in the global biogeochemical cycles of carbon, nitrogen, phosphorus, sulfur, water, and sediments. Data are for the mid-1900s.

Element	Flux	Magnitude of flux (millions of metric tons per year)		% change due to human activities
		Natural	Anthropogenic	
C	Terrestrial respiration and decay CO_2	61,000		
	Fossil fuel and land use CO_2		8,000	+13
N	Natural biological fixation	130		
	Fixation owing to rice cultivation, combustion of fossil fuels, and production of fertilizer		140	+108
P	Chemical weathering	3		
	Mining		12	+400
S	Natural emissions to atmosphere at Earth's surface	80		
	Fossil fuel and biomass burning emissions		90	+113
O and H (as H_2O)	Precipitation over land	111×10^{12}		
	Global water usage		18×10^{12}	+16
Sediments	Long-term preindustrial river suspended load	1×10^{10}		
	Modern river suspended load		2×10^{10}	+200

Falkowski, P., Scholes, R.J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V., Steffen, W., 2000. The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. Science 290, 291-296.

Ciclo del Nitrógeno en el ecosistema



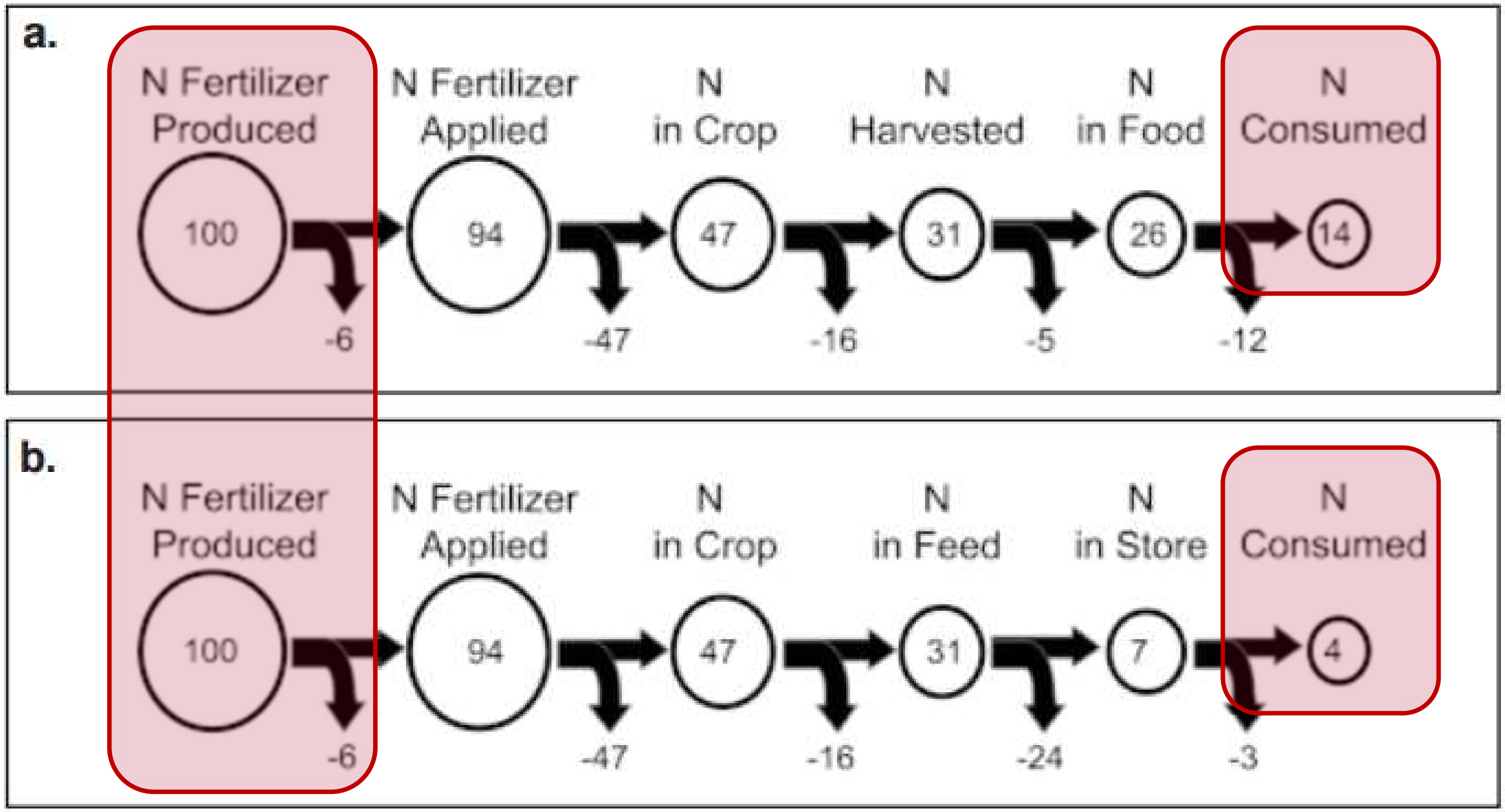


Figure 2. The fate of fertilizer N produced by the Haber-Bosch process from the factory to the mouth for (a) vegetarian diet, and (b) carnivorous diet.

Galloway, J. N. and E. B. Cowling (2002). "Reactive Nitrogen and The World: 200 Years of Change." AMBIO: A Journal of the Human Environment 31(2): 64-71.

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YEAR OF PLANET EARTH FEATURE

An Earth-system perspective of the global nitrogen cycle

Nicolas Gruber & James N. Galloway

With humans having an increasing impact on the planet, the interactions between the nitrogen cycle, the carbon cycle and climate are expected to become an increasingly important determinant of the Earth system.

The massive acceleration of the nitrogen cycle as a result of the production and industrial use of artificial nitrogen fertilizers worldwide has enabled humankind to greatly increase food production, but it has also led to a host of environmental problems, ranging from eutrophication of terrestrial and aquatic systems to global acidification. The findings of many national and international research programmes investigating the manifold consequences of human alteration of the nitrogen cycle have led to a much improved understanding of the scope of the anthropogenic nitrogen problem and possible strategies for managing it. Considerably less emphasis has been placed on the study of the interactions of nitrogen with the other major biogeochemical cycles, particularly that of carbon, and how these cycles interact with the climate system in the presence of the ever-increasing human intervention in the Earth system[1]. With the release of carbon dioxide (CO_2) from the burning of fossil fuels pushing the climate system into uncharted territory[2], which has major consequences for the functioning of the global carbon cycle, and with nitrogen having a crucial role in controlling key aspects of this cycle, questions about the nature and importance of nitrogen–carbon–climate interactions are becoming increasingly pressing. The central question is how the availability of nitrogen will affect the capacity of Earth's biosphere to continue absorbing carbon from the atmosphere (see page 289), and hence continue to help in mitigating climate change. Addressing this and other open issues with regard to nitrogen–carbon–climate interactions requires an Earth-system perspective that investigates the dynamics of the nitrogen cycle in the context of a changing carbon cycle, a changing climate and changes in human actions.

The anthropogenic perturbation of the nitrogen cycle

Nitrogen is a fundamental component of living organisms; it is also in short supply in forms that can be assimilated by plants in both marine and land ecosystems. As a result, nitrogen has a critical role in controlling primary production in the biosphere. Nitrogen is also a limiting factor for the plants grown by humans for food. Without the availability of nitrogenous fertilizer produced by the industrial process known as the Haber–Bosch process, the enormous increase in food production over the past century, which in turn has sustained the increase in global population, would not have been possible. All the nitrogen used in food production is added to the environment, as is the nitrogen emitted to the atmosphere during fossil-fuel combustion. In the 1990s, these two sources of anthropogenic nitrogen to the environment amounted to more than 160 teragrams (Tg) N per year (Fig. 1). On a global basis, this is more than that supplied by natural biological nitrogen fixation on land (110 Tg N per year) or in the ocean (140 Tg N per year) (Fig. 1). Given expected trends in population, demand for food, agricultural practices and energy use, anthropogenic nitrogen fluxes are fated to increase; that is, humans are likely to be responsible for doubling the turnover rates not only of the terrestrial nitrogen cycle but also of the nitrogen cycle of the entire Earth.

The negative consequences of these nitrogen additions are substantial and manifold, ranging from eutrophication of terrestrial and aquatic systems to global acidification and stratospheric ozone loss[3]. Of particular concern is the fact that chemical transformations of nitrogen along its transport pathway in the environment often lead to a cascade of effects. For example, an emitted molecule of nitrogen oxide can first cause photochemical smog and then, after it has been oxidized in the atmosphere to nitric acid and deposited on the ground, can lead to ecosystem acidification and eutrophication. Although there is still much to understand about the implications of nitrogen accumulation in the environment, there is also much to understand about how the increased availability of nitrogen interacts with other biogeochemical element cycles and how those interactions affect global climate change.

Nitrogen and the perturbation of other element cycles

The human acceleration of the nitrogen cycle did not occur in isolation, as humans have altered the cycles of many other elements as well, most notably those of phosphorus, sulphur and carbon[1]. Of particular relevance is the acceleration of the global carbon cycle, because of the central role of atmospheric CO_2 in controlling climate[4]. As a result of the burning of fossil fuels and carbon emissions from land-use change, atmospheric CO_2 has increased to levels that are more than 30% above those of pre-industrial times. This increase in atmospheric CO_2 has been identified as the primary cause for the observed warming over the past century, particularly that of the past 30 years[2].

The perturbations of the global nitrogen and carbon cycles caused by human activity are in part linked to each other. This is mostly a result of the atmosphere's being very efficient in spreading the nitrogen oxides and ammonia emitted as a result of energy and food production, and also because this nitrogen is deposited on the ground in a form that is readily available to plants, thereby stimulating productivity and enhancing the uptake of CO_2 from the atmosphere.

The existence of a largely unexplained, but substantial, carbon sink in the Northern Hemisphere terrestrial biosphere[5] (that is, in exactly the region that receives most of the anthropogenic nitrogen from the atmosphere) would seem to support this conjecture. However, nitrogen-addition and modelling studies suggest that the contribution of nitrogen fertilization to the Northern Hemisphere carbon land sink has been small. This issue needs to be resolved, because the different processes that are being considered to explain the current Northern Hemisphere carbon sink have very different future trajectories. If CO_2 fertilization is responsible — that is, the direct effect of elevated CO_2 on plant growth — one could expect this process to continue largely unabated into the future. If nitrogen fertilization is responsible, however, one could expect

Gruber, N. & J. N. Galloway, 2008. An Earth-system perspective of the global nitrogen cycle. Nature 451(7176):293-296.

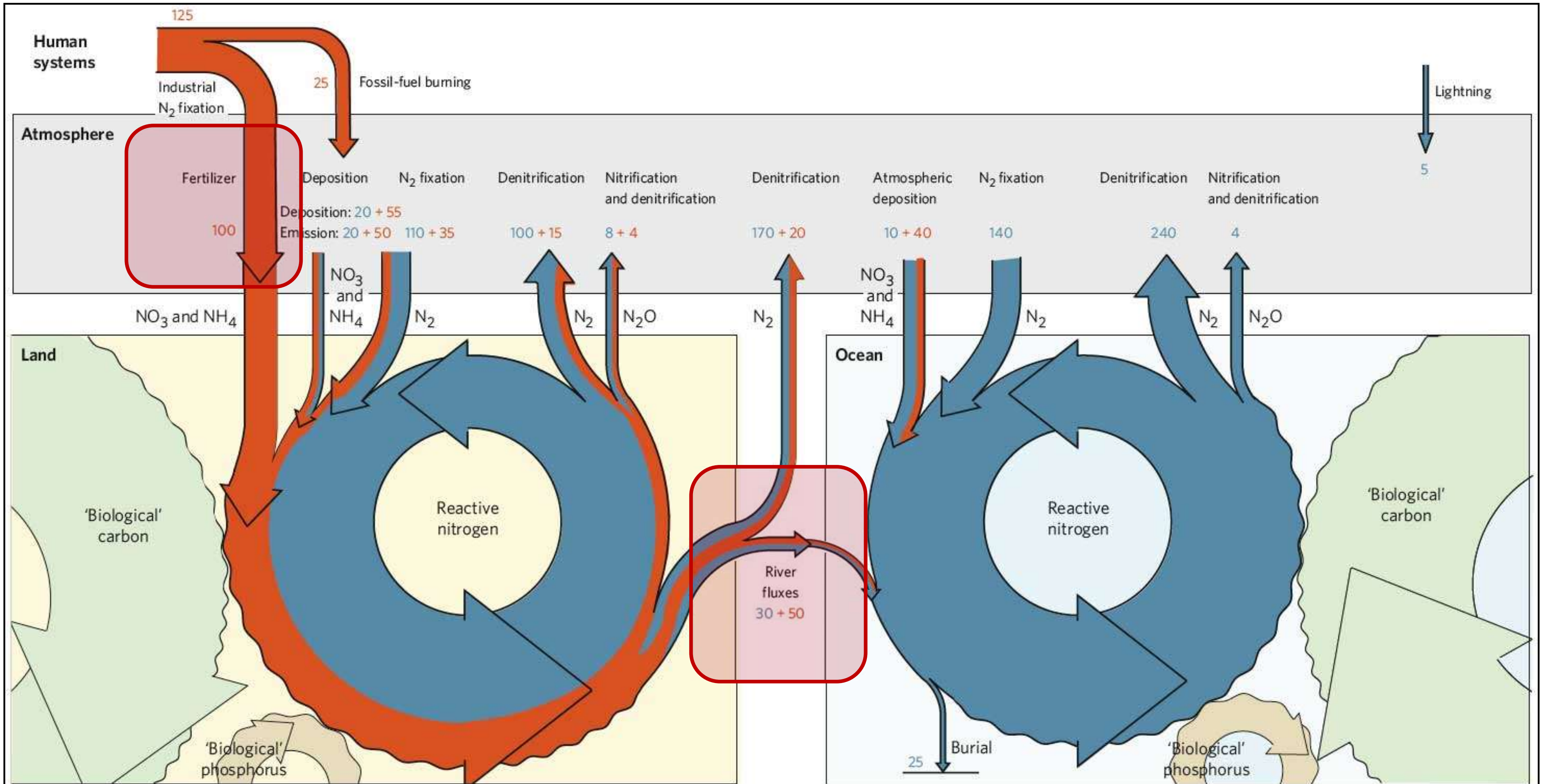

Figure 1 | Depiction of the global nitrogen cycle on land and in the ocean. Major processes that transform molecular nitrogen into reactive nitrogen, and back, are shown. Also shown is the tight coupling between the nitrogen cycles on land and in the ocean with those of carbon and phosphorus. Blue fluxes denote 'natural' (unperturbed) fluxes; orange fluxes denote anthropogenic perturbation. The numbers (in Tg N per year) are values for the 1990s (refs 13, 21). Few of these flux estimates are known to better than ±20%, and many have uncertainties of ±50% and larger[13,21].

1 Tg = 1 Teragramo = 1.000.000.000.000 gramos

Gruber, N. & J. N. Galloway, 2008. An Earth-system perspective of the global nitrogen cycle. Nature 451(7176):293-296.

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Reducing Phosphorus to Curb Lake Eutrophication is a Success

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ABSTRACT: As human populations increase and land-use intensifies, toxic and unsightly nuisance blooms of algae are becoming larger and more frequent in freshwater lakes. In most cases, the blooms are predominantly blue-green algae (Cyanobacteria), which are favored by low ratios of nitrogen to phosphorus. In the past half century, aquatic scientists have devoted much effort to understanding the causes of such blooms and how they can be prevented or reduced. Here we review the evidence, finding that numerous long-term studies of lake ecosystems in Europe and North America show that controlling algal blooms and other symptoms of eutrophication depends on reducing inputs of a single nutrient: phosphorus. In contrast, small-scale experiments of short duration, where nutrients are added rather than removed, often give spurious and confusing results that bear little relevance to solving the problem of cyanobacteria blooms in lakes.

INTRODUCTION

Eutrophication, the scientific term that describes algal blooms and associated problems that are caused by the response of natural waters to excessive inputs of nutrients, is one of the greatest environmental problems facing humanity. Growing human populations produce increasing volumes of waste and require increasing areas and intensity of land use to feed the growing population. The effects of higher water temperatures under global warming act in concert with increasing nutrients, to paint a bleak future for a problem that is already acute.[1]

The scientific study of algal blooms dates from the earliest days of the science of limnology (the study of inland waters). Limnologists used quantitative methods to observe increases in the size and duration of algal blooms in Zürichsee, Switzerland as early as 1890.[2] The term *eutrophic*, derived from Greek meaning rich in food, was first applied to lakes with algal blooms by Einar Naumann in the early years of the 20th century. The term *eutrophication* was coined to describe the process by which lakes become nutrient enriched, which was believed to occur naturally as lakes slowly filled with sediment, concentrating nutrients in less and less water.

By the mid-20th century it was clear that human activity was accelerating the eutrophication process. The problem was found to be more widespread and to have occurred much earlier than had been previously realized, in lakes near centers of human activity. Hutchinson et al.[3] were able to deduce from lake sediments that algal blooms developed in Lago di Monterosi as the Romans built and used the adjacent Via Appia. Even in the high arctic, eutrophication occurred at sites where prehistoric Inuit whalers butchered their prey on the shores of freshwater lakes.[4] As human populations increased exponentially and modern intensive agriculture developed in Europe and North America in the early 20th century, the problem reached epidemic proportions. The term *cultural eutrophication* was used to refer to the acceleration of bloom development and other symptoms of eutrophication by human activity.

Until the mid-20th century, the causes of eutrophication were a mystery. By comparing the chemical composition of algae with water chemistry, limnologists were able to deduce that the problem had something to do with nutrient enrichment. Logically, the nutrients with the highest ratio of concentration in algae relative to concentration in lake water were suspected to be the culprits, and that led to an early focus on phosphorus, nitrogen, and carbon. Later studies suggested that the abundance of trace elements, and even major ions also might play a role. Indeed, speakers at a 1967 symposium on the topic sponsored by the U.S. National Academy of Sciences (NAS) presented a wide variety of opinions on the causes of eutrophication and did not reach a consensus as to what nutrients must be controlled to rein in the problem.[5]

The rapid development of modern water chemistry in the latter half of the 20th century allowed limnologists to quickly

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It Takes Two to Tango: When and Where Dual Nutrient (N & P) Reductions Are Needed to Protect Lakes and Downstream Ecosystems

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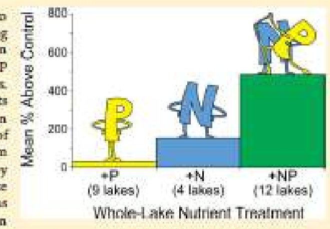
ABSTRACT: Preventing harmful algal blooms (HABs) is needed to protect lakes and downstream ecosystems. Traditionally, reducing phosphorus (P) inputs was the prescribed solution for lakes, based on the assumption that P universally limits HAB formation. Reduction of P inputs has decreased HABs in many lakes, but was not successful in others. Thus, the "P-only" paradigm is overgeneralized. Whole-lake experiments indicate that HABs are often stimulated more by combined P and nitrogen (N) enrichment rather than N or P alone, indicating that the dynamics of both nutrients are important for HAB control. The changing paradigm from P-only to consideration of dual nutrient control is supported by studies indicating that (1) biological N fixation cannot always meet lake ecosystem N needs, and (2) that anthropogenic N and P loading has increased dramatically in recent decades. Sediment P accumulation supports long-term internal loading, while N may escape via denitrification, leading to perpetual N deficits. Hence, controlling both N and P inputs will help control HABs in some lakes and also reduce N export to downstream N-sensitive ecosystems. Managers should consider whether balanced control of N and P will most effectively reduce HABs along the freshwater-marine continuum.



INTRODUCTION

The need to reduce nutrient inputs to the world's surface waters is intensifying as water quality deteriorates and clean water demands increase along the freshwater to marine continuum (Figure 1). In lakes, the problem is often addressed by reducing phosphorus (P) inputs based on the premise that P universally limits primary productivity, algal biomass, and harmful algal bloom (HAB) formation.[1] This practice was successful in some but not all lakes.[2,3] Therefore, we argue that generalizing the "P-only" paradigm is not appropriate, nor is it responsible to shift the eutrophication burden to vulnerable ecosystems downstream (e.g., the Gulf of Mexico, Baltic Sea) by only controlling P upstream. HAB-impacted lakes and reservoirs include some of the world's largest and culturally most important waterbodies (e.g., Lakes Erie and Okeechobee, North America; Lake Victoria, Africa; Lakes Taihu and Dianchi, China; Lakes Balaton and Maggiore, Europe; Lakes Rotorua and Rotoiti, New Zealand). These lakes exhibit varying nutrient loading and cycling patterns, including periods of P or nitrogen (N) limitation, as well as periods of balanced growth, where N and P act in concert to stimulate biomass production.[2,4−7] Based on geographically diverse evidence presented below, scientists and resource managers should take a more holistic view regarding P-only vs N and P control of HABs for both lakes and coastal ecosystems.

The increasing uses of anthropogenic and bioavailable N and P with increasing population size, intensifying agricultural land use, and associated applications of chemical fertilizers are stressing aquatic resources. This trend has led to increased

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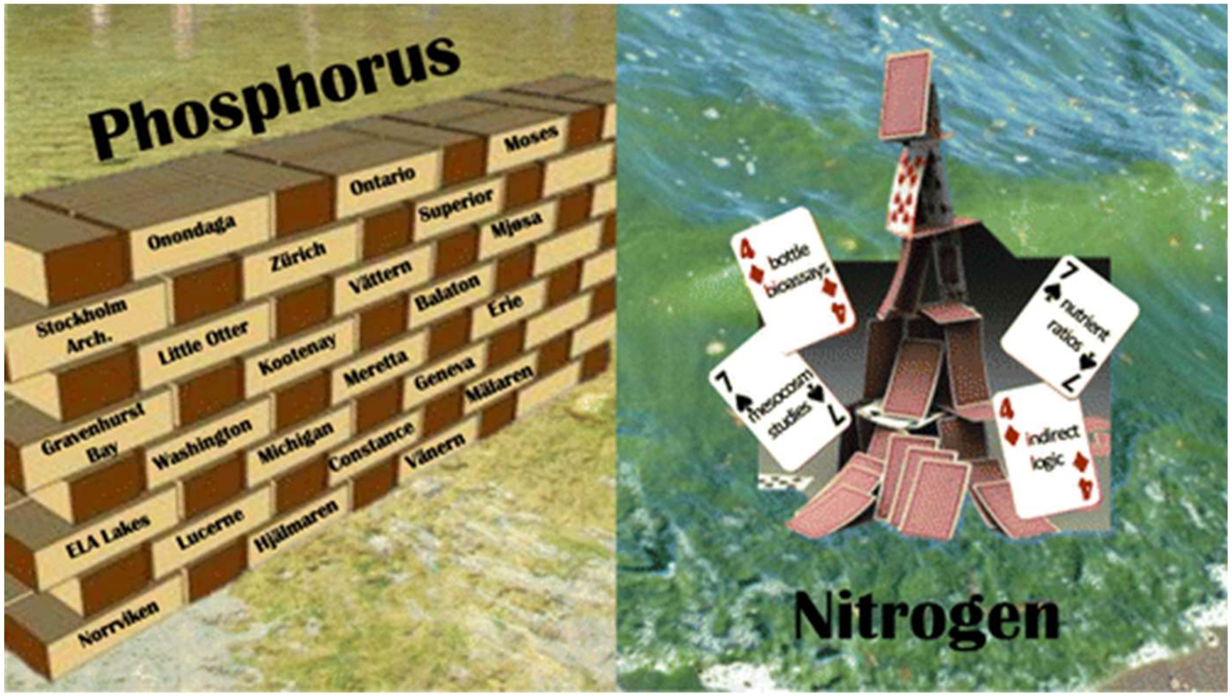
Phosphorus
Onondaga
Ontario
Moses
Superior
Zürich
Mjøsa
Vättern
Stockholm
Arch.
Balaton
Erie
Little Otter
Kootenay
Meretta
Geneva
Gravenhurst
Bay
Mälaren
Washington
Michigan
Constance
Vänern
ELA Lakes
Lucerne
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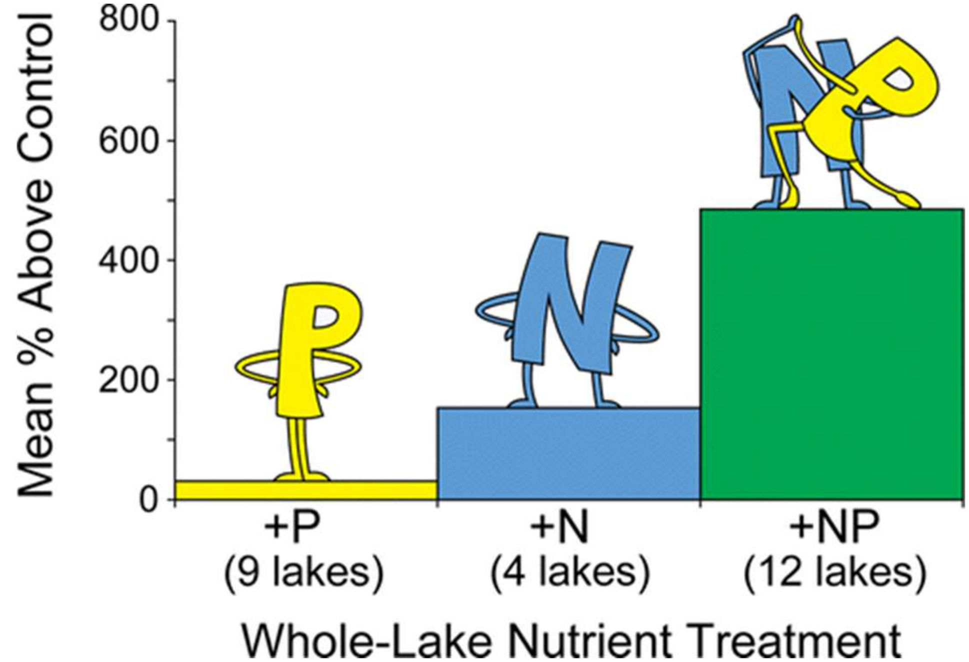
Mean % Above Control
800
600
400
200
0
+P
(9 lakes)
+N
(4 lakes)
+NP
(12 lakes)
Whole-Lake Nutrient Treatment

Dr. Guillermo Goyenola goyenola@gmail.com 04/2024