The Use of Nitrogen and its Consequences on Aquatic Ecosystems

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São Pedro, SP

Outline of the lecture

- N as limiting nutrient in aquatic ecosystems
- N and eutrophication of aquatic ecosystems
- Harmful algal blooms and why it is a concern
- N and acidification of some freshwaters
- Toxicity of inorganic N compounds to biota

N and P as limiting nutrients

- N and P are generally considered to be the two primary limiting nutrients for algae and vascular plants in aquatic ecosystems because both are frequently in short supply relative to their cellular demands for growth.
- Most of our knowledge of the relative importance of N versus P as growth-limiting nutrients is based primarily on indirect evidence based on elemental ratios or from direct evidence from bioassays (in which the response of algal growth to nutrient addition is evaluated).

The Redfield ratio

- Redfield (1958) proposed that the nutrient content of marine phytoplankton could be caracterized on average by a molar ratio of 106C:16N:1P (40C:7N:1P by weight).
- Thus, algae that experience an N:P supply ratio less than the Redfield ratio should be limited by N. Conversely, algae experiencing an N:P supply ratio greater than the Redfield ratio should be limited by P.
- Redfield ratio has often been used in the empirical assessment of nutrient limitation

Biogeochemistry **37**: 237–252, 1997.

Marine nitrogen: Phosphorus stoichiometry and the global N:P cycle

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Key words: freshwater, limitation, marine, nitrogen, phosphorus, ratio, stoichiometry, trace elements

Abstract. Nitrogen supply is often assumed to limit marine primary production. A global analysis of total nitrogen (N) to phosphorus (P) molar ratios shows that total N:P is low (<16:1) in some estuarine and coastal ecosystems, but up to 100:1 in open oceans. This implies that elements other than N may limit marine production, except in human impacted, estuarine or coastal ecosystems. This pattern may reconcile conflicting enrichment studies, because N addition frequently increases phytoplankton growth where total N:P is expected to be low, but P, Fe, or Si augment phytoplankton growth in waters where total N:P is high. Comparison of total N:P stoichiometry between marine and freshwaters yields a model of the form of the aquatic N:P cycle.

Limnol. Oceanogr., 37(5), 1992, 936–945

The nitrogen : phosphorus relationship in lakes

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Abstract

Published data on mean annual epilimnetic total N (TN) and P (TP) were analyzed to find how TN : TP varies with lake trophic status. TN : TP is high in oligotrophic lakes and very low in eutrophic lakes, declining in a curvilinear fashion with increased TP. Comparison of this trend with published N : P in lake nutrient sources suggests that TN : TP reflects the source of nutrients: the ratio is high in oligotrophic lakes because they receive their N and P from natural, undisturbed watersheds which export much less P than N; mesotrophic and eutrophic lakes receive various mixtures of nutrient sources that have lower average N : P; and very eutrophic lakes have N : P that correspond very nearly to the N : P of sewage. Two inflection points were identified in the TN : TP relationship (~20 and ~100 μg TP liter^{-1}) the first probably reflecting the large difference between TN : TP in nutrient export from undisturbed terrestrial ecosystems and that of meso- and eutrophic sources such as urban and pasture land runoff and sewage, and the second probably reflecting increased rates of denitrification in eutrophic lakes. Analysis of published manipulation experiments shows that N limitation is not only significantly more frequent in lakes of low ambient TN : TP (TN : TP mass ratio $\leq$ 14) but is also significantly more frequent in lakes with TP $>$ 30 μg liter^{-1}.

Hydrobiologia
DOI 10.1007/s10750-015-2578-5

PRIMARY RESEARCH PAPER

Drought-induced water-level reduction favors cyanobacteria blooms in tropical shallow lakes

**Jandeson Brasil · José L. Attayde ·
Francisco R. Vasconcelos · Danyhelton
D. F. Dantas · Vera L. M. Huszar**

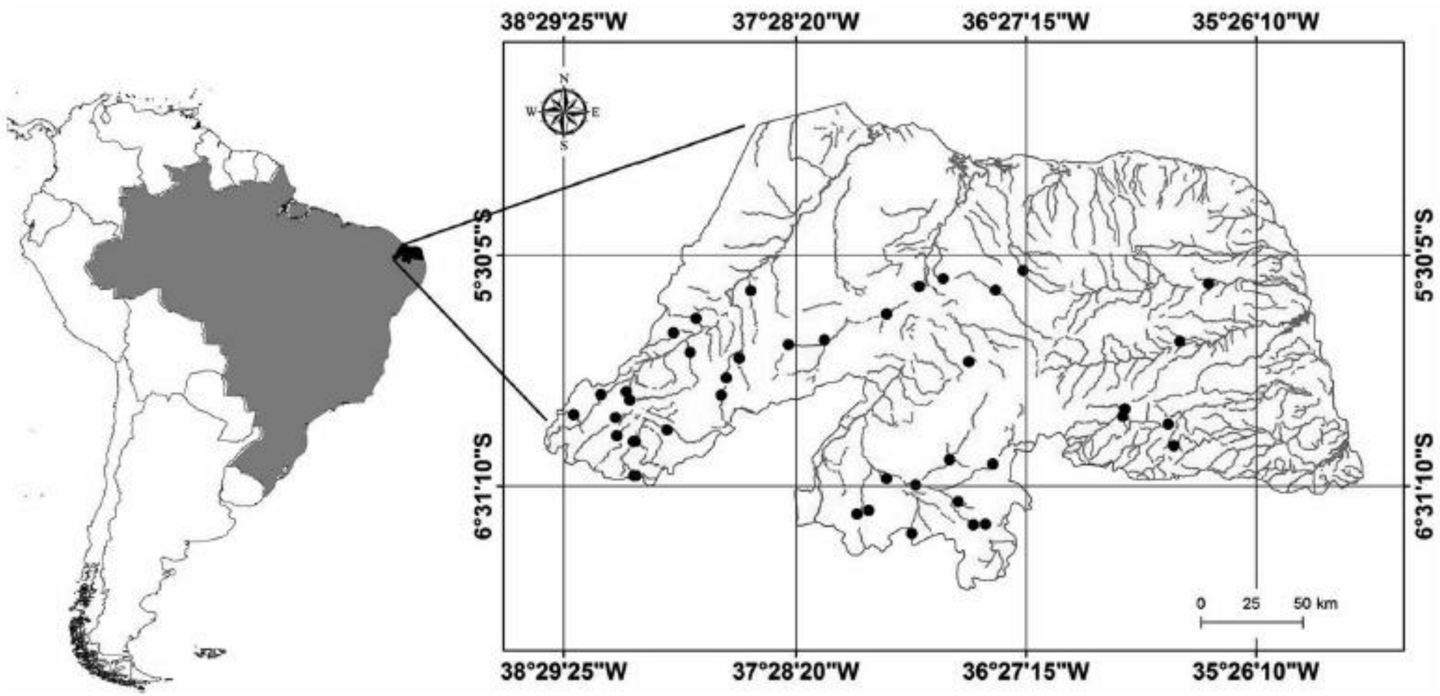
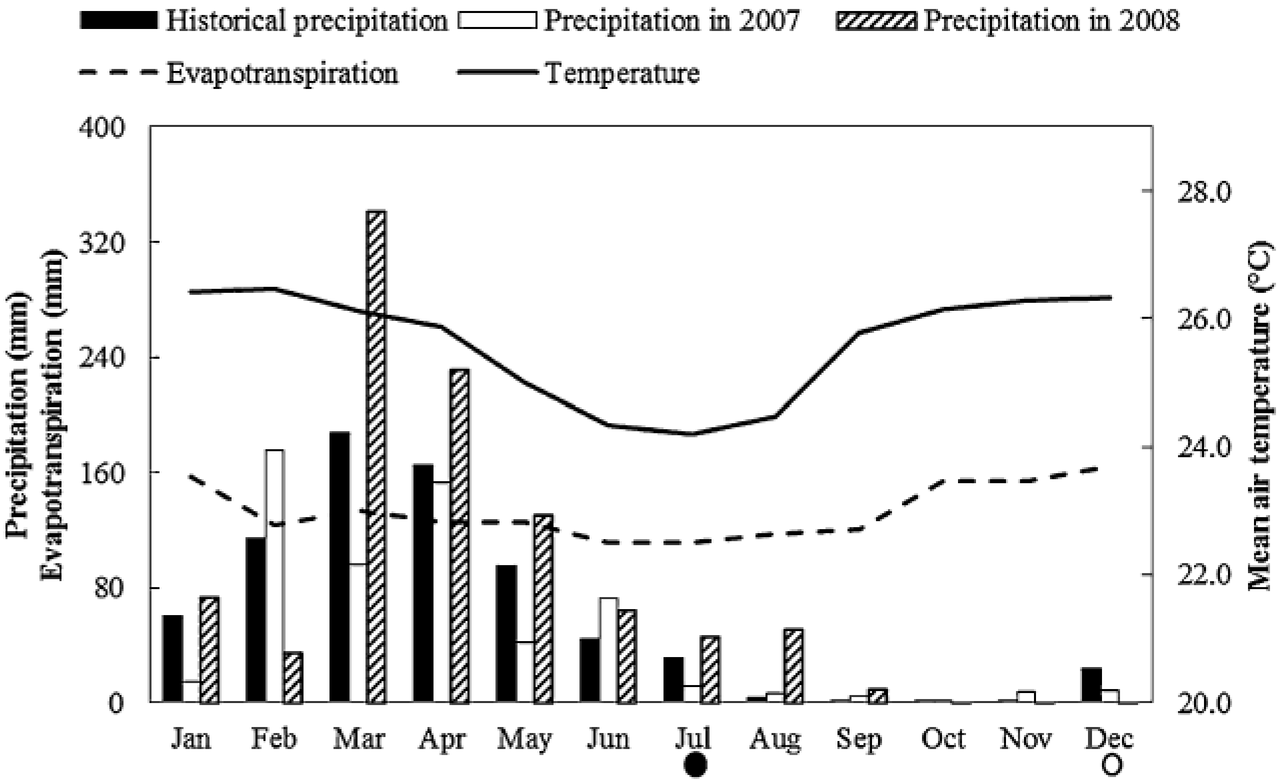


Fig. 1 Map and location of Rio Grande do Norte, Brazil, showing the 40 man-made lakes studied (dots)

Fig. 2 Mean values of historical (1960–2006 period) monthly mean precipitation, air temperature, evapotranspiration, and precipitation in the two study years. Open circle indicates sampling month in 2007 and closed circle in 2008 (Data source: Empresa de Pesquisa Agropecuária do Rio Grande do Norte—EMPARN)



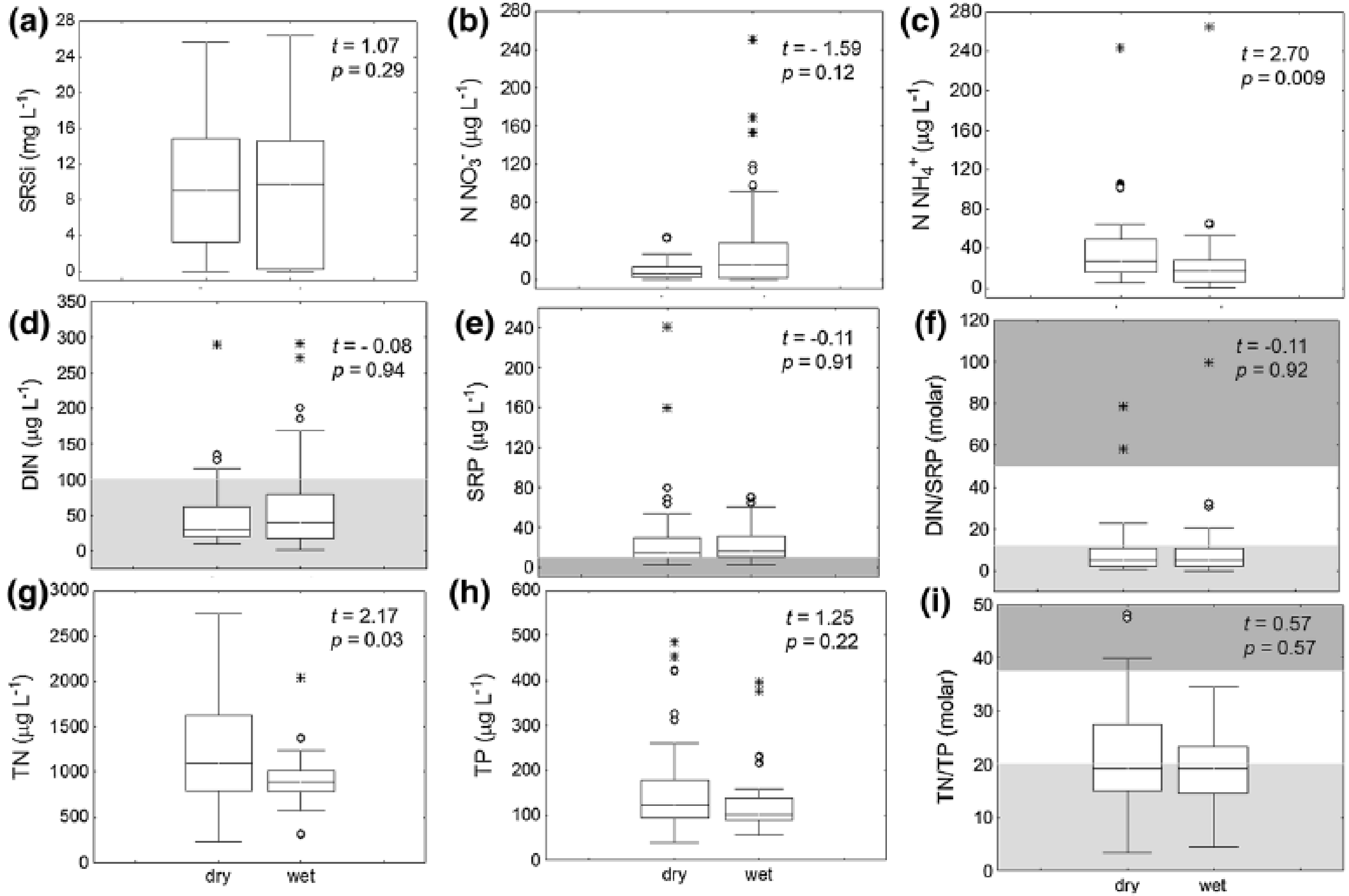


Fig. 4 Box plots of **a** SRSi, soluble reactive silica; **b** *N* NO_3^- nitrate; **c** N NH_4^+, ammonium; **d** *DIN* dissolved inorganic nitrogen; **e** *SRP* soluble reactive phosphorus; **f** DIN:SRP molar ratio; **g** TN total nitrogen; **h** *TP* total phosphorus; **i** TN:TP molar ratio found in 40 man-made lakes in Rio Grande do Norte, Brazil, in the dry and wet seasons ($n = 80$). The *horizontal lines* inside the box plots indicate the median, and the boundaries of the box plots indicate the 25th and 75th percentiles. *Whiskers* above and below indicate the 90th and 10th percentiles. Dots and stars are outliers and extreme points, respectively. *Light-gray* areas represent potentially N-limited conditions; *dark-gray* areas represent potentially P-limited conditions; and white, no limitation

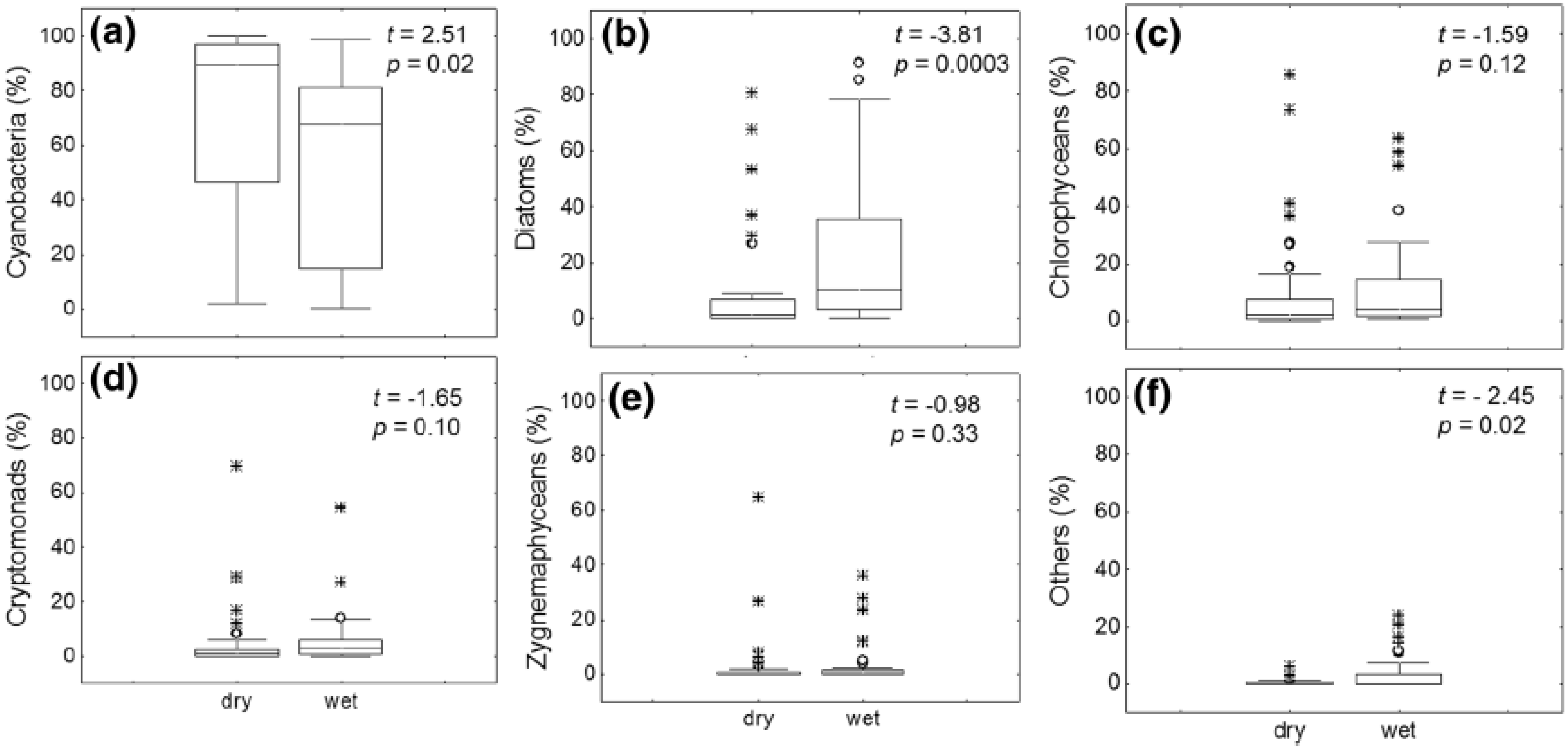
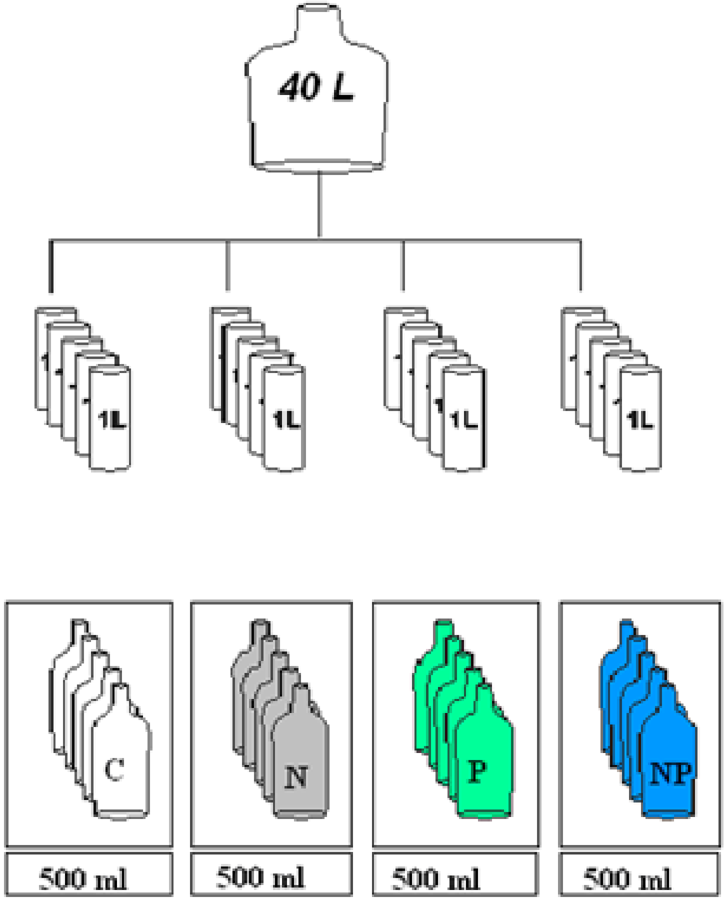
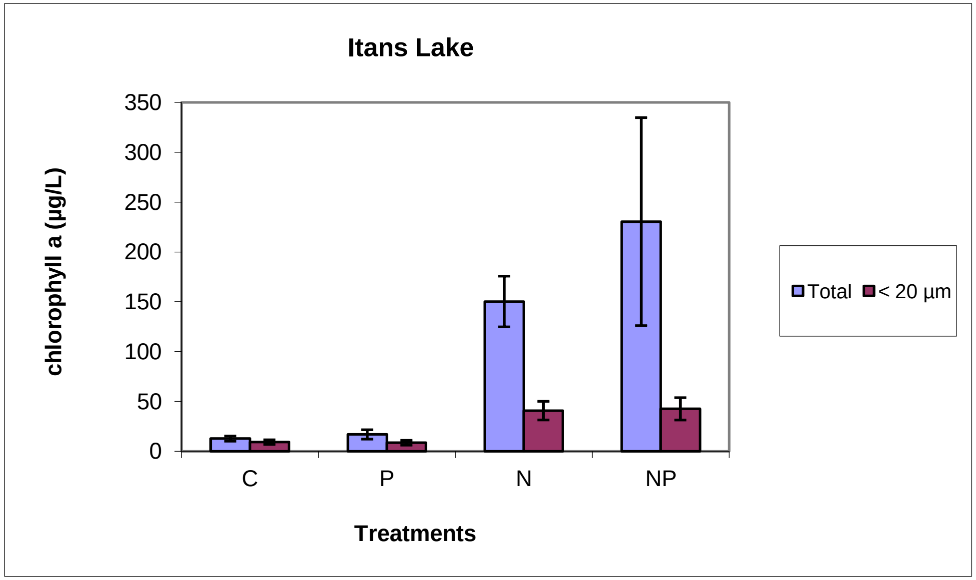
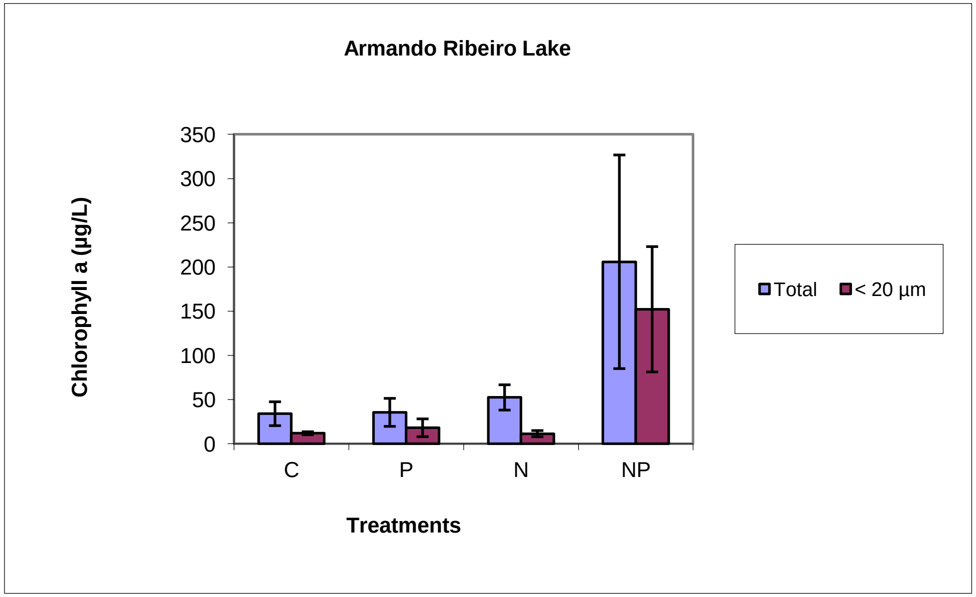


Fig. 6 *Box plots* of percentages of total phytoplankton biovolume of **a** cyanobacteria; **b** diatoms; **c** chlorophyceans; **d** cryptomonads; **e** zygnemaphyceans; **f** other phytoplankton groups (dinoflagellates, euglenoids, and xanthophyceans) found in 40 man-made lakes in Rio Grande do Norte, Brazil, in the dry and wet seasons ($n = 80$). The *horizontal line*s inside the box plots indicate the median, and the boundaries of the box plots indicate the 25th and 75th percentiles. *Whiskers* above and below indicate the 90th and 10th percentiles. *Dots* and *stars* are outliers and extreme points, respectively

Evidence from Bioassays







Ecology Letters, (2007) **10**: 1135–1142 doi: 10.1111/j.1461-0248.2007.01113.x

LETTER

Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems

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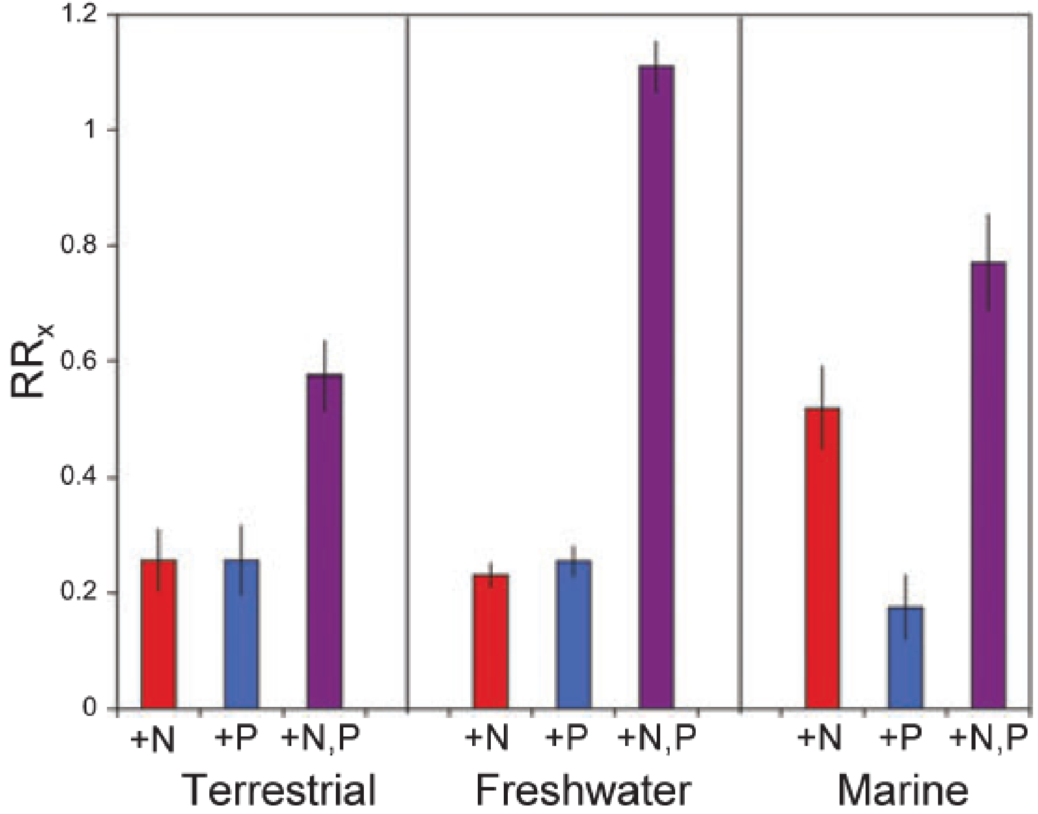


Figure 1 Responses of autotrophs to single enrichment of N (red) or P (blue) or to combined N + P enrichment (purple) in terrestrial, freshwater and marine ecosystems. Data are given as natural-log transformed response ratios (RR_x) in which autotroph biomass or production in the enriched treatment is divided by its value in the control treatment and then ln-transformed (see Methods). Thus, a value of 0.5 indicates a value in the manipulated treatment that is *c.* 1.6 times its value in the control, while a value of 1.0 indicates a 2.7-fold increase. Sample sizes +N, +P and +N&P treatments were 112, 107 and 126 for terrestrial studies, 509, 506 and 618 for freshwater studies and 149, 141 and 197 for marine systems, respectively. Error bars indicate plus or minus one standard error.

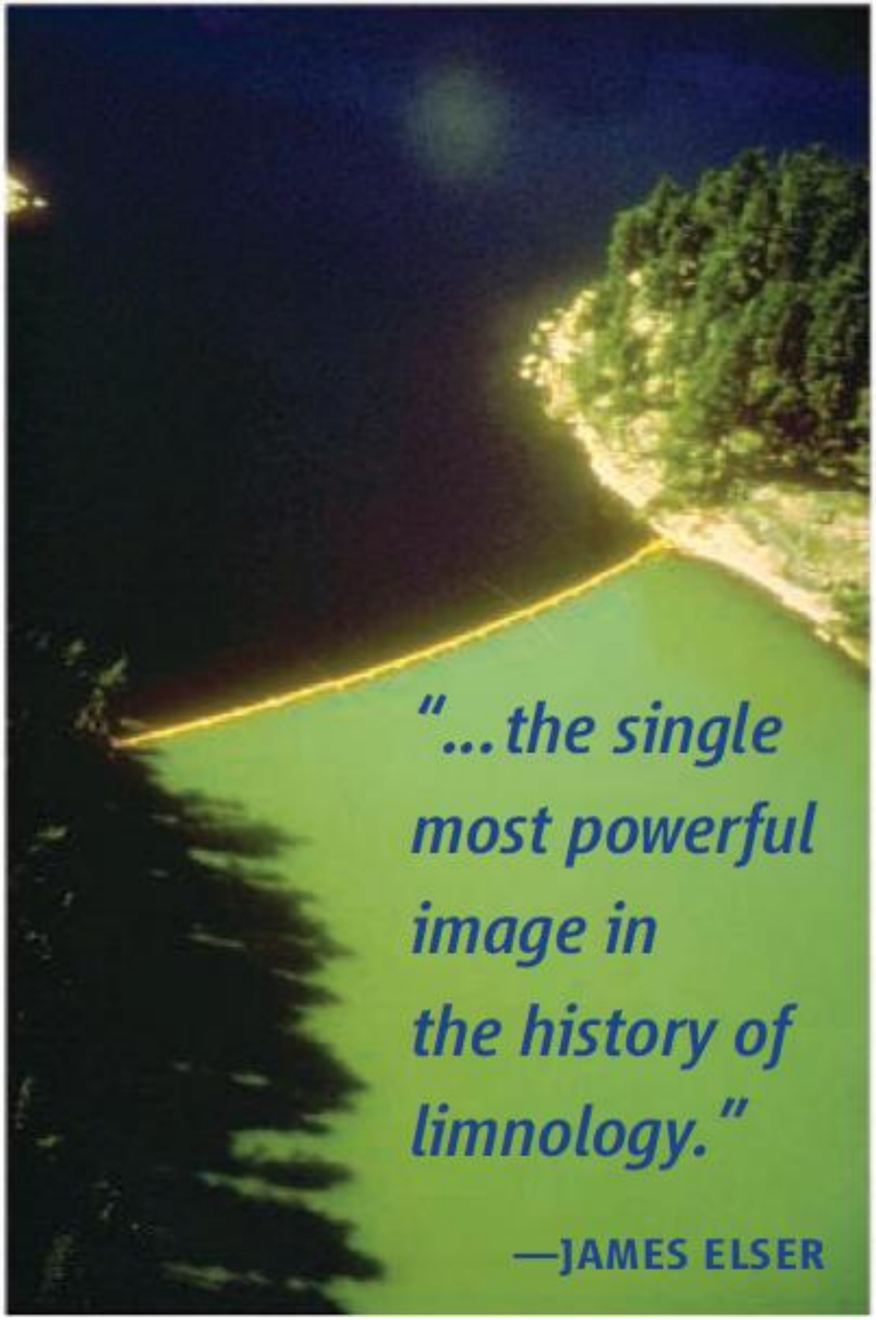
These results show that:

- The magnitude of producer response to P enrichment is similar in marine, freshwater and terrestrial ecosystems
- Combined N and P enrichment produces similarly strong sinergistic effects in all habitats
- N and P limitation appear to be of equal importance in terrestrial and freshwater ecosystems, but N limitation is stronger in marine systems

Whole-Lake Experiments

David W. Schindler

But whole-lake experiments in temperate regions of North America and Europe has shown strong evidence for phosphorus as the limiting nutrient in freshwaters. Excess P has then been considered the cause of lake eutrophication and lake management has focused on P control. However, this paradigm has been challenged in the last decade...



"...the single most powerful image in the history of limnology."

—JAMES ELSER

Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment

David W. Schindler[*][†], R. E. Hecky[*], D. L. Findlay[§], M. P. Stainton[§], B. R. Parker[*], M. J. Paterson[§], K. G. Beaty[§], M. Lyng[§], and S. E. M. Kasian[§]

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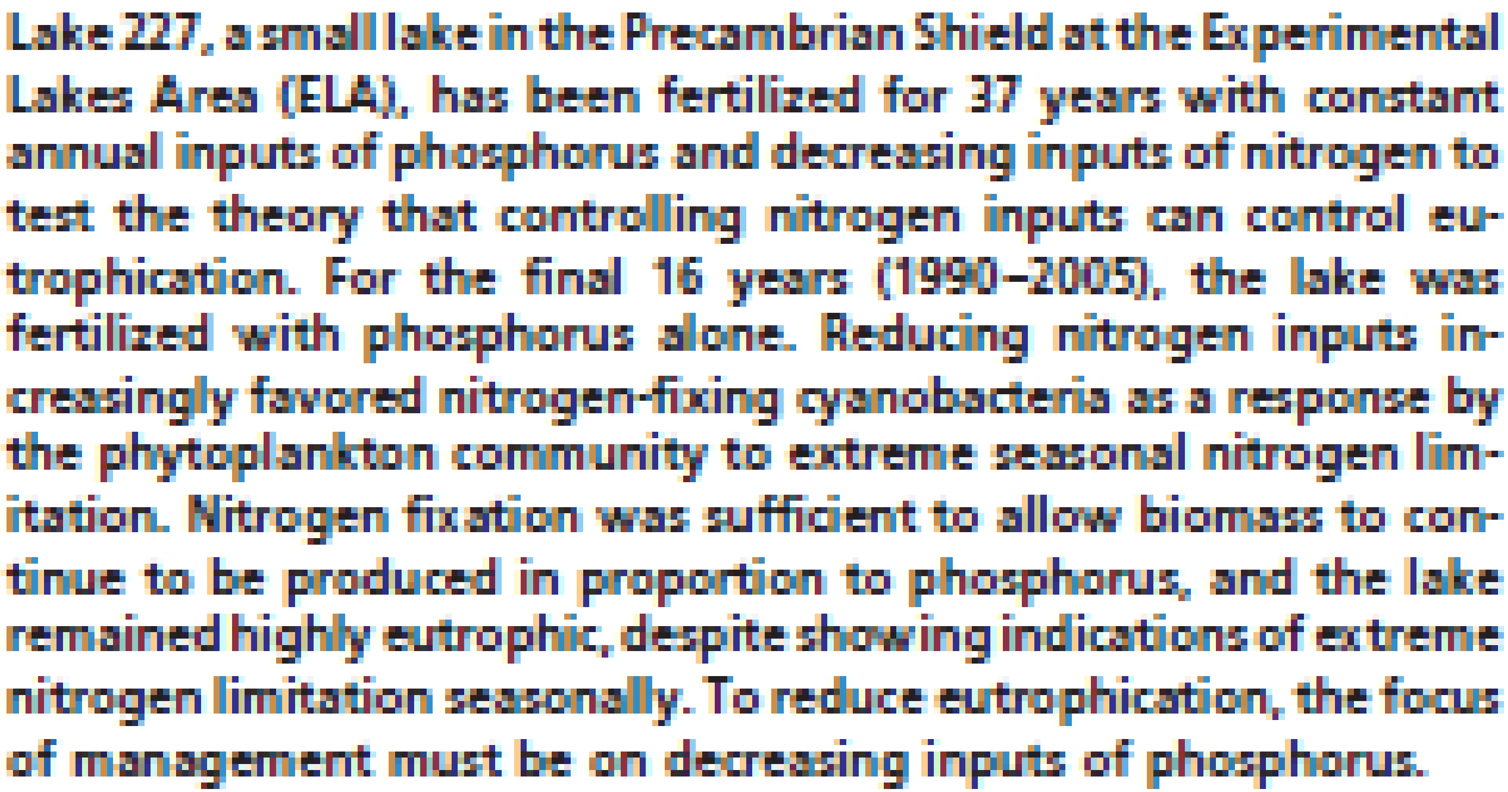
Contributed by David W. Schindler, May 28, 2008 (sent for review March 25, 2008)

11254–11258 | PNAS | August 12, 2008 | vol. 105 | no. 32



Lake 227, a small lake in the Precambrian Shield at the Experimental Lakes Area (ELA), has been fertilized for 37 years with constant annual inputs of phosphorus and decreasing inputs of nitrogen to test the theory that controlling nitrogen inputs can control eutrophication. For the final 16 years (1990–2005), the lake was fertilized with phosphorus alone. Reducing nitrogen inputs increasingly favored nitrogen-fixing cyanobacteria as a response by the phytoplankton community to extreme seasonal nitrogen limitation. Nitrogen fixation was sufficient to allow biomass to continue to be produced in proportion to phosphorus, and the lake remained highly eutrophic, despite showing indications of extreme nitrogen limitation seasonally. To reduce eutrophication, the focus of management must be on decreasing inputs of phosphorus.

Global Change Biology (2006) **12**, 635–643, doi: 10.1111/j.1365-2486.2006.01129.x

Atmospheric nitrogen deposition has caused nitrogen enrichment and eutrophication of lakes in the northern hemisphere

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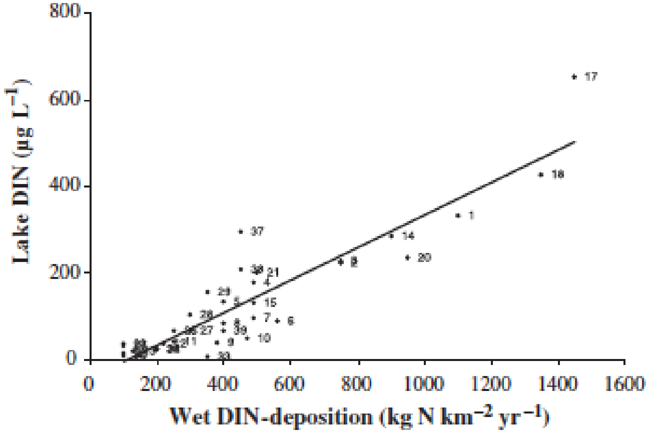

Fig. 2 The relationship between mean dissolved inorganic nitrogen (DIN) concentration (μg L^{-1}) and mean wet inorganic nitrogen deposition (wet DIN deposition; kg N km^{-2} yr^{-1}) in unproductive lakes in different regions in North America and Europe.

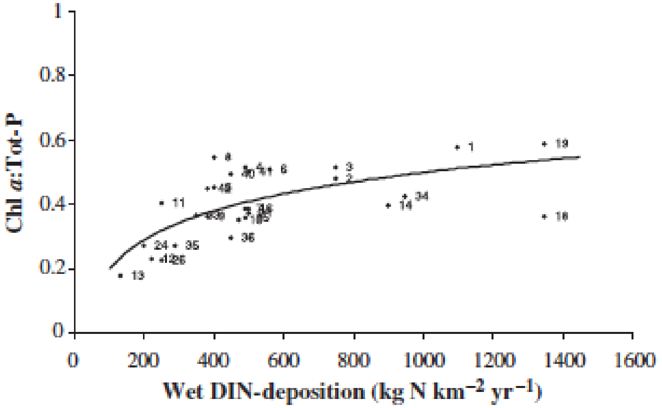

Fig. 3 The relationship between chlorophyll *a* concentration (μg L^{-1}) and total phosphorus concentration (μg L^{-1}) (Chl *a*:Tot-P ratios) and mean wet inorganic nitrogen deposition (wet DIN deposition, kg N km^{-2} yr^{-1}) in unproductive lakes situated in different regions in North America and Europe.

N and Eutrophication

- Evolving views over five decades:
  - The 1960s: first studies on lake eutrophication
  - The 1970s: development of separate lake and estuarine sciences of eutrophication
  - The 1980s: continued emphasis on nitrogen in temperate estuaries and an eventual start toward freshwater-estuarine-marine comparisons
  - The 1990s: development of a consensus for nitrogen control of coastal eutrophication
  - The 2000s: development of criteria for N regulation in freshwater, estuarine and marine ecosystems

Sources of nutrients

- Point sources of nutrients: domestic and industrial sewage
- Non-point sources of nutrients: rural and urban drainage, soil erosion and atmospheric deposition in the watershed
- Non-point sources are more important. They are much more difficult to control and regulate than point sources.

Ecological Applications, 8(3), 1998, pp. 559–568

NONPOINT POLLUTION OF SURFACE WATERS WITH PHOSPHORUS AND NITROGEN

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Table 3. Nitrogen and phosphorus discharges to surface waters (in 10^3 Mg/yr) from nonpoint and point sources in the United States.

Source	Nitrogen	Phosphorus
Nonpoint sources		
Croplands	3204	615
Pastures	292	95
Rangelands	778	242
Forests	1035	495
Other rural lands	659	170
Other nonpoint sources	695	68
Total	6663	1658
Total point sources	1495	330
Total discharge (nonpoint + point)	8158	2015
Nonpoint as percentage of total	82%	84%

Consequences of eutrophication

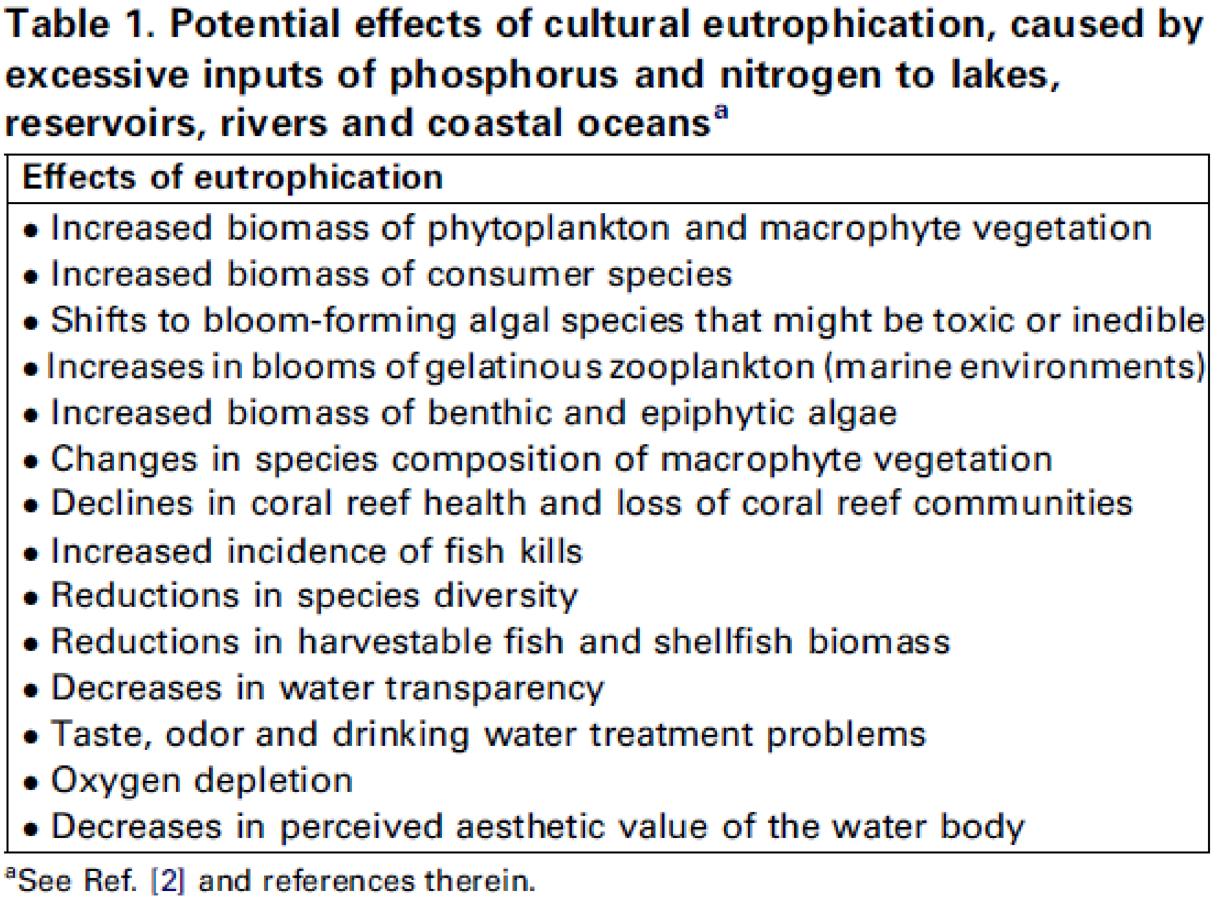


Table 1. Potential effects of cultural eutrophication, caused by excessive inputs of phosphorus and nitrogen to lakes, reservoirs, rivers and coastal oceans[a]

Effects of eutrophication
• Increased biomass of phytoplankton and macrophyte vegetation
• Increased biomass of consumer species
• Shifts to bloom-forming algal species that might be toxic or inedible
• Increases in blooms of gelatinous zooplankton (marine environments)
• Increased biomass of benthic and epiphytic algae
• Changes in species composition of macrophyte vegetation
• Declines in coral reef health and loss of coral reef communities
• Increased incidence of fish kills
• Reductions in species diversity
• Reductions in harvestable fish and shellfish biomass
• Decreases in water transparency
• Taste, odor and drinking water treatment problems
• Oxygen depletion
• Decreases in perceived aesthetic value of the water body

[a] See Ref. [2] and references therein.

2 Smith, V.H. (2003) Eutrophication of freshwater and marine ecosystems: a global problem. *Environ. Sci. Pollut. Res. Int.* 10, 126–139

Effects on primary production

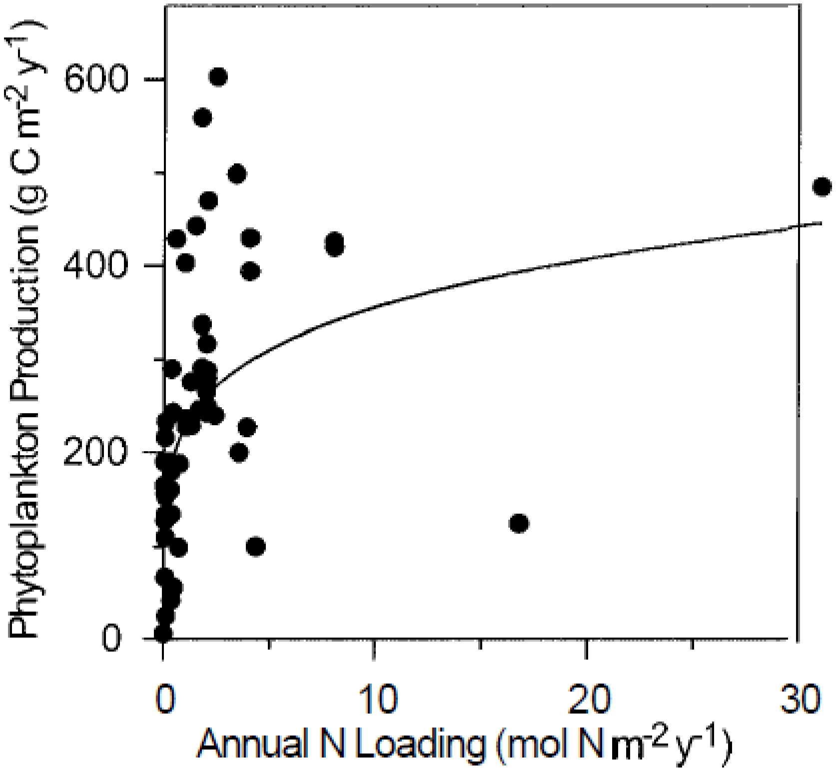


Fig. 5. Annual phytoplankton primary production versus annual N loading for coastal waters and mesocosms. Data from Borum (1996), Fig. 9.11. Fitted curve is the function $y = 244 + 175\log(x)$ ($r^2 = 0.36$; $n = 51$)

SOME FILTERS:

Light conditions
Tidal flushing
Trophic structure

Tidal flushing

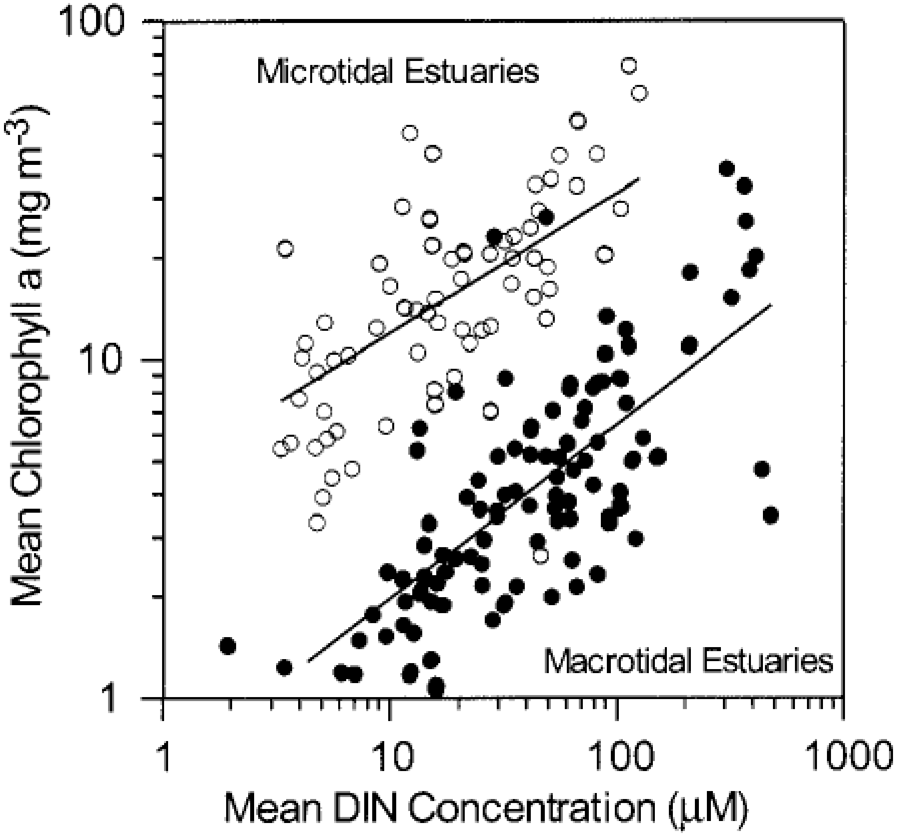
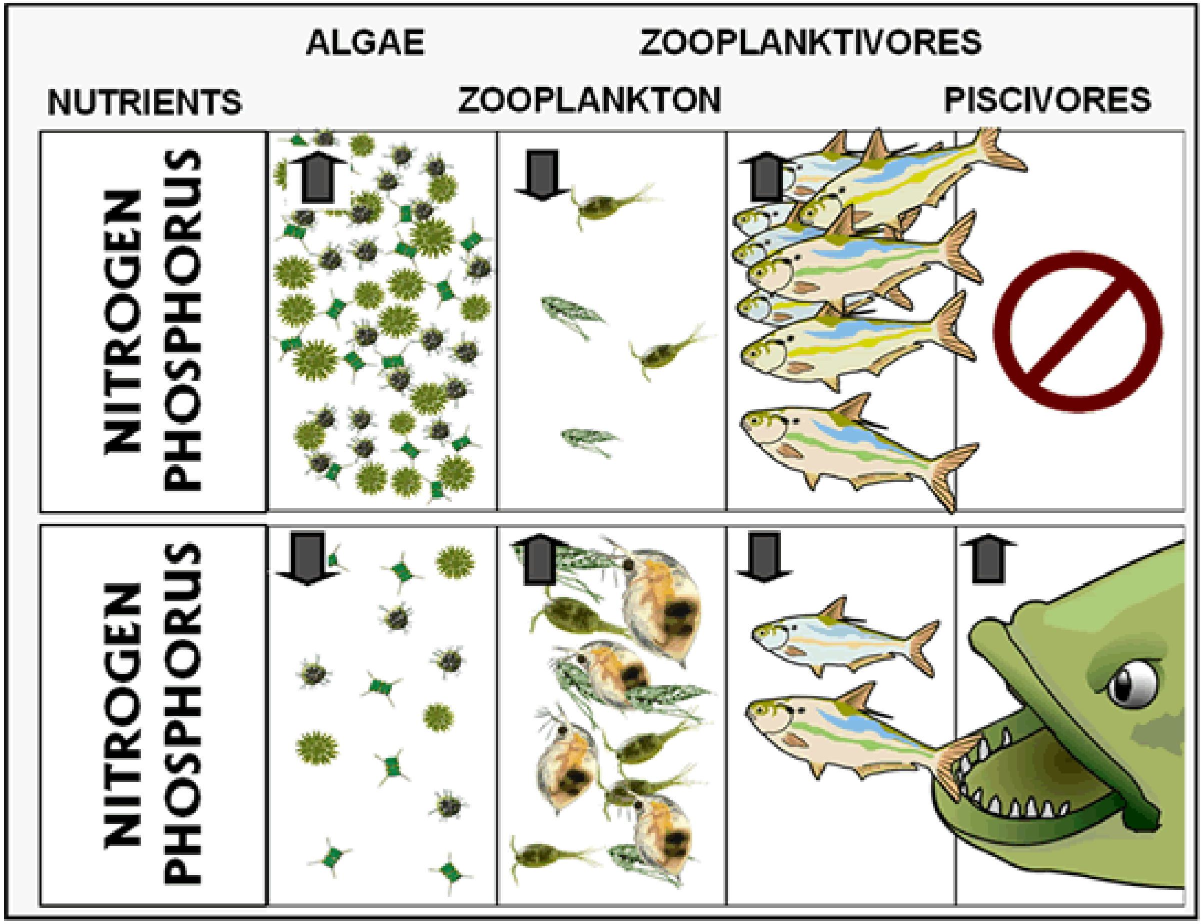


Fig. 25. Example of a response (mean annual chlorophyll *a* concentration) to the signal of mean DIN concentration, after estuaries are separated into macrotidal (mean tidal range >2 m) and microtidal (mean tidal range <2 m) bins. Redrawn from Monbet (1992), Fig .2

Trophic Structure



Explains about 50% of the variance in phytoplankton biomass

Harmful algal blooms

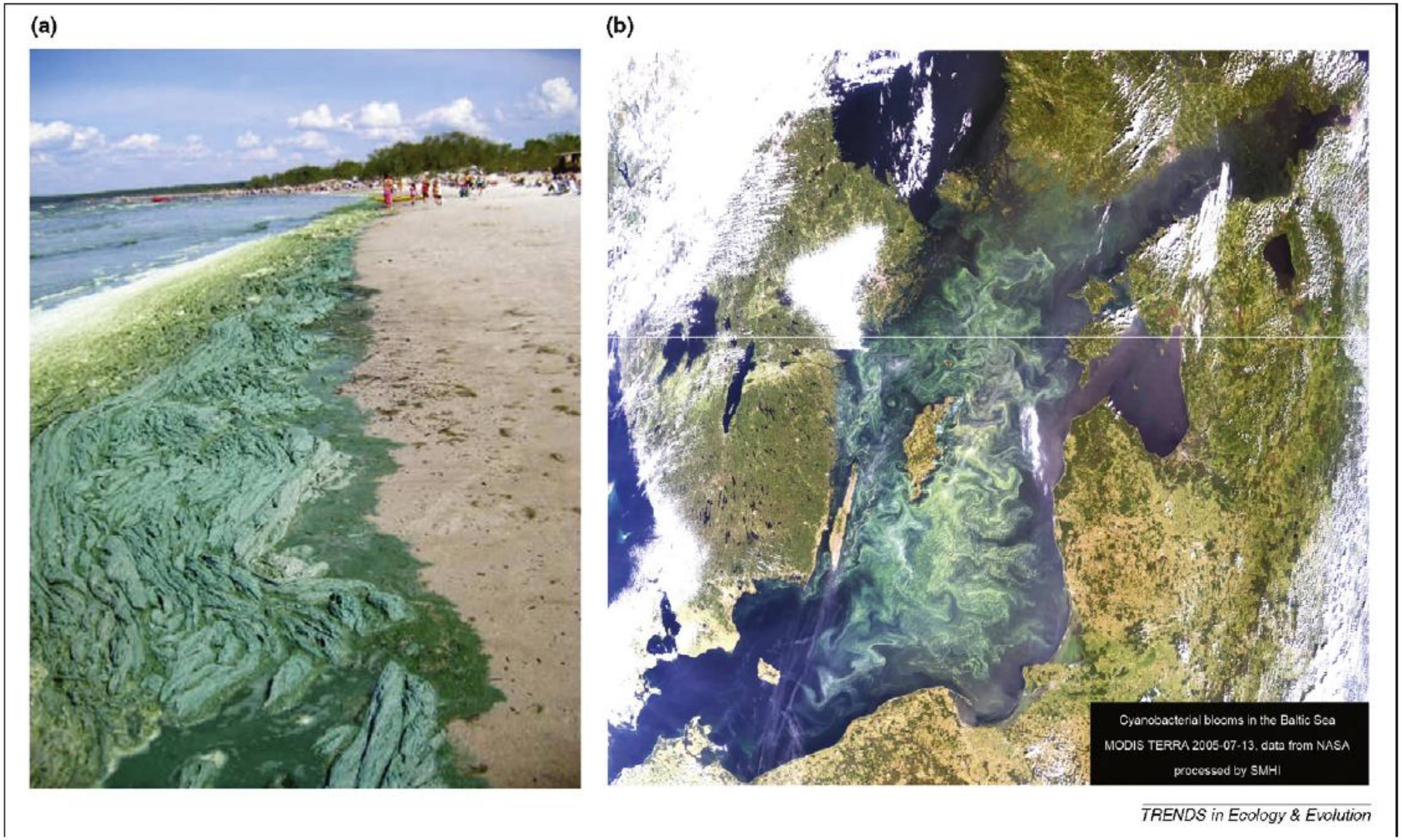
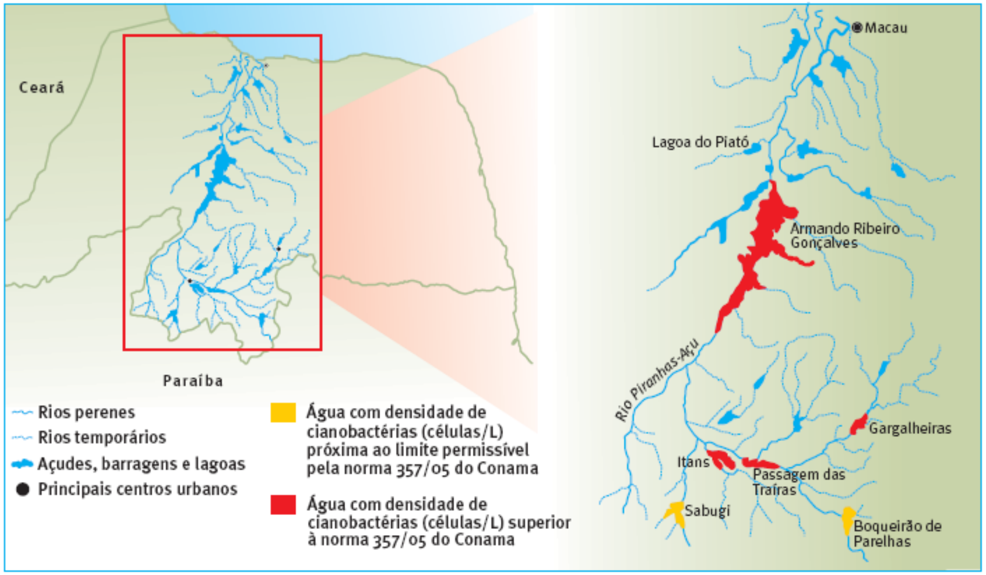


Figure 1. Excessive nutrient enrichment, or eutrophication, of surface waters frequently results in the appearance of harmful algal blooms in both freshwater lakes and coastal ecosystems. **(a)** Surface bloom of cyanobacteria at Grand Beach, Lake Winnipeg, Canada (photo by Lori Volkart). **(b)** Extensive surface blooms of cyanobacteria in the Baltic Sea (NASA, GES Distributed Active Center, as processed by SMHI, http://www.smhi.se/weather/baws_ext/info/2005/Baltic_algae_2005_en.htm). Reproduced, with permission, from University of Alberta Press [57].

LIMNOLOGIA Gestão inadequada ameaça reservas de água do semi-árido brasileiro

Águas potiguares: oásis ameaçados



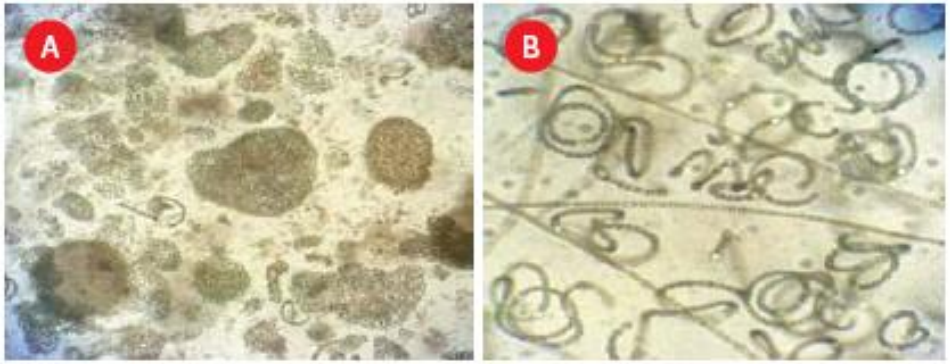


Figura 2. Cianobactérias encontradas em alguns reservatórios do Rio Grande do Norte: em A, espécies do gênero *Microcystis*; em B, *Anabaena circinalis (formas 'enroscadas')* e *Planktothrix agardhii* (formas retilíneas)

Figura 4. Aspectos de uma floração de cianobactérias no reservatório Armando Ribeiro Gonçalves, no Rio Grande do Norte, em julho de 2004

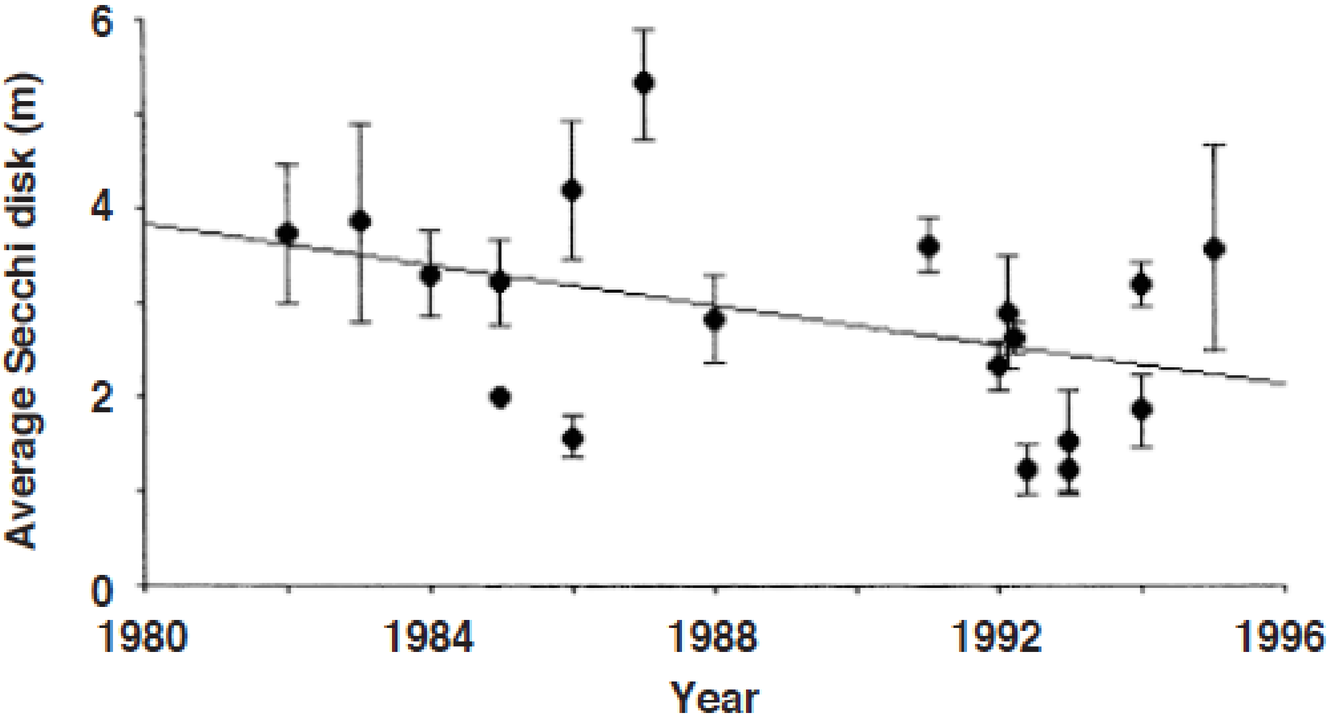
Letal Toxicity of several compounds listed in "WHO Guidelines for Drinking Water Quality"

compound	source	IARC class	GV $\mu g\ L^{-1}$	LD_{50} $mg\ kg^{-1}$ BW
endrin	pesticide	n.carc.	0.6	1.4
carbofuran	pesticide	n.carc.	7	2
Microcystin-LR	peptide	2B	1[a]	5
pentachlorophe	wood	2B	9[a]	36
aldrin/dieldrin	pesticide	3	0.03	44
chlorpyrifos	pesticide	n.carc.	30	60
acrylamide	indust. chemical	2A	0.5	107
DDT	pesticide	2B	1	135
chlordane	pesticide	2B	0.2	145
arsenic	metal	1	10	145
atrazine	pesticide	3	2	850
simazine (rat)	pesticide	3	2	971
metolachlor	pesticide	n.carc.	10	1150
cadmium (rat)	metal	2A	3	2330
dioxan	indust. chemical	2B	50	5300

a: GV provisório; dados de toxicidade compilados dosis.nlm.nih.gov/chemical.html; 1: carcinogênico; 2A: provavelmente carc.; 2B: possivelmente carc.; 3 não classificável; n.carc.: não carcinogênico.

Effects on water transparency

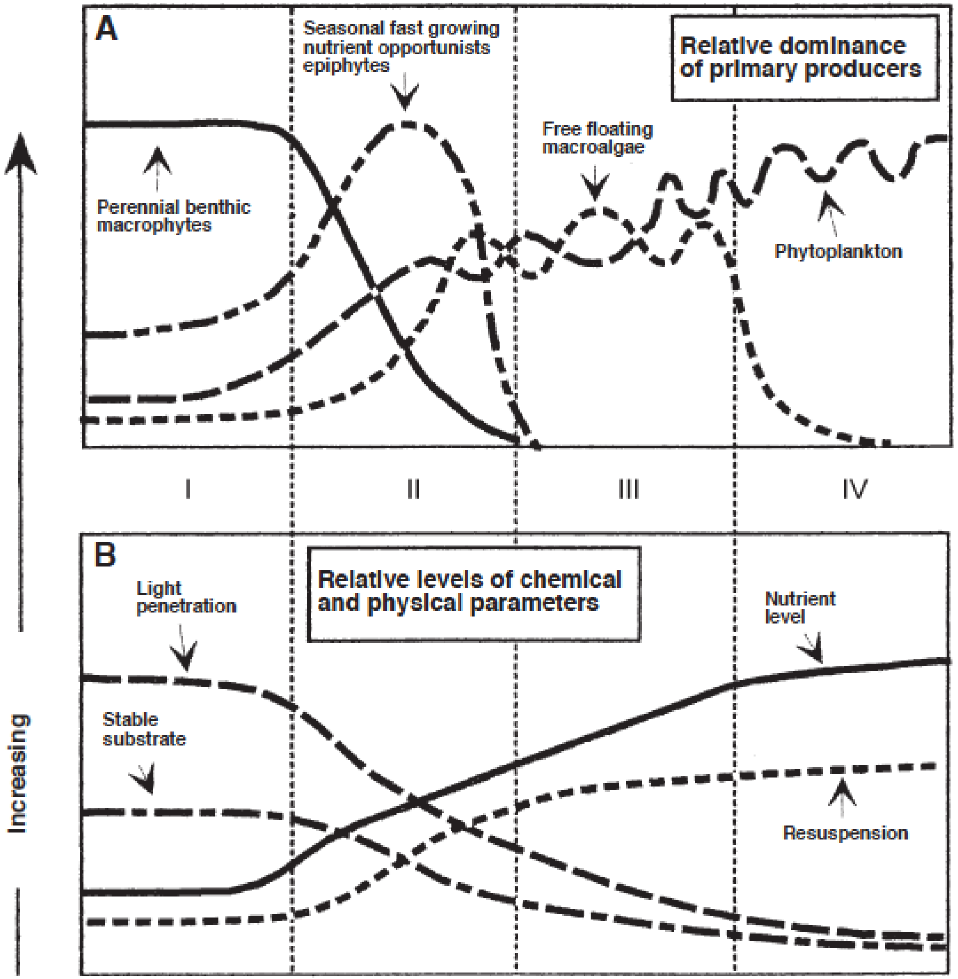
Figure 6. The change in the Secchi disk depth on the Louisiana shelf west of the Mississippi River delta for the period indicated (38). The data are restricted to stations with surface-water salinity between 20 and 25 psu and depths between 10 and 100 m. The slope of the regression line is significant at the 8% level of significance. The error bars are ± s.e.



Source : Rabalais 2002 Nitrogen in Aquatic Ecosystems. Ambio 31 (2): 102-112

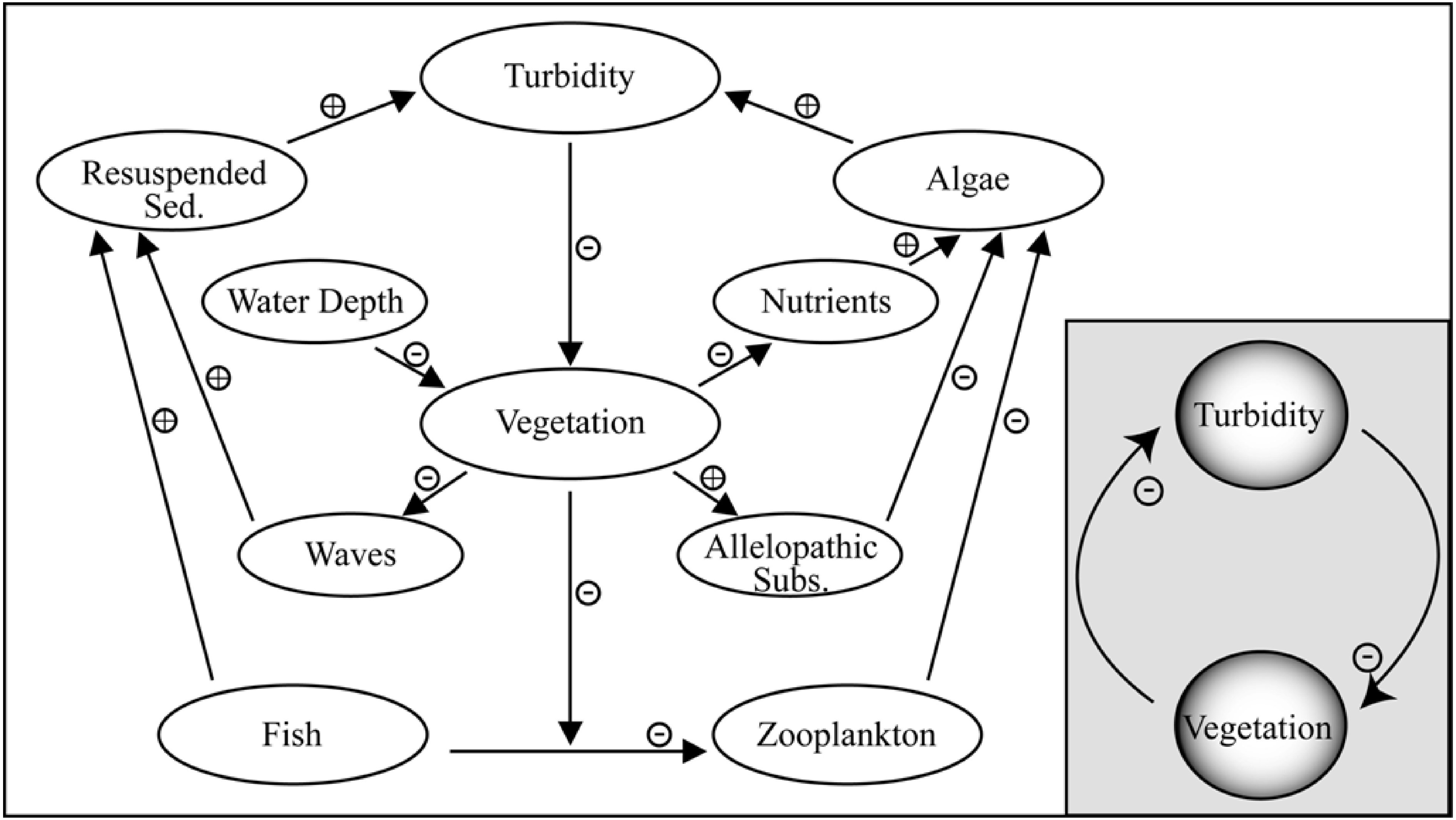
Effects on benthic producers

Figure 7. The qualitative changes in phytoplankton and macroalgal communities with increasing eutrophication from left to right through stages I–IV as described in text (modified from 72, with kind permission of Kluwer Academic Publishers).



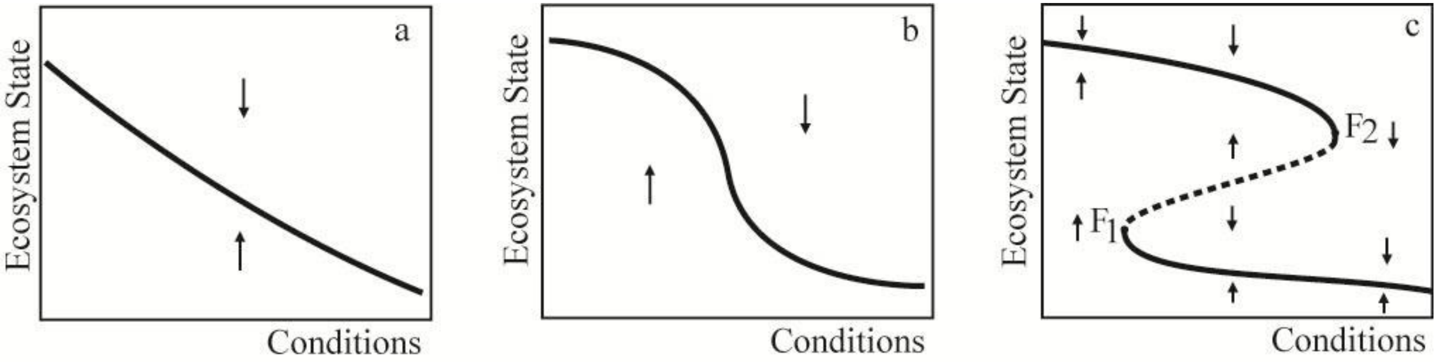
Source : Rabalais 2002 Nitrogen in Aquatic Ecosystems. Ambio 31 (2): 102-112

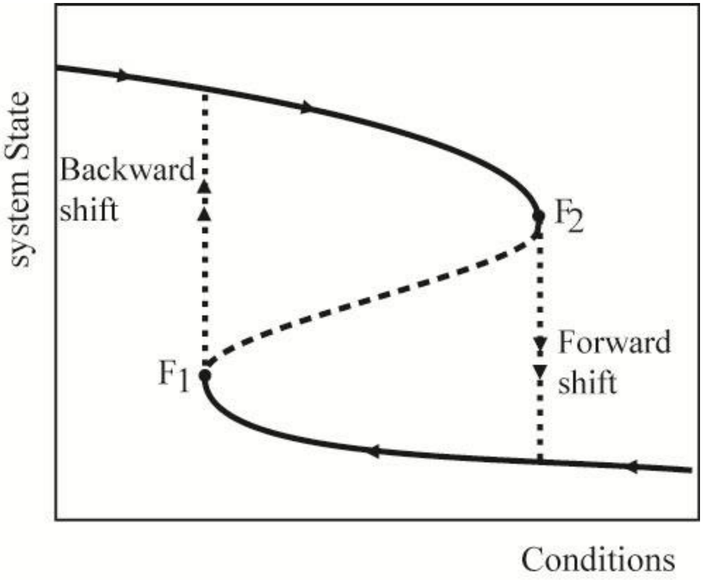
Shallow Lakes Theory



Source: Scheffer 2009 Critical Transitions in Nature and Society. Princeton University Press

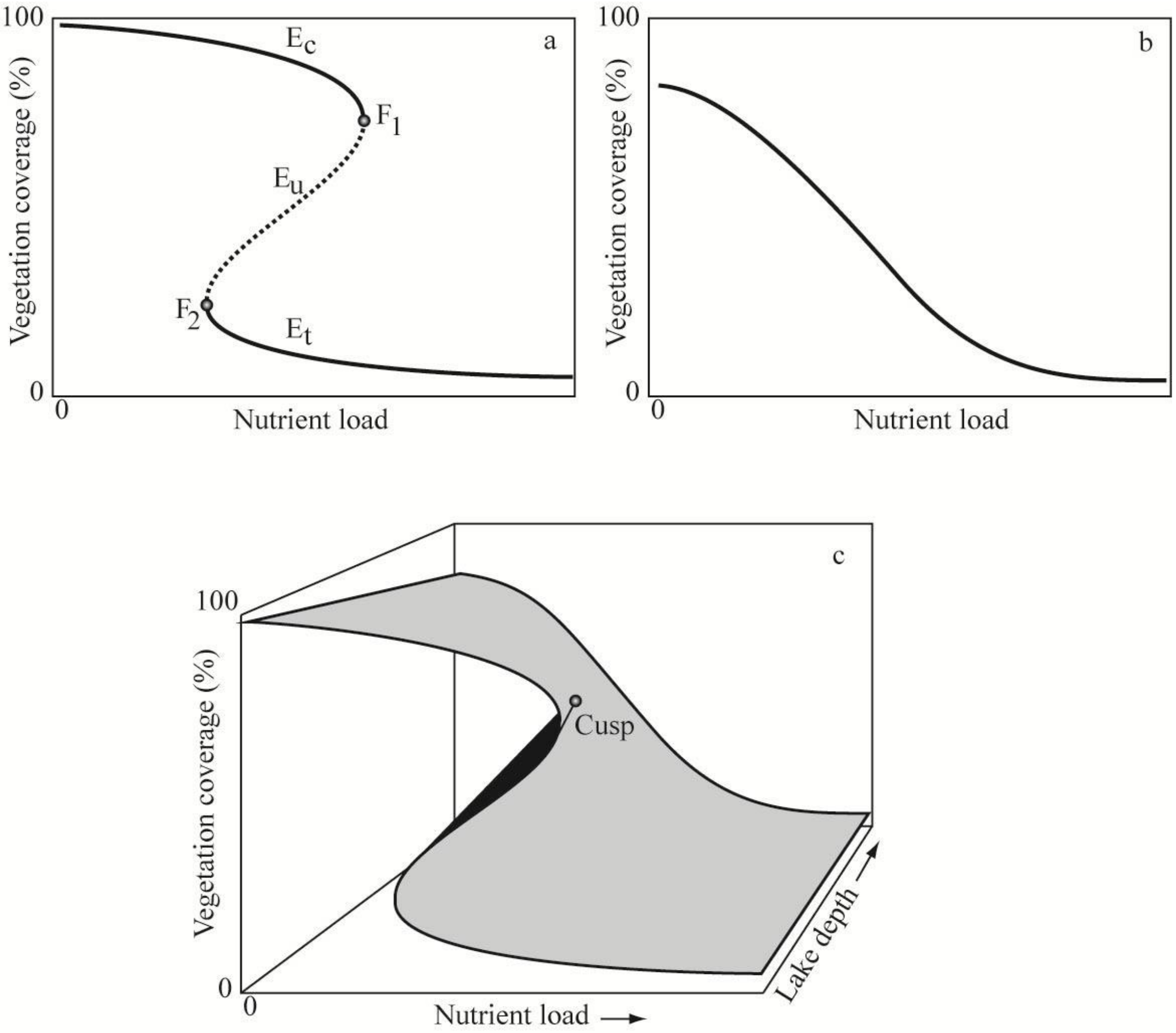
How ecosystems change with increasing nutrients ?





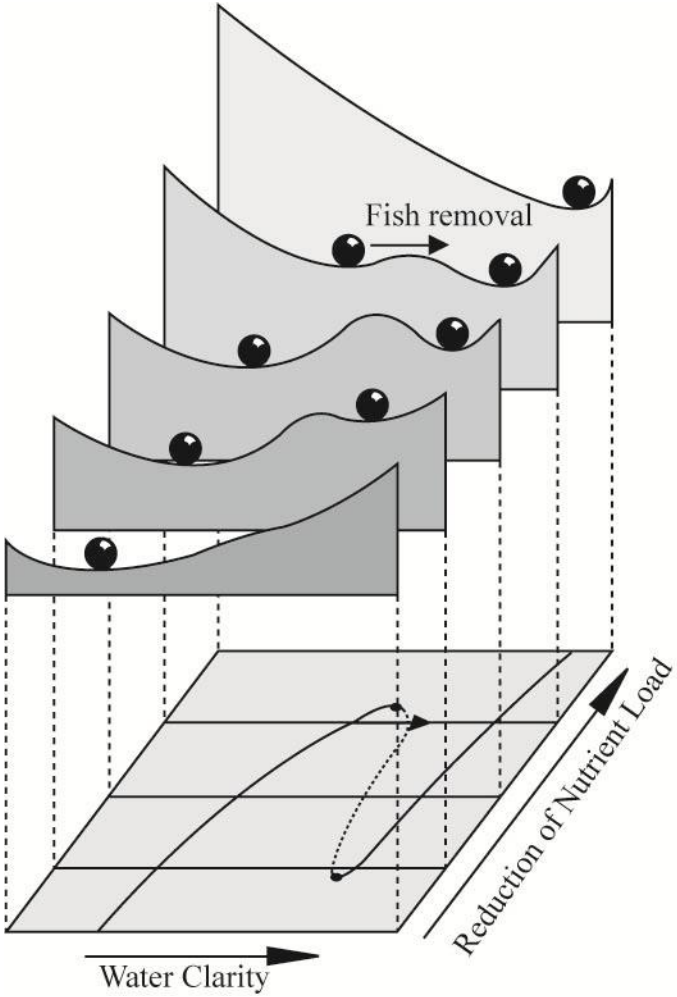
Source: Scheffer 2009 Critical Transitions in Nature and Society. Princeton University Press

It depends on lake depth ...



Source: Scheffer 2009 Critical Transitions in Nature and Society. Princeton University Press

Implication for lake management



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Alternative states in coral reefs

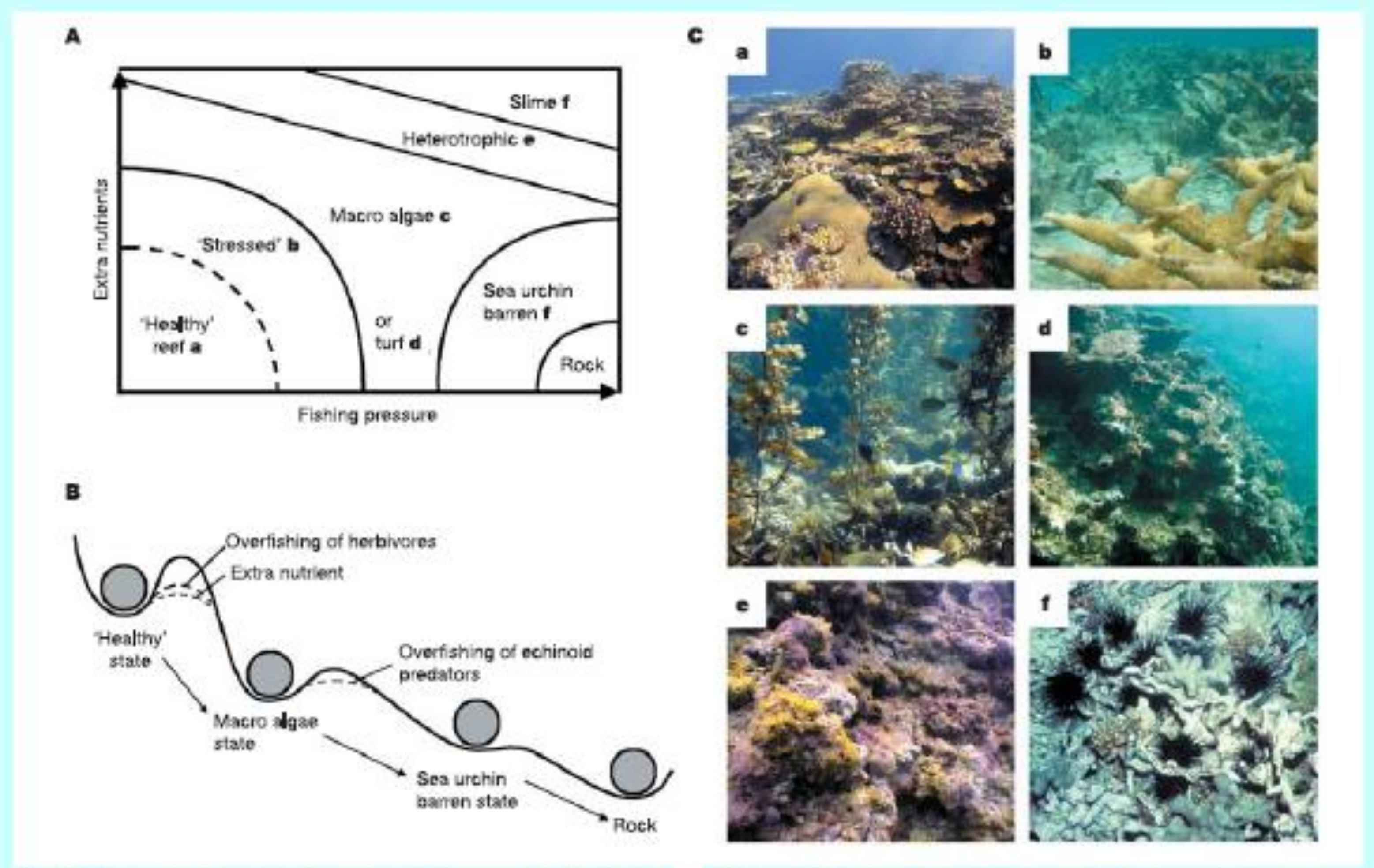
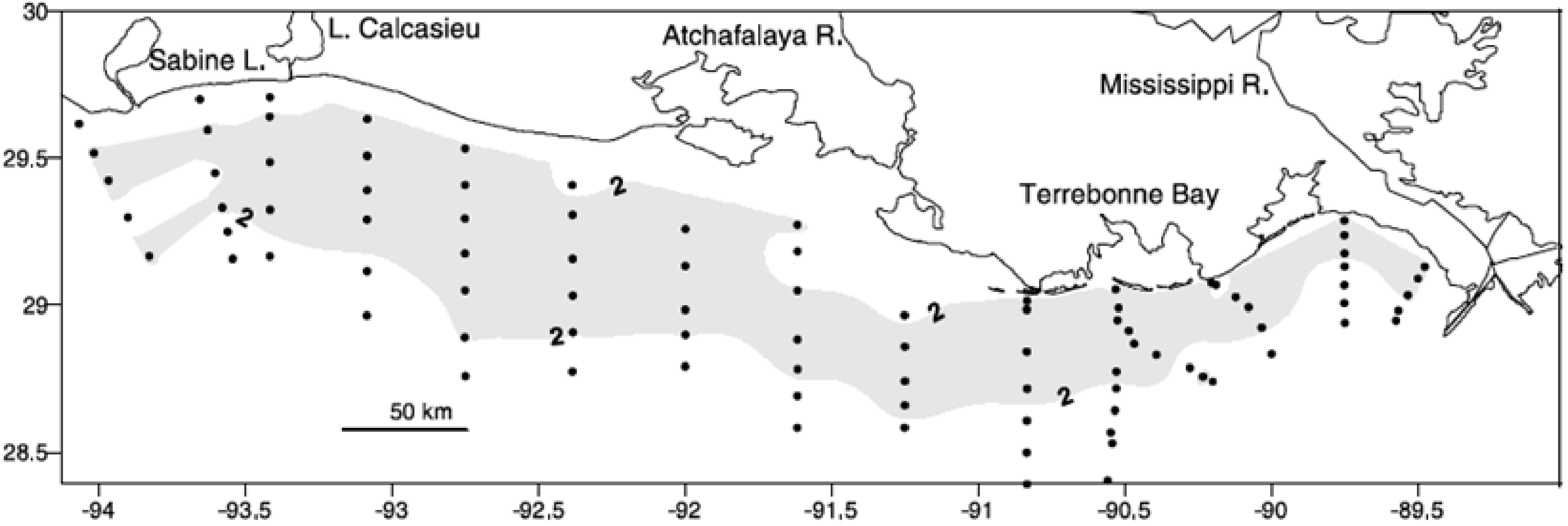


Figure 2 Alternate states in coral reef ecosystems. **A**, A conceptual model showing human-induced transitions between alternate ecosystem states based on empirical evidence of the effects from fishing and excess nutrients[15–17]. The 'stressed' state illustrates loss of resilience and increased vulnerability to phase-shifts. **B**, A graphic model depicting transitions between ecosystem states. 'Healthy' resilient coral-dominated reefs become progressively more vulnerable owing to fishing pressure, pollution, disease and coral bleaching. The dotted lines illustrate the loss of resilience that becomes evident when reefs fail to recover from disturbance and slide into less desirable states. **C**, Six characteristic reef states (as in **A**) from sites on the Great Barrier Reef (**a**, **c**, **d**, **e**) and in the Caribbean (**b**, **f**).

Fonte: Bellwood et al. 2004. Confronting the coral reef crisis. Nature 429: 827-833

Effects on dissolved oxygen

Figure 8. Distribution of bottom-water dissolved oxygen values less than 2 mg L^{-1} during a shelfwide assessment cruise in late July 2001; the area is 20 700 km^2 (88).



Source : Rabalais 2002 Nitrogen in Aquatic Ecosystems. Ambio 31 (2): 102-112

Effects on aquatic consumers

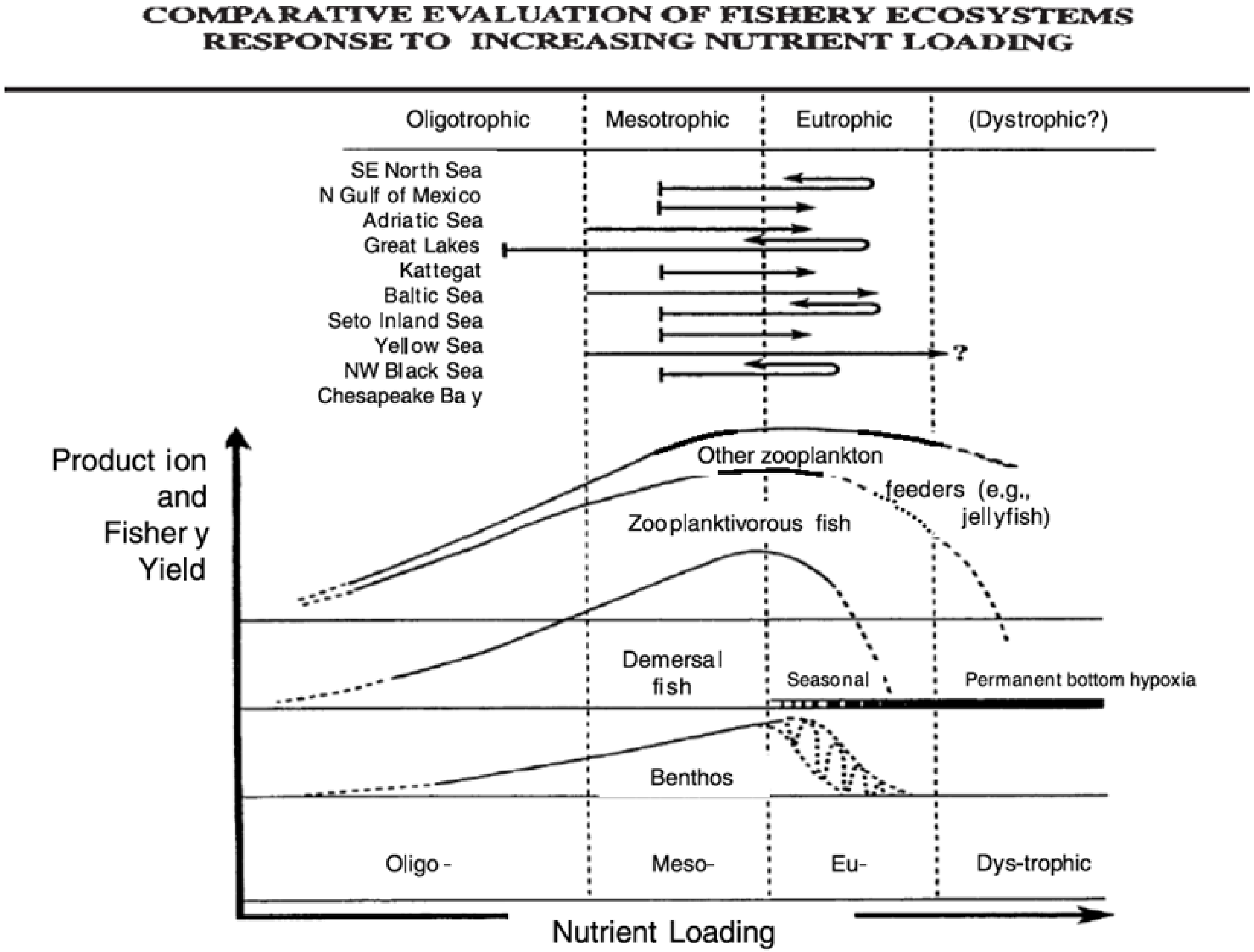


Figure 5. The generalized relationship of production and fishery yield as nutrient loading increases with varying effects of eutrophication expressed as seasonal and permanent bottom-water anoxia; a spectrum of enclosed seas (modified from 13, with kind permission of Inter-Research Science Publisher).

Source : Rabalais 2002 Nitrogen in Aquatic Ecosystems. Ambio 31 (2): 102-112

Effects on fish trophic position

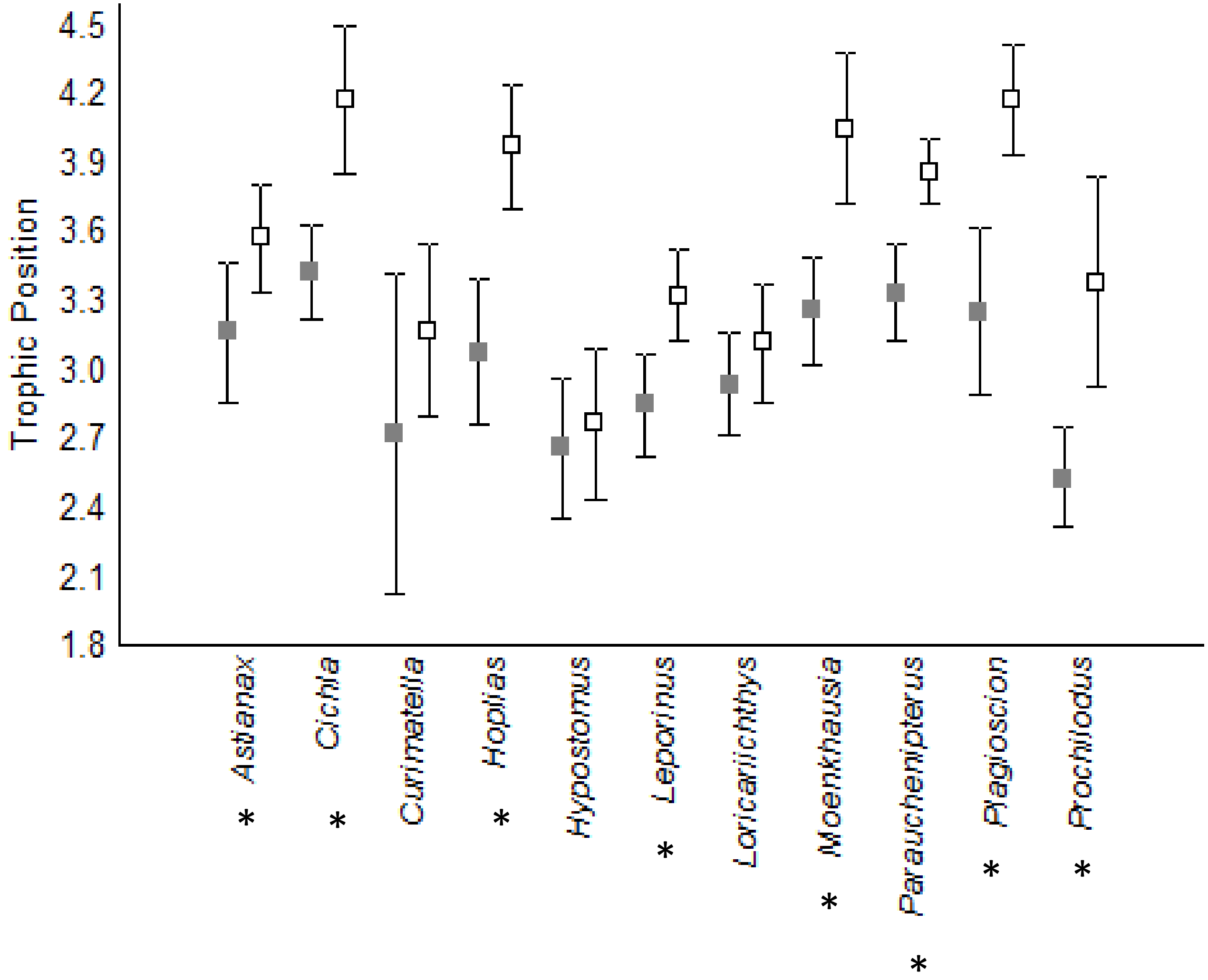
$$TP = 2 + (\delta^{15}N_{Cons} - \delta^{15}N_{Base})/3.4$$

TP = Trophic Position
2 = TP of herbivores
$\delta^{15}N_{Cons} = \delta^{15}N_{fish}$
$\delta^{15}N_{Base} = \delta^{15}N_{Molusc}$
3.4 = average fractionation factor for non-herbivore consumers (Post 2002)

Rocha et al. 2016 (in prep.)

Santa Cruz Lake
Mesotrophic (white)

Pau dos Ferros Lake
Eutrophic (gray)



Eutrophication reduces trophic position of omnivorous fish and consequently of piscivores

N and freshwater acidification

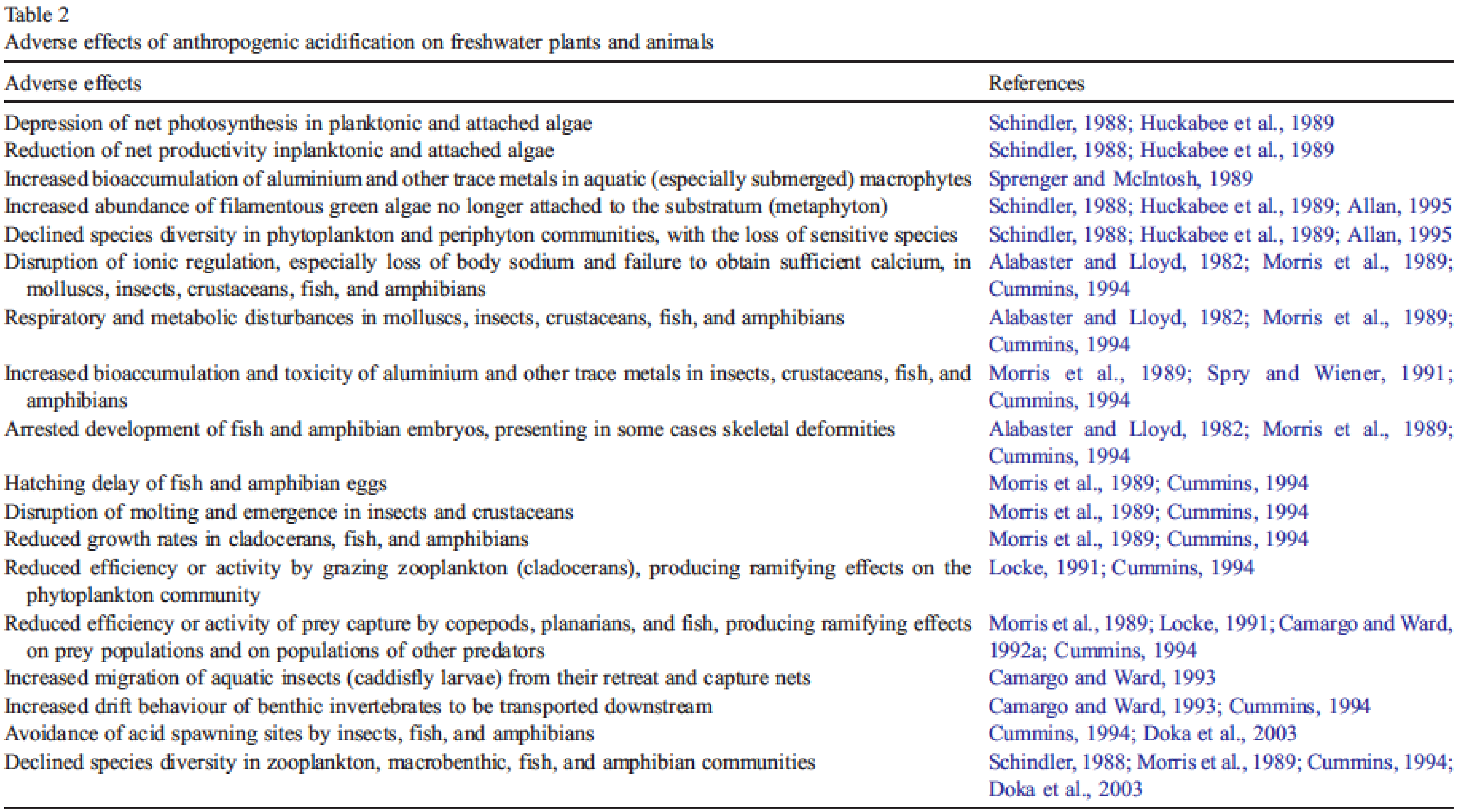


Table 2
Adverse effects of anthropogenic acidification on freshwater plants and animals

Adverse effects	References
Depression of net photosynthesis in planktonic and attached algae	Schindler, 1988; Huckabee et al., 1989
Reduction of net productivity inplanktonic and attached algae	Schindler, 1988; Huckabee et al., 1989
Increased bioaccumulation of aluminium and other trace metals in aquatic (especially submerged) macrophytes	Sprenger and McIntosh, 1989
Increased abundance of filamentous green algae no longer attached to the substratum (metaphyton)	Schindler, 1988; Huckabee et al., 1989; Allan, 1995
Declined species diversity in phytoplankton and periphyton communities, with the loss of sensitive species	Schindler, 1988; Huckabee et al., 1989; Allan, 1995
Disruption of ionic regulation, especially loss of body sodium and failure to obtain sufficient calcium, in molluscs, insects, crustaceans, fish, and amphibians	Alabaster and Lloyd, 1982; Morris et al., 1989; Cummins, 1994
Respiratory and metabolic disturbances in molluscs, insects, crustaceans, fish, and amphibians	Alabaster and Lloyd, 1982; Morris et al., 1989; Cummins, 1994
Increased bioaccumulation and toxicity of aluminium and other trace metals in insects, crustaceans, fish, and amphibians	Morris et al., 1989; Spry and Wiener, 1991; Cummins, 1994
Arrested development of fish and amphibian embryos, presenting in some cases skeletal deformities	Alabaster and Lloyd, 1982; Morris et al., 1989; Cummins, 1994
Hatching delay of fish and amphibian eggs	Morris et al., 1989; Cummins, 1994
Disruption of molting and emergence in insects and crustaceans	Morris et al., 1989; Cummins, 1994
Reduced growth rates in cladocerans, fish, and amphibians	Morris et al., 1989; Cummins, 1994
Reduced efficiency or activity by grazing zooplankton (cladocerans), producing ramifying effects on the phytoplankton community	Locke, 1991; Cummins, 1994
Reduced efficiency or activity of prey capture by copepods, planarians, and fish, producing ramifying effects on prey populations and on populations of other predators	Morris et al., 1989; Locke, 1991; Camargo and Ward, 1992a; Cummins, 1994
Increased migration of aquatic insects (caddisfly larvae) from their retreat and capture nets	Camargo and Ward, 1993
Increased drift behaviour of benthic invertebrates to be transported downstream	Camargo and Ward, 1993; Cummins, 1994
Avoidance of acid spawning sites by insects, fish, and amphibians	Cummins, 1994; Doka et al., 2003
Declined species diversity in zooplankton, macrobenthic, fish, and amphibian communities	Schindler, 1988; Morris et al., 1989; Cummins, 1994; Doka et al., 2003

Source : Camargo and Alonso 2006. Ecological and toxicological effects of nitrogen pollution in aquatic ecosystems: a global assessment. Environment International 32: 831-849

Toxicity of N inorganic compounds

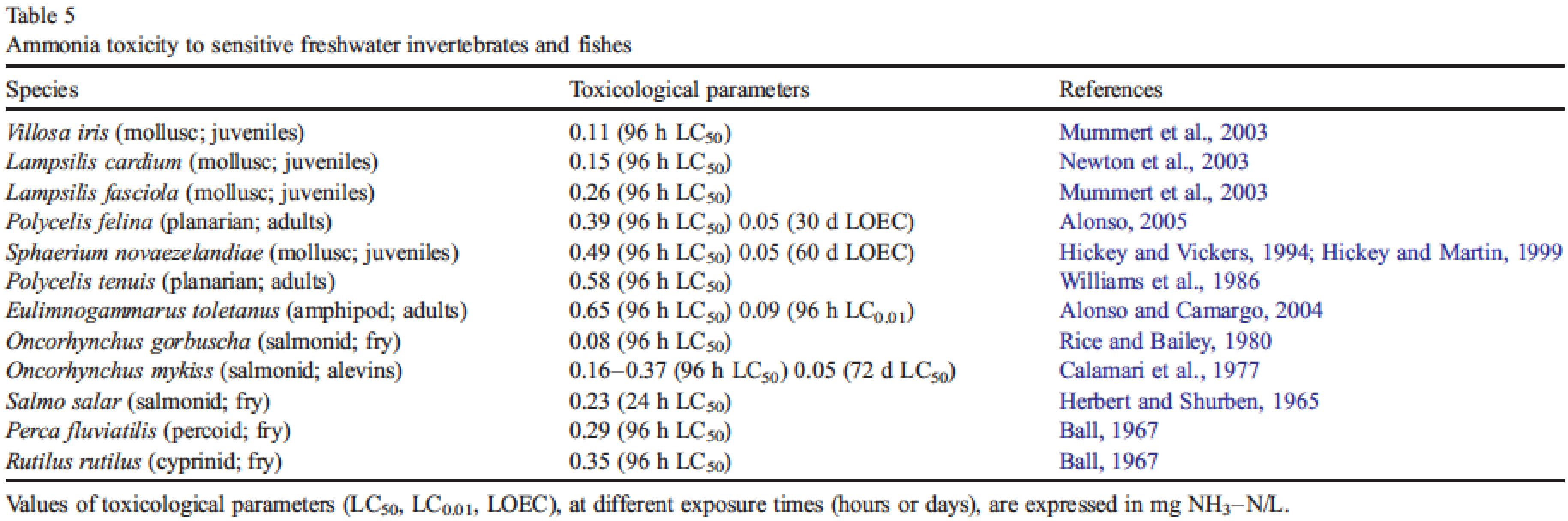


Table 5
Ammonia toxicity to sensitive freshwater invertebrates and fishes

Species	Toxicological parameters	References
Villosa iris (mollusc; juveniles)	0.11 (96 h LC_{50})	Mummert et al., 2003
Lampsilis cardium (mollusc; juveniles)	0.15 (96 h LC_{50})	Newton et al., 2003
Lampsilis fasciola (mollusc; juveniles)	0.26 (96 h LC_{50})	Mummert et al., 2003
Polycelis felina (planarian; adults)	0.39 (96 h LC_{50}) 0.05 (30 d LOEC)	Alonso, 2005
Sphaerium novaezelandiae (mollusc; juveniles)	0.49 (96 h LC_{50}) 0.05 (60 d LOEC)	Hickey and Vickers, 1994; Hickey and Martin, 1999
Polycelis tenuis (planarian; adults)	0.58 (96 h LC_{50})	Williams et al., 1986
Eulimnogammarus toletanus (amphipod; adults)	0.65 (96 h LC_{50}) 0.09 (96 h $LC_{0.01}$)	Alonso and Camargo, 2004
Oncorhynchus gorbuscha (salmonid; fry)	0.08 (96 h LC_{50})	Rice and Bailey, 1980
Oncorhynchus mykiss (salmonid; alevins)	0.16–0.37 (96 h LC_{50}) 0.05 (72 d LC_{50})	Calamari et al., 1977
Salmo salar (salmonid; fry)	0.23 (24 h LC_{50})	Herbert and Shurben, 1965
Perca fluviatilis (percoid; fry)	0.29 (96 h LC_{50})	Ball, 1967
Rutilus rutilus (cyprinid; fry)	0.35 (96 h LC_{50})	Ball, 1967

Values of toxicological parameters (LC_{50}, $LC_{0.01}$, LOEC), at different exposure times (hours or days), are expressed in mg NH_3–N/L.

Source : Camargo and Alonso 2006. Ecological and toxicological effects of nitrogen pollution in aquatic ecosystems: a global assessment. Environment International 32: 831-849

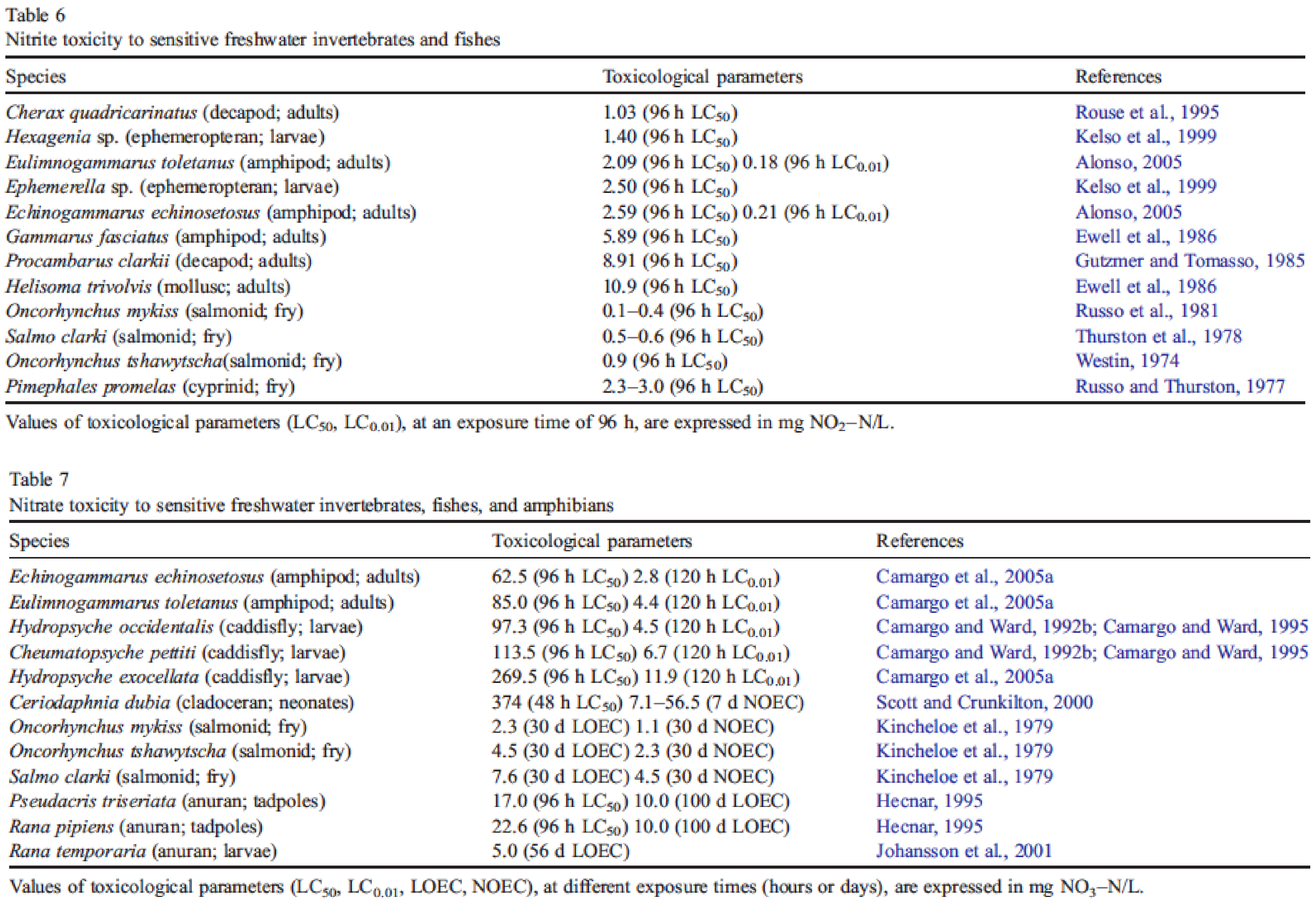


Table 6
Nitrite toxicity to sensitive freshwater invertebrates and fishes

Species	Toxicological parameters	References
Cherax quadricarinatus (decapod; adults)	1.03 (96 h LC_{50})	Rouse et al., 1995
Hexagenia sp. (ephemeropteran; larvae)	1.40 (96 h LC_{50})	Kelso et al., 1999
Eulimnogammarus toletanus (amphipod; adults)	2.09 (96 h LC_{50}) 0.18 (96 h $LC_{0.01}$)	Alonso, 2005
Ephemerella sp. (ephemeropteran; larvae)	2.50 (96 h LC_{50})	Kelso et al., 1999
Echinogammarus echinosetosus (amphipod; adults)	2.59 (96 h LC_{50}) 0.21 (96 h $LC_{0.01}$)	Alonso, 2005
Gammarus fasciatus (amphipod; adults)	5.89 (96 h LC_{50})	Ewell et al., 1986
Procambarus clarkii (decapod; adults)	8.91 (96 h LC_{50})	Gutzmer and Tomasso, 1985
Helisoma trivolvis (mollusc; adults)	10.9 (96 h LC_{50})	Ewell et al., 1986
Oncorhynchus mykiss (salmonid; fry)	0.1–0.4 (96 h LC_{50})	Russo et al., 1981
Salmo clarki (salmonid; fry)	0.5–0.6 (96 h LC_{50})	Thurston et al., 1978
Oncorhynchus tshawytscha(salmonid; fry)	0.9 (96 h LC_{50})	Westin, 1974
Pimephales promelas (cyprinid; fry)	2.3–3.0 (96 h LC_{50})	Russo and Thurston, 1977

Values of toxicological parameters (LC_{50}, $LC_{0.01}$), at an exposure time of 96 h, are expressed in mg NO_2–N/L.

Table 7
Nitrate toxicity to sensitive freshwater invertebrates, fishes, and amphibians

Species	Toxicological parameters	References
Echinogammarus echinosetosus (amphipod; adults)	62.5 (96 h LC_{50}) 2.8 (120 h $LC_{0.01}$)	Camargo et al., 2005a
Eulimnogammarus toletanus (amphipod; adults)	85.0 (96 h LC_{50}) 4.4 (120 h $LC_{0.01}$)	Camargo et al., 2005a
Hydropsyche occidentalis (caddisfly; larvae)	97.3 (96 h LC_{50}) 4.5 (120 h $LC_{0.01}$)	Camargo and Ward, 1992b; Camargo and Ward, 1995
Cheumatopsyche pettiti (caddisfly; larvae)	113.5 (96 h LC_{50}) 6.7 (120 h $LC_{0.01}$)	Camargo and Ward, 1992b; Camargo and Ward, 1995
Hydropsyche exocellata (caddisfly; larvae)	269.5 (96 h LC_{50}) 11.9 (120 h $LC_{0.01}$)	Camargo et al., 2005a
Ceriodaphnia dubia (cladoceran; neonates)	374 (48 h LC_{50}) 7.1–56.5 (7 d NOEC)	Scott and Crunkilton, 2000
Oncorhynchus mykiss (salmonid; fry)	2.3 (30 d LOEC) 1.1 (30 d NOEC)	Kincheloe et al., 1979
Oncorhynchus tshawytscha (salmonid; fry)	4.5 (30 d LOEC) 2.3 (30 d NOEC)	Kincheloe et al., 1979
Salmo clarki (salmonid; fry)	7.6 (30 d LOEC) 4.5 (30 d NOEC)	Kincheloe et al., 1979
Pseudacris triseriata (anuran; tadpoles)	17.0 (96 h LC_{50}) 10.0 (100 d LOEC)	Hecnar, 1995
Rana pipiens (anuran; tadpoles)	22.6 (96 h LC_{50}) 10.0 (100 d LOEC)	Hecnar, 1995
Rana temporaria (anuran; larvae)	5.0 (56 d LOEC)	Johansson et al., 2001

Values of toxicological parameters (LC_{50}, $LC_{0.01}$, LOEC, NOEC), at different exposure times (hours or days), are expressed in mg NO_3–N/L.

Source : Camargo and Alonso 2006. Ecological and toxicological effects of nitrogen pollution in aquatic ecosystems: a global assessment. Environment International 32: 831-849

Thanks!

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Students Assignment

- Phosphorus has been considered guilty of <u>freshwater</u> eutrophication and has been already condemned.
- Nitrogen has now been acused to be a partner of phosphorus in this terrible crime, but is there enough evidence for considering N guilty?
- Your mission is to defend/acuse N in a court where Zebu will play the judge and the other teachers will play the popular jury
- Each group must search for evidence from your own geographical region