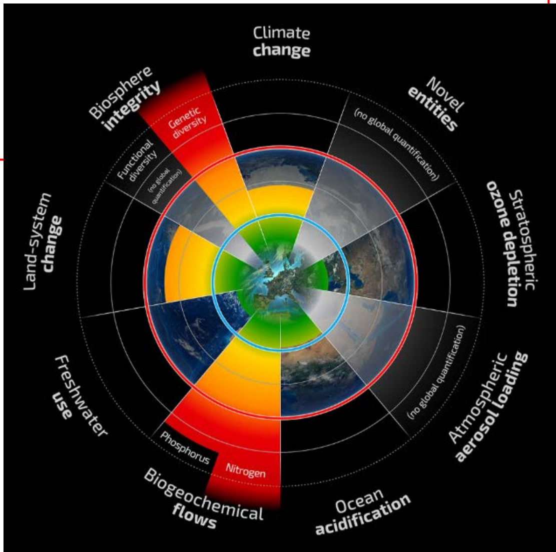
# III. Stratospheric Ozone Depletion

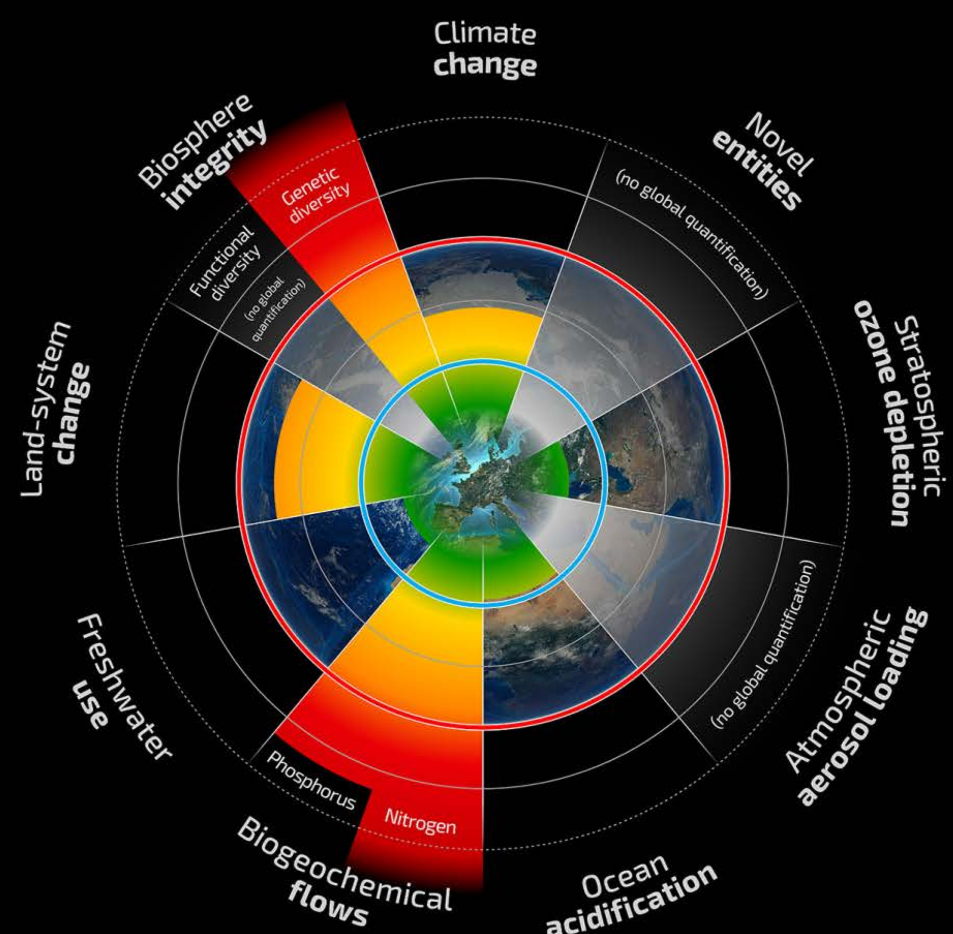
| Earth-system process | Control variable(s) | Planetary boundary (zone of uncertainty) | Current value of control variable |
|---|---|---|---|
| Stratospheric ozone depletion (R2009: same) | Stratospheric $O_3$ concentration, DU | <5% reduction from pre-industrial level of 290 DU (5%–10%), assessed by latitude | Only transgressed over Antarctica in Austral spring (~200 DU) |

**Boundary:** Average conc. of stratospheric $O_3$ no lower than 276 Dobson units
**Current level:** 283 Dobson units
**Diagnosis:** Safe, and improving



# Planetary Boundaries

A safe operating space for humanity




**Beyond zone of uncertainty** (high risk)
**In zone of uncertainty** (increasing risk)
**Below boundary** (safe)
**Boundary not yet quantified**

**Source:** Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, *Science*, 16 January 2015.
**Design:** Globaïa

# History of Ozone Depletion Research

# 1974

## Stratospheric Chlorine: a Possible Sink for Ozone

R. S. Stolarski and R. J. Cicerone

*Space Physics Research Laboratory, The University of Michigan, Ann Arbor, Michigan 48105*

Received January 18, 1974

This study proposes that the oxides of chlorine, $ClO_x$, may constitute an important sink for stratospheric ozone. A photochemical scheme is devised which includes two catalytic cycles through which $ClO_x$ destroys odd oxygen. The individual ClX constituents (HCl, Cl, ClO, and OClO) perform analogously to the respective constituents ($HNO_3$, NO, $NO_2$, and $NO_3$) in the $NO_x$ catalytic cycles, but the ozone destruction efficiency is higher for $ClO_x$. Our photochemical scheme predicts that ClO is the dominant chlorine

(Reprinted from Nature, Vol. 249, No. 5460, pp. 810–812, June 28, 1974)

## Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone

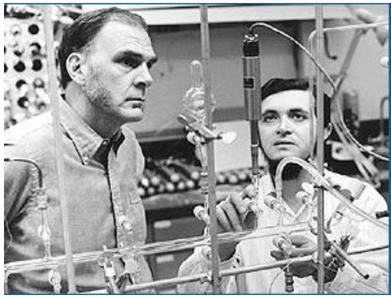
**Mario J. Molina & F. S. Rowland**

Department of Chemistry, University of California, Irvine, California 92664

*Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40–150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone.*

Halogenated aliphatic hydrocarbons have been added to the

effective rates of vertical diffusion of molecules at these altitudes are also subject to substantial uncertainties. Vertical mixing is frequently modelled through the use of 'eddy' diffusion coefficients[10,16–18], which are presumably relatively insensitive to the molecular weight of the diffusing species. Calculated using a time independent one-dimensional vertical diffusion model with eddy diffusion coefficients of magnitude $K \sim (3 \times 10^3)$–$10^4$ cm$^2$ s$^{-1}$ at altitudes 20–40 km (refs 10, 15–18), the atmospheric lifetimes of $CFCl_3$ and $CF_2Cl_2$ fall into the range of 40–150 yr. The time required for approach toward a steady state is thus measured in decades, and the concentrations of chlorofluoromethanes in the atmosphere can be expected to reach



- 1 atom of chlorine can decompose circa 100 000 $O_3$ molecules!

# 1978

- CFC (chloro-fluoro-carbons) banned in sprays in USA
- CFC consumption in other applications, however, still grows

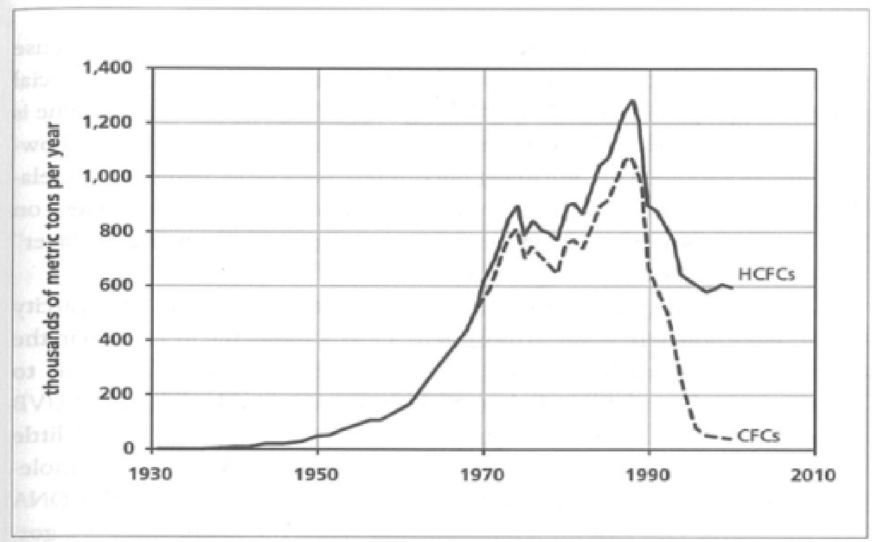




FIGURE 5-1 World Production of Chlorofluorocarbons

# 1984

- Halley Bay station in Antartica measured 40 % $O_3$ decrease
- the same dramatic decrease verified in another station 1000 miles away

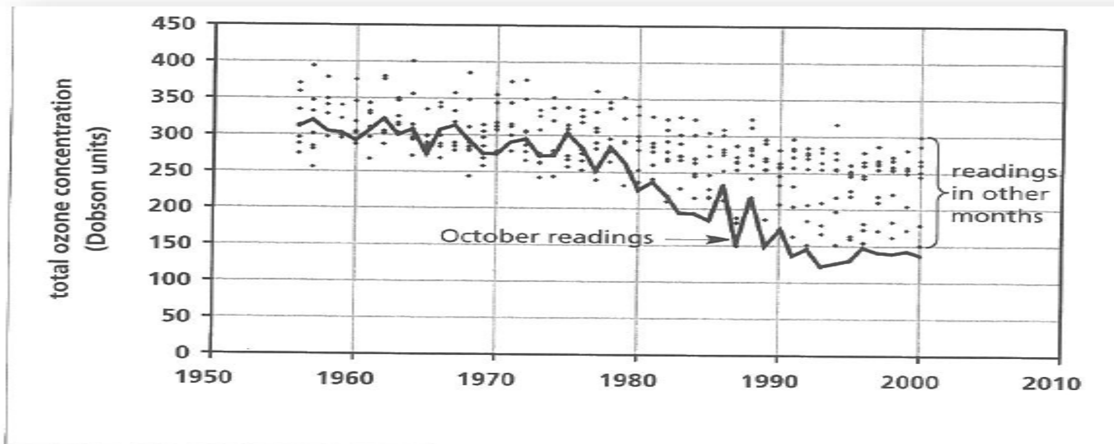


FIGURE 5-4 Ozone Measurements at Halley, Antarctica

## Large losses of total ozone in Antarctica reveal seasonal $ClO_x/NO_x$ interaction


**J. C. Farman, B. G. Gardiner & J. D. Shanklin**

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK



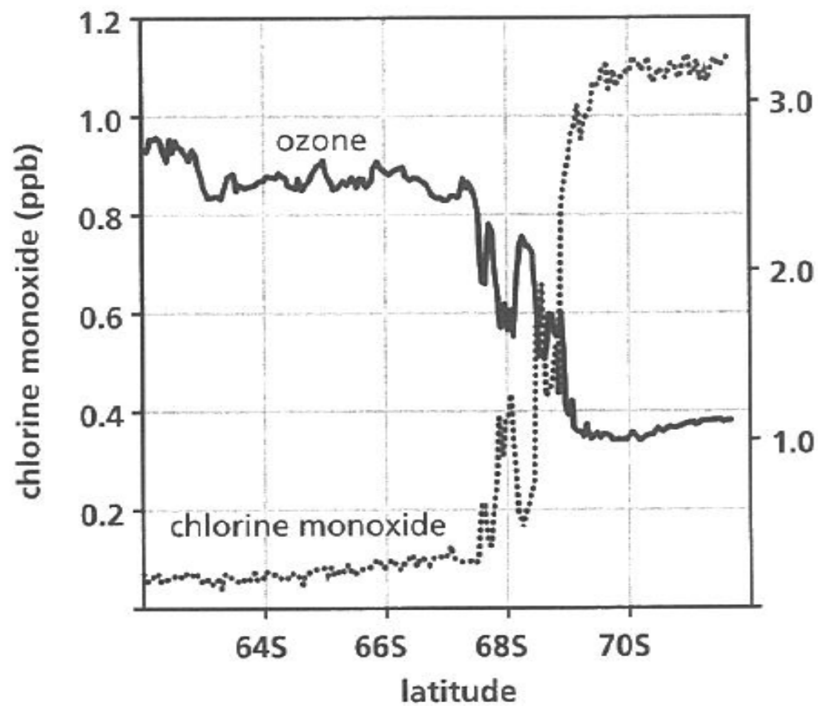
**Recent attempts[1,2] to consolidate assessments of the effect of human activities on stratospheric ozone ($O_3$) using one-dimensional models for 30° N have suggested that perturbations of total $O_3$ will remain small for at least the next decade. Results from such models are often accepted by default as global estimates[3]. The inadequacy of this approach is here made evident by observations that the spring values of total $O_3$ in Antarctica have now fallen considerably. The circulation in the lower stratosphere is apparently unchanged, and possible chemical causes must be considered. We suggest that the very low temperatures which prevail from midwinter until several weeks after the spring equinox make the Antarctic stratosphere uniquely sensitive to growth of inorganic chlorine, ClX, primarily by the effect of this growth on the $NO_2/NO$ ratio. This, with the height distribution of UV irradiation peculiar to the polar stratosphere, could account for the $O_3$ losses observed.**


Total $O_3$ has been measured at the British Antarctic Survey stations Argentine Islands, 65° S 64° W and Halley Bay

# 1987

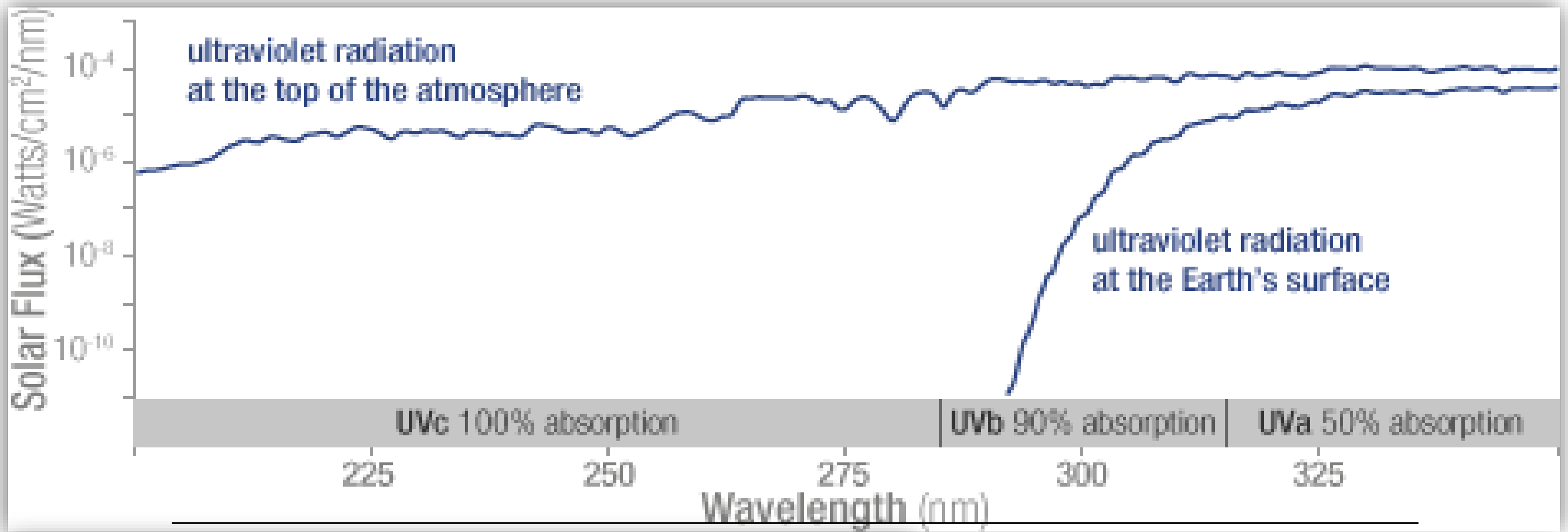
- **chlorine-ozone hypothesis confirmed** by the fly of a exploratory plane through the ozone hole measuring concentration of $O_3$ and ClO

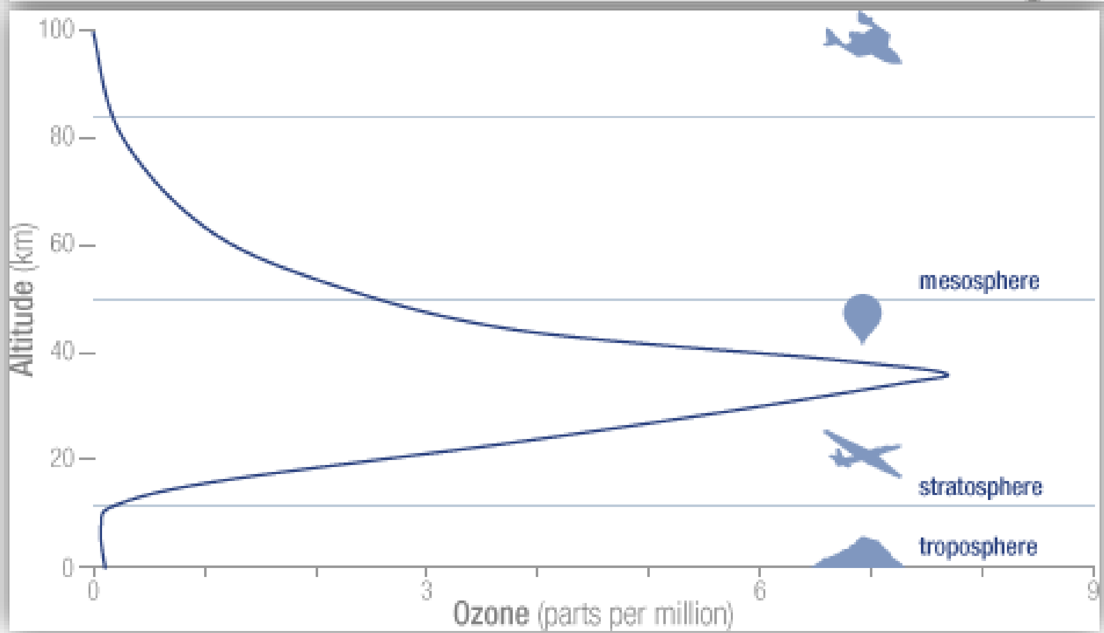
- there was found strong negative correlation between the concentration of both determined compounds

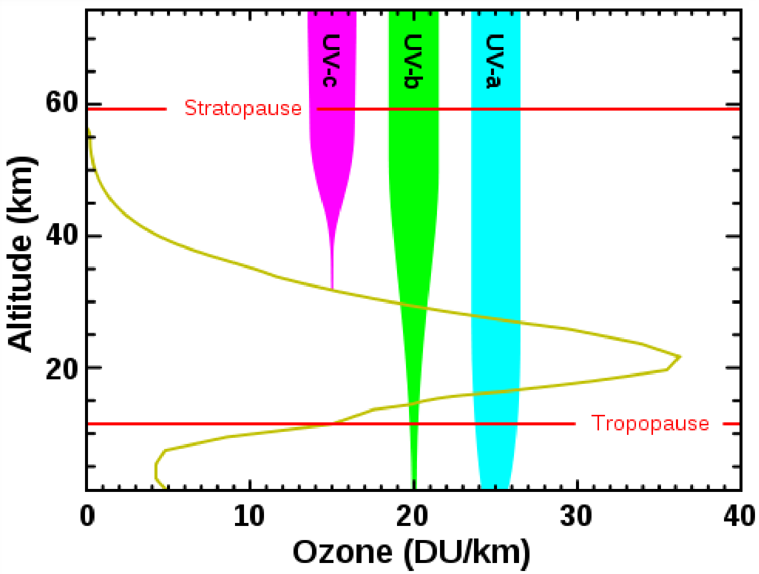


# Significance of the Ozone Depletion

# $O_3$ – protection of biosphere against harmful UVB radiation

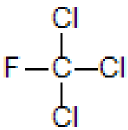


# Degradation of $O_3$ layer

- Cl radicals from Chloro-fluoro-carbons (CFC, Freon)
- Br radicals from Bromo-fluoro-carbons (BFC, Halons)



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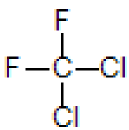

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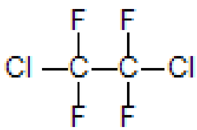

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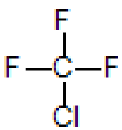

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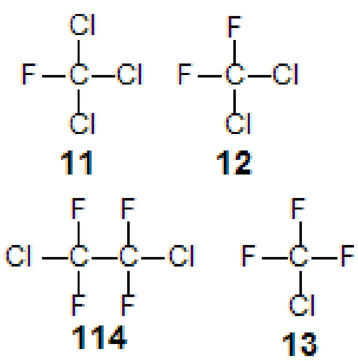
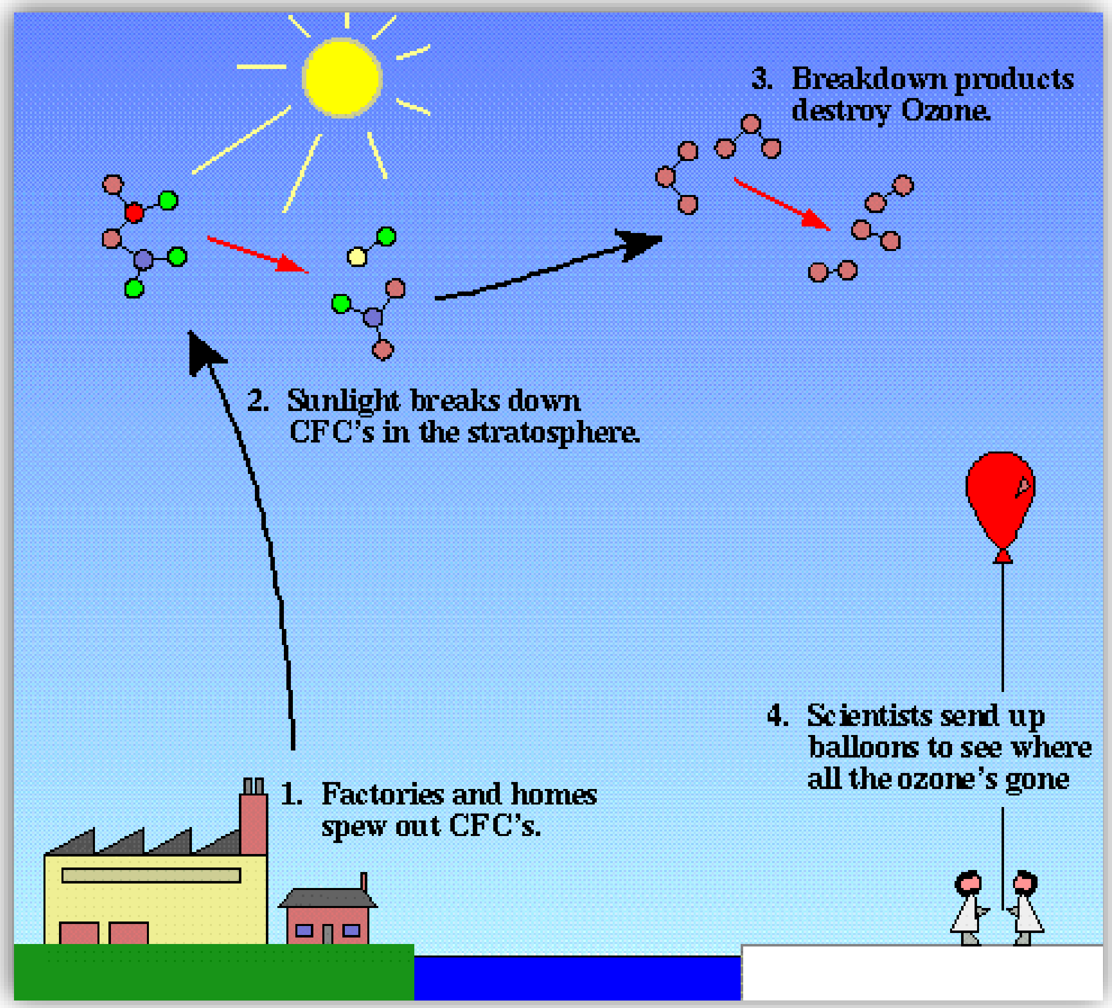
# Degradation of $O_3$ layer

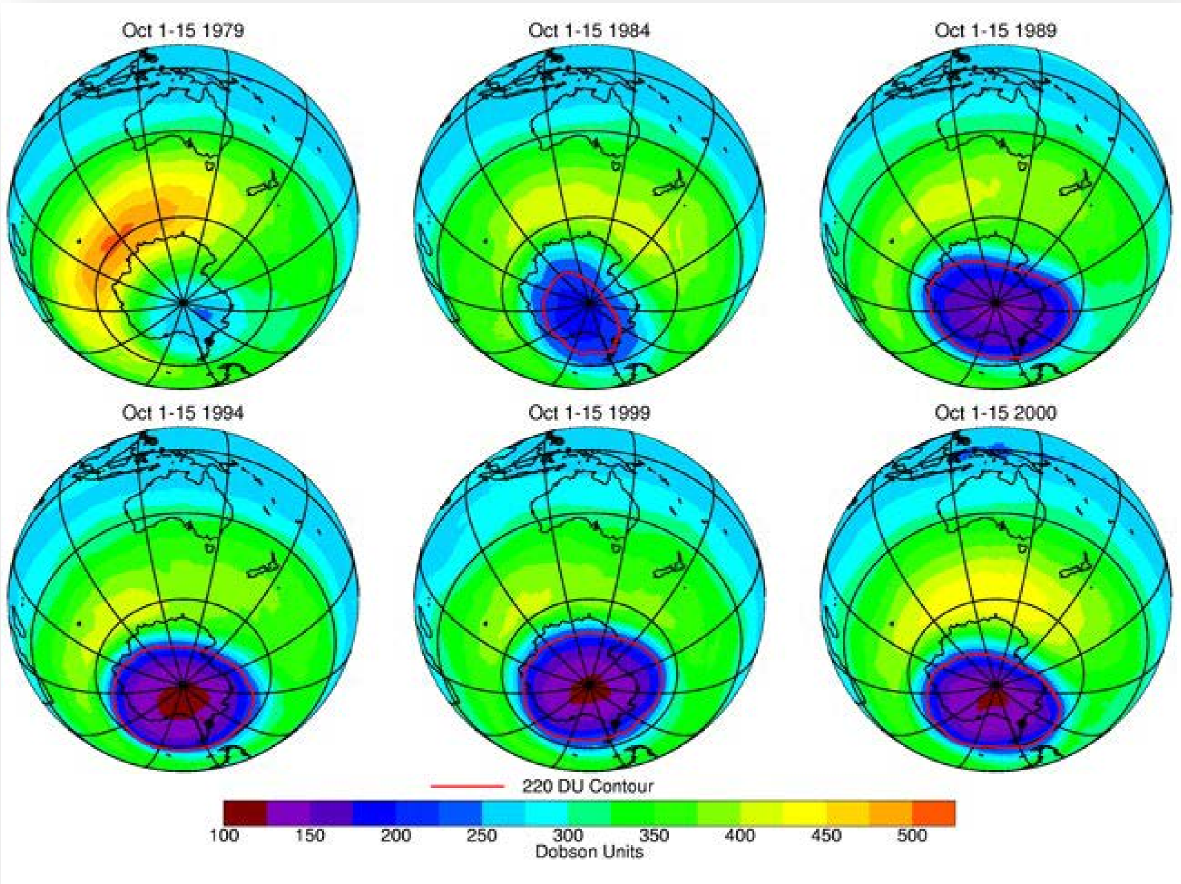
- Cl· radicals from Chloro-fluoro-carbons (CFC, Freon)
- Br· radicals from Bromo-fluoro-carbons (BFC, Halon)

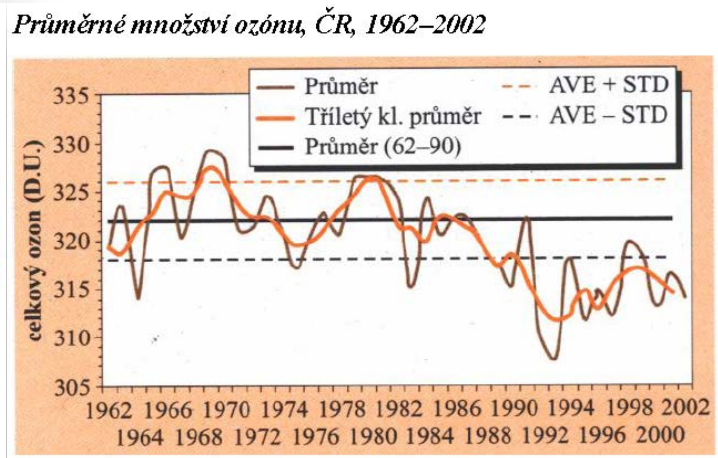


# Ozone hole

- ozone depletion primarily over the South pole area
- however, significant $O_3$ depletion observed everywhere

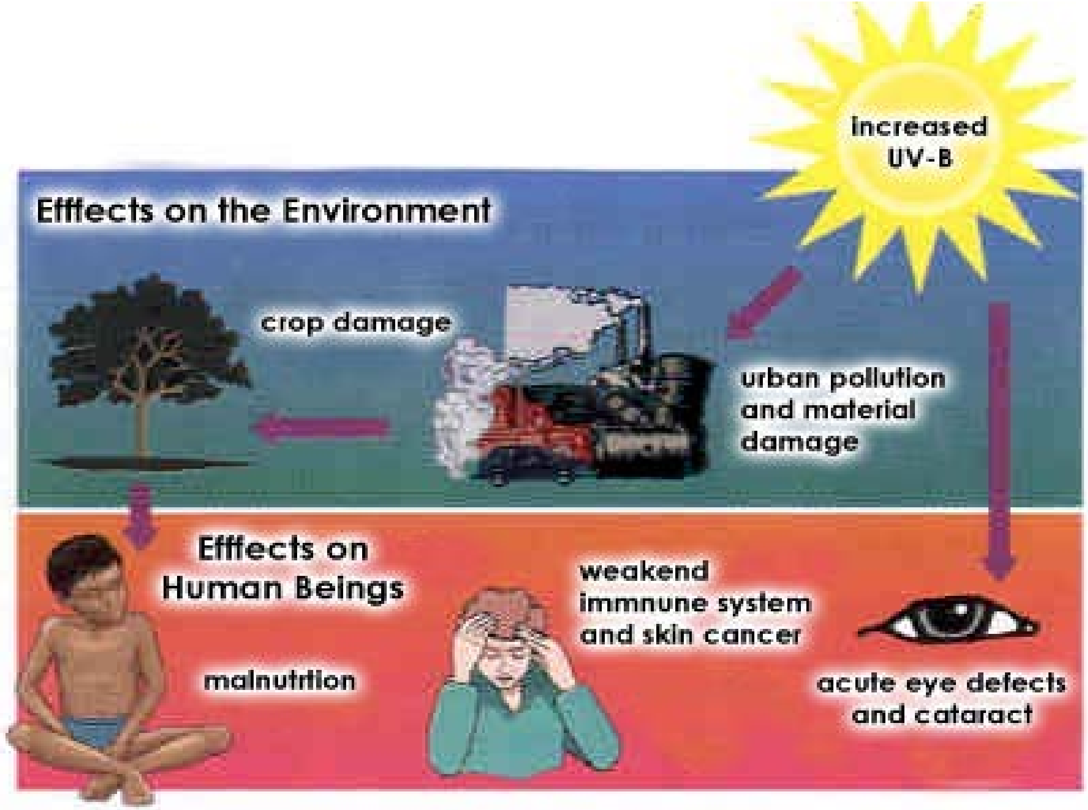


# Consequences of $O_3$ depletion

# Less $O_3$ = more cancer

1% ↓ conc. $O_3$ ≈ 2% ↑ intensity UVB ≈ 4% ↑ skin cancer hazard




- majority of melanoms are on sunlit parts of the skin
- greatest incidence in Australia

# Impact of increased UVB irradiaton on crop

| Possible changes in plant characteristics | Consequences | Selected sensitive crops |
|---|---|---|
| ■ Reduced **photosynthesis** | | Rice |
| ■ Reduced **water-use efficiency** | Enhanced plant fragility | Oats |
| ■ Enhanced **drought stress sensitivity** | | |
| ■ Reduced **leaf area** | Growth limitation | Sorghum |
| ■ Reduced **leaf conductance** | | |
| ■ Modified **flowering** (either inhibited or stimulated) | Yield reduction | Soybeans |
| ■ Reduced **dry matter production** | | Beans |

NB: Summary conclusions from artificial exposure studies.

Source: modified from Krupa and Kickert (1989) by Runeckles and Krupa (1994) in: Fakhri Bazzaz, Wim Sombroek, *Global Climate Change and Agricultural Production*, FAO, Rome,1996.

# Ozone hole

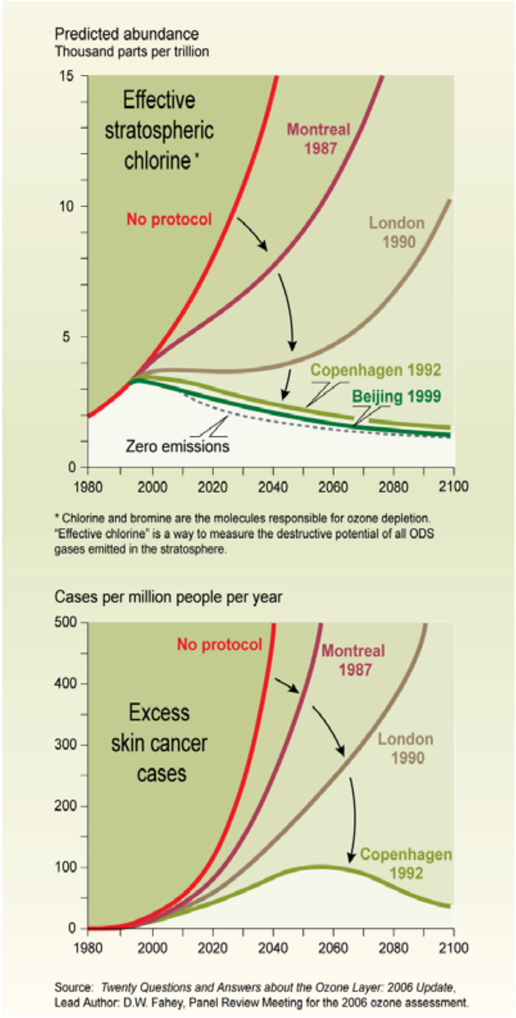
# - solution

# Effect of accepted solutions

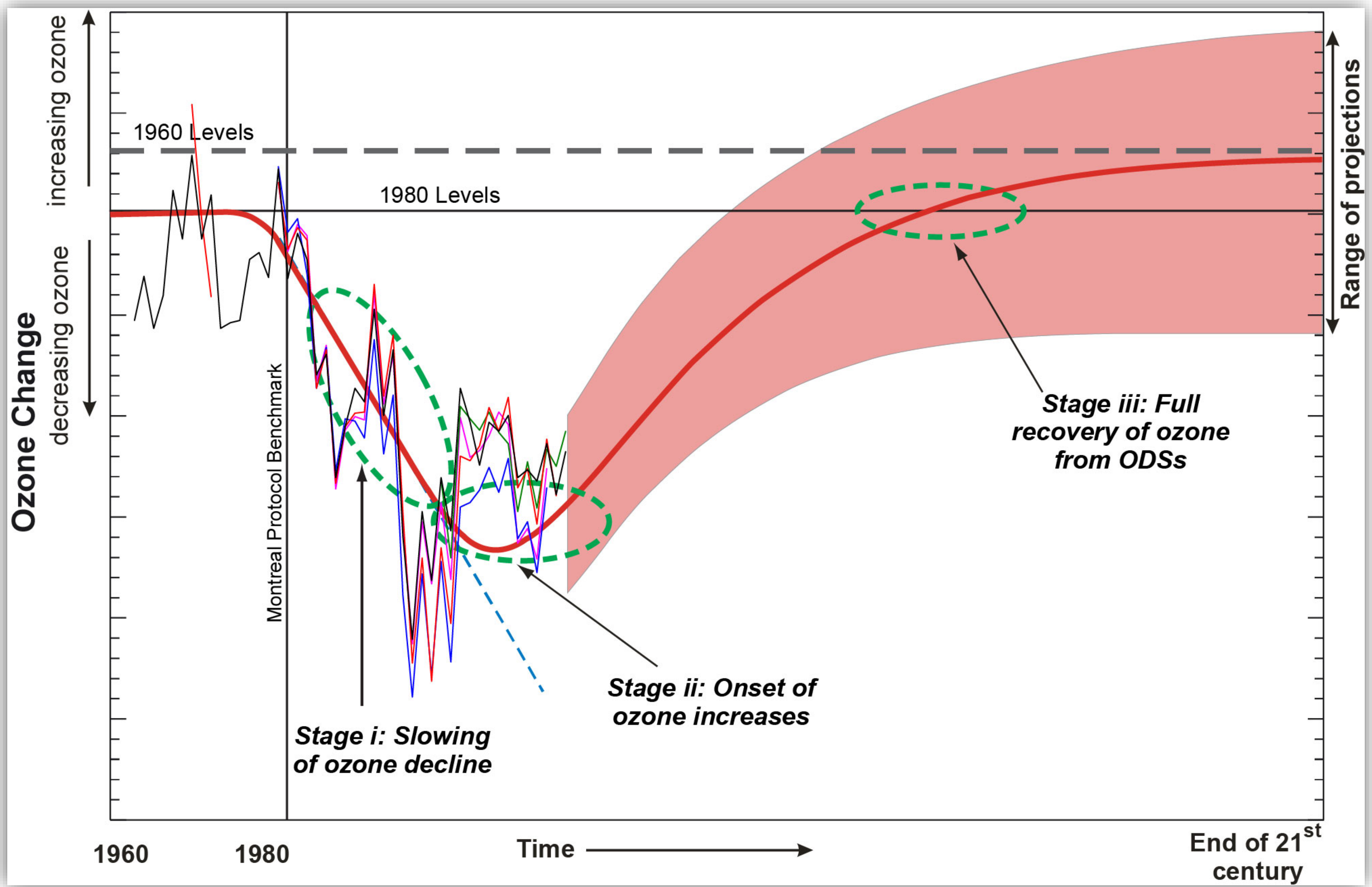
**1985** – Vienna Convention for the Protection of the Ozone Layer

**1987** – Montreal protocol + amendments

THE EFFECTS OF THE MONTREAL PROTOCOL AMENDMENTS AND THEIR PHASE-OUT SCHEDULES



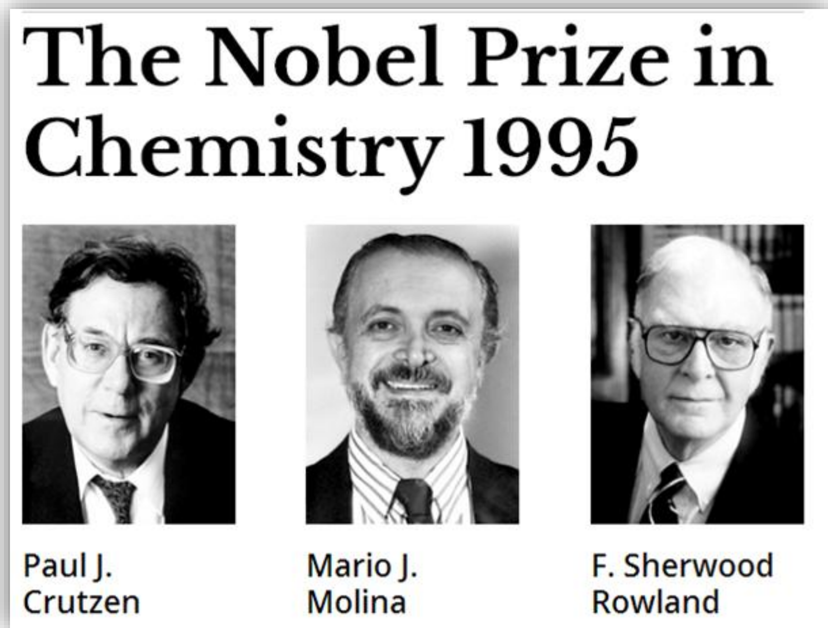
# Time delay – ozone depletion and recovery

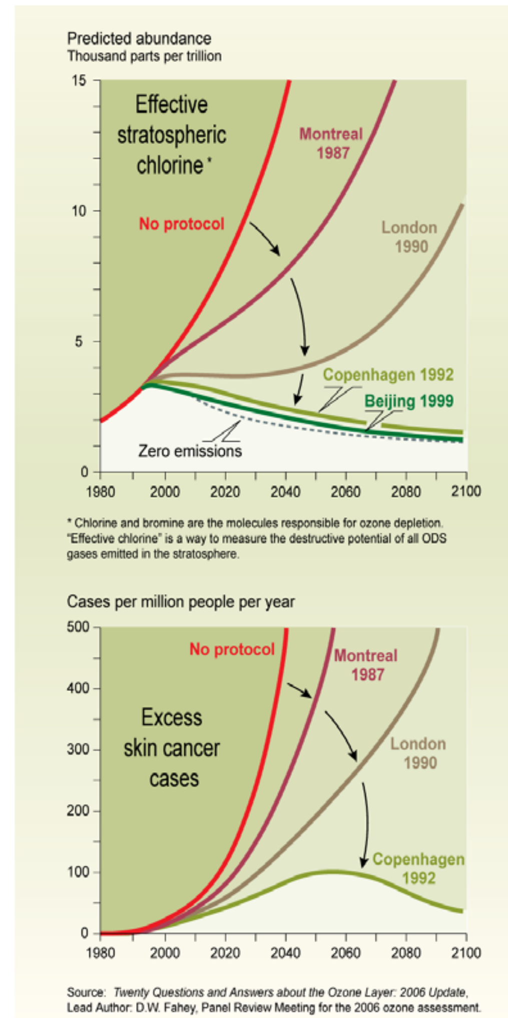


# Řešení a důsledky

**1985** – Vienna Convention for the Protection of the Ozone Layer
**1987** – Montreal protocol + amendments

THE EFFECTS OF THE MONTREAL PROTOCOL AMENDMENTS
AND THEIR PHASE-OUT SCHEDULES



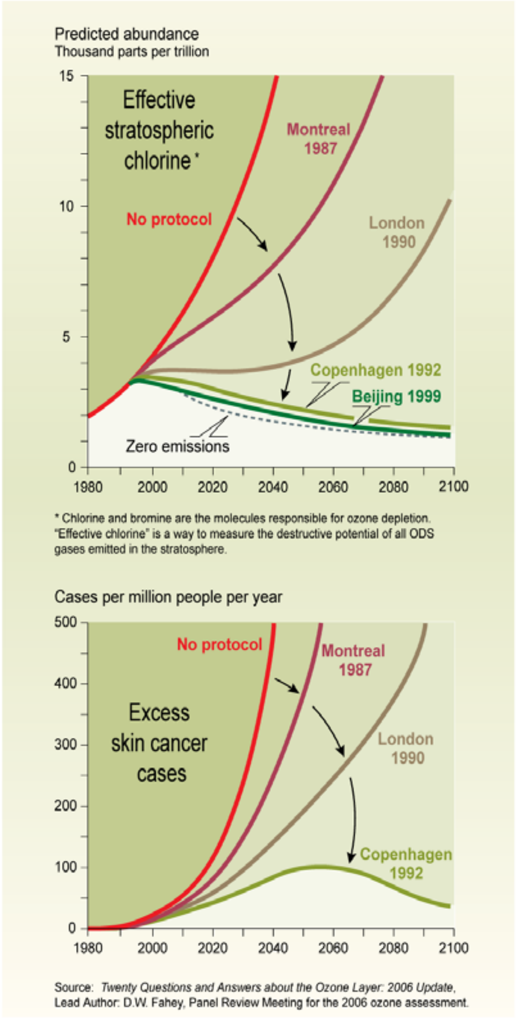

*„for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone.“*

# Effect of accepted solutions

**1985** – Vienna Convention for the Protection of the Ozone Layer

**1987** – Montreal protocol + amendments

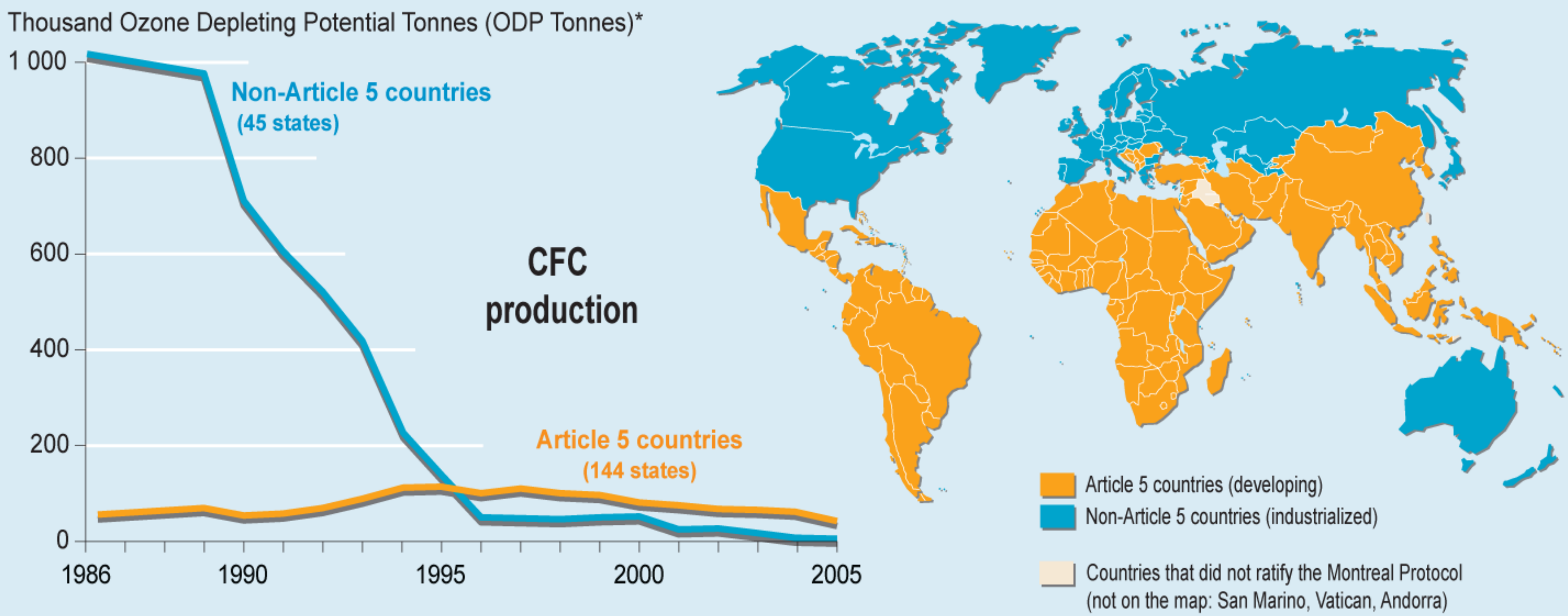
THE EFFECTS OF THE MONTREAL PROTOCOL AMENDMENTS AND THEIR PHASE-OUT SCHEDULES




## Costs of CFC abandonment

- 1988-2000 – product. decreased for 90%
- overal costs of abandonment - 40 bil. $
- no job losses
- 1/3 simply not necessary
- new HFC in cars increased car price for 50-150 $ (prognosed 1000-1500 $)
- $CH_3Br$ for soil sterilisation replaced e.g. with crop rotation
- $CH_3Br$ for stores fumigation replaced with $CO_2$

# A common but differentiated responsibility




* Tonnes multiplied by the ozone depleting potential of the considered gas.

Source: United Nations Environment Programme Ozone Secretariat

UNEP GRID ARENDAL

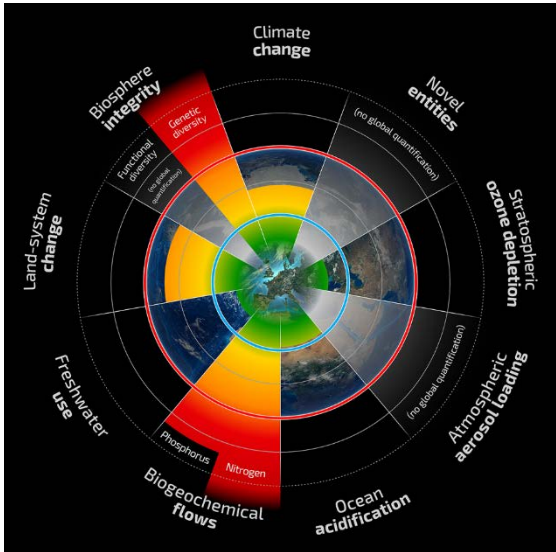
# Lesson from successful solution of global issue

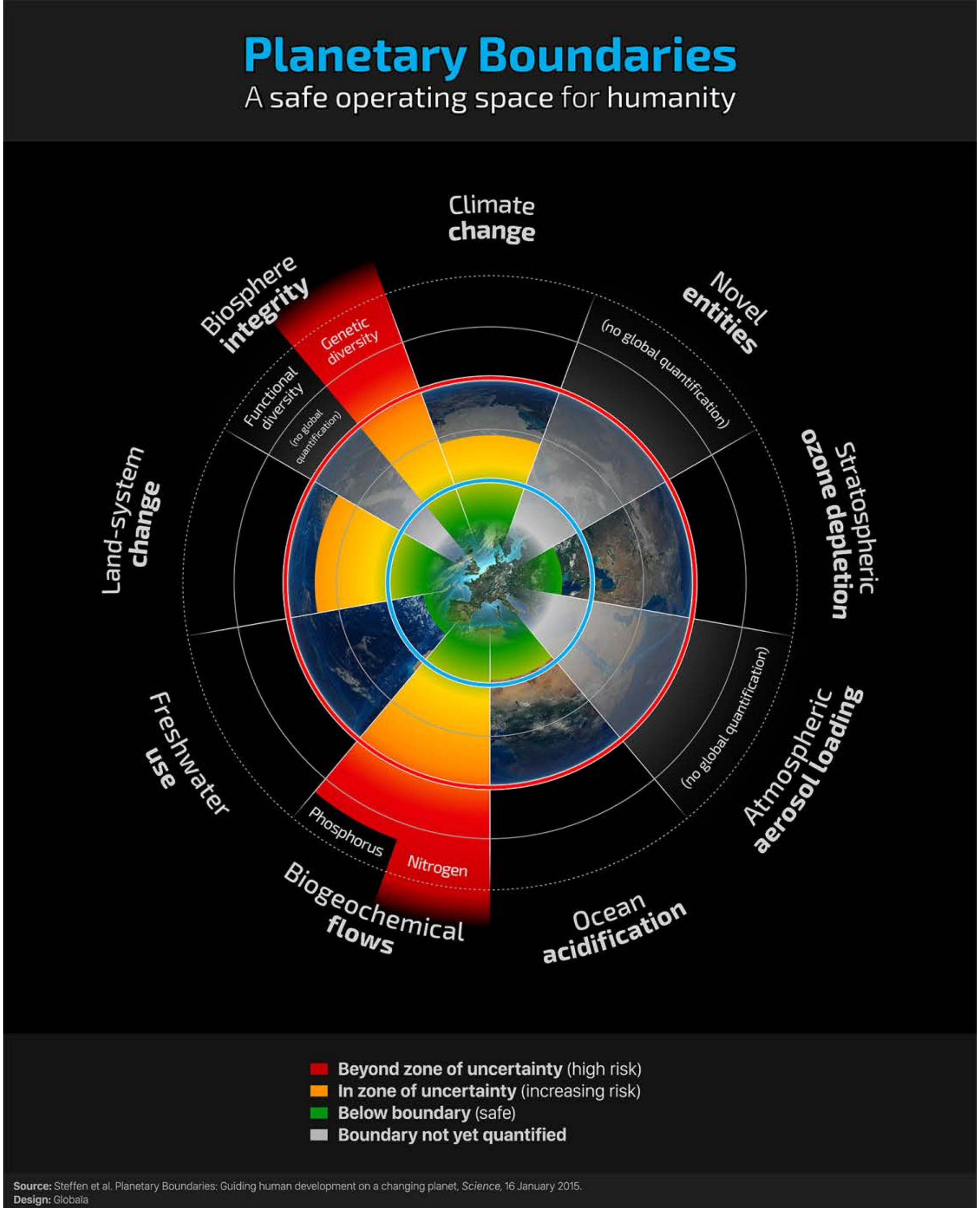
- cooperation of all the following stakeholders:

- scientific discoveries and monitoring – **problem notification**
- UNEP – **international coordinator of legal measures**
- environemntal activists – **pressure to solve the issue**
- responsible consuments – **purchasing according to env. info**
- technical experts - **developing env.-friendly alternatives**
- flexible and responsible industry

# IV. Ocean acidification

| Earth-system process | Control variable(s) | Planetary boundary (zone of uncertainty) | Current value of control variable |
|---|---|---|---|
| Ocean acidification (R2009: same) | Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite ($\Omega_{arag}$) | ≥80% of the pre-industrial aragonite saturation state of mean surface ocean, including natural diel and seasonal variability (≥80%– ≥70%) | ~84% of the pre-industrial aragonite saturation state |

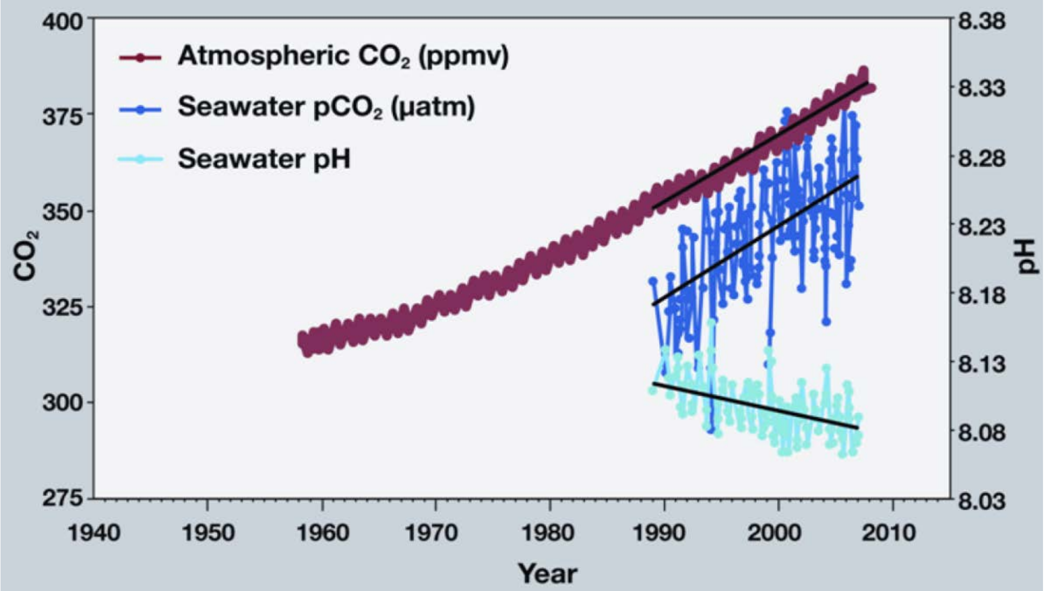


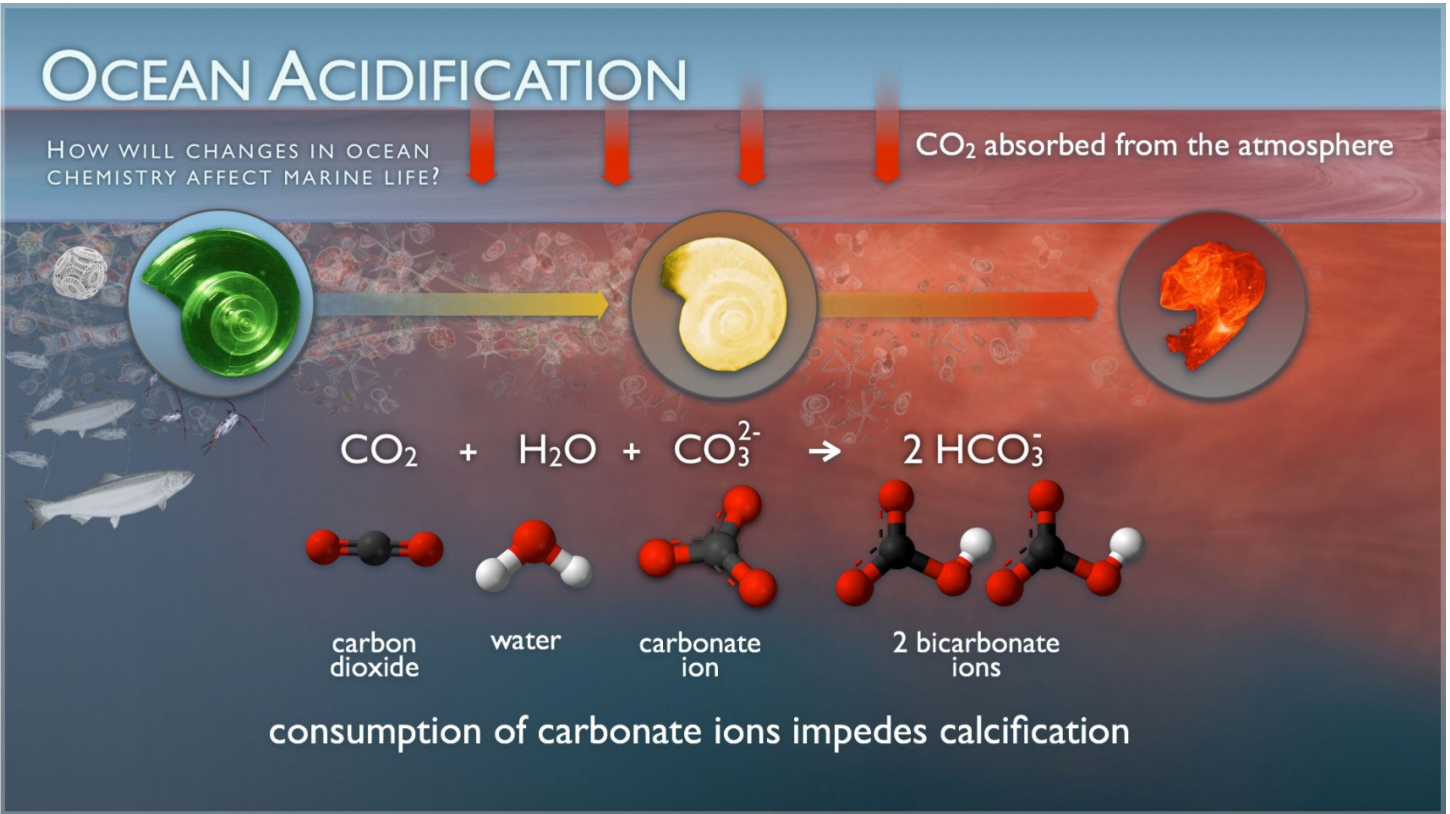


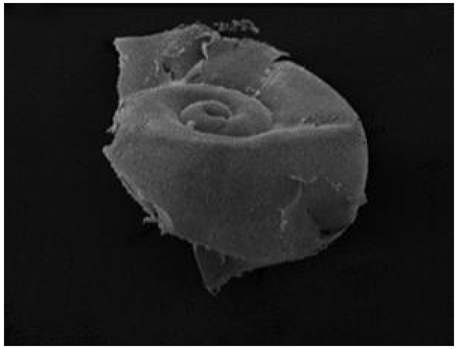
Planetary Boundaries
A safe operating space for humanity
Climate change
Novel entities
(no global quantification)
Stratospheric ozone depletion
Atmospheric aerosol loading
(no global quantification)
Ocean acidification
Biogeochemical flows
Phosphorus
Nitrogen
Freshwater use
Land-system change
Biosphere integrity
Genetic diversity
Functional diversity
(no global quantification)
Beyond zone of uncertainty (high risk)
In zone of uncertainty (increasing risk)
Below boundary (safe)
Boundary not yet quantified
Source: Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, Science, 16 January 2015.
Design: Globaïa

# Ocean acidification

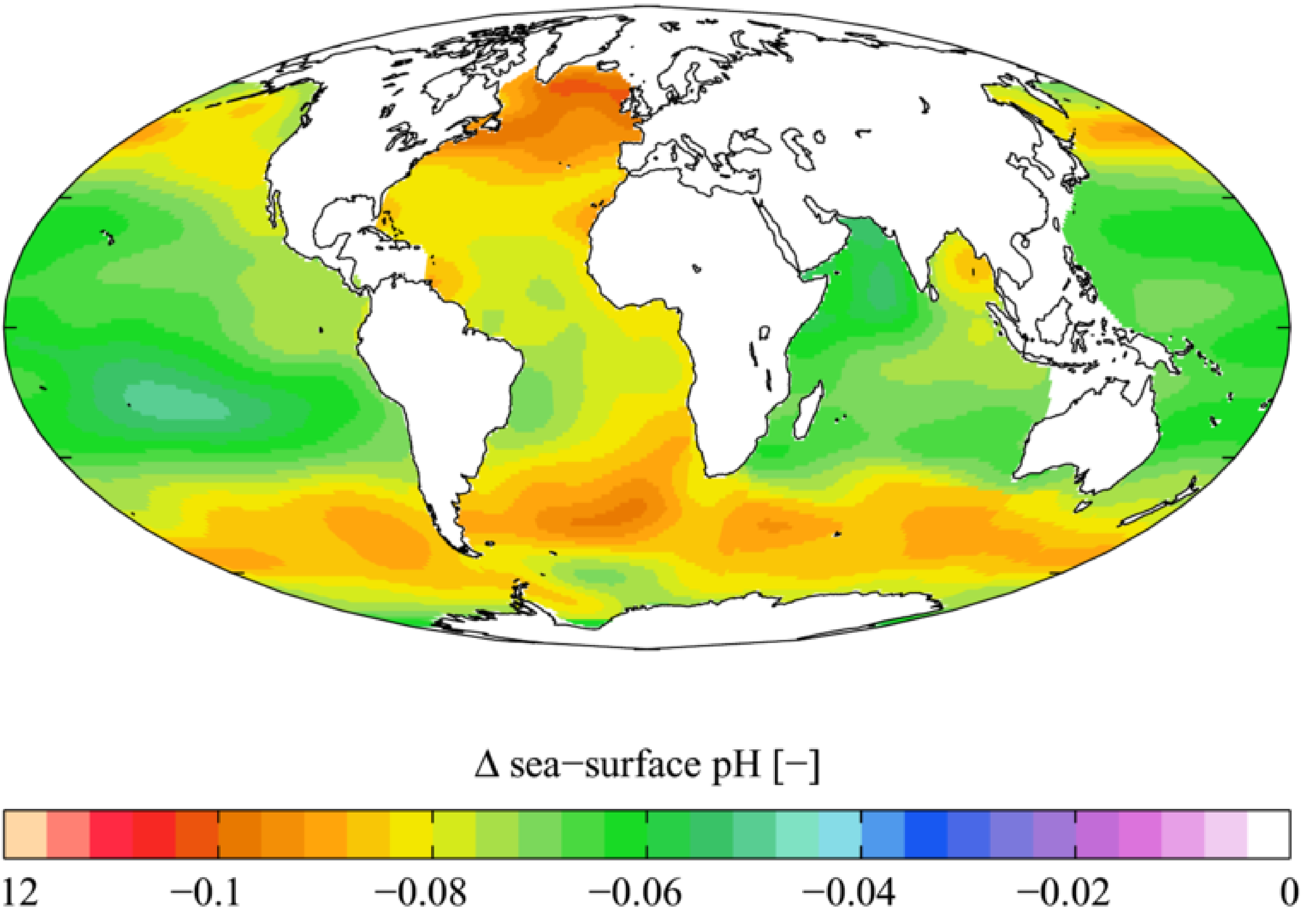
- what is the cause?



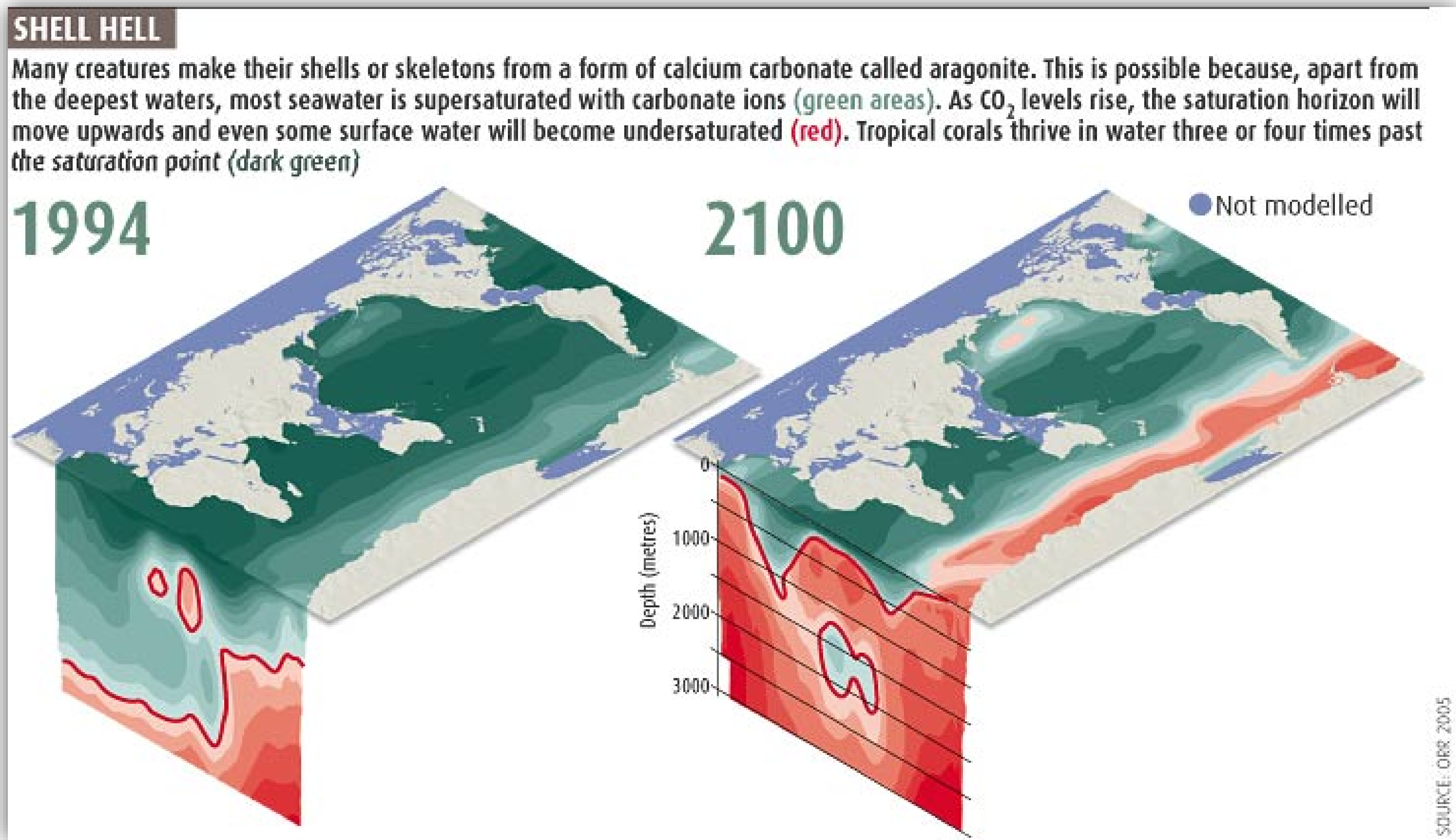



# Change in pH of oceans 1700-2000



# Change in pH of oceans - 3D distribution



# „Natural laboratory“

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## Natural lab shows sea's acid path

By Richard Black
Environment correspondent, BBC News website

Scientists study conditions at the bottom of the Mediterranean Sea

Natural carbon dioxide vents on the sea floor are showing scientists how carbon emissions will affect marine life.

Dissolved CO2 makes water more acidic, and around the vents, researchers saw a fall in species numbers, and snails with their

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26 March 2014 Last updated at 23:03 GMT

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## How climate change will acidify the oceans

**By Roger Harrabin**
BBC environment analyst, Normanby Island

**Off the remote eastern tip of Papua New Guinea a natural phenomenon offers an alarming glimpse into the future of the oceans, as increasing concentrations of CO2 in the atmosphere make sea water more acidic.**

Streams of volcanic CO2 bubbles emerge from deep under the seabed here, like a giant jacuzzi.

As the bubbles of carbon dioxide dissolve into the water, carbonic acid is

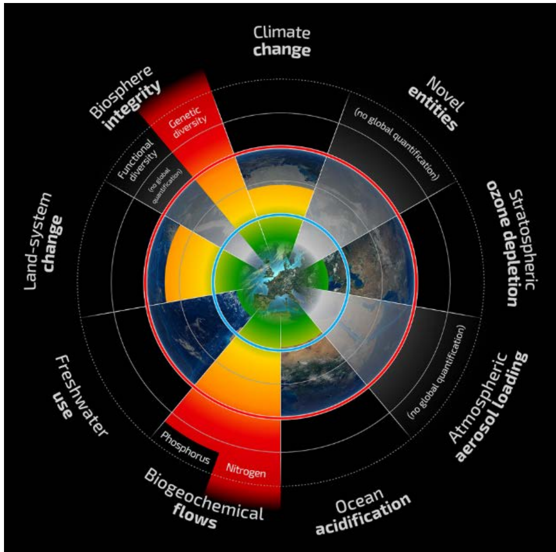
**In today's Magazine**

One lonely man and his hoard of Nazi art

Malaysia plane: 10 questions that are still unresolved

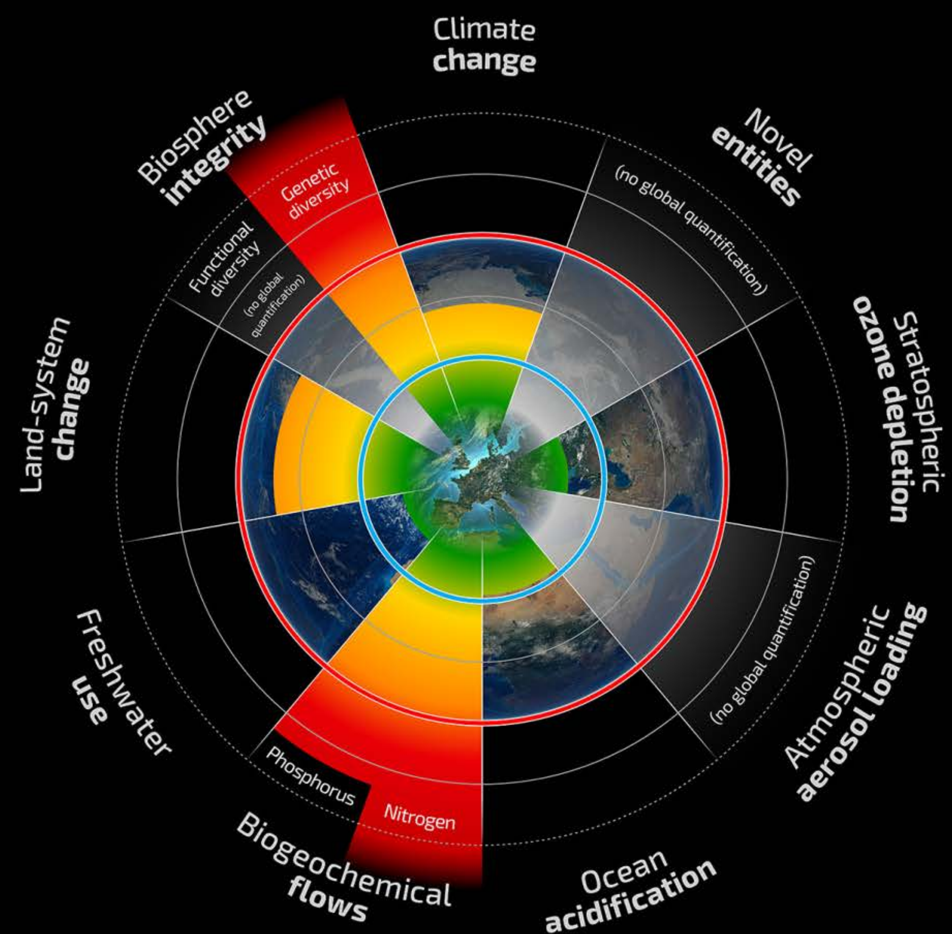
# V and VI. Biogeochemical flows of P and N

| Earth-system process | Control variable(s) | Planetary boundary (zone of uncertainty) | Current value of control variable |
|---|---|---|---|
| Biogeochemical flows: (P and N cycles) (R2009: Biogeochemical flows: (interference with P and N cycles)) | *P Global*: P flow from freshwater systems into the ocean | 11 Tg P $yr^{-1}$ (11–100 Tg P $yr^{-1}$) | ~22 Tg P $yr^{-1}$ |
| | *P Regional*: P flow from fertilizers to erodible soils | 6.2 Tg $yr^{-1}$ mined and applied to erodible (agricultural) soils (6.2-11.2 Tg $yr^{-1}$). Boundary is a global average but regional distribution is critical for impacts. | ~14 Tg P $yr^{-1}$ |
| | *N Global*: Industrial and intentional biological fixation of N | 62 Tg N $yr^{-1}$ (62–82 Tg N $yr^{-1}$). Boundary acts as a global 'valve' limiting introduction of new reactive N to Earth System, but regional distribution of fertilizer N is critical for impacts. | ~150 Tg N $yr^{-1}$ |



# Planetary Boundaries

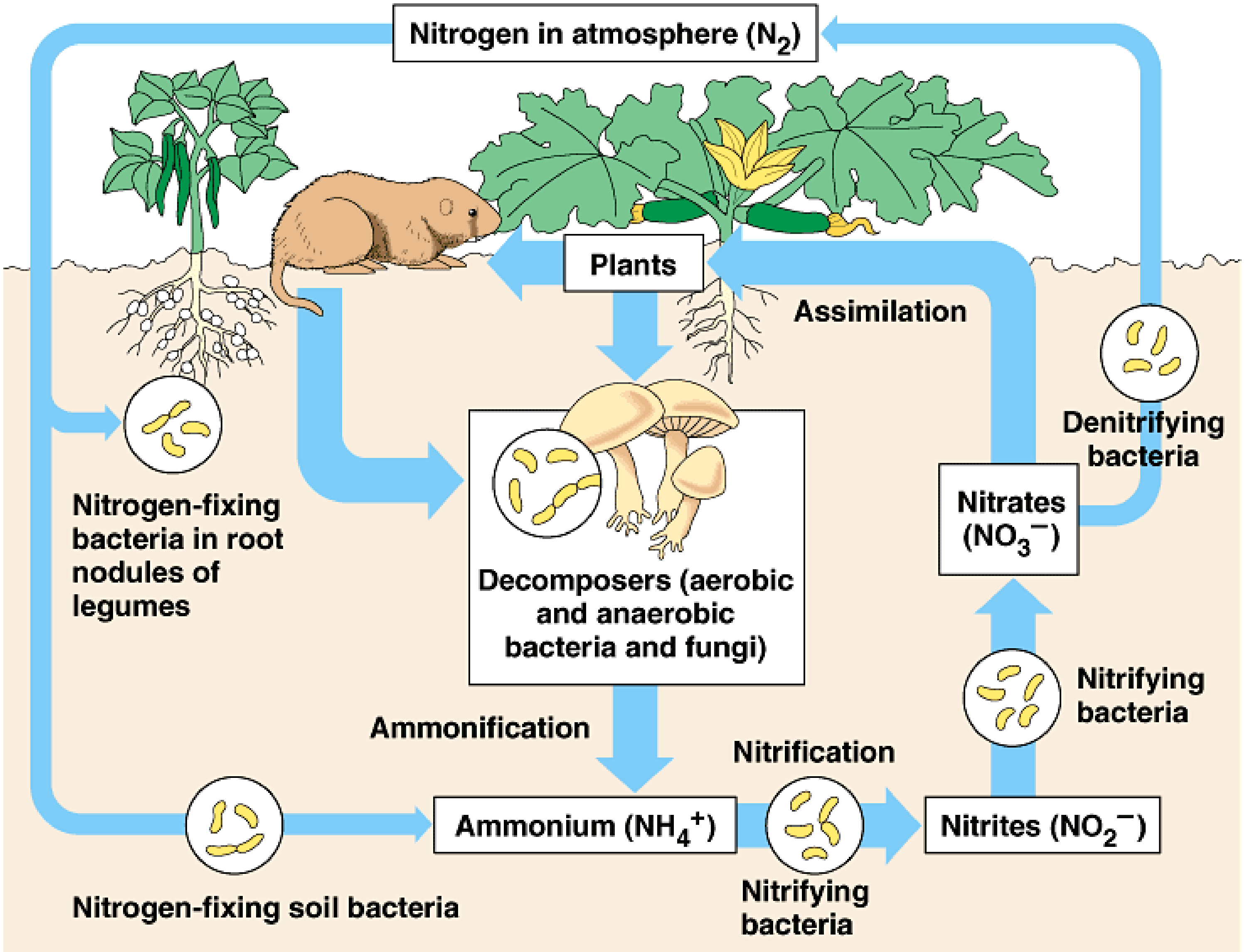
A safe operating space for humanity



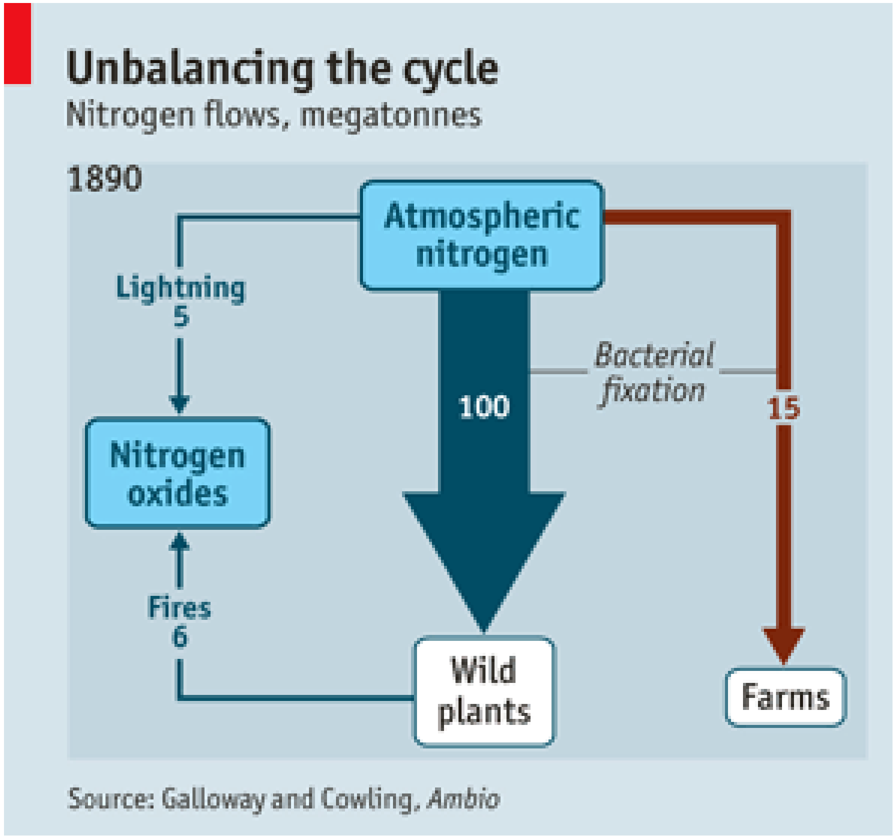

- **Beyond zone of uncertainty** (high risk)
- **In zone of uncertainty** (increasing risk)
- **Below boundary** (safe)
- **Boundary not yet quantified**

**Source:** Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, *Science*, 16 January 2015.
**Design:** Globaïa

# N - Nitrogen – natural geochemical cycle

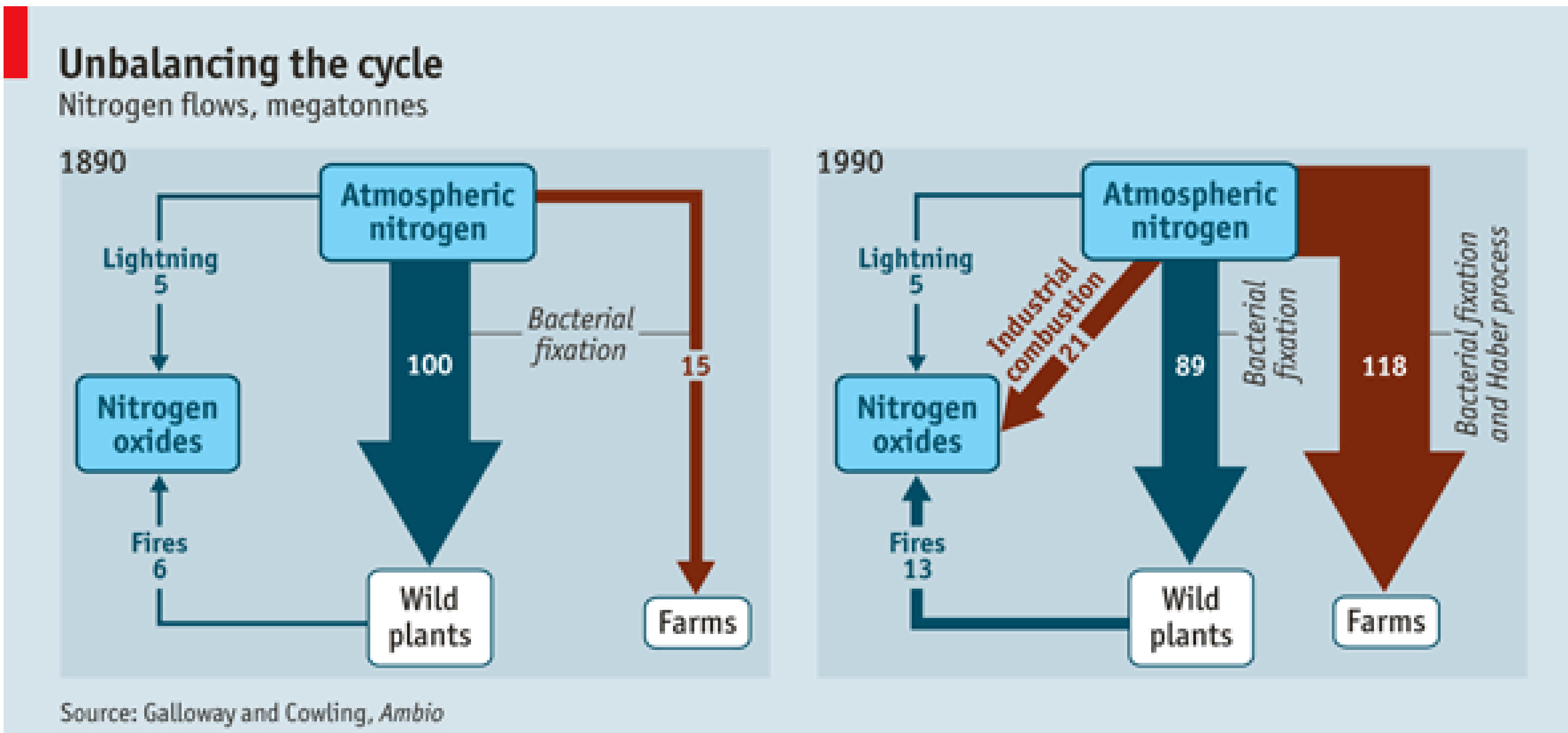


# N - Nitrogen


Unbalancing the cycle
Nitrogen flows, megatonnes
1890
Atmospheric nitrogen
Lightning
5
Nitrogen oxides
Fires
6
100
Bacterial fixation
15
Wild plants
Farms
Source: Galloway and Cowling, *Ambio*

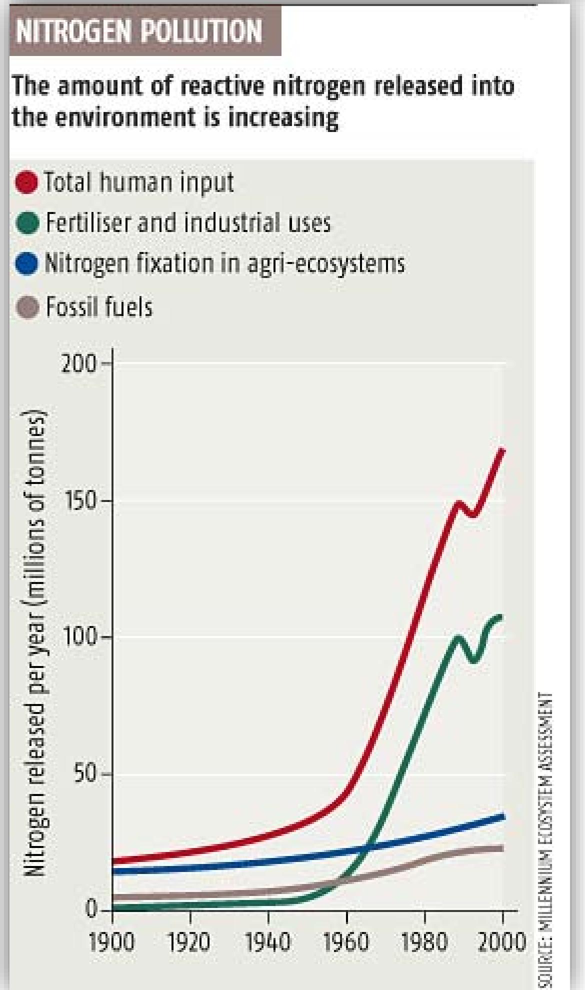
# N - Nitrogen

- today, human activity changes more $N_2$ to reactive forms of N than all terestrial processes together
- Haber-Bosch 80 $Mt_N$/yr, leguminosis 40 $Mt_N$/yr, fossil fuels combustion 20 $Mt_N$/yr, biomass combustion10 $Mt_N$/yr



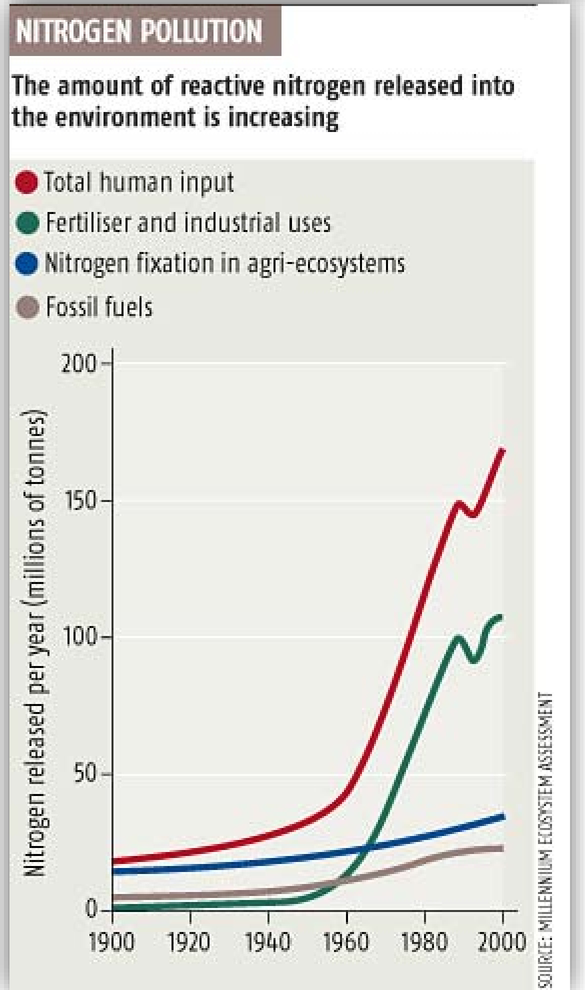
# N - Nitrogen

- major reason of $N_2$ fixation ?

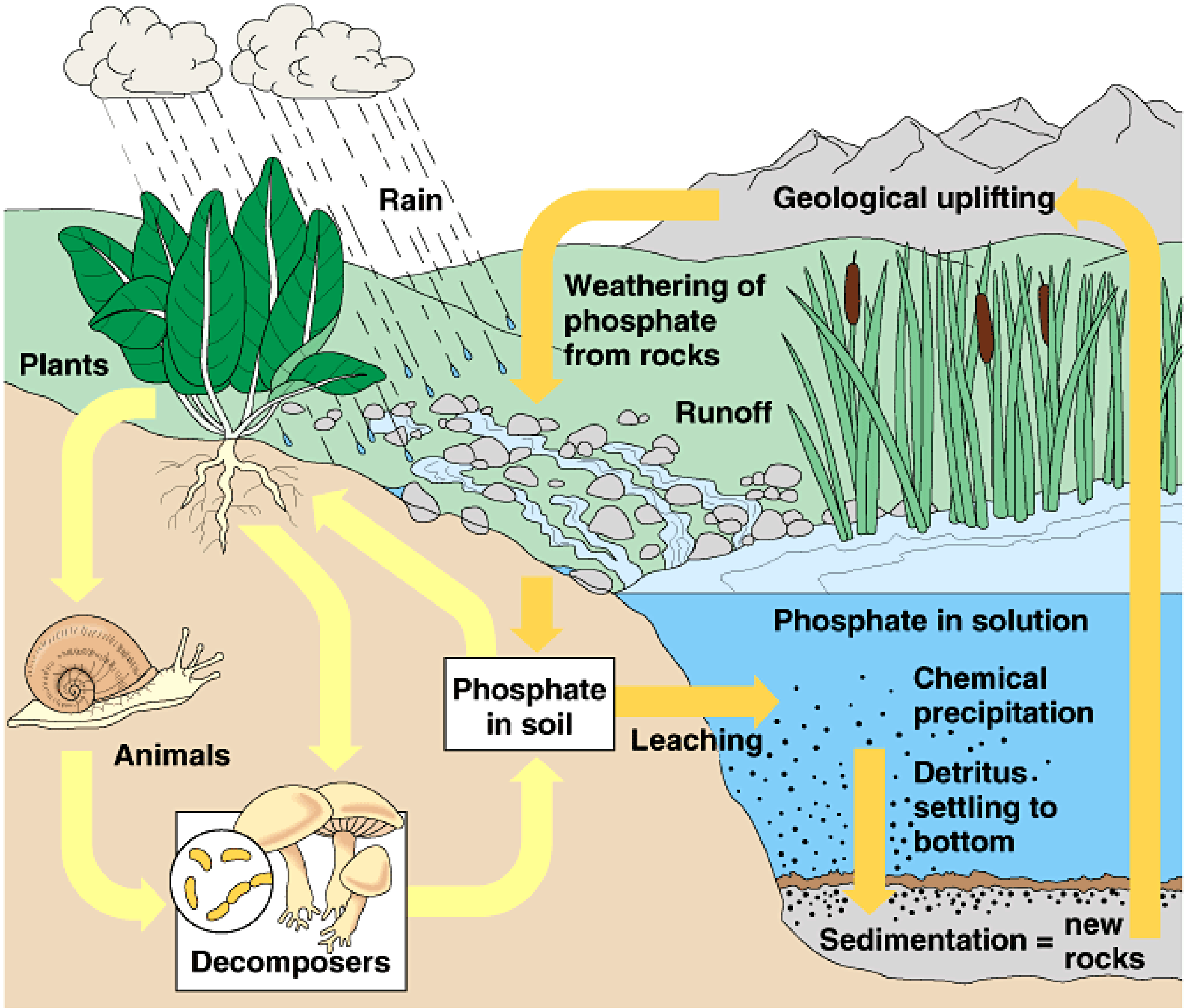


# N - Nitrogen

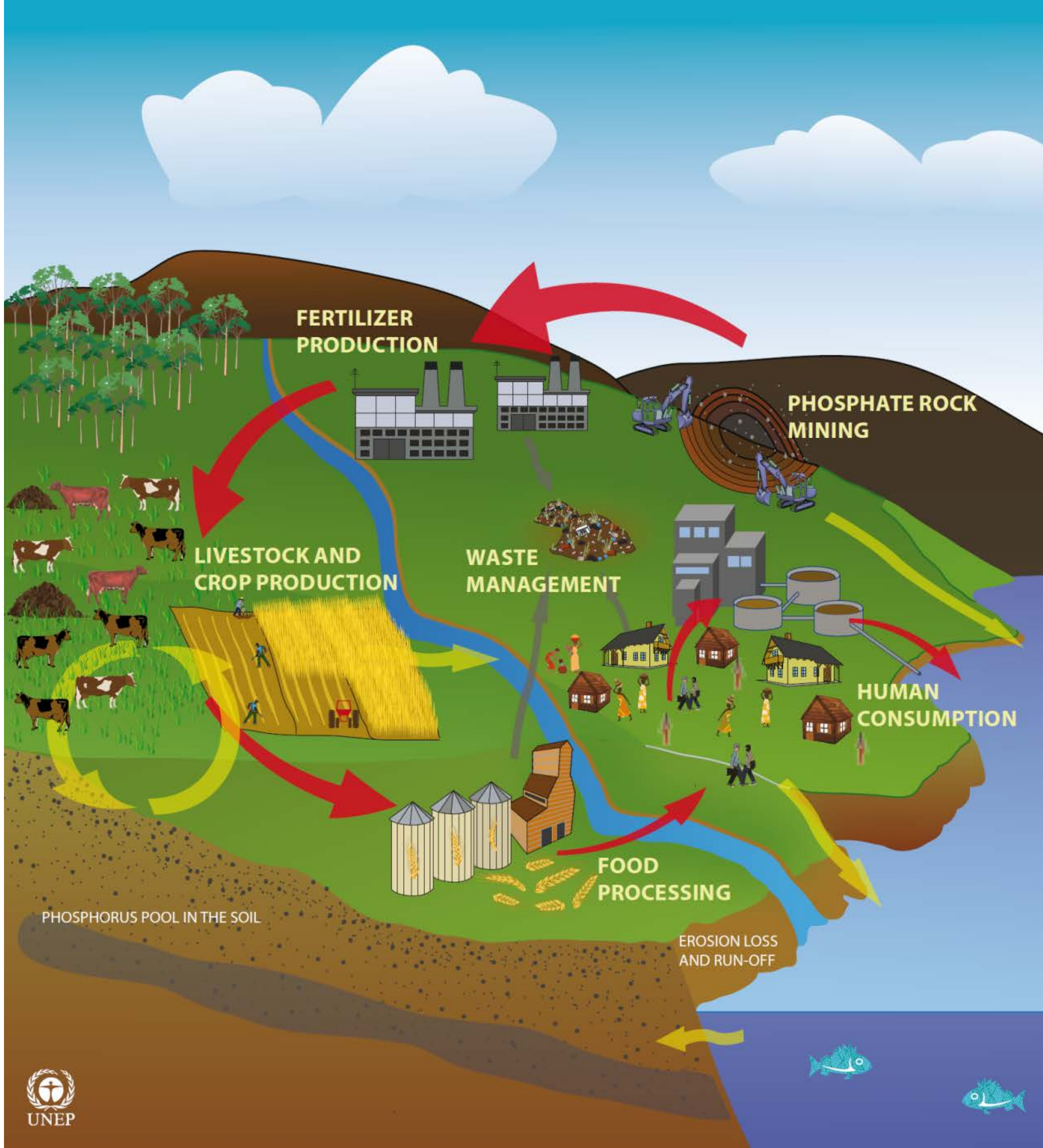
- major reason of $N_2$ fixation ?
- N-fertilizers
- significant part ends in water – eutrofication and nitrates issue
- significant part ends in atmosphere $N_2O$ is GHG and $O_3$ decomp.
- owerall decrease of resilience of planetary systems thanks to high input of reactive nitrogen molecules



# P – phosphorus – natural geochemical cycle

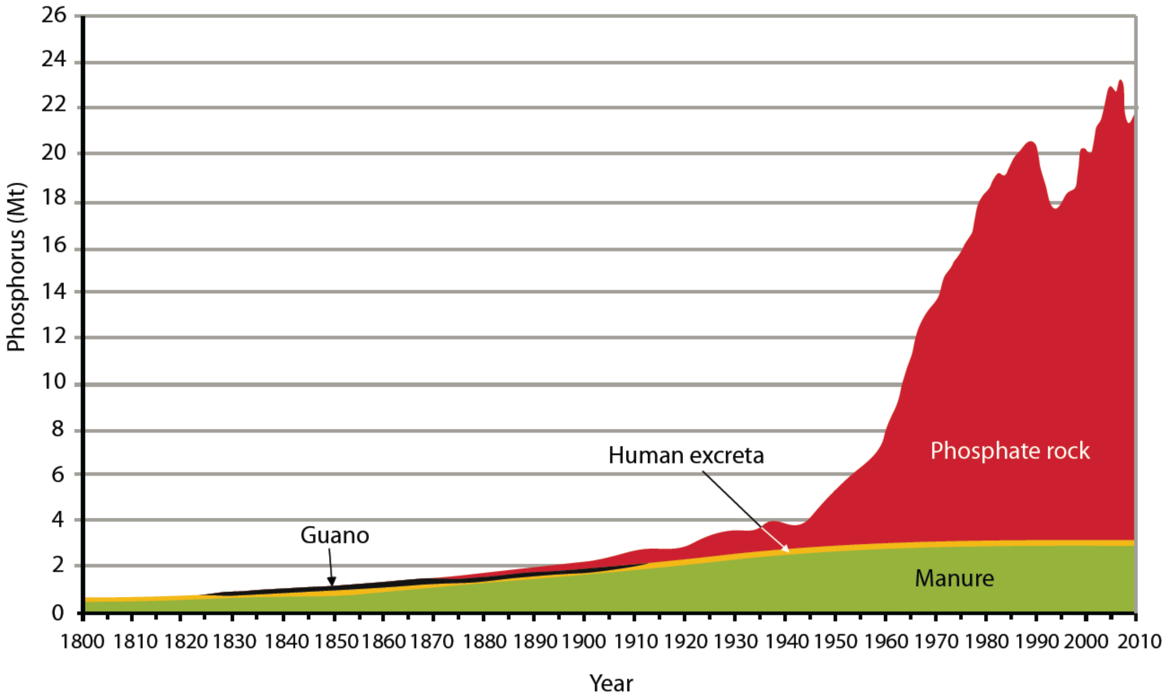


# Human intervention to P cycle



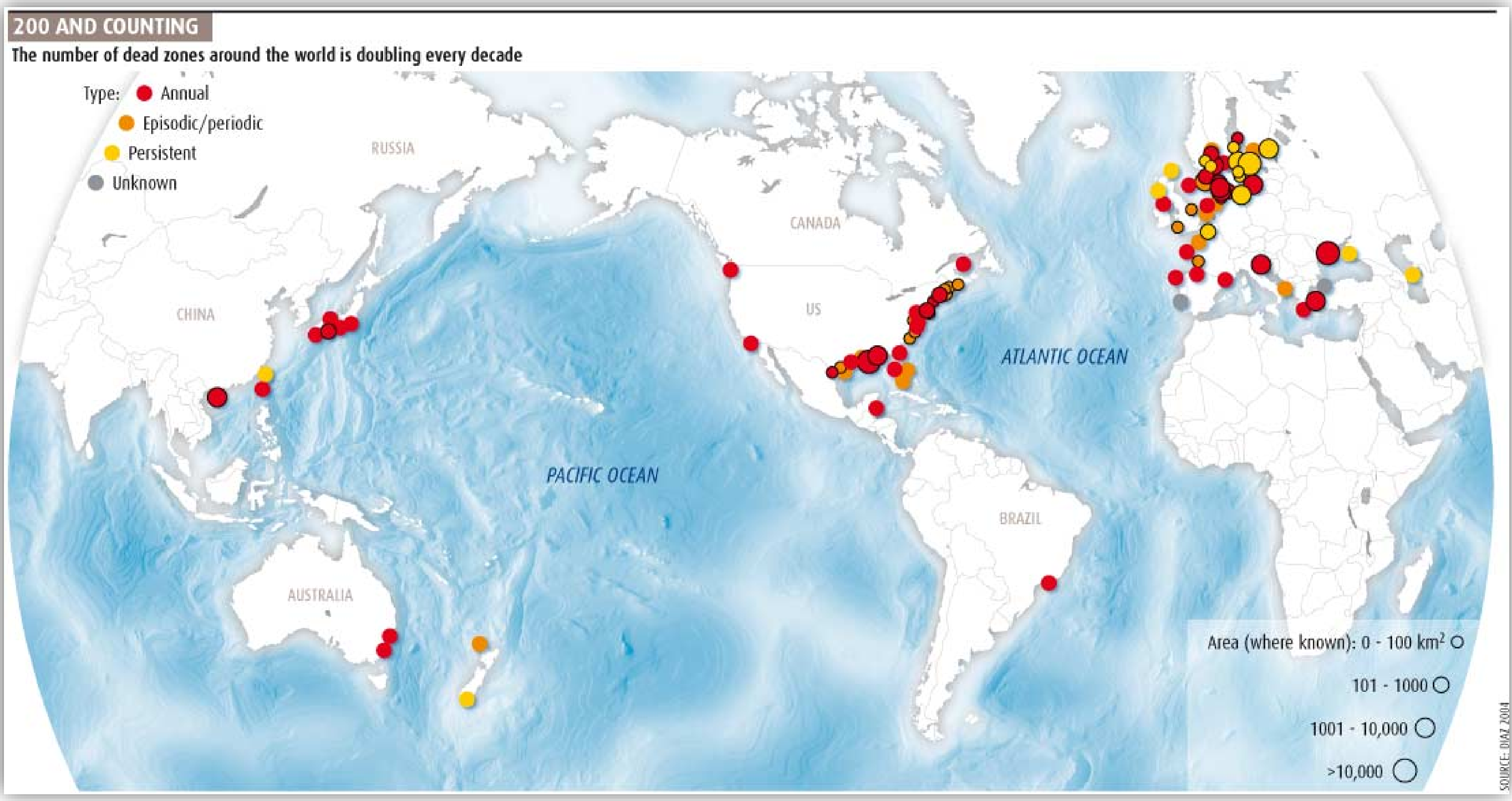
# P - phosphorus

- primary source - weathering or apatite mining
- anthropogenic flow to oceans - 8-9x higher amount
- from 20 $Mt_N$/yr industr. P – half ends in oceans
- higher risk of anoxic events

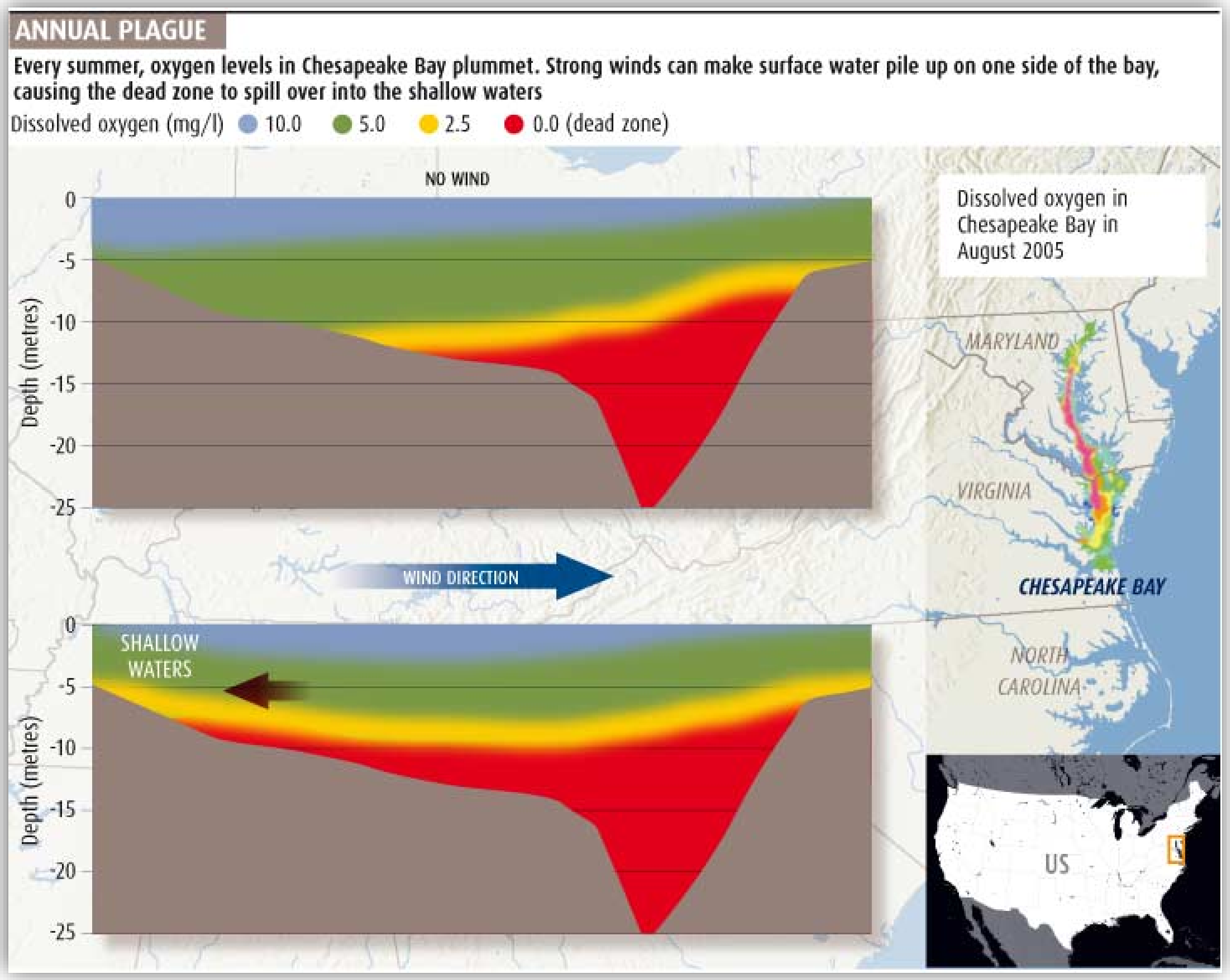


# Consequences of guano mining - Nauru

# P + N = anoxic zones in oceans



# P + N = anoxic zones in oceans



# Not clear everything on anoxic zones...

My New Scientist

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## Pacific dead zone has been shrinking for a century

› 19:00 07 August 2014 by Anna Williams
› For similar stories, visit the Endangered Species , Mysteries of the Deep Sea and Climate Change Topic Guides



Huge areas of ocean could suffocate as a result of global warming. But one of these "dead zones" has been shrinking for a century, we now know. Freak local conditions may be at work, but the discovery offers hope that at least one region of the ocean will still be breathable.

Weakening winds can help dead zones recover
*(Image: Image Source/Getty)*

Most tropical coastlines have oxygen minimum zones, which form when plankton die, sink and get eaten by bacteria, a process that consumes oxygen. The majority of marine animals cannot breathe in low-oxygen water, and either leave or die.

Around the world, oxygen minimum zones have been growing, partly due to the effects of global warming. But one such zone, in the eastern Pacific off the coast of North and Central America, has been bucking the trend, says Curtis Deutsch of the University of Washington in Seattle.

Using coastal sediments that carry traces of past oxygen levels, Deutsch and his colleagues reconstructed changes in oxygen levels in the eastern tropical Pacific since 1850. They found that the oxygen minimum zone has been shrinking nearly all that time.

# Not clear everything on anoxic zones...

My New Scientist

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## Pacific dead zone has

› 19:00 07 August 2014 by Anna W
› For similar stories, visit the Enda

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## The oceans are heating, acidifying and choking

› 19:58 04 October 2013 by Fred Pearce
› For similar stories, visit the Climate Change Topic Guide



We know the oceans are warming. We know they are acidifying. And now, to cap it all, it turns out they are suffocating, too. A new health check on the state of the oceans warns that they will have lost as much as 7 per cent of their oxygen by the end of the century.

The cascade of chemical and biological changes now under way could see coral reefs irreversibly destroyed in 50 to 100 years, with marine ecosystems increasingly taken over by jellyfish and toxic algal blooms.

The review is a repeat of a study two years ago by the International Programme on the State of the Ocean (IPSO), a coalition of scientists. It concludes that things have become worse since the first study.

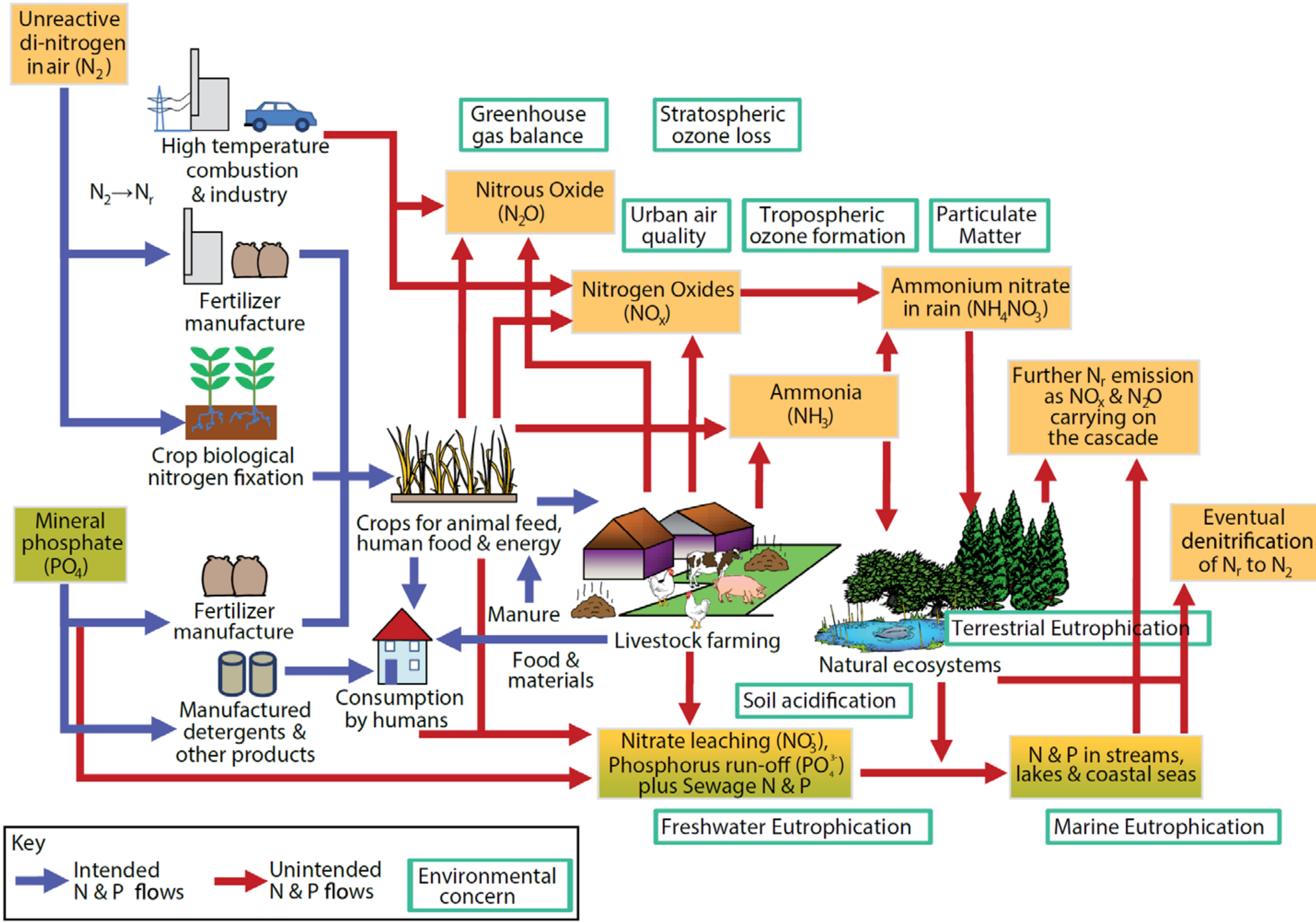
"The health of the oceans is spiralling downwards far more rapidly than we had thought, exposing organisms to intolerable and unpredictable evolutionary pressure," says Alex Rogers at the University of Oxford, the scientific director of IPSO.

### Deadly trio

Rogers describes a "deadly trio" of linked global threats. The first is global warming: surface sea water has been warming almost as fast as the atmosphere. The second is acidification – a result of the water absorbing ever more $CO_2$ from the atmosphere. The third is deoxygenation.

Getting harder to breathe underwater *(Image: Incredible Features/Barcroft Media)*

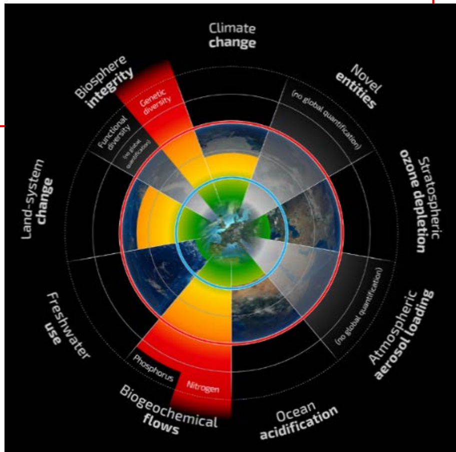
# Simplified view of the nitrogen and phosphate cascade



# VII. Global freshwater consumption

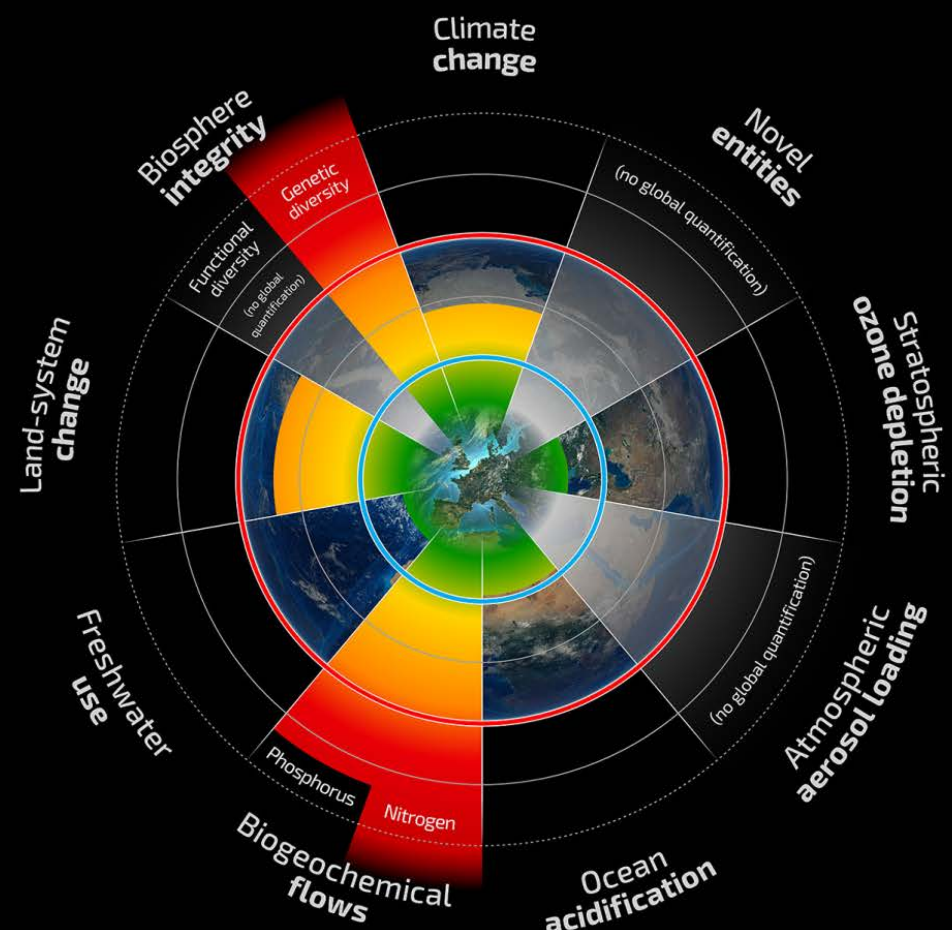
| Earth-system process | Control variable(s) | Planetary boundary (zone of uncertainty) | Current value of control variable |
|---|---|---|---|
| Freshwater use (R2009: Global freshwater use) | *Global:* Maximum amount of consumptive blue water use ($km^3 yr^{-1}$)<br><br>*Basin*: Blue water withdrawal as % of mean monthly river flow | *Global:* 4000 $km^3$ $yr^{-1}$ (4000–6000 $km^3$ $yr^{-1}$)<br><br>*Basin:* Maximum monthly withdrawal as a percentage of mean monthly river flow. For low-flow months: 25% (25–55%); for intermediate-flow months: 30% (30–60%); for high-flow months: 55% (55–85%) | ~2600 $km^3$ $yr^{-1}$ |

**Boundary:** No more than 4000 $km^3$ of fresh water consumed per year
**Current level:** 2600 $km^3$ per year
**Diagnosis:** Boundary will be approached by mid-century



# Planetary Boundaries

A safe operating space for humanity




**Beyond zone of uncertainty** (high risk)
**In zone of uncertainty** (increasing risk)
**Below boundary** (safe)
**Boundary not yet quantified**

**Source:** Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, *Science*, 16 January 2015.
**Design:** Globaïa

# FW issue

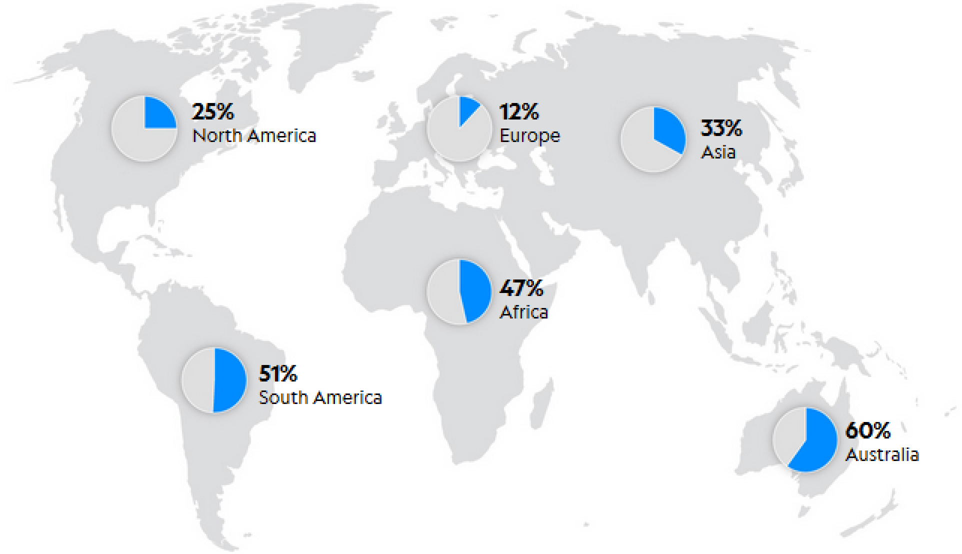
- man is a dominant force changing flow of water in rivers
- cca 25 % water not reach the ocean
- consequences for biodiversity,

nutrition, aquatic and terestrail ecosystems

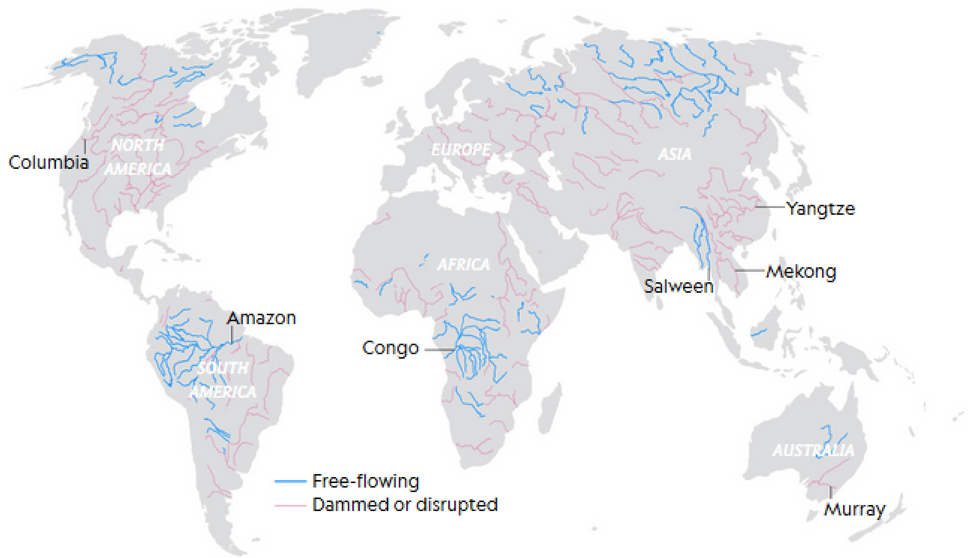

# The world's remaining free-flowing rivers

Only 37 percent of world's largest rivers are free of dams or other disruptions. Free-flowing rivers are found primarily in the Amazon and Congo Basins, and in the Arctic.

**Percentage of very large rivers (longer than 1,000 km) that remain free-flowing, by continent**

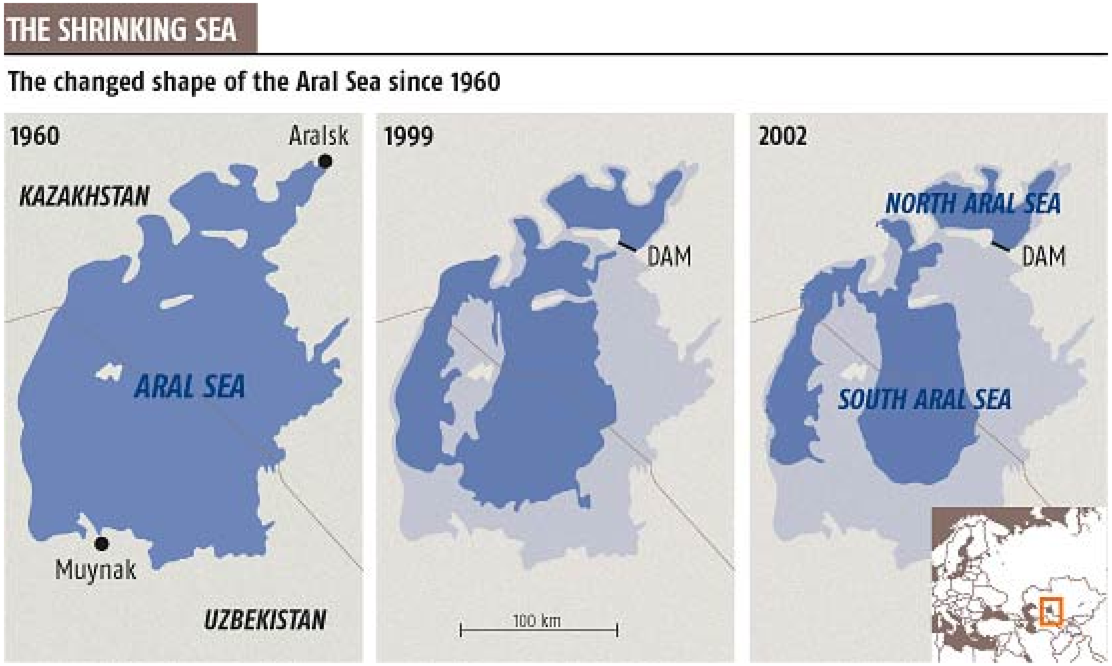



**Distribution of very large rivers**

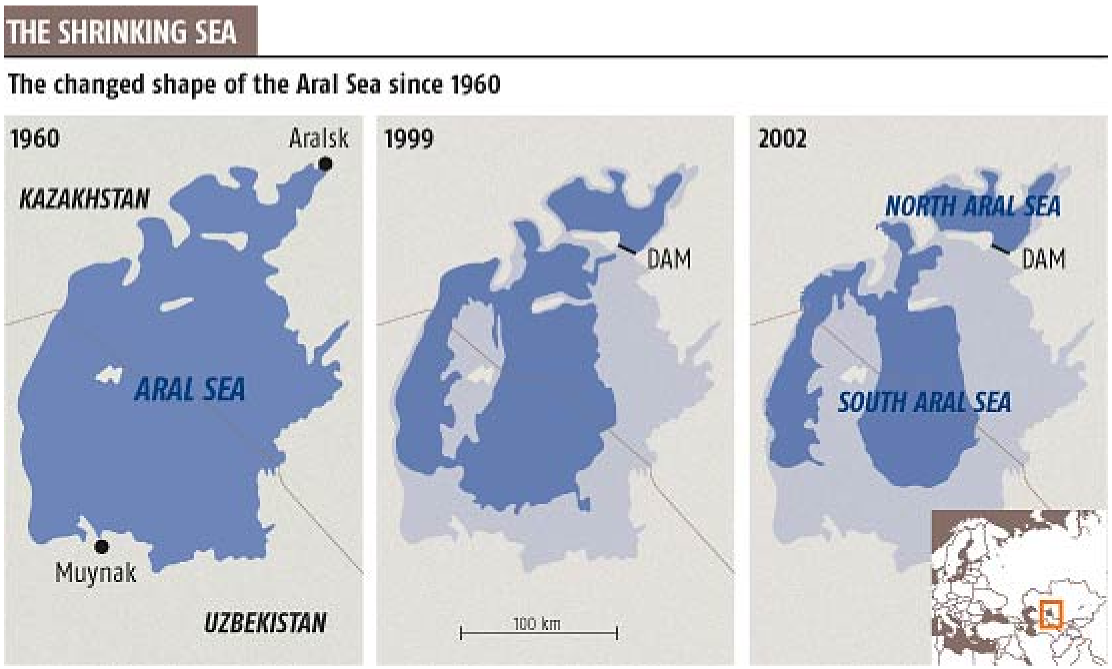



THEODORE SICKLEY AND RYAN MORRIS, NG STAFF
SOURCE: *NATURE*

# Aral See
# - Kazachstan, Uzbekistan




- 2005 – dam betwee N and South part
- what happened?

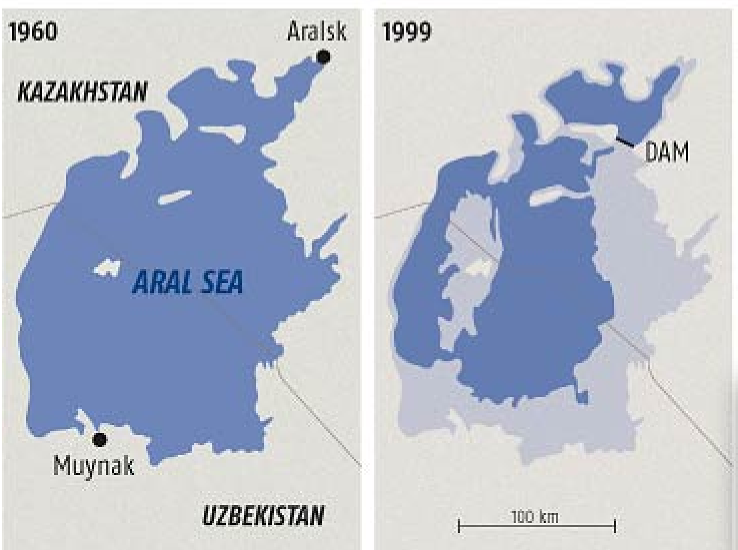


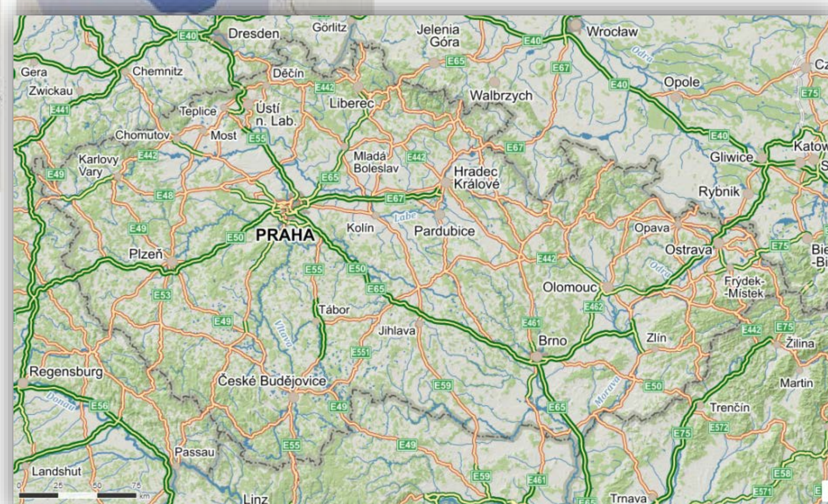


- 2005 – dam betwee N and South part
- what happened?

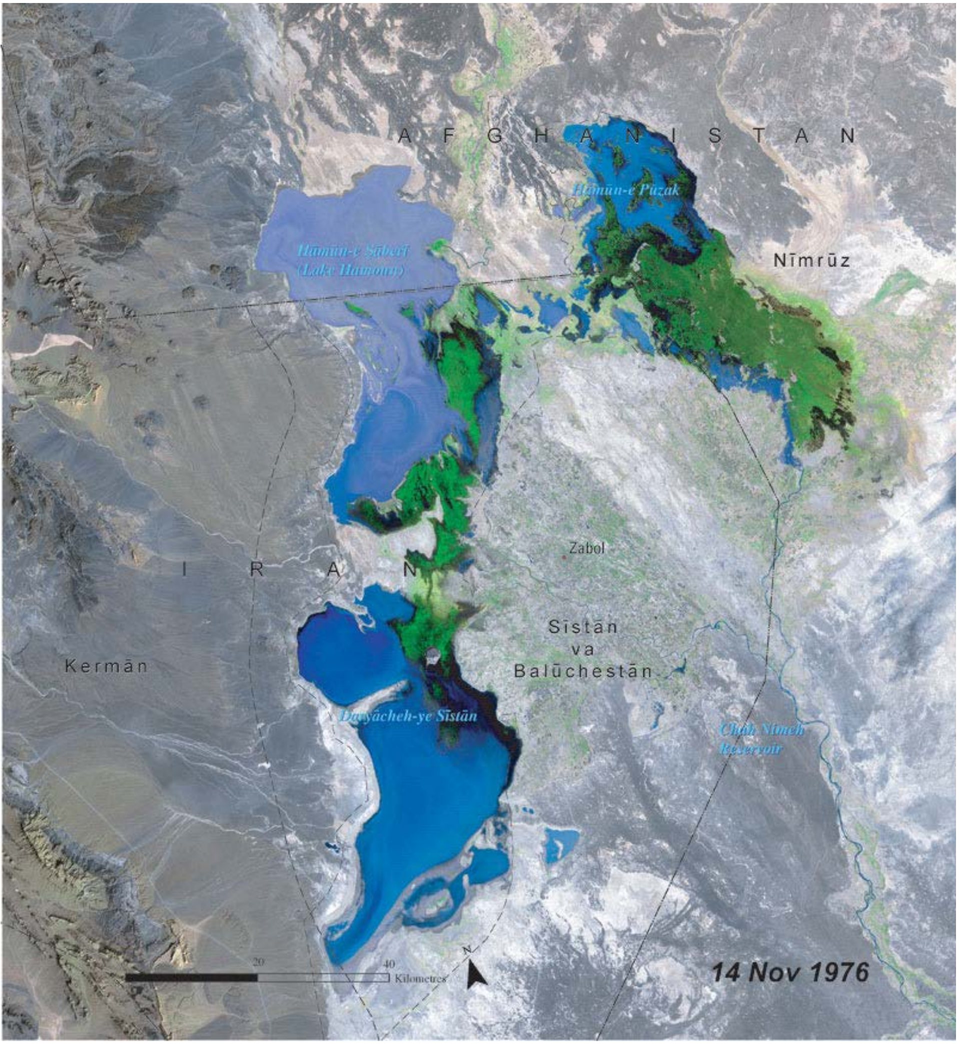
THE SHRINKING SEA

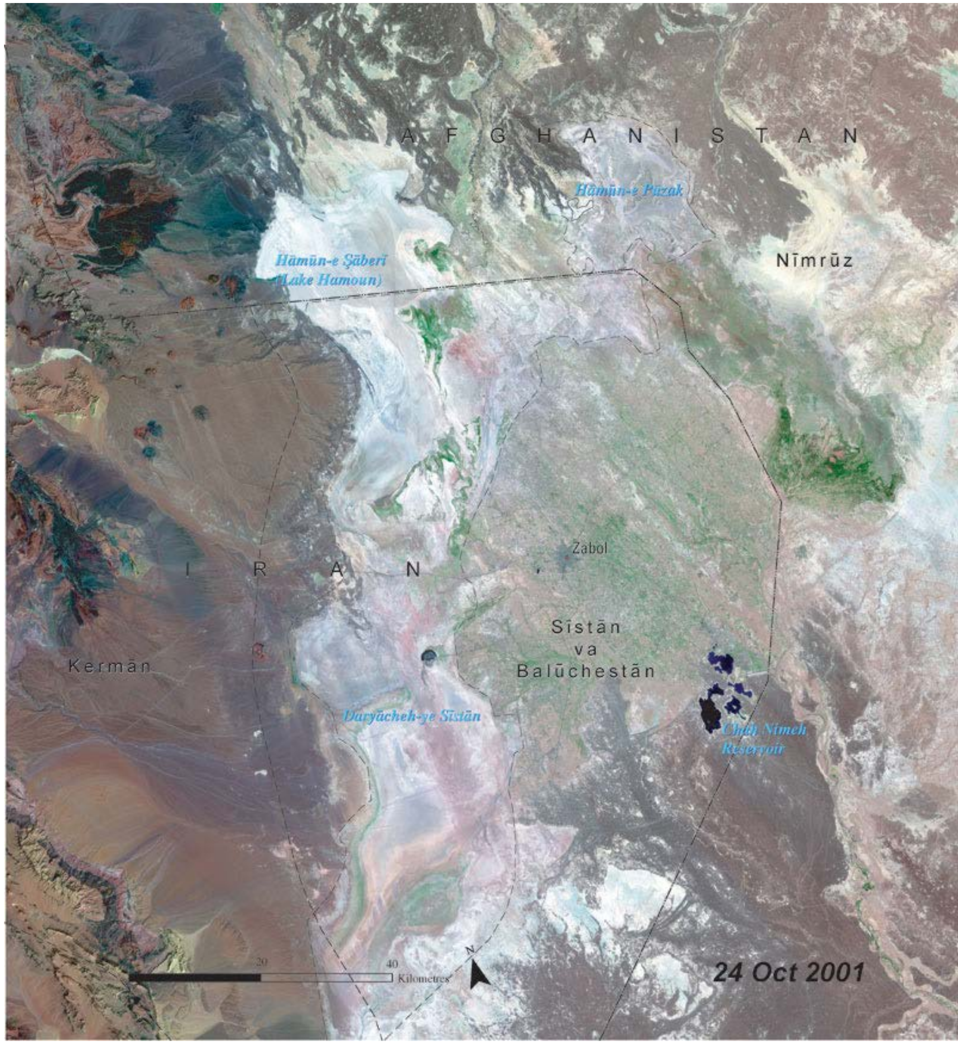
The changed shape of the Aral Sea since 1960



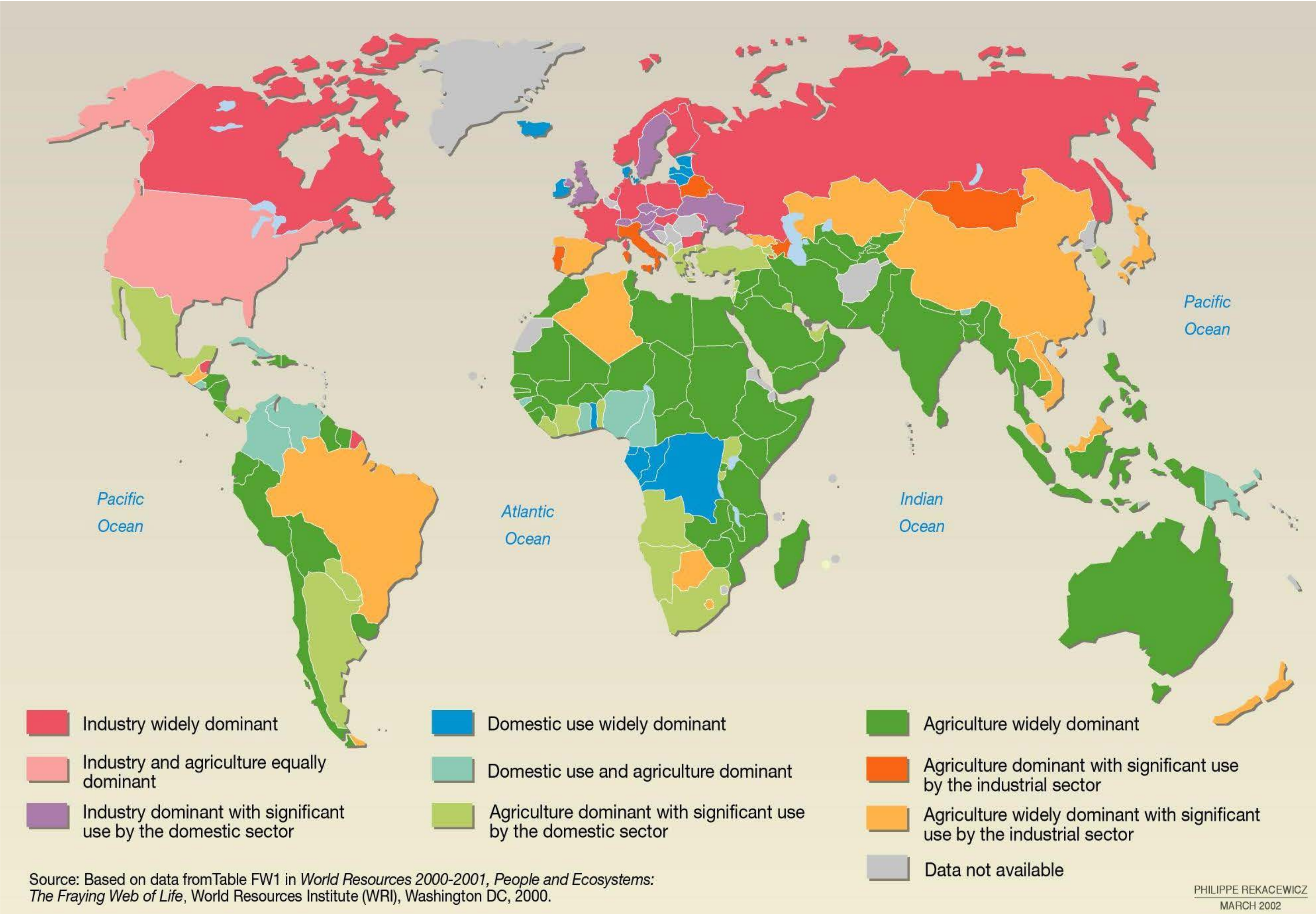



# Lake Hamoun – Iran, Afghanistan

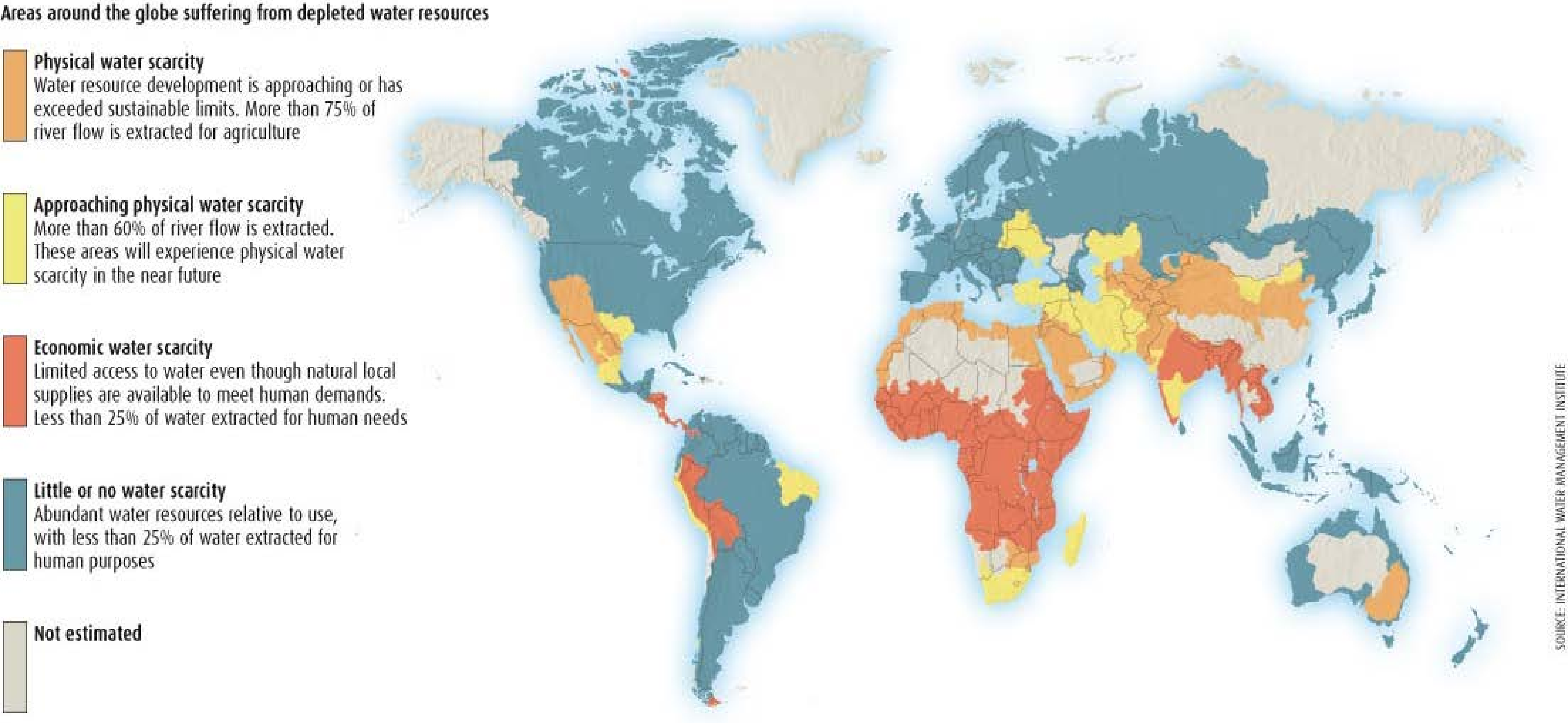


# Areas of water consumption

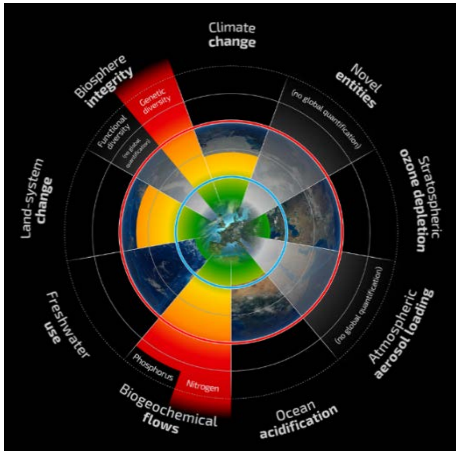


# Areas and types of water scarcity



# VIII. Land use

| Earth-system process | Control variable(s) | Planetary boundary (zone of uncertainty) | Current value of control variable |
|---|---|---|---|
| Land-system change (R2009: same) | *Global:* Area of forested land as % of original forest cover | *Global:* 75% (75–54%) Values are a weighted average of the three individual biome boundaries and their uncertainty zones | 62% |
| | *Biome*: Area of forested land as % of potential forest | *Biome*:<br>Tropical: 85% (85–60%)<br>Temperate: 50% (50–30%)<br>Boreal: 85% (85–60%) | |



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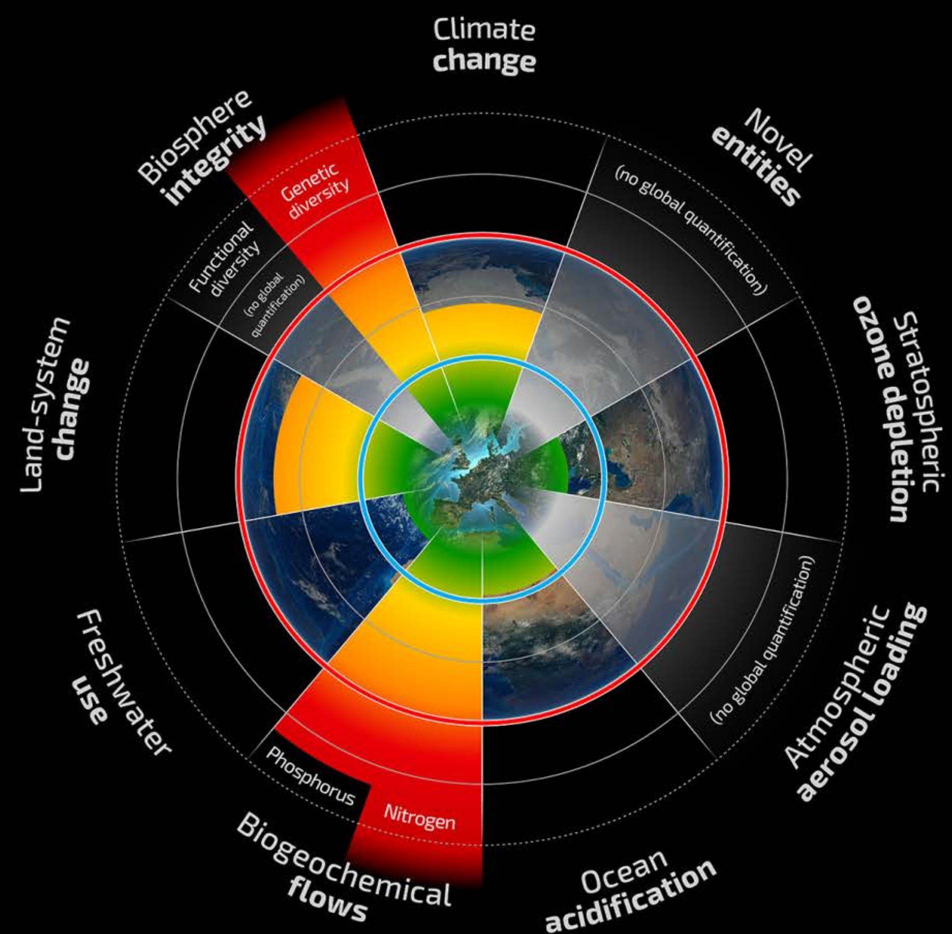


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- **Below boundary** (safe)
- **Boundary not yet quantified**

**Source:** Steffen et al. Planetary Boundaries: Guiding human development on a changing planet, *Science*, 16 January 2015.
**Design:** Globaïa

# Santa Cruz, Bolívia

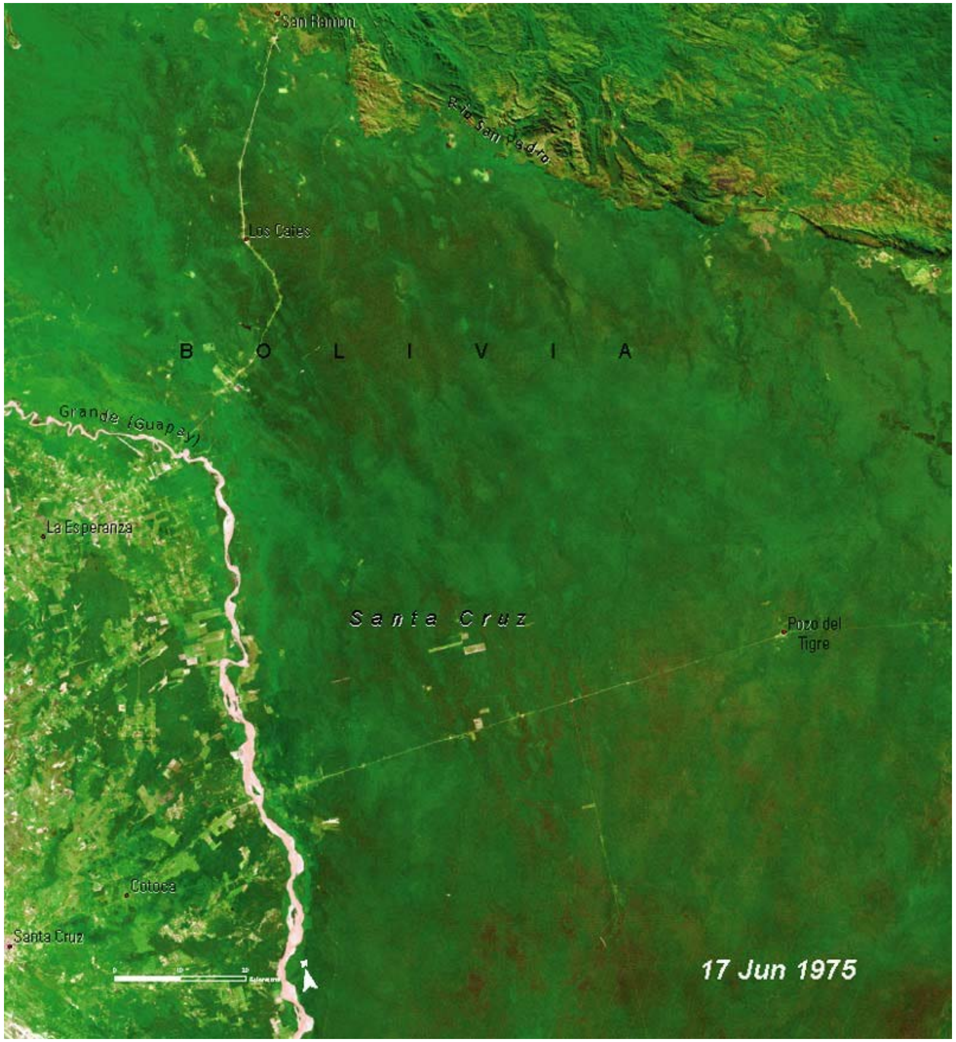
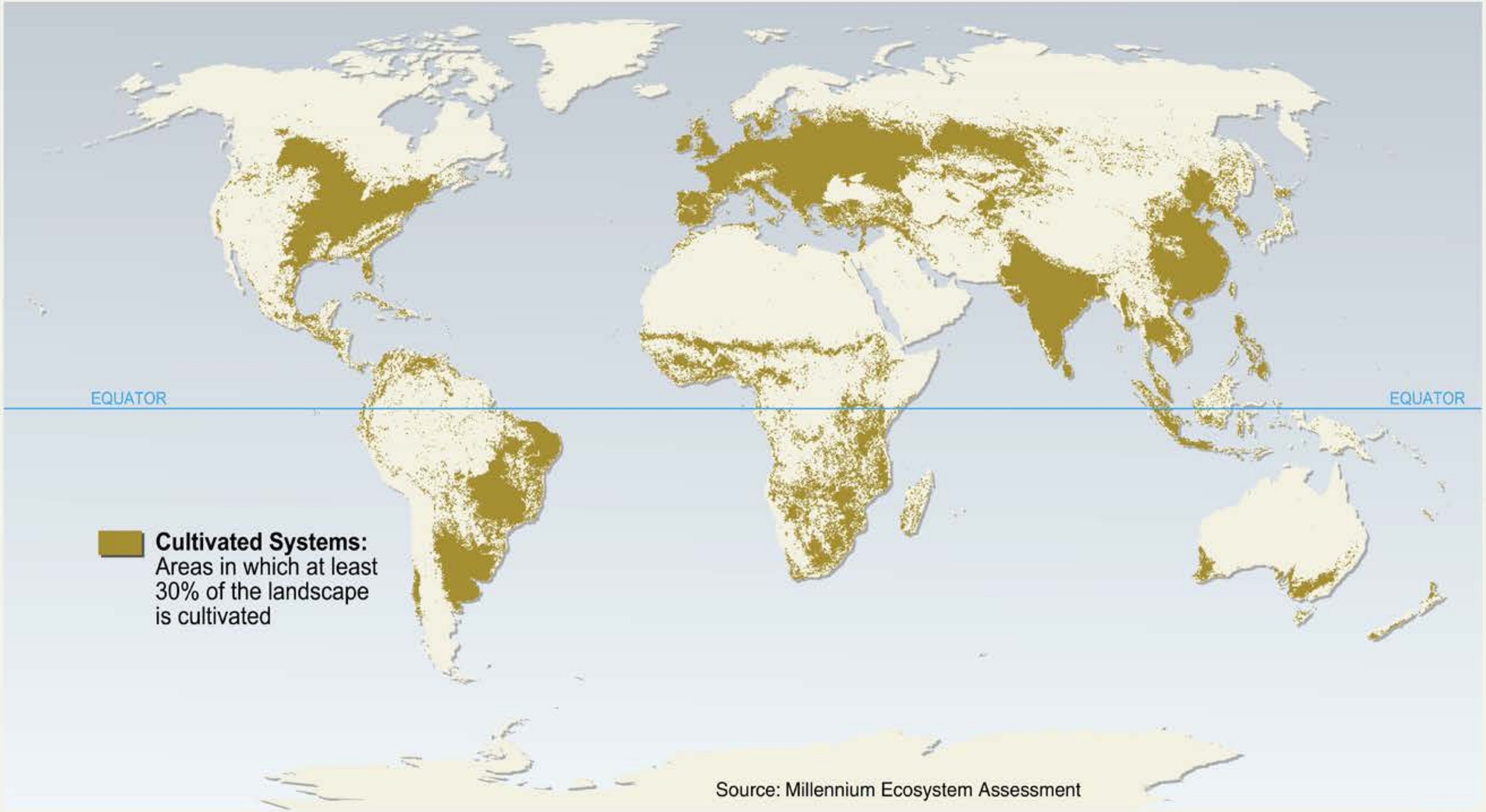
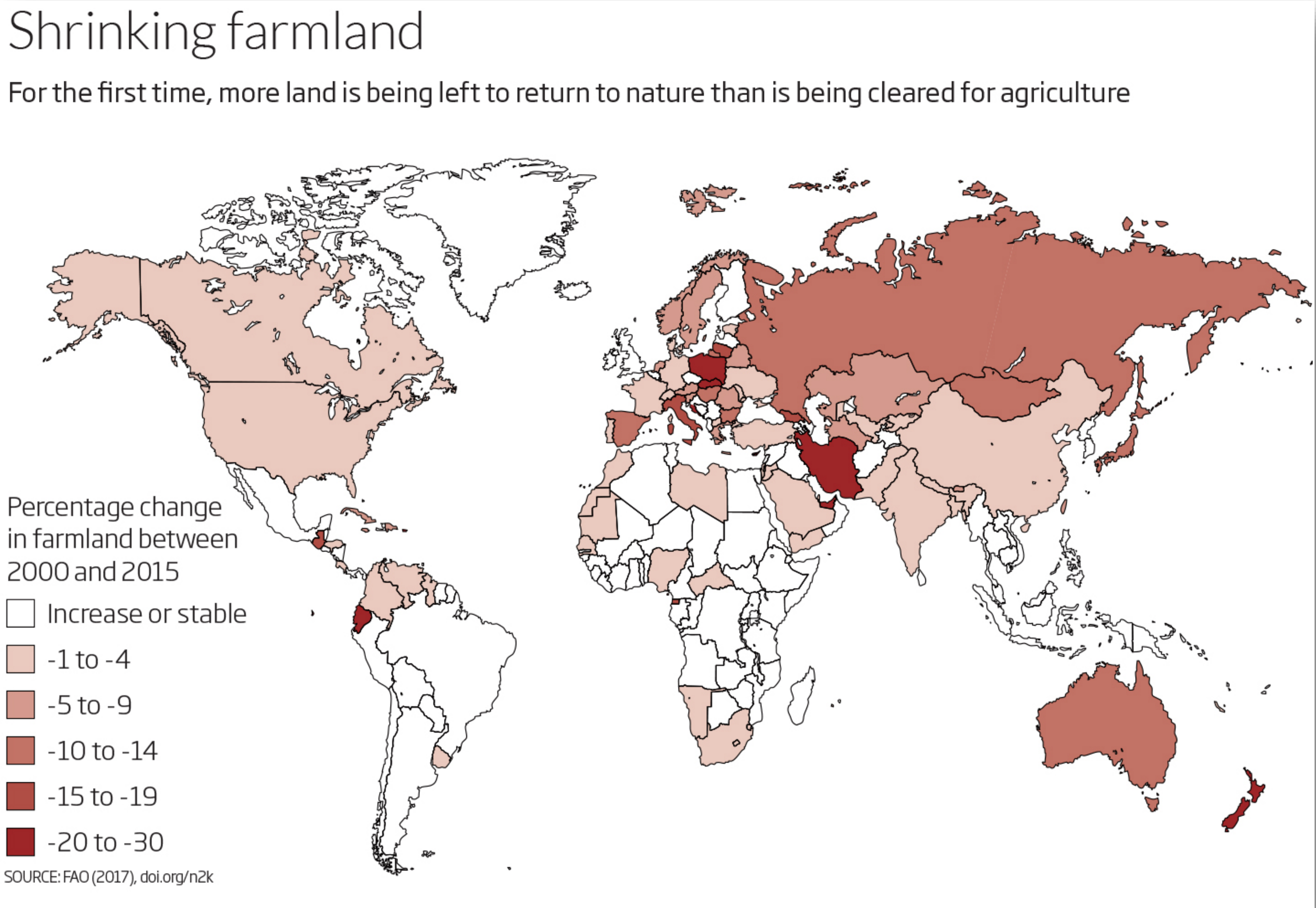



**Figure 1.** EXTENT OF CULTIVATED SYSTEMS, 2000. Cultivated systems cover 24% of the terrestrial surface.



# Optimistic future?




FUTURE
PAST
PRESENT

LEADER 11 October 2017

# It looks like an oxymoron, but Earth optimism is worth a try

Decades of environmental doom-mongering have fallen on deaf ears. Maybe a new environmental campaign with a message of hope is just what we need

FEATURE 11 October 2017

# Is positive thinking the way to save the planet?

Move over doom and gloom, there is a new environmental movement in town. Earth optimists say focusing on small successes is the way forward