The eutrophication of Lake Victoria: Consequences on the functioning of the lakes and on its use for the production of drinking water, monitoring strategies

WASaF project team Kampala - Uganda
What are the main functions of lakes?

- **Water supply**
  (Domestic, industrial, agriculture)
- **Power production**
- **Food production**
- **Recreational activities / Existence services**
- **Navigation**
- **Other ecosystem services**
  (Carbon sequestration, nutrient cycling, wildlife habitats, hydrology...)

Lake Victoria
The eutrophication of freshwater ecosystems, a worldwide problem

→ Growth of the world human population, with many consequences...

Increase of fertilizer use

Increase of wastewater volumes

Changes in land use
How to describe the process of eutrophication?
Understanding the biological functioning of a lake

Phytoplankton

Primary production

Nutrients (Phosphorus + Nitrogen + ...)

\[ \text{CO}_2 \]
Understanding the biological functioning of a lake

**Nutrients** (Phosphorus + Nitrogen + ...)

**Primary production**

Phytoplankton

Zooplankton

Fishes
Key factors and processes controlling the phytoplankton communities in lakes

**Oligotrophic**
- Bottom-up: Nutrients (P & N) + Light
- Top-down: Grazing + parasitism
- Large diversity
- Small biomass

**Eutrophic**
- Bottom-up: Nutrients (Phosphorus)
- Top-down: Grazing + parasitism
- Small diversity
- Large biomass
Key factors and processes controlling the phytoplankton communities in lakes?

### Trophic levels in lakes

<table>
<thead>
<tr>
<th>Trophic Level</th>
<th>Phosphorus conc. (µg.L⁻¹)</th>
<th>Chlorophyll conc. (µg.L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligotrophic</td>
<td>0-10</td>
<td>0-3</td>
</tr>
<tr>
<td>Mesotrophic</td>
<td>10-30</td>
<td>3-10</td>
</tr>
<tr>
<td>Eutrophic</td>
<td>30-100</td>
<td>10-30</td>
</tr>
<tr>
<td>Hypereutrophic</td>
<td>&gt;100</td>
<td>30-400</td>
</tr>
</tbody>
</table>

+ Nutriments (P et N)

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Schindler

Oligotrophic lake: Baïkal

Hypereutrophic lake: Taihu

Victoria
What are the origins of nutrients (N & P) in lakes?

**Nutrients** (Phosphorus + nitrogen + ...)

Primary production

Phytoplankton

Zooplankton

Bacteria

Fishes

CO₂
What are the origins of nutrients (N & P) in lakes?

Phytoplankton

Sediment discharge

Zooplankton

Nutrients (Phosphorus + nitrogen + ...)

Bacteria

Primary production

Fishes

CO₂

Internal recycling
What are the origins of nutrients (N & P) in lakes?

- Phytoplankton
- Zooplankton
- Bacteria
- Fishes
- Aerial depositions
- River inputs
- Nutrients (Phosphorus + nitrogen + ...)
- Sediment discharge
- Internal recycling

Primary production
Aerial deposition = Dry and wet deposition

Tamatamah et al., Biogeochem. 2005
Aerial deposition = Dry and wet deposition

Tamatamah et al., Biogeochem. 2005

Terrestrial/river inputs

Scheren et al., J. Env. Manag. 2000
How to explain the degradation of Lake Victoria?

<table>
<thead>
<tr>
<th>Regions:</th>
<th>Boreal</th>
<th>Temperate</th>
<th>Tropical</th>
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<tbody>
<tr>
<td>Ecosystems:</td>
<td>Baltic Sea</td>
<td>Baikal</td>
<td>Superior</td>
</tr>
<tr>
<td>Population (million)</td>
<td>85</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>Lake area (km²)</td>
<td>415,000</td>
<td>31,500</td>
<td>82,100</td>
</tr>
<tr>
<td>Lake drainage (km²)</td>
<td>1,700,000</td>
<td>560,000</td>
<td>128,000</td>
</tr>
<tr>
<td>Volume (km³)</td>
<td>21,547</td>
<td>23,600</td>
<td>12,230</td>
</tr>
<tr>
<td>Shoreline length (km)</td>
<td>8000</td>
<td>2000</td>
<td>4387</td>
</tr>
<tr>
<td>Mean depth (m)</td>
<td>53</td>
<td>740</td>
<td>149</td>
</tr>
<tr>
<td>Maximum depth (m)</td>
<td>459</td>
<td>1741</td>
<td>407</td>
</tr>
<tr>
<td>Residence time (y)</td>
<td>30</td>
<td>350</td>
<td>107</td>
</tr>
<tr>
<td>Age (10³ y)</td>
<td>15</td>
<td>30,000</td>
<td>10</td>
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Dobiesz et al., J. Great Lakes Res 2010
How to explain the degradation of Lake Victoria?

Large surface / « small » volume
→ Importance of the aerial depositions

Dobiesz et al., J. Great Lakes Res 2010
How to explain the degradation of Lake Victoria?

Dobiesz et al., J. Great Lakes Res 2010

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Large surface / « small » volume

→ Importance of the aerial depositions

Very large catchment area and high human population density

→ Very high anthropogenic pressures
How to explain the degradation of the Lake Victoria?

→ Very strong increase of the population density around the lake
Consequences of the increase of the density of human populations living around Lake Victoria

1996
pelagic cyanobacteria bloom
Nile perch population surges, indigenous fish stocks collapse
lake-level rise floods riparian wetlands

1980
railroad arrives in Kampala, Uganda
Ugandan cotton exports
railroad arrives in Kisumu, Kenya
founding of Kampala, Buganda
Arab trade with Buganda
discovered by European explorers
Buganda kingdom

1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
250

agricultural production (% of 1960 value)

catchment population (millions)

Baring of soils
Deforestation
Use of fertilizers and pesticides

Table 2. Number of sewered and unsewered people in urban populations (from 33).

<table>
<thead>
<tr>
<th>Country</th>
<th>Total population (1000 people)</th>
<th>Urban Population (1000 people)</th>
<th>Sewered</th>
<th>Unsewered</th>
<th>Number of Towns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>10 200</td>
<td>390</td>
<td>630</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Uganda</td>
<td>5600</td>
<td>210</td>
<td>870</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Tanzania</td>
<td>5200</td>
<td>27</td>
<td>340</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Rwanda</td>
<td>5900</td>
<td>-</td>
<td>400</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Burundi</td>
<td>2800</td>
<td>-</td>
<td>140</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29 700</strong></td>
<td><strong>627</strong></td>
<td><strong>2380</strong></td>
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Verschuren et al., Proc R Soc Lond B 2012

Odada et al., Ambio 204
Potential influence of global warming?

Increase of phytoplankton blooms during the periods of lake surface warming and water column stability

Cosar et al., PLoS ONE 2012
What are the main consequences of the eutrophication on the biological functioning and on the production of drinking water?
What are the main effects of eutrophication on the uses of lakes?

- **Water supply** (Domestic, industrial, agriculture)
- **Power production**
- **Food production**
- **Recreational activities/Existence services**
- **Navigation** (*Water hyacinth*)
- **Other ecosystem services** (Carbon sequestration, nutrient cycling, wildlife habitats...)

[Image of green algae]
In light limiting conditions, which species are favored?

→ Ability to occupy the surface layer of the lakes

Cyanobacteria

Floating plants
What are the main problems due to cyanobacterial blooms?

Health problems:
- Production of harmful cyanotoxins (microcystins)
- Interactions with pathogenic bacteria?

Problems for the production of drinking waters:
- Difficulties to remove cyanobacteria (and their toxins) in the water treatment plants
- High biomasses = high quantities of carbon (Total Organic Carbon) → Many problems for the water production and for the drinking water quality
The specific cases of the bays and gulfs in Lake Victoria
Numerous cities located on the shoreline of bays and gulfs

- High drinking water needs
- Significant wastewater discharges
- Higher susceptibility of the bays and gulfs to pollutants (semi closed environments)
The example of Murchison Bay (Uganda)

Haande et al., Limnologica 2010
The example of Murchison Bay (Uganda)

Fig. 3. Turbidity trends for raw water at Gaba waterworks intake, Murchison Bay, Uganda.
The example of Speke Gulf (Tanzania)

Mwanza North Bay, urban pollution (MZ)
Magu Bay, agricultural pollution (MG)
Kayenze Bay (KY)

Shayo et al., AEHM 2011
The example of Kavirondo gulf (Kenya)

→ Massive development of hyacinth (and cyanobacteria) in bays and gulfs
To conclude on bays and gulfs...

→ The quality of the water in bays and gulfs is strongly influenced by the terrestrial inputs (rivers, wastewater channels...)

→ A particular attention should be paid for the protection of these environments that are critical for many people.
And now, what steps can be taken?

Needs for a land management strategies (implemented on a multinational, basin-wide scale) severely restricting nutrient input to the lake and its tributaries

Scoreboard for 2020 for Geneva Lake (Switzerland/France)
And now, what steps can be taken?

**Needs for a global long term monitoring of the lake and of the main tributaries in order to detect the global trends in its evolution**
And now, what steps can be taken?

Needs for a global long term monitoring of the lake and of the main tributaries in order to detect the global trends in its evolution

→ Monitoring of the whole lake

→ Specific monitoring of bays and gulfs
And now, what steps can be taken?

Needs for local monitorings in bays and gulfs in order (i) to improve the production of drinking water and (ii) to limit the sanitary risks for human populations living on the shores.

**Physical parameters**
- Water temp.; Transparency;
- Turbidity; Conductivity; TSS and TDS

**Chemical parameters**
- Nutrients (N, P, Si), pH
- Heavy metals (Zn, Fe, Cd, Hg)
- Pestices (Organochlorines, Pharmaceuticals, Arsenic...), O2

**Biological parameters**
- Phytoplankton (Chlorophyll, Cyanobacteria counting and toxicity, TOC)
- Pathogens (E. coli & Faecal Streptococci)
Local monitoring of water quality, including cyanobacteria

Main problems for the monitoring of cyanobacteria:

- Strong horizontal heterogeneity in their distribution
- Strong vertical heterogeneity in their distribution
- High temporal variations in these spatial heterogeneities
Local monitoring of water quality, including cyanobacteria

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Local monitoring of water quality, including cyanobacteria

Influence of the sampling effort

Influence of the sampling frequency

Pobel et al., Water Research 2011
Recommendations for the sampling strategy

WaSAf programme (2016 - 2019)

Monitoring and Sustainable Management of Surface Freshwater Sources in Africa.

1. Sampling in several points of the monitored area
   - Use of transect
   - More or less distant from the shoreline
2. Sampling at several depths in each sampling point
3. One sampling strategy for all the monitoring period
Recommendations for the sampling strategy

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Continuous or semi continuous monitoring of the raw water in the water treatment plant:

1. Detection of short term variations occurring in the cyanobacterial population density

→ Needs for tools allowing to perform *in situ* measurements
New tools for the monitoring of cyanobacteria and of environmental parameters

→ Spectrofluorimetric and phycocyanin probes for the survey of cyanobacteria
New tools for the monitoring of cyanobacteria and of environmental parameters

→ Multiparameter probes for the monitoring of the water column
Many thanks for your attention