Hydrological drivers of organic matter quality, mineralization and export in a tropical dam-impacted floodplain system

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The Zambezi River Basin

- 8 riparian countries
- Rainfall 950 mm evaporation >90%
- 4 existing dams
- 6 planned dams

Kafue River Basin:
- 152,000 km²
- 2 large dams built in 1970s
Introduction

The Kafue Flats

Itezhi Tezhi Dam

Kafue River

Kafue Gorge Dam

Lusaka

6,500 km²
Introduction

Upstream Itezhi-Tezhi dam (closed 1978)
Introduction

Kafue River in the Kafue Flats

G. Shanungu
Introduction

The Kafue Flats

- Seasonal flooding
- Dams changed flooding patterns
- Affected plant and wildlife ecology
- No biogeochemical evidence

(from Mumba & Thompson 2005)
Introduction

Importance of tropical floodplain ecosystems

- Floodplains = high-value ecosystems
  - habitat, water supply, flood mitigation, food production

- Important reactors for C and nutrient turnover

- Hydrological exchange: crucial process
  - Biogeochemistry
  - Ecological functioning

- Dam impact on exchange?

Flood pulse concept
Junk et al. 1989

Bayley, 1995 / epa.gov
Introduction

Research objectives

1. **Hydrological drivers**
   Quantify the hydrological exchange between Kafue River and floodplain. Related to dam operation?

2. **Mineralization**
   Effects of river-floodplain exchange on the dissolved oxygen regime

3. **Organic matter quality and export**
   Effects of lateral exchange and dam operation on fluxes and quality of organic C and N
Approach

Sampling strategy

![Map and diagram showing river levels and sampling strategy](image)

- **Kafue River**
- **Floodplain**

**Stage (m a.s.l.)**

- May 2008
- Oct 2008
- May 2009
- May 2010

**Q (m$^3$/s)**

- May 2008
- Oct 2008
- May 2009
- May 2010

**Dam release**
River-floodplain exchange and dissolved oxygen

**Dissolved oxygen (DO)**

- **Hypotheses:**
  - Inflow of low-DO water
  - Injection of labile OM to river
  - Exchange with the floodplain

**Plot:**
- Steep DO decline over 40 km
- Low DO levels for 150 km
- Floodplain DO <15 µM
River-floodplain exchange and dissolved oxygen

Discharge (Q) and natural tracers

May 2010 - flooding season

1 steep Q decline
  - ~80 % loss to floodplain
  - no outflows detected

2 increase in tracers at constant Q (DO decline)

3 gain in Q after 300 km and tracer increase (evaporation)
River-floodplain exchange and dissolved oxygen

Channel morphology

1. Reduction in channel cross section
   Water forced into the floodplain

2. Flow and transect area constant

3. River channel expansion
   $\rightarrow$ inflow of floodplain water
River-floodplain exchange and dissolved oxygen

Tracer mixing model: $\delta^{18}O$

1. No exchange
2. Intense exchange at constant flow
3. $>80\%$ of discharge from floodplain

Mass balance calculations:
Lateral exchange $\rightarrow$ DO decline

- Seasonal variations?
- Role of upstream dam?
River-floodplain exchange over longer time scales

Comparison with data since the 1960s

FE = measure of river-floodplain exchange

Fractional exchange ratio FE:

\[
if \ Q_{out} - Q_{in} \geq 0 \quad FE = \frac{Q_{out} - Q_{in}}{Q_{out}}
\]

\[
if \ Q_{out} - Q_{in} < 0 \quad FE = \frac{Q_{out} - Q_{in}}{Q_{in}}
\]
River-floodplain exchange and dissolved oxygen

River-floodplain exchange over longer time scales

- Upstream: outflows from Oct-May
- Downstream: consistent inflows
- Similar seasonality
- Reduction in FE amplitude

Dams have reduced river-floodplain exchange by 50%
River-floodplain exchange and dissolved oxygen

Conclusions

- River-floodplain exchange: dominant hydrological driver
  - Flooding season: >80% of water passes through floodplain
  - Driven by channel morphology
  - Beyond current concepts
  - Impacts on DO regime of the river
  - 50% reduction by dam operation

Effects on source and fate of organic C and N in the Kafue River?

Hypothesis: Large change in organic matter quality
Organic C and N

Carbon and nitrogen speciation

- Along sections of high exchange:
  - DOC increase, POC decrease
- High contribution of DON
- Low (<2 µM) DIN concentrations

Loads, source and quality of OM?
Organic C and N

Export of OC and ON

OC and N loads: \( C \times Q \ [t \ d^{-1}] \)

- 4-fold increase in OC, mostly DOC
- 5-fold increase in N, mostly DON
- Deficit: 1,300 t N per year

Large OC and ON exports,
>70% mobilized from floodplain
Organic C and N

**Sources of DOM and POM**

- **$^{13}$C (‰)**
  - C$_4$ plants
  - C$_3$ plants
  - soils, sediments
  - phytoplankton

- **$^{15}$N (‰)**
  - DOM
  - POM

- **C:N ratio**
  - ITT sediments
  - N$_2$-fixation
  - Spectroscopy: terrestrial origin
    - humic/fulvic acids
  - Constant $\delta^{15}$N-DON, high N$_2$-fixation?

- **DOM, POM**
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- **Terrestrial DOM, phytoplankton POM**

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$k^a$ Kunz et al. 2011
Conclusions

- Mobilization and export of floodplain DOM
- Little variation in DOM composition
  - Stable, refractory (from upstream wetlands?)
  - No change during reservoir transit

DOM: mobilized from floodplain

- Terrestrial POM trapped by dam (Kunz et al. 2011)
- Discharge of phytoplankton POM

POM: PP from reservoir and floodplain
  → high dam impact