Integration of ecological, hydrological and socio-economic data into a Bayesian Network model for the sustainable utilization of papyrus wetlands

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Introduction...

Occurrence of papyrus dominated wetlands

- Lacustrine
- Riverine
- Floodplains
Introduction...

One resource—many interest
Exploitation for livelihoods

Patches of harvested areas

Cereal production

Extensive conversion

Mat making
Seasonal dynamics: Dry season
Seasonal dynamics:
Wet season

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Multifaceted view of wetland use
Questions?

- Can papyrus wetlands be utilised for livelihoods while sustaining functions and services?
- How do drivers affect wetland livelihoods and ecosystem functions?
- How does uncertainty of flooding affect livelihoods?
- What if the river is regulated upstream?
- ...

Hydrology

Ecology

Socio economics and governance

Information Integration - BN

Knowledge for sustainable wetland utilisation

Stakeholder workshops

Stakeholder information

NYANDO WETLAND

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Objectives

- Overall objective:
  - To develop a trans-disciplinary framework of Nyando wetland, Kenya.

- Specific objectives:
  1. Identify drivers of change and carry out a functional analysis;
  2. Formulate a causal network in the context of ecosystem services and functions;
  3. Operationalize the DPSIR causal network using a Bayesian Network model;
  4. Update the Bayesian network model with information from field data experts and stakeholders (resource users, policy makers).
Methods

Study area: Nyando wetland, Kenya

Nyando basin: 3587 km$^2$
Nyando wetland: 50 km$^2$
## Generating DPSIR

<table>
<thead>
<tr>
<th>Driver (Indirect driver)</th>
<th>Pressure (Direct driver)</th>
<th>State (Ecosystem)</th>
<th>Impact (Service/function)</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Fishing, Flooding</td>
<td>Area of natural papyrus vegetation, water quality</td>
<td>Fish yield</td>
<td>Economic, fishery and wetland policy</td>
</tr>
<tr>
<td>Economy</td>
<td>Wetland conversion, Flooding</td>
<td>Size of seasonal wetland</td>
<td>Crop yield</td>
<td></td>
</tr>
<tr>
<td>Governance</td>
<td>Flooding, Grazing, Wetland conversion, Biomass harvesting</td>
<td>Area of natural papyrus vegetation</td>
<td>Livestock production, Papyrus yield, Biodiversity, Nutrient retention, Sediment retention</td>
<td>Economic, agricultural and wetland policy</td>
</tr>
</tbody>
</table>
eDPSIR causal network for Nyando wetland

- Indirect driver
  - Population density
  - Unemployment
  - Awareness of wetland value
  - Papyrus market value
  - Papyrus crafts innovation
  - Non-wetland income
  - Rainfall in catchment
  - Rainfall Lake Victoria
  - River discharge

- Direct driver/Pressure
  - Wetland fishing
  - Conversion for agriculture
  - Vegetation harvesting
  - LV water level
  - Wetland flooding

- State
  - Permanent wetland area
  - Seasonal wetland area
  - Flooded inundated area
  - Seasonal wetland vegetation area
  - Wetland/crop area

- Impact
  - Wetland fish catch
  - Livestock production
  - Papyrus yield
  - Crop yield
  - Wetland habitat/biodiversity
  - Groundwater recharge
  - Nutrient and sediment retention
  - Drinking water supply
  - Livelihoods
  - Ecosystem functions
Stakeholder Participation
- Communities
- Government & NGOs
- Experts

Scenarios and Decision making
- Ecological
- Hydrological
- Socio-economic

Data

Master network

Feedback

Preliminary network

Consultation

DPSIR framework

Stakeholder Participation
- Communities
- Government & NGOs
- Experts

Field research & modelling
- Ecological
- Hydrological
- Socio-economic

Updated network
Stakeholder consultation

- Nyando wetland community members
- Government and NGO involved in the wetland
- Experts

- Variables sufficiency
- Relationships
- Definition of variables & states
- Information for CPT
Nodes, states and links

Node probability

Catchement_Rainfall

1900 to 2200 10.0
1600 to 1900 20.0
1300 to 1600 40.0
900 to 1300 20.0
500 to 900 10.0

1430 ± 380

Wetland_Flooding

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>50.0</td>
</tr>
<tr>
<td>Low</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Nodes linked by conditional probability
Links and CPT

The links between nodes are defined by Bayes Theorem

\[
P(B|A) = \frac{P(A|B)P(B)}{P(A)}
\]

Prior distribution

Data

Posterior probability

Wetland_Flooding

River_Discharge

<table>
<thead>
<tr>
<th>High</th>
<th>50.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>50.0</td>
</tr>
</tbody>
</table>

| >= 50 | 50.0 |
| 0 to 50 | 50.0 |
Results

• **Important indirect drivers:**
  Population density, unemployment/poverty, wetland policy, public awareness on sustainable use of wetlands among others.

• **Important direct drivers:**
  Lake Victoria water level, rainfall, land use change, Biomass harvest, grazing, flood, etc.
Bayesian Network model of Nyando wetland

Netica 4.16 (Norsys Software Corp., Vancouver, Canada)
Bayesian Network model of Nyando wetland
Changes in selected ecosystem functions and services
Selected ecosystem functions and services

- Fish yield
- Livelihoods sustainability
- Biodiversity
- Livestock numbers per household
- Seasonal wetland vegetation area
- Papyrus yield in permanent wetland
- Size of permanent wetland
- Papyrus yield in seasonal wetland
- Wetland crop production

Ecosystem Function:
- Good: 85.5
- Moderate: 13.3
- Poor: 0.77

Livelihoods:
- Good: 6.03
- Moderate: 60.9
- Poor: 33.1

Legend:
- Drought
- Flood
Ecosystem function and livelihoods during dry and wet conditions

Current situation

Ecosystem functions

Livelihoods

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Sensitivity analysis

Sensitivity of livelihoods (% entropy reduction)

Sensitivity of ecosystem function (% entropy reduction)

WCA = wetland crop area
WFL = wetland flooding
CR = catchment rainfall
LG = livestock grazing
VBH = vegetation harvesting
Further work

Data on Socio-economics and governance

Hydrological Data or models(s) output

Stakeholder and expert input

ECOLIVE framework

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Data collection: livelihoods

- Nyando wetland households with higher incomes depend less on wetland
- Lowest incomes are most dependent on papyrus harvesting

Data collection: livelihoods

Importance of livelihoods activities in three communities in Nyando wetland, Kenya

- Wetland farming, livestock grazing, water and papyrus harvesting are most important activities
- Differences between communities in livelihoods activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Score*</th>
<th>Rank</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland farming</td>
<td>Singida</td>
<td>Wasare</td>
<td>Ogenya</td>
</tr>
<tr>
<td>Wetland farming</td>
<td>7</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Livestock Grazing</td>
<td>6</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Water for Irrigation</td>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Papyrus Harvesting</td>
<td>3</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Collecting Firewood</td>
<td>1</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Fishing</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Harvesting med. plants</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Fish farming</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Sand Harvesting</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Harvesting grass</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hunting</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Liquor brew</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

*Scores are from cumulative pairwise importance ranking; Nasongo & Rongoei (2011) Unpublished results
Data collection: hydrology

- Seasonal variation in rainfall, river discharge and lake level
- River and wetland mostly disconnected (flooding only 1-2 times per year when > 50 m$^3$/sec
- Daily flooding from lake

Data collection: ecology

- Strong effect of flooding conditions on species composition and diversity

**Shannon index**

Effect of season on species composition (permanent wetland)

<table>
<thead>
<tr>
<th>Species</th>
<th>Wet Season</th>
<th>Dry Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cybab</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Cyppap</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Comspe</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Ipaqua</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Ranspec</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Source: Rongoei, P. et al. (2011) Unpublished results. INTECOL 9 JUNE 2012, ORLANDO FL USA
Summary

- BN provides integration of diverse qualitative and quantitative data in a model.
- Flooding regime in the wetland seems to have considerable effect on ecosystem function and livelihood activities.
- Wetland ecosystem functions are better off when the wetland is flooded whilst livelihoods are on average moderate due to the adaptive nature of the local communities.
Summary

• Trade-off between provisioning and regulating services
• Model is adaptive and will be further improved using on-going research, including socio-economic, hydrological and ecological model output
• Stakeholder involvement is important for model quality and for subsequent use of model in management
Application

Stakeholder and expert input

Hydrological data

Information on Socio-economics and governance

Ecological data

- Qualitative and quantitative value of the objective variables
- Evaluation Scenarios and management options

Guidelines for wise use

Policy recommendations

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THANK YOU

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