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ORIGINAL PAPER

Towards decision support-based integrated management planning of papyrus wetlands: a case study from Uganda

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Abstract Management and decision making for wetlands need an integrated approach, in which all ecosystem services are identified, their importance are assessed and objectives are formulated about their desired outputs. This approach has been applied successfully in European wetlands with sufficient scientific data. The main objective of this study was to evaluate the application of this approach in the context of a data-poor, multi-use African wetland. The Namatala wetland in Uganda, a wetland under intense pressure from wastewater discharge, conversion to agriculture and vegetation harvesting, was used as a case study. After characterisation of the wetland ecosystem and stakeholder analysis, three management options, subdivided into 13 sub-options, were identified for the wetland. These options were combined into six management solutions. A set of 15 indicators, subdivided into five categories (livelihood; human health; ecology; costs; risk of failure), were identified to assess the performance of these management solutions. Stakeholders' preferences were taken into consideration by means of weights attached to the indicators, and a best-compromise solution was derived which consisted of a combination of sustainable agriculture in the upper Namatala wetland, papyrus buffer strips along the Namatala river channel, sustainable land use (vegetation harvesting, fishing) in lower Namatala wetland, and papyrus buffer zones at the waste-water discharge points.

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Despite differences of opinion among stakeholder groups about the relative importance of the indicators, the same compromise solution resulted for all stakeholders. It was concluded that this systematic approach and the stakeholder dialogue about the management options were beneficial to the management process, although the approach would benefit from more and better data about the wetland system and from model-derived predictions.

Keywords Decision support · Integrated wetland management · Namatala wetland · Papyrus · Sustainable use · WETwin project

Introduction

Wetlands are valuable elements of river basins worldwide. On the one hand they provide habitats for a wide range of plants and animals (including several protected species), while on the other hand they deliver ecosystem services ranging from water quality and quantity regulation, through provisioning drinking water, food and raw materials, to providing cultural services of recreation and ecotourism (MEA 2005; TEEB 2010). Some of these functions are only of local importance, while others have impacts on basin and country scales. Management and decision making for wetlands need an integrated approach, in which all ecosystem services are identified, their importance is assessed and objectives about their desired outputs are formulated (Brouwer et al. 2003; de Groot et al. 2010; Ramsar Convention Secretariat 2010a; Rebelo et al. 2013). This is not easy, as not all ecosystem services are easily quantifiable and different ES are affected by environmental conditions and human activity differently (Carpenter et al. 2009; Maltby and Acreman 2011). The Ramsar Convention on Wetlands supports member countries with implementation of integrated wetland management through its "wise use" concept ("Wise use of wetlands is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development") and related management tools (Ramsar Convention Secretariat 2010b).

In African wetlands, riparian communities often depend on wetlands directly for food, fuel and fibre (Rebelo et al. 2010), and knowledge about the regulating and habitat services is often limited. For example, papyrus wetlands (dominated by the sedge *Cyperus papyrus* L.) are important for the livelihoods of millions of people (Kipkemboi et al. 2007; Rongoei et al. 2013). The papyrus culms are harvested for weaving baskets and covering roofs, many papyrus wetlands are used for seasonal agriculture and they are excellent habitats for bird and fish species (MWLE 2004). Some papyrus wetlands are used for treating wastewater thanks to their high purification capacity (Kansiime and Nalubega 1999). Because of their importance for food and materials, the provisioning services of papyrus wetlands are often favoured compared to their ecological functions and other services, and they are threatened by overexploitation. Examples of this were described for various sites, such as Nakivubo wetland in Uganda (Kansiime and Nalubega 1999) and Nyando and Yala wetlands in Kenya (Rongoei et al. 2013; Thenya et al. 2006). In the Namatala wetland in Uganda, most of the papyrus stands were lost as a result of agricultural encroachment (Zsuffa and Cools 2011). The intense competition for the highly productive lands of this wetland has even led to conflicts over land use in which farmers were killed (Edyegu 2010). In Namatala, increasing wastewater loads present further threats of ecosystem degradation (Namaalwa et al. 2013). Thus, papyrus wetlands are vulnerable and new sustainable management strategies are needed for their preservation.

As indicated above, wetland management is essentially an integrated decision problem with multiple sectors, stakeholders and objectives, some of which can be in conflict with each other. In European wetland management, the integrated approach often uses some form of decision support framework (DSF) to arrive at an optimum solution. Multi-Criteria Analysis (MCA) usually forms a core module in these DSFs. For example, a MCA-based DSF was applied successfully to identify and rank new management strategies for the Danube riparian Lobau wetland in Austria (Hein et al. 2006). The top-ranked solutions were proposed for implementation as the 'best compromises' among the multiple functions and services of this wetland. In cases like this, the successful application of a DSF was facilitated by the availability and accessibility of a wealth of hydrological, geomorphological, ecological and economic data, which enabled quantitative, model-based evaluations of alternative management solutions during the MCA process.

The integrated approach can also contribute to improving management strategies for African wetlands and thus be a tool for African governments in implementing the Ramsar Convention. It can help them to manage wetlands in a sustainable manner that supports livelihoods and economic development while not losing the vital ecological functions that wetlands perform. However, application of an integrated approach in African wetlands may be a challenge because of specific boundary conditions and limiting factors, such as data scarcity. This challenge was explored in the EU-FP7-funded WETwin project 'Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives' (Zsuffa et al. 2012). The methodological basis was an MCA-based DSF that was designed to cope with data-poor conditions (Johnston et al. 2013).

The main objective of this study is to evaluate application of the WETwin DSF in the context of an African multi-use wetland. As a case study the Namatala wetland is used, a papyrus wetland in north-eastern Uganda under intense pressure from wastewater discharge, conversion to agriculture and vegetation harvesting (Namaalwa et al. 2013). To improve the health of the Namatala wetland in a sustainable and integrated way, an appropriate management solution needs to be elaborated and implemented. Specific objectives of this study were (1) to characterise the wetland ecosystem including stakeholders, pressures and ecosystem services; (2) to identify management options addressing specific management issues or problems; and (3) to formulate alternative management solutions and evaluate them using criteria that reflect the interests of the stakeholders.

Materials and methods

Study area

Namatala is a highly modified wetland with an approximate size of 260 km^2. Two parts of the wetland can be distinguished: the upper part, which is located between Mbale town and Naboa village; and the lower part, stretching from Naboa to the southwest where the Namatala River joins the Manafwa system (Fig. 1). In the upper wetland, the original papyrus

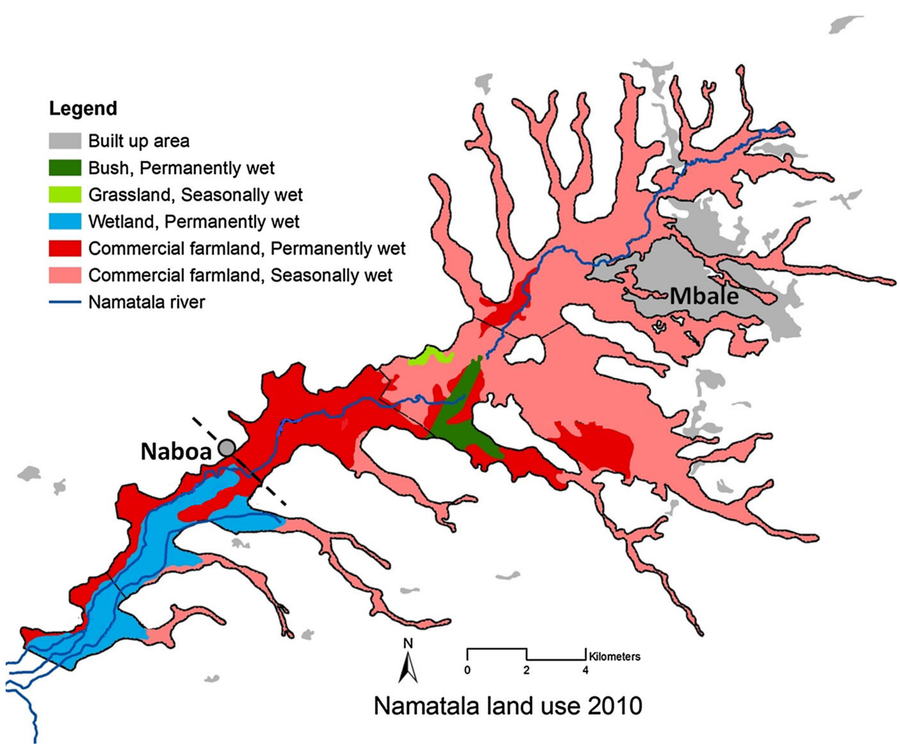

Fig. 1 Land use in the Namatala wetland, Uganda (based on figure by Namaalwa et al. 2013). Namatala river flows from the northeast to the southwest. The *dotted line* indicates the transition from the upper wetland (dominated by agricultural land use) to the lower wetland (dominated by original wetland vegetation), close to Naboa village

vegetation has been replaced completely by commercial rice fields and by small-scale mixed cropping (sugarcane, maize, cassava, potatoes, yam, etc.). The wastewater of Mbale town is treated in stabilisation ponds (where the main process is sedimentation of solid substances) before being discharged into the wetland.

The lower wetland is deeper and therefore seasonal agriculture is mainly practiced at the fringes, although in dry years (as e.g. in 2010 and 2011) the deeper parts of the wetland are also encroached upon. In some parts of the lower wetland, the original papyrus vegetation is still intact and other livelihoods activities related to the original wetland vegetation (fishing, vegetation harvesting) are practiced. Detailed analyses of the climatic, hydrological, ecological, land use and institutional conditions of the Namatala wetland were carried out by Namaalwa et al. (2013).

Decision support framework (DSF)

The WETwin DSF is based on existing trade-off analysis methods, such as the ‘Participative multi-criteria analysis’ method of Paneque Salgado et al. (2009), the ‘Social multi-criteria evaluation’ method of Gamboa (2006), the ‘Framework for integrated assessment and valuation of wetland services’ of de Groot et al. (2006) and the MULINO Decision Support System (mDSS) of Giupponi (2007). Trade-off analysis for a given wetland consists of evaluating potential effects of alternative development strategies (“management solutions”) to make informed decisions about options for sustainable, multi-functional use of wetland ecosystem services (SCBD 2007). The final goal is achieving “wise use” of wetlands, i.e., best compromise management solutions that are ecologically sustainable, socially acceptable, and economically sound (de Groot et al. 2006).

The DSF has the following main steps:

Step 1. Stakeholder analysis: All relevant stakeholders at wetland, basin, district and country levels are identified and their interests, influence, relationships and conflicts explored. Knowledge, opinions and preferences of stakeholders play a fundamental role in the DSF and are solicited at several stages.

Step 2. Characterisation and problem definition: For the characterisation of the natural and socio-economic status of the wetlands, the DSF uses the Ecosystem Services approach according to the methodology of the Millennium Ecosystem Assessment (MEA 2005) and The Economics of Ecosystems & Biodiversity (TEEB 2010) projects. The problems and issues to be dealt with are revealed and characterised using the DPSIR approach (analysis of Drivers–Pressures–State–Impacts–Responses; EEA 2005). In addition to identifying the actual and potential problems of the wetland with regard to its ecosystem services, DPSIR reveals the cause–effect chains behind these problems.

Step 3. Generation of management solutions: First, management options are formulated: well-defined actions that address specific issues or problems, and usually operate in a single management domain. Then, management solutions are derived by combining management options into compatible, practical packages of action that address all the relevant issues, problems and domains of the wetland. Thus, a management solution may be turned into the management plan of the entire wetland, given that the decision makers support it. Formulation of solutions requires a pragmatic approach to selecting feasible combinations of options. Narrowing down the choice of solutions can be done arbitrarily and subjectively, based on stakeholder preferences and practical considerations for implementation. It is recommended to design a range of management solutions, including extremes of the trade-offs that favour certain ecosystem services and stakeholders, as well as compromise solutions between the conflicting ecosystem services. Designing viable solutions thus has a subjective component, and consultation with stakeholders is essential throughout the process.

Step 4. Evaluation of the solutions: Solutions are evaluated according to indicators from three key domains: ecosystem services; ecosystem health and integrity; and feasibility of implementation. In order to make the different indicators commensurable and comparable, the raw indicator values are normalized between 0 and 1 with the help of value functions. The so-derived values are the criteria scores, indicating how the investigated management solution scores on each domain in a range from unacceptable or undesirable (score = 0) to optimal (score = 1). Where possible, quantitative indicators, that can be measured in the system or estimated by appropriate models, are identified. However such indicators cannot always be found for all important criteria, especially under data-poor conditions. To avoid ignoring important values and skewing the analysis because a criterion cannot be quantified, qualitative indicators estimated based on available information and expert judgement can be used.

Evaluations should also account for external drivers such as population growth and climate change. After quantifying them with appropriate social and climate models (or by means of expert judgement in case of data scarcity), these drivers form boundary conditions for the evaluations. Uncertainty can be taken into consideration by forming alternative scenarios for these drivers.

Criteria scores of the solutions are input to MCA methods, where the solutions are ranked according to the preferences of stakeholders. Based on the different stakeholder-specific rankings a single compromise ranking can be derived. High-ranked solutions can be recommended to the decision makers and stakeholders for implementation. If they are not satisfied with any of them, then the process loops back for identifying and evaluating new (improved) management solutions. Step 4 of the DSF is facilitated by the MULINO Decision Support System (mDSS) software (Giupponi 2007).

For more details about the generic methodological basis of the DSF, see Johnston et al. (2013).

Application of the DSF to Namatala wetland

For Namatala wetland, Steps 1 and 2 were described in Namaalwa et al. (2013) and are only summarized here. Stakeholders were identified and a number of stakeholder meetings were held to analyse management problems of Namatala wetland and elicit stakeholder views on management options and solutions. Characterization of the system was done using DPSIR analysis (EEA 2005) and creating a casual network for Namatala wetland using the method described by Niemeijer and de Groot (2008).

In this paper, focus is on generation and evaluation of management solutions for the Namatala wetland (Steps 3 and 4 of the DSF). Three main management options were identified. These options were combined into six management solutions. A set of 15 indicators, subdivided into five categories (livelihood; human health; ecology; costs; risk of failure), were identified to assess the performance of these management solutions. Nine indicators (rice, fish and papyrus production; wetland and crop areas; water quality) were assessed quantitatively using available data on the wetland and simple relationships. Eight other indicators (mainly risk and cost factors) were estimated qualitatively by expert judgment. The further steps of the evaluation of the management solutions took place in the mDSS decision support tool (Giupponi 2007).

After normalization of the indicator values, the criteria scores were weighted by the different stakeholder groups, expressing their different, often conflicting, interests in the management and utilization of the Namatala wetland. For this study, this was only done for the five main indicator categories. The weights can further be refined within each criteria group, but this was done only for the ‘Expert weighting’. For the other stakeholder groups the weights were equally distributed within category.

Criteria scores and weight sets were then input for a MCA technique that ranked the alternative solutions. Simple Additive Weighting (SAW) was used to calculate the weighted sum of criteria scores to measure the performance of a solution:

$$\Phi_i = \sum_{j=1}^{n} w_j \cdot u_{ij}$$

where w_j: weight assigned to criterion j; u_{ij}: score of solution i at criterion j; n: number of criteria. The solution with the highest weighted sum was ranked first according to the given weight set. Because of their different preferences, this resulted in separate ranking of alternative solutions for each stakeholder group. A compromise ranking of solutions was achieved by using the Borda method of the mDSS.

The impact of population growth was also taken into consideration as it is expected to cause (1) increasing demand for food and related agricultural production, probably resulting in continued agricultural encroachment; (2) increasing (urban) wastewater load, creating pollution and contamination risk. Both aspects threaten to further degrade the Namatala wetland partially or even entirely. With regard to climate change, two future precipitation datasets for the Namatala region show opposing trends: −2.32 mm/year (data from the PIK, Potsdam Institute for Climate Impact Research) and +0.12 mm/year (Hirabayashi et al. 2008). Because of this uncertainty climate change was not considered in this study.

Results

Stakeholder analysis and problem definition (Steps 1 and 2)

Stakeholders in Namatala wetland were identified and grouped according to their interests, influences and relationships. This resulted in the following groups: water managers, resource users, political leaders, environmentalists, civil society and community service providers.

Problems were identified and analysed in close cooperation with the stakeholders (Namaalwa et al. 2013). Agricultural encroachment was highlighted as a major concern by most stakeholder groups, followed closely by biodiversity loss which most stakeholders related to encroachment through land use change and pollution from urban wastewater and agriculture. Farmers, papyrus harvesters, and fishers (the resource users) pinpointed diversion of rivers and streams and land use and ownership conflicts as the most important problems. For them, wetland pollution and loss of biodiversity had lower priority. The major driving force behind the problems in Namatala wetland is population growth. Other drivers mentioned by stakeholders were: scarcity of arable land, lack of alternative livelihood opportunities, and inadequate regulation and enforcement of legislation by wetland management institutions. These drivers and pressures have led to the degradation of water quality and habitats, which in turn resulted in the degradation of cultural and regulating services (Fig. 2). These

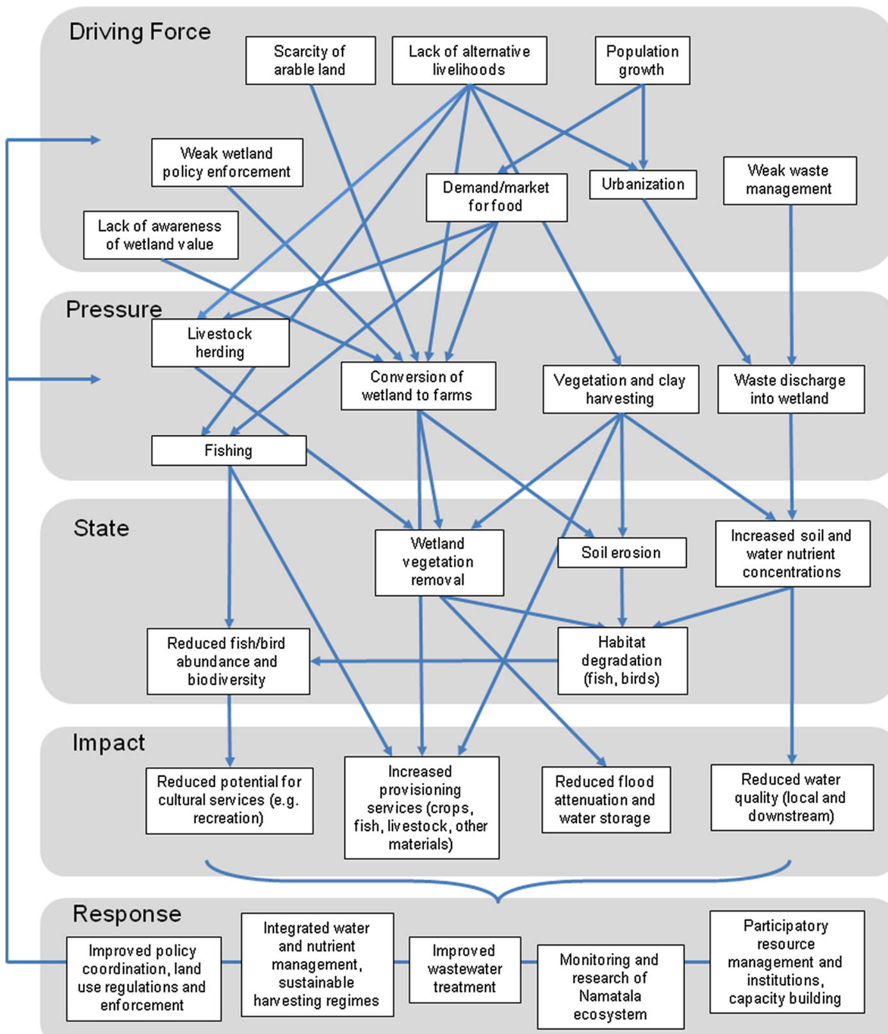

Fig. 2 Causal network based on the Driver–Pressure–State–Impact–Response framework (eDPSIR; see EEA 2005; Niemeijer and De Groot 2008) of the Namatala wetland based on analysis by stakeholders of actual and potential issues (Namaalwa et al. 2013)

problems will likely be exacerbated in the future, due first of all to the rapid growth of population. The DPSIR analysis also provided suggestions for potential management responses, which we used as starting points for developing management solutions for the Namatala wetland.

Management options and solutions for Namatala wetland (Step 3)

Three main management options for Namatala wetland were identified with the help of the stakeholders (Table 1). The options were: (A) Land-use planning in the upper wetland, consisting primarily of implementing more sustainable agricultural methods and the creation of papyrus buffer zones. Rationale behind this option is the reduction of nutrient and sediment release in the upper wetland (from agricultural practice and wastewater release) to reduce pressure from erosion and eutrophication on the lower wetland and downstream areas. (B) Land-use planning in the lower wetland, consisting mainly of conservation of the remaining natural wetland vegetation. Rationale is the conservation of the ecological functions and biodiversity, which are mainly safeguarded by the lower wetland (Namaalwa et al. 2013). (C) Improved wastewater management, by rehabilitation and improved management of the wastewater treatment facilities. Rationale is the reduction of nutrients, pathogens and toxic substances that are currently released into the wetland as wastewater from Mbale town. Treatment facilities are limited and wastewater is only treated partially. Each of these main options was broken down into several sub-options of increasing intensity, ranging from Business-As-Usual (BAU) to active investments and strict enforcement (Table 1).

These options were combined into four main Management Solutions (MS), two of which had a low financial effort and a high financial effort version, leading to a total of six management solutions (Table 2). Management Solution 0 (MS 0) represented "Business As Usual", meaning continued exploitation of the wetland without additional management measures. With the current trend in agricultural development, the remaining wetland is expected to be completely replaced by farmland (mainly rice) during the next 20 years. Currently, fertiliser and pesticide use is low but there is a tendency for intensified agricultural practice to increase yields. The use of fertilisers and pesticides will have a strong negative impact on water quality in the system.

In MS 1 ("Water Quality Improvement"), the priority objective was the prevention of contamination of the agricultural wetland area with pathogens and toxic substances to reduce health risks. Additionally, wastewater treatment and the creation of buffer zones reduce the risk of degradation of the natural papyrus stands in the lower wetland and downstream regions by reducing nutrient and sediment loads into the lower wetland. The low financial effort solution (MS1a) entailed promotion of sustainable agriculture in the upper wetland, promotion of sustainable use in the lower wetland, and rehabilitation of the existing wastewater treatment facilities. MS1b (higher financial effort) included additional measures like the implementation of buffer zones in the upper wetland to further reduce nutrient input in the river and the lower wetland, and expansion of wastewater treatment facilities.

In MS 2 ("Land use management/planning—conservation and nature harvesting"), the main objective was optimization of the (lower) wetland for conservation and harvesting of natural goods. In the current status, the lower papyrus wetland (approximately 10 % of the wetland area) is important for nature conservation (papyrus, endemic bird species, indigenous fish species) and for local people's livelihoods (fishing, papyrus harvesting). MS2a (low financial effort) included sustainable agriculture and buffer strips in the upper wetland, sustainable use in the lower wetland, and buffer zones at the wastewater treatment plants to reduce nutrient discharge. In MS2b (higher financial effort), awareness campaigns among the wetland communities about the importance of wetland conservation and strict enforcement of protection measures were added to this.

MS 3 ("Integrated Management") was an integrated management solution, combining all of the proposed management options of the other management solutions.

Evaluation of management solutions (Step 4)

Values of the 15 indicators at the management solutions are presented in Table 3 (for the evaluation matrix with normalized scores, refer to Online resource 1). Land use management and integrated

Table 1 Management options formulated for the Namatala wetland

A. Land-use planning in upper Namatala: sustainable agriculture and creation of papyrus buffer zones. Different sizes of buffer zones can be investigated	A.1, BAU (Business As Usual): maintaining the present status: commercial rice and small-scale mixed cropping. Agricultural practices in the wetland have a strong impact on water quality. Fertilizer use is limited to some commercial plots, but may increase if yields cannot be maintained, or if higher yields are desired. Erosion-exacerbating soil management practices and channelization are common and lead to increased sediment release to downstream
	A.2: Sustainable agriculture: current production is likely based on nutrients from the wastewaters of Mbale town that enter the wetland through the stabilization ponds. While this presents some health and environmental risks, maintaining this nutrient recycling while reducing risks should be explored. After legalizing the agricultural use of the wetland, ecologically sound, sustainable agriculture can be stimulated by *farmer training* and extension activities (no or very limited fertilizer use, integrated pest management, controlled drainage and channelization, introducing crop diversity, integrated cultures and rotation). All these should lead to a *community-based management plan* for the upper wetland
	A.3: Creating papyrus buffer strips to reduce diffuse-source nutrient and sediment loads on the wetland, prevent contamination with pathogens and toxic substances, and enhance biodiversity (esp. birds). This is only realistic along 30 m-wide strips on the banks of the river channel between the Mbale-Kampala highway and the point where the smaller streams join the main channel from the south
B. Land-use planning in lower Namatala: conservation of the remaining natural wetland vegetation. Lower Namatala should be protected as a natural wetland to conserve the ecological functions and biodiversity	B.1, BAU: Maintaining the present status: increasing agricultural encroachment
	B.2: Sustainable use. This includes sustainable fishing but not crop production. Papyrus harvesting regimes (from no harvesting to harvesting of 15 % of the total biomass once per year) would be applied. *Training on sustainable fishing and harvesting.* All these should lead to a *community-based management plan* for the lower wetland
	B.3: Awareness campaign among communities (churches, schools, etc.) on wetland values and sustainable use. *Complementary to B.2*!
	B.4: Strict enforcement of national wetland and land ownership policies to conserve natural hydrological and ecological functions. Regular monitoring. *Complementary to B.2*!
C. Rehabilitation, improved management and extension of wastewater treatment facilities: Water quality management is currently characterized by only partial treatment of wastewater from Mbale town, limited treatment facilities both in terms of capacity (number of ponds) and effectiveness, and health risks associated with pathogens and toxic substances released into the wetland	C.1, BAU: Leave the waste stabilization ponds as they are
	C.2: Rehabilitate the current treatment facilities, improve maintenance and operation
	C.3: Increase the capacity of the present stabilisation ponds to the present or projected flow of wastewater from Mbale municipality. *C.2 is a prerequisite*!
	C.4 Increased onsite treatment of household wastes and established mechanism for collection & disposal
	C.5: Provision of faecal sludge treatment unit(s)
	C.6: Reduce risk of contamination by pathogens, toxic substances or heavy metals (from industrial/cottage industry effluents) by establishment of papyrus buffer zone at the outlets of stabilisation ponds

Table 2 Components making up the management solutions for Namatala

Options (for detailed description of the options see Table 1)		Solutions					
		MS 0	MS 1		MS 2		MS 3
			a	b	a	b	
A: Land use planning in upper wetland	A.1 BAU (Business As Usual)	X					
	A.2 Sustainable agriculture		X	X	X	X	X
	A.3 Papyrus buffer strips along Namatala River			X	X	X	X
B: Land use planning in lower wetland	B.1 BAU	X					
	B.2 Sustainable use		X	X	X	X	X
	B.3 Awareness campaign among communities on wetland values and sustainable use					X	X
	B.4 Strict enforcement of national wetland and land ownership policies					X	X
C: Improving wastewater treatment facilities	C.1 BAU	X					
	C.2 Rehabilitation and improved management of treatment facilities		X	X			X
	C.3 Increase the capacity of treatment facilities			X			X
	C.4 Increased onsite treatment of household wastes and established mechanism for collection & disposal			X			X
	C.5 Construction of faecal sludge treatment facility						X
	C.6 Papyrus buffer zone at discharge with harvesting regime			X	X	X	X

solutions lead to lower rice production (upper wetland) but higher fish and papyrus production (lower wetland). On the other hand, these solutions lead to better indicators for water quality and ecosystem functions like nutrient and sediment removal. The tendency for these more ambitious solutions is to have higher costs and a higher risk of failure.

There were several differences in the weighting of the five indicator categories by different stakeholder groups (Table 4). Perhaps somewhat surprisingly, all stakeholder groups put most emphasis on the ecological indicators (all >20 %), with resource users allocating even 32 % of the weight here. Most stakeholder groups allocated 25 % of the weight to the livelihoods indicators, except resource users (higher, 27 %) and water managers and political leaders (lower, at 17 and 19 %, respectively). All stakeholders weighted risk of failure similarly (17–18 %) except the experts (25 %). Largest differences in weighting were for human health and cost indicators.

The compromise ranking clearly identified MS2a as the best compromise solution with all stakeholder groups ranking this solution first. This solution consists of the following management options (see also Fig.3):

- A.2 Sustainable agriculture in Upper Namatala wetland
- A.3 Papyrus buffer strips along Namatala River
- B.2 Sustainable land use in lower Namatala
- C.6 Papyrus buffer zones at the waste-water discharge points; harvesting regime in these zones

Discussion and recommendations

The characterization of the Namatala wetland emphasized the importance of both the provisioning ecosystem services of the wetland (rice, fish and papyrus production) and the regulating services (wastewater treatment and retention of nutrients and sediment). Because of the strong population pressure and the need for increased food production, there is a tendency to convert the wetland into agricultural crops at the expense of the natural wetland system. This is a trend that occurs throughout the African continent and in this sense Namatala wetland is representative of many

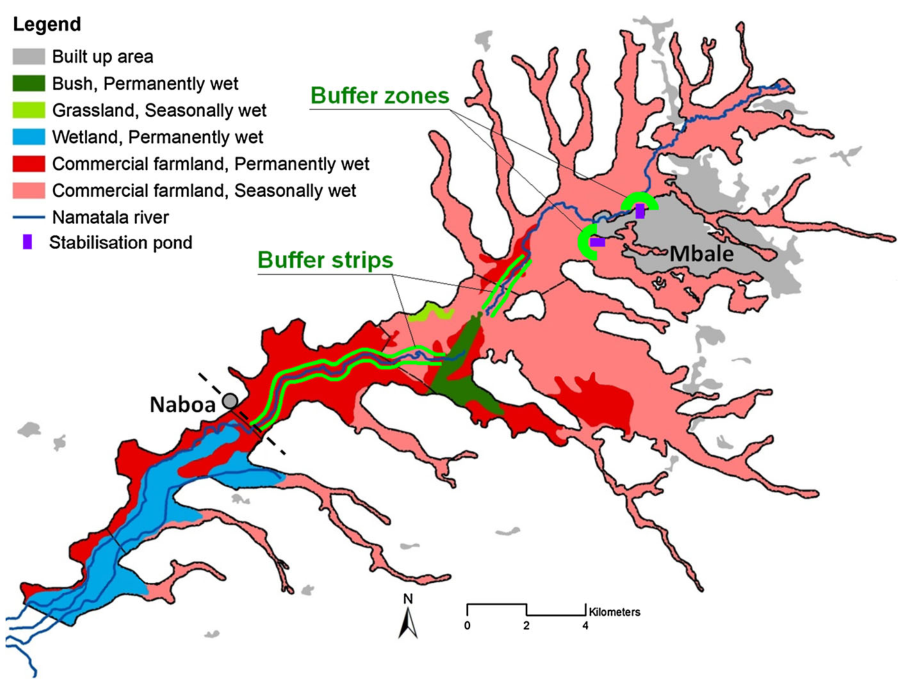

Fig. 3 Buffer strips along Namatala river, and buffer zones around the wastewater stabilization ponds as proposed for construction in the Namatala wetland according to the MS2a management solution

Table 3 The Analysis Matrix: indicator scores of the alternative management solutions developed for the Namatala wetland (for the Evaluation Matrix containing the normalized criteria scores, please refer to Online resource 1)

Category	No.	Indicators	Actual state	Management solutions					
				Business as ususal (Agr. Encroach) MS 0	Water quality (low effort) MS la	Water quality (high effort) MS lb	Land use mgmt (low effort) MS 2a	Land use mgmt (high effort) MS 2b	Integrated mgmt MS 3
Livelihood	1	Total rice production in wetland (t/year)	24,000	45,000	45,000	45,000	24,000	12,000	7,000
	2	Total fish production in wetland (t/year)	35	7	7	7	35	42	42
	3	Total production of papyrus biomass (t/year)	461	45	82	82	461	625	625
Human health	4	Disease risk (water-borne diseases)	Medium	High	Medium	Low	Medium	Medium	Low
Ecology	5	Area of Papyrus wetland	2,000	200	200	200	2,000	3,200	3,200
	6	Area of Papyrus buffer strips	0	0	0	18	18	18	18
	7	Downstream water quality							
		Suspended solids	46.0	100.0	100.0	100.0	36.8	29.9	23.0
		Nitrogen	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Phosphorus	0.3	0.5	0.5	0.5	0.25	0.20	0.15
	8	Nutrient removal by rice (t/year)	272	509	509	509	272	136	80
	9	Nutrient removal by papyrus (t/year)	4.2	0.5	0.8	0.8	4.2	5.7	5.7
Costs	10	Investment WWTP	No	No	Low	Medium	No	No	High
	11	Cost of training of communities	No	No	High	High	High	High	High
	12	Cost of awareness campaign	No	No	No	No	No	High	High
Risk of failure	13	Risk of technical failure	Low	Low	Medium	Medium	Low	Low	Medium
	14	Risk of non-acceptance by community	Low	Low	Low	Low	Medium	High	High
	15	Lack of institutional capacity	Unlikely	Unlikely	Unlikely	Possibly	Possibly	Likely	Likely

other multi-use wetland sites. Application of the DSF could contribute greatly to more rational management strategies for wetlands, as it has been proven by case studies from other continents. An example for such case studies is the one dealing with the Lobau wetland in Austria (Hein et al. 2006).

Application of the DSF to Namatala wetland brought out challenges with respect to the data needs for this

Table 4 Weights assigned by the different stakeholder groups to the criteria

		Expert weighting	Water managers	Resource users	Political leaders	Environmentalists	Civil society	Community services
Livelihood (%)		25.00	17.00	27.00	19.00	25.00	25.00	25.00
1	Total rice production in wetland (t/year)	0.50	0.33	0.33	0.33	0.33	0.33	0.33
2	Total fish production in wetland (t/year)	0.20	0.33	0.33	0.33	0.33	0.33	0.33
3	Total production of papyrus biomass (t/year)	0.30	0.33	0.33	0.33	0.33	0.33	0.33
Human health (%)		10.00	21.00	18.00	20.00	19.00	25.00	15.00
4	Disease risk (water-born diseases)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ecology (%)		25.0	27.00	32.00	26.00	28.00	25.00	15.00
5	Area of Papyrus wetland	0.30	0.20	0.20	0.20	0.20	0.20	0.20
6	Area of papyrus wetland	0.10	0.20	0.20	0.20	0.20	0.20	0.20
7	Downstream Water quality (SS, N, P)	0.20	0.20	0.20	0.20	0.20	0.20	0.20
8	Nutrient removal by rice	0.25	0.20	0.20	0.20	0.20	0.20	0.20
9	Nutrient removal by papyrus (t/year)	0.15	0.20	0.20	0.20	0.20	0.20	0.20
Costs (%)		15.0	18.00	5.00	18.00	10.00	8.00	15.00
10	Investment WWTP	0.33	0.33	0.33	0.33	0.33	0.33	0.33
11	Cost of training communities	0.33	0.33	0.33	0.33	0.33	0.33	0.33
12	Cost of awareness campaign	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Risk of failure (%)		25.0	17.00	18.00	17.00	18.00	17.00	18.00
13	Risk of technical failure	0.25	0.33	0.33	0.33	0.33	0.33	0.33
14	Risk of non-acceptance by community	0.35	0.33	0.33	0.33	0.33	0.33	0.33
15	Lack of Institutional capacity	0.40	0.33	0.33	0.33	0.33	0.33	0.33
		100.00 %	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %

quantitative framework. One of the reasons for using the DSF successfully in the restoration of the Lobau was the availability of well-calibrated hydrodynamic and ecological models for evaluating the alternative management solutions (Hein et al. 2006). This was made possible by the excellent availability of data for model calibration and validation. Ideally, the qualitative expert judgement-based evaluations, as well as the simple quantitative assessments used in this study would be replaced by more model-based assessments. Hydrological modelling could use for example the SWIM rainfall-runoff model with its intrinsic wetland module which was successfully applied at the other pilot study wetlands of the WETwin project (Liersch et al. 2013). The papyrus model of Hes et al. (2011) would support the DSF process in multiple ways:

- Enables the accurate calculation of the total papyrus biomass production (see Table 3) under given hydrological, land use and harvesting conditions defined by the management solutions and by the climatic conditions.
- Calculates nutrient removal by papyrus.
- Contributes to the quantification of downstream water quality by deriving the nitrogen outflow from the papyrus fields.

- Supports the detailed design of the papyrus buffer zones and strips, and the harvesting strategies to be applied upon them.

Production, nutrient removal and nutrient outflows from the flooded rice fields of Namatala wetland can be calculated with the help of crop models, such as the CropSyst model of Stöckle et al. (2003) which has been adapted successfully to flooded rice (Confalonieri and Bocchi 2005). Set-up, calibration and validation of these wetland models require data on hydrology and climate and remote-sensed satellite images to refine the land use and land cover distribution over the wetland. While some data from local monitoring of hydrological and water quality parameters and land use was available at Namatala, generally the resolution was low and there were considerable gaps in historical datasets. Moreover, data was often scattered among different government departments (e.g. National Water and Sewerage Corporation, Wetlands Management Department) and often it was not clear if data were available for research and management purposes, and at what cost.

Another challenge for application of the DSF was stakeholder participation. There are many stakeholders with an interest in the Namatala wetland from different levels and sectors and the relationships among them are complex (Namaalwa et al. 2013). In addition, like in many other African countries, the parallel existence of official government institutions (policies, regulations) and traditional, often local institutions makes the situation even more complicated. In Uganda, this complexity is set against the background of the government's decentralization policy (Hartter and Ryan 2010). Stakeholder involvement is thus a complex and challenging issue which requires time and attention in the management process. It is necessary to strengthen the capacity of stakeholders to take part in this process, and it is also important to better support the stakeholders in expressing their true preferences. For example, stakeholders may not be interested in all criteria. They must be allowed to select first the criteria they are interested in (and/or add new ones), and disregard the rest.

The management options that were identified, and on which the management solutions were based, focused on land use change in the upper and lower wetland and on strengthening the existing wastewater treatment facilities. With continuing population growth in the Mbale area and the need to support the livelihoods of this growing population as well as maintain a healthy living environment, more ambitious management options might need to be explored to create a wider range of solutions for stakeholders to consider. These options could involve not only the wetland but also the wider catchment of the Namatala river. A major part of the nutrient load into the wetland comes from the main river channel (Namaalwa et al. 2013) and therefore upstream catchment management will have a major impact on the Namatala wetland ecosystem. Other options that could be considered are integrated nutrient management in combination with improved wastewater treatment. Experiments with integrated wetland production systems have shown that it is possible to use nutrients in wastewaters effectively to increase food production and increase the value of the provisioning ecosystem services without affecting the regulating services. Constructed wetlands can be used in combination with aquaculture ponds or vegetable production (Lin et al. 2002; Scholz et al. 2007). Seasonal self-stocking fishponds may provide opportunities to increase fish production without interfering with the natural functions of the wetland (Kipkemboi et al. 2007). Another possibility would be the development of ecotourism, which increases the value of an intact wetland ecosystem for the benefit of the communities (Pemberton and Mader-Charles 2005).

This was a first endeavour to apply a complex decision support system to a multi-use papyrus wetland in eastern Africa. As more data and tools become available, African governments will increasingly make use of these for improved management of wetland resources. Although real problems were handled and real stakeholders were involved, this application should still be viewed as an experiment as the DSF and its components need to be developed further before applying them in real decision making contexts. Nevertheless, some important conclusions for wetland management in Africa can be drawn: (1) In many countries, where monitoring and research programmes are scarce, expert judgment-based evaluations remain unavoidable—they are still better than nothing. For these countries, data collection and model development must be high priorities since quantitative tools based on the thorough knowledge of all relevant physical, chemical and biological processes are essential for the reliable evaluation of management solutions; (2) Model-based quantitative evaluations require data that are available, accessible and of good quality. These all necessitate a reliable, efficient and transparent data management system in the country; (3) Stakeholder organization and capacity building are of paramount importance, as community-based management cannot be enforced by central government. Integration of traditional governance structures into modern arrangements is essential and there are now several examples of engaging wetland communities in policy making (Wood et al. 2013); (4) When expert judgment-based evaluation is used (e.g. because of financial constraints), it is recommended to improve the reliability of this methodology as much as possible. Existing wetland-specific rapid assessment tools, such as the WET-Health (Macfarlane et al. 2008) and the WET-EcoServices (Kotze et al. 2008) tools, are recommended to be adapted and embedded into the DSF.

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References

Brouwer R, Georgiou S, Turner RK (2003) Integrated assessment and sustainable water and wetland management. A review of concepts and methods. Integr Assess 4:172–184

Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Díaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM, Perrings C, Reid WV, Sarukhan J, Scholes RJ, Whyte A (2009) Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. Proc Natl Acad Sci 106:1305–1312

Confalonieri R, Bocchi S (2005) Evaluation of CropSyst for simulating the yield of flooded rice in northern Italy. Eur J Agron 23:315–326

de Groot R, Stuip M, Finlayson M, Davidson N (2006) Valuing wetlands: guidance for valuing the benefits derived from wetland ecosystem services. Ramsar Technical Report No. 3, CBD Technical Series No. 27. Ramsar Convention Secretariat, Gland, Switzerland & Secretariat of the Convention on Biological Diversity, Montreal, Canada

de Groot R, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol Complex 7:260–272

Edyegu D (2010) Floods retarding border demarcation. The new vision. http://www.newvision.co.ug/news/615830-floods-retarding-border-demarcation.html. Accessed 4 July 2010

EEA (2005) European environmental outlook. European Environment Agency, Copenhagen

Gamboa G (2006) Social multi-criteria evaluation of different development scenarios of the Aysén region, Chile. Ecol Econ 59:157–170

Giupponi C (2007) Decision support systems for implementing the European water framework directive: the MULINO approach. Environ Model Softw 22(2):248–258

Hartter J, Ryan SJ (2010) Top-down or bottom-up? Decentralization, natural resource management, and usufruct rights in the forests and wetlands of western Uganda. Land Use Policy 27:815–826

Hein T, Blaschke AP, Haidvogl G, Hohensinner S, Kucera-Hirzinger V, Preiner S, Reiter K, Schuh B, Weigelhofer G, Zsuffa I (2006) Optimized management strategies for the biosphere reserve Lobau, Austria-based on a multi criteria decision support system. Int J Ecohydrol Hydrobiol 6:25–36

Hes EMA, Niu R, van Dam AA (2011) A simulation model for nitrogen and carbon cycling in natural rooted papyrus wetlands in East Africa. Paper presented at the joint meeting of society of wetland scientists, WETPOL and wetland biogeochemistry symposium, Prague, 3–7 July 2011. Book of abstracts. Available at http://www.sws2011.com

Hirabayashi Y, Kanae S, Motoya K, Masuda K, Döll P (2008) A 59-year (1948–2006) global near-surface meteorological data set for land surface models. Part I: development of daily forcing and assessment of precipitation intensity. Hydrol Res Lett 2:36–40

Johnston R, Cools J, Liersch S, Morardet S, Murgue C, Mahieu M, Zsuffa I, Uyttendaele GP (2013) WETwin: a structured approach to evaluating wetland management options in data-poor contexts. Environmental Science & Policy. Special Issue: Management of wetlands in river basins: the WETwin project

Kansiime F, Nalubega M (1999) Wastewater treatment by a natural wetland: the Nakivubo swamp, Uganda. Processes and implications. PhD Thesis, A. A. Balkema Publishers, Rotterdam, The Netherlands

Kipkemboi J, van Dam AA, Ikiara MM, Denny P (2007) Integration of smallholder wetland aquaculture–agriculture systems (Fingerponds) into riparian farming systems at the shores of Lake Victoria, Kenya: socio-economics and livelihoods. Geogr J 173:257–272

Kotze D, Marneweck G, Batchelor A, Lindley D, Collins N (2008) WET-EcoServices: a technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report TT339/08. Water Research Commission, Pretoria

Liersch S, Cools J, Kone B, Koch H, Diallo M, Aich V, Fournet S, Hattermann FF (2013) Vulnerability of food production in the Inner Niger Delta to water resources management under climate variability and change. Environmental Science & Policy. Special Issue: Management of wetlands in river basins: the WETwin project

Lin YF, Jinga SR, Lee DY, Wang TW (2002) Nutrient removal from aquaculture wastewater using a constructed wetlands system. Aquaculture 209:169–184

Macfarlane D, Kotze D, Ellery W, Walters D, Koopman V, Goodman P, Goge C (2008) WET-health: a technique for rapidly assessing wetland health. WRC Report TT 340/08. Water Research Commission, Pretoria

Maltby E, Acreman MC (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrol Sci J 56:1341–1359

MEA (2005) Ecosystem and human well-being: wetlands and water synthesis. Millennium Ecosystem Assessment, World Resources Institute, Washington DC

MWLE (2004) Nabajjuzi community based wetland management plan (2004–2008). Ministry of Water, Lands and Environment, Kampala, Uganda

Namaalwa S, van Dam AA, Funk A, Ajie GS, Kaggwa RC (2013) A characterization of the drivers, pressures, ecosystem functions and services of Namatala wetland, Uganda. Environmental Science & Policy. Special Issue: Management of wetlands in river basins: the WETwin project

Niemeijer D, de Groot RS (2008) Framing environmental indicators: moving from causal chains to causal networks. Environ Dev Sustain 10:89–106. doi:10.1007/s10668-006-9040-9

Paneque Salgado P, Corral Quintana S, Guimares Pereira Ã, del Moral Ituarte L, Pedregal Mateos B (2009) Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Malaga). Ecol Econ 68:990–1005

Pemberton CA, Mader-Charles K (2005) Ecotourism as a means of conserving wetlands. J Agric Appl Econ 37:463–474

Ramsar Convention Secretariat (2010a) Managing wetlands: frameworks for managing wetlands of international importance and other wetland sites. In: Ramsar handbooks for the wise use of wetlands, 4th edn, vol 18. Ramsar Convention Secretariat, Gland, Switzerland

Ramsar Convention Secretariat (2010b) Wise use of wetlands: concepts and approaches for the wise use of wetlands. In: Ramsar handbooks for the wise use of wetlands, 4th edn, vol 1. Ramsar Convention Secretariat, Gland, Switzerland

Rebelo LM, McCartney MP, Finlayson CM (2010) Wetlands of sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. Wetl Ecol Manag 18:557–572

Rebelo LM, Johnston R, Hein T, Weigelhofer G, DHaeyer T, Kone B, Cools J (2013) Challenges to the integration of wetlands into IWRM: the case of the Inner Niger Delta (Mali) and the Lobau Floodplain (Austria). Environmental Science & Policy. Special Issue: Management of wetlands in river basins: the WETwin project

Rongoei PJK, Kipkemboi J, Okeyo-Owuor JB, van Dam AA (2013) Ecosystem services and drivers of change in Nyando floodplain wetland, Kenya. Afr J Environ Sci Tech 7:274–291

SCBD (2007) An exploration of tools and methodologies for valuation of biodiversity and biodiversity resources and functions. Note by the Executive Secretary, Secretariat of the Convention on Biological Diversity, CBD Technical Series UNEP/CBD/SBSTTA/11/INF/8

Scholz M, Harrington R, Carroll P, Mustafa A (2007) The integrated constructed wetlands (ICW) concept. Wetlands 27:337–354

Stöckle CO, Donatelli M, Nelson R (2003) CropSyst, a cropping systems simulation model. Eur J Agron 18:289–307

TEEB (2010) The economics of ecosystems and biodiversity for local and regional policy makers. TEEB project document

Thenya T, Wassmann R, Verchot L, Mungai D, Odada EO, Olago DO, Ochola W, Ntiba M, Wandiga S, Gichuki N, Oyieke H (2006) Degradation of the riparian wetlands in the Lake Victoria basin—Yala swamp case study. In: Proceedings of the 11th world lakes conference, vol 2, pp 483–494

Wood A, Dixon A, McCartney M (eds) (2013) Wetland management and sustainable livelihoods in Africa. Routledge, London

Zsuffa I, Cools J (2011) Drivers–States–Impacts–Responses. DSIR analyses at the study sites. WETwin project report. Available at http://www.wetwin.eu/downloads.html

Zsuffa I, Johnston R, Cools J, D'Haeyer T (2012) Final publishable summary report of the WETwin project. European Commission, Community Research and Development Information Service (CORDIS), http://www.cordis.europa.eu/result/report/rcn/56368_en.html