Natural capital accounting to support assessment of the "no net loss" principle for biodiversity and people for an infrastructure project in Uganda

Helena Newell

August 2018

A thesis submitted for the partial fulfilment of the requirements for the degree of Master of Science at Imperial College London

Submitted for the MSc in Conservation Science (CID: 01426974)

DECLARATION OF OWN WORK

I declare that this thesis,

"Natural capital accounting to support assessment of the "no net loss" principle for biodiversity and people for an infrastructure project in Uganda"

is entirely my own work, and that where material could be construed as the work of others,

it is fully cited and referenced, and/or with appropriate acknowledgement given.

Signature ___________________________________

Name of student: Helena Newell

Name of Supervisor(s):	Professor EJ Milner-Gulland	(Oxford University)
	Dr Julia Baker	(Balfour Beatty)
	Dr Morena Mills	(Imperial College London)
Collaborators:	Simon Nampindo	(WCS Uganda)
	Beatrice Kyasiimire	(WCS Uganda)

Photo: Mwola CFR project area. H. Newell 2018

Word count : 5990

TABLE OF CONTENTS

LIST OF ACRONYMS

BBOP	The Business and Biodiversity Offsets Programme
CFR	Central Forest Reserve
ES	Ecosystem services
ESIA	Environmental and Social Impact Assessment
IFC	International Finance Corporation
MEA	Millennium Ecosystem Assessment
NaFFIRI	National Fisheries Resources Research Institute
NaFFORI	National Forestry Resources Research Institute
NC	Natural Capital
NCA	Natural Capital Accounting
NFA	National Forest Authority
NNL	No net loss
NWSC	National Water and Sewerage Corporation
QGIS	Quantum Geographic Information System
UBOS	Ugandan Bureau of Statistics
UGX	Ugandan Shillings

ACKNOWLEDGEMENTS

I am deeply grateful to the Darwin-funded project team of “Achieving No Net Loss For Communities And Biodiversity In Uganda” for their support, advice, assistance and funding throughout this project; namely EJ Milner-Gulland, Julia Baker, Joe Bull and Victoria Griffiths. A huge acknowledgement is also owed to Simon Nampindo and Beatrice Kyasiimire at WCS Uganda who suggested the case study, contributed to its delivery and provided significant assistance and guidance, particularly when I was in Uganda. The wider WCS Uganda team were also welcoming and helpful throughout the process. Racheal Nabayinda and Winnie Kayuza were integral in the project - engaging with stakeholders and conducting the observations – they made the project great fun and had unbelievable patience as the project changed week to week. Derek Pomeroy and Herbert Tushabe at Makerere University and National Biodiversity Data Bank were hugely helpful in providing data and assistance while I was in Uganda. I am also grateful to Francis Ogwal at NEMA, Denis Taremwa and Helen Izama at NWSC and Tom Rukundo at NFA for their advice and their support of the project. The Zirimiti NFA team were also incredibly welcoming and helpful during the project. A huge thanks to Morena Mills as well for her feedback and guidance on the project. I am also incredibly grateful to my friends and family, in both the UK and Uganda, who supported me throughout the process.

Natural capital accounting to support assessment of the "no net loss" principle for biodiversity and people for an infrastructure project in Uganda

ABSTRACT

A boom in infrastructure projects is occurring all over the world, particularly in developing countries that contain some of the world's biodiversity hotspots. Environmental and social impact assessments are failing to recognise projects' full impact on biodiversity. Project-level natural capital accounting could improve the assessment of infrastructure projects and operationalise the principle of no net loss for biodiversity and people. We conducted an ex ante natural capital account for an infrastructure project in Uganda. Our case study assessed impacts of the project on the stocks of the biodiversity components of natural capital and the flows of ecosystem services using secondary data and observations. We tested how the decisions of the baseline, counterfactual, and future scenarios affected the natural capital account. We found that these decisions significantly influenced the output of the natural capital account and hence the predicted delivery of no net loss. Therefore, natural capital accounts should be recognised as a tool to aid decision-making allowing consideration of all project impacts and dependencies on biodiversity, rather than purely a set of numerical accounts. Natural capital accounts should be based on transparent decisions, and used to monitor and evaluate the delivery of no net loss. Primary data collection on well-being is required if no net loss for people is to be evidenced. Further research is required about how to maximise the provision of ecosystem services while ensuring the project's dependencies and the stocks of the biodiversity components of natural capital are sustained.

KEYWORDS

Impact, Dependencies, Uncertainty, Decision-making, Ecosystem services

INTRODUCTION

Introduction to Natural Capital Accounting

A boom in infrastructure projects is occurring all over the world, particularly in developing countries that contain some of the world's biodiversity hotspots (Slingenberg et al. 2009). Although aiding global development, projects are obtaining approval despite causing losses in biodiversity (Laurance 2018). Best practice requires environmental and social impact assessments (ESIAs) to identify the significant impacts of development and associated compensation measures (IFC 2012a, 2012b). However, ESIAs typically do not account for all biodiversity impacts and for the full social and economic consequences of biodiversity loss (Laurance 2018). Governments and businesses are committing to no net loss (NNL) of biodiversity to address the negative impacts of infrastructure projects on biodiversity (Maron et al. 2016). Best practice guidelines have been published that cover both biodiversity and social perspectives of NNL (BBOP 2012; IFC 2012b; Griffiths et al. 2018). However, there remain conceptual, ecological and social challenges to its delivery (Gardner et al. 2013; Bull et al. 2014).

Natural Capital Accounting (NCA) is a relatively new mechanism to assess the impact and dependencies of development on biodiversity and mainstream it into decision-making in a systematic manner (Bolt et al. 2016; Natural Capital Coalition 2016). Natural capital refers to the stocks of nature that produce benefits to people through ecosystem services, as well as the natural processes and functions that underpin their operation, with biodiversity as one component (Figure 1) (Natural Capital Committee 2013; Natural Capital Coalition 2016). Natural Capital Accounts are a set of accounts that provide information on the stocks of natural capital and the derived flows of ecosystem services, which can be conducted at a national, sub-national, habitat or project-level (eftec et al. 2015; Natural Capital Coalition 2016). Natural Capital Accounts have the potential to support and improve the current methods for assessing infrastructure projects, including ESIAs and NNL, and form the basis for compensation (Forest Trends & eftec 2017).

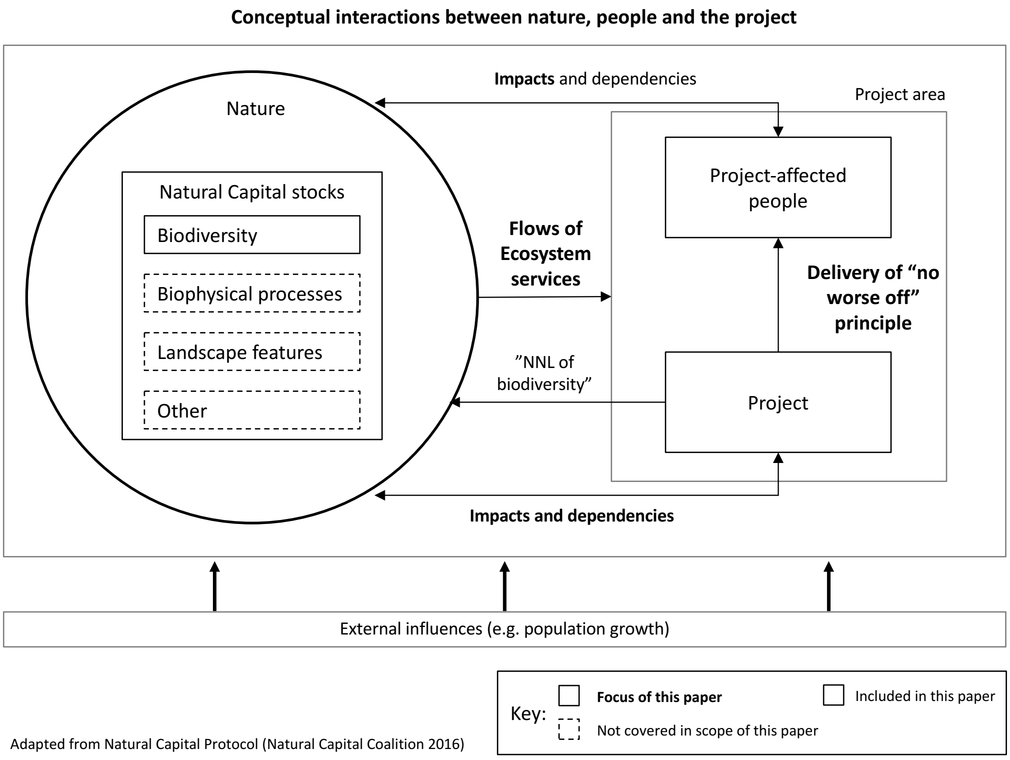


Figure 1: *Conceptual interactions between nature, people and the project*

To date, the focus has been undertaking NCAs at a national-level (Spurgeon 2014). However, two project-level frameworks have been developed; The Natural Capital Protocol and the Corporate Natural Capital Accounting framework (eftec et al. 2015; Natural Capital Coalition 2016). The Corporate NCA framework was adapted to include NNL and involves developing a Natural Capital Asset Register, classifying ecosystem services and developing physical and monetary flow accounts for a baseline and multiple points in the future (eftec et al. 2015; Forest Trends & eftec 2017). Both frameworks are relatively new with only a few case studies, and even fewer, if any, that have helped companies deliver NNL (eftec et al. 2015; Forest Trends & eftec 2017). The majority of case studies are retrospective and in developed countries (eftec et al. 2015; Forest Trends & eftec 2017; Natural Capital Coalition 2018).

Key decisions within a NCA

Natural Capital Accounts remain challenging to implement despite the creation of frameworks, with decisions required at each stage. There are scoping decisions, including defining the purpose, boundary and consideration of dependencies (Natural Capital Coalition 2016). There are also methodological decisions including how to collect data, classify habitats and quantify or monetise the flow of ecosystem services (Natural Capital Coalition 2016).

For NCAs supporting the delivery of NNL for biodiversity and people (Figure 1), they should deliver NNL of biodiversity which "refers to the point where biodiversity gains from targeted conservation activities match the losses of biodiversity due to the impacts of a specific development project, so that there is no net reduction overall in the type, amount and condition (or quality) of biodiversity over space and time" (BBOP 2012). They should also adhere to the "no worse off" principle for people, which is defined as "project-affected people (appropriately aggregated) should perceive the component of their well-being associated with biodiversity losses and gains to be at least as good as a result of the development project and associated biodiversity offset, throughout the project life cycle, than if the development had not been implemented" (Griffiths et al. 2018).

No net loss assessments also require the project and no project scenarios to be defined. If the NCA is ex ante, the project scenario relies on projections of the stocks of the biodiversity components of natural capital and flows ecosystem services (Forest Trends & eftec 2017). The no project scenario requires definition of the baseline, the measurement of the area before the project, and the counterfactual, a comparison by which to assess whether NNL has been achieved (Bull et al. 2014). Counterfactuals are based on assumptions of future trends of biodiversity and anthropogenic impacts (Bull et al. 2014).

Natural Capital Accounts face significant uncertainty, including both epistemic and linguistic (Regan et al. 2002). There are model uncertainties, potential data biases and uncertainties over the future scenarios. These uncertainties need to be exposed and made explicit to avoid misleading results (Milner-Gulland & Shea 2017).

The case study

Uganda is one of the most biodiverse countries in the world and is currently undergoing a period of rapid infrastructure development (Winterbottom & Eilu 2006). Poverty remains a significant issue and, although improving access to basic infrastructure services could increase standards of living, it may harm the large rural population who depend on biodiversity (World Bank 2016). The Ugandan government is initiating the use of NNL, supporting national-level ecosystem accounting and undertaking a new project to further develop national-level NCAs (COMBO 2016; UNEP-WCMC & IDEEA 2017, UNEP-WCMC, personal communication). However, in Uganda, currently there is no application of NCAs for infrastructure projects and no links between the natural capital national-level accounts and project-level NNL assessments.

There has been limited evaluation of the project-level NCAs that have been undertaken and the influence that the decisions and uncertainties have on the NCA. To address this, we completed a NCA of an infrastructure project in Uganda with the aim of supporting the design and evidence-base for NNL of biodiversity that is sustainable and fair to project-affected people. We explored how the decisions and uncertainties will influence the output and the operational use of the NCA. Our objectives were to: i) quantify the stocks of the biodiversity components of natural capital and the flows of ecosystem services for a baseline, post-construction and 30 years after construction (Figure 1), in order ii) to explore how decisions on the baseline, counterfactuals and scenarios affect the flows of ecosystem services, and iii) evaluate how this influences the operational use of the NCA to design NNL. We have considered the output as the numerical accounts and qualitative discussion and the operational use as the effect the accounts have on project decision-making and the requirements for offsets. We focused on the flows of ecosystem services derived from the project area in order to consider the no worse off principle.

METHODS

Structure for ex ante NCA

From a literature review, we identified the project-level NCA frameworks - the Natural Capital Protocol and Corporate NCA - and adapted these to create a structure for undertaking an ex ante NCA on biodiversity losses and gains, including both impacts and dependencies (Figure 2) (Natural Capital Coalition 2016; Forest Trends & eftec 2017). Impacts were disaggregated into impacts on the stocks of the biodiversity components of natural capital and the flows of ecosystem services. From the frameworks and the NNL literature, we identified key decisions for the NCA (Supporting Information) (Bull et al. 2013; Natural Capital Coalition 2016; Griffiths et al. 2018). We focused on a subset of these decisions which are under-represented in the ESIA and NCA literature and had a significant influence on the output of this particular NCA (Figure 2).

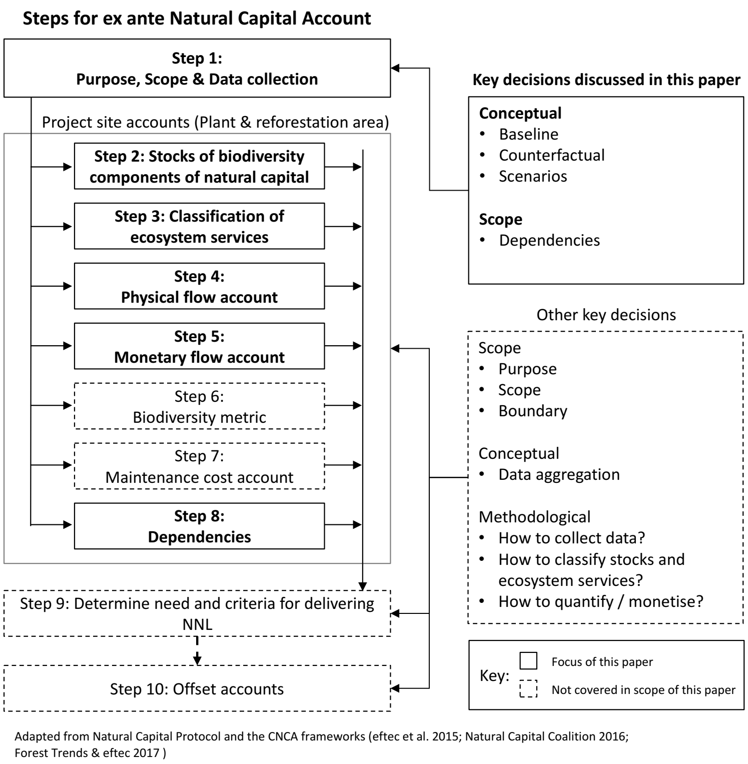


Figure 2: *Structure for ex ante Natural Capital Account*

Case study description

Our case study is the National Water and Sewerage Corporation's (NWSC) Katosi Water Treatment Project in the Mukono District, Uganda. The project is designed to deliver drinking water to the residents of Kampala and surrounding areas by 2020 (NWSC, personal communication). Water abstraction is planned to occur from Lake Victoria (Figure 3), with the water treatment plant to be constructed in the Mwola Central Forest Reserve (CFR), an area of forest managed by the National Forest Authority (NFA) (NFA 2012; GKW Consult GmbH 2016; UNEP-WCMC & IUCN 2018). The communities around the CFR are mainly engaged in farming and fishing for subsistence and small-scale commercial activities, with lake access at Sumbwe Bay (Figure 3). They use the Mwola CFR to collect water, non-timber forest products and firewood, however, there has been substantial timber extraction and farming within the forest, which are not allowed under the NFA forest management plan (NFA 2012). In the project's ESIA, an illegal fishing village was identified at Sumbwe Bay but in early 2018, it was demolished by the Fisheries Protection Unit (GKW Consult GmbH 2016; NWSC, personal communication).

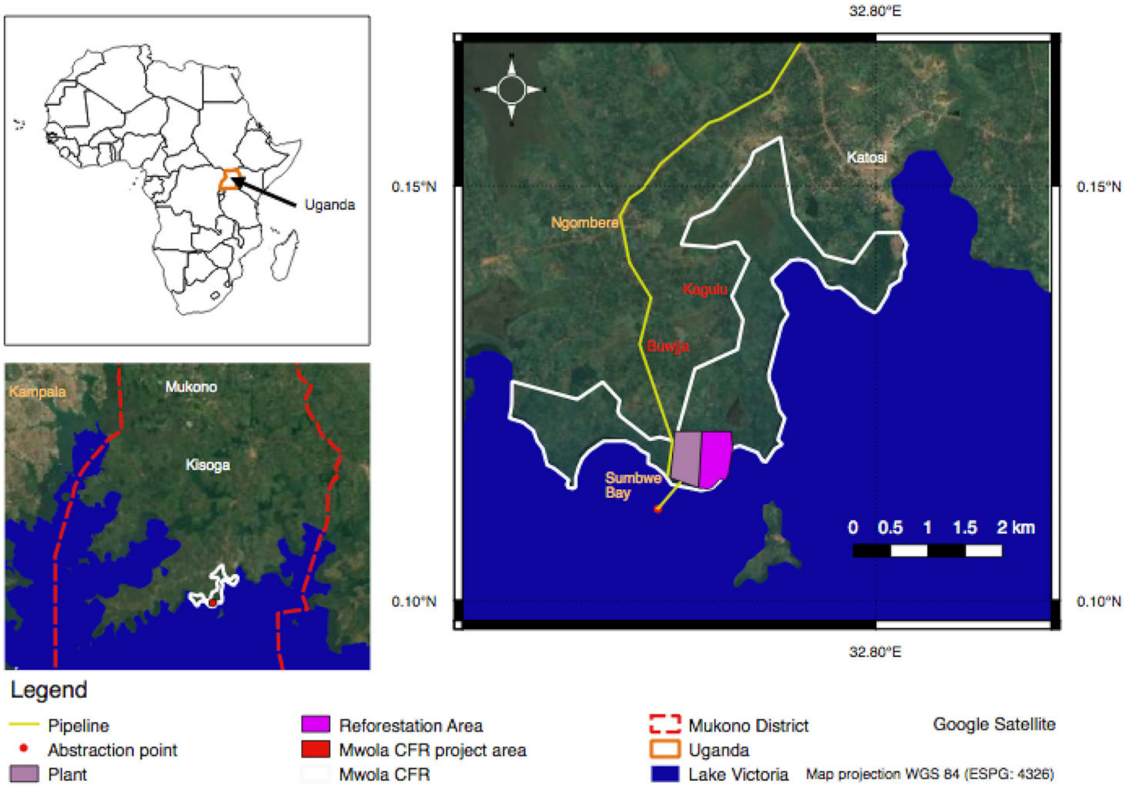


Figure 3: *Project area in the Mwola Central Forest Reserve, Mukono District, Uganda. The project area is divided into the Plant and reforestation area, with the local communities (red) and closest markets (white) identified on the map*

Data collection

Data collection consisted of compiling secondary data and undertaking observations (see Supporting Information for further details).

Secondary data

We gathered information on the stocks of habitats within the project area, and the use of the project area and forests by local communities in Uganda. We obtained this information from the NWSC, NFA, National Biodiversity and Data Bank at Makerere University and Ugandan Bureau of the Statistics. We completed specific data searches within Google,

Google Scholar and Web of Science to access peer-reviewed and non-peer reviewed literature. To evaluate the influence of decisions on NCA outputs, we conducted specific data searches within Google and Google Scholar for anticipated changes, including projections for population growth, and the use of medicinal plants and firewood.

Observational information

The purpose of the observations was to assess whether the secondary data was representative of the project area. It was also used to calculate charcoal provision, fishing volumes, the number of households and market prices, due to the lack of estimates from secondary data. We completed site visits over 5 weeks during June and July 2018. Daily observational walks were conducted for a 9-day period around the Plant and reforestation area (Figure 3) by two local research assistants, who recorded the activities observed e.g. charcoal burning. The route covered 3.7 km along the main paths, and approximately 20% of the project area. At Sumbwe bay, on 4 mornings (8am to 1pm) and 3 afternoons (1pm to 6pm), the research assistants recorded the number and type of fishing boats leaving and arriving. The research assistants noted the number of dwellings along all the roads from the project area to Ngombere (Figure 3).

We conducted market observations in the 3 closest markets to the project area in July 2018 (Figure 3) (NWSC and NFA, personal communication). We used the observations to estimate the prices of goods obtained from the project area. The research assistants chose stalls randomly and observed the prices and quantities of goods. Three visits were conducted per market and an average of 38 estimates obtained per good (Supporting Information). The assumption that the observations made were representative of typical activities and volumes was necessitated by logistical limitations.

ESIA

The ESIA was conducted in 2016. It established a static baseline of environmental conditions of the project site. It also contained an economic valuation of this baseline (Supporting Information). We used ESIA estimates on the stocks of timber, poles and above ground biomass (GKW Consult GmbH 2016). However, we did not use the economic valuation because there were limited details on data collection and data for the reforestation area and illegal use were omitted.

Conducting the NCA

For this study, we completed Steps 1–5 and 8 (Figure 2; Supporting Information)

Step 1 – Purpose and Scope

The purpose of our NCA was to inform the project's design of biodiversity NNL that is fair and sustainable for project-affected people (as defined in Table 1). It was designed to assess whether the Plant and reforestation area can deliver NNL or if further offsets are required. The scope of the NCA only regarded direct losses and gains in habitat and ecosystems that are predicted to result from the project footprint within the Mwola CFR, and ecosystem services associated with these habitats and ecosystems, including access to Sumbwe Bay. The scope did not include any biodiversity impacts of the project outside of the Mwola CFR.

We used a “design freeze” on the basis of the project plan given in the 2016 ESIA (GKW Consult GmbH 2016). From the ESIA, we estimated that the project area within Mwola CFR will be c.55 hectares; of which c.26 hectares will be the Plant and c.29 hectares will be a reforestation area (Table 1; Figure 3).

We assumed the project-affected people to be the households surrounding the project area up to Ngombere (Figure 3). For the base case, we did not include the illegal fishing village because its removal is likely to have occurred without the project (New Vision 2018; Daily Monitor 2018). We selected the 2016 baseline of the status of biodiversity and ecosystem services as the base case counterfactual against which to compare losses and gains.

Table 1: *Definition of terms used in this paper*

TERM	DEFINITION USED IN THIS PAPER
Project area	c.55 hectare area under the stewardship of NWSC, consists of the Plant and reforestation area (Figure 3)
Plant area	c.26 hectare area for the Water Treatment Plant. The area will be cleared of all vegetation (Figure 3)
Reforestation area	c.29 hectare area for replanting and regeneration (Figure 3)
Base case	The original scenario under which the stocks of the biodiversity components of natural capital and the flows of ecosystem services were assessed for the 2016 baseline, post-construction and after 30 years.
Project-affected people	For the baseline, we assumed that the households affected by the project are living between the project area and Ngombere; the communities of Buwjja and Kagulu (Figure 3). For post-construction and after 30 years, we have assumed the same spatial catchment, with projected population growth (UBOS 2015). For water provision for the baseline, due to observations of two boreholes in Kagulu, we have assumed the project-affected people for this estimate to be the Buwjja households.
Baseline	The baseline is the measurement of the stock of the biodiversity components of natural capital and the flows of ecosystem services as at 2016. For the base case, this excludes the use of the project area by the illegal fishing village.
Counterfactual	The counterfactual is the reference scenario by which to assess whether NNL has been achieved; it represents the stocks of the biodiversity components of natural capital and flows of ecosystem services for the project area in a no project scenario (Bull et al. 2014). For the base case, we have used the 2016 baseline as the static reference scenario, as established in the ESIA. For the alternative reference scenarios, we made assumptions about the anthropogenic and biodiversity changes in a no project scenario.
Alternative scenarios	In order to assess the influence of decisions on the flows of ecosystem services, we have developed scenarios based on different decisions and compared the resulting output of the NCA to the base case. These alternatives include different baselines, counterfactuals or external factors affecting future scenarios (Figure 1).

We assessed stocks of the biodiversity components of natural capital and the flows of ecosystem services at the 2016 baseline, post-construction (2020) and 30 years after construction (2050), based on the ESIA project details and NWSC communication. In the post-construction scenario, the Plant would be operational and cleared of vegetation, with no access for project-affected people to the reforestation area and to Sumbwe Bay. The reforestation area would be planted in the final stage of the construction period, so has negligible re-generation effect. 30 years after construction, the reforestation program should have been completed. The project-affected people (Table 1) would be permitted to harvest firewood and collect medicinal plants from the reforestation area, but not cultivate crops, graze cattle or burn charcoal as stipulated in the NFA's current forest management plan (NFA 2012). For the base case, we assumed that the project-affected people's use of forest products would remain stable at 2016 levels. The local communities would be connected to piped water by NWSC, without charge, by the time the plant is operational (NWSC, personal communication).

Step 2 – Stocks of the biodiversity components of natural capital

We used 2015 land cover data and classification from the NFA and project details to map and classify the habitats within the project area in QGIS, version 2.18 (Diisi 2009; GKW Consult GmbH 2016). We used the ESIA's estimates for the stocks of timber and poles generated by the project area and estimated the stocks of carbon up-taken by the project area based on the habitat classification and previous studies (Bush et al. 2004; NatureUganda 2011; GKW Consult GmbH 2016).

Step 3 – Flow of ecosystem services

We used the Millennium Ecosystem Assessment to categorise ecosystem services as this is currently the most widely recognised classification (MEA 2005). We constructed a total list of potential ecosystem services provided by the project area from previous studies on the use of forests in Uganda, refining the list to those we considered relevant using the ESIA and observations (Bush et al. 2004; NatureUganda 2011; GKW Consult GmbH 2016). We used secondary data and observations to categorise the ecosystem services into those that had i) sufficient data and were appropriate to quantify and monetize, ii) insufficient data, but appropriate, to quantify and/or monetise, and iii) inappropriate to quantify and/or monetize, even if data were sufficient (Supporting Information). We identified 9 provisioning services and 5 regulating services that had sufficient data to be quantified and monetized (Table 2) out of 17 provisioning and 12 regulating services that were deemed relevant (Supporting Information).

Step 4 and 5 – Physical and monetary flow accounts

For the physical flow account, we used secondary data and observations to estimate the yearly flow of ecosystem services (Table 2; Supporting Information). From market observations and secondary data, we constructed yearly monetary flow estimates but without discounting to minimise inter-generational equity issues (TEEB 2010). For the provisioning services, except medicinal plants, we used direct market pricing to estimate the market value of the forest products based on the average price from our market observations (Farber et al. 2006). For medicinal plants, we used the avoided cost of expenditure on clinics (Farber et al. 2006; UBOS 2017a).

For carbon, we used estimates of the volume and value of carbon sequestered per year to estimate the market value of carbon (Bush et al. 2004; NatureUganda 2011). For other regulating services (micro-climate regulation; air quality regulation; erosion prevention; and, water treatment), we used value benefit transfer (Natural Capital Coalition 2016). For the baseline, we used the minimum value for tropical forests from De Groot et al. (2010)'s global study (De Groot et al. 2010). For the after 30 years scenario, we assumed a 1% growth rate from the baseline value to account for the increase in above ground biomass for the reforestation area (De Groot et al. 2010).

Step 8 – Dependencies

We defined dependencies as “a business reliance on or use of natural capital” during the operational phase of the Plant and used previous studies on Water Treatment Plants to identify potential dependencies of the Katosi project on the biodiversity components of natural capital (Natural Capital Coalition 2016; Thames Water 2016).

Table 2: *Formulae for quantifying provisioning ecosystem services for baseline, post-construction and after 30 years*[a]

ECOSYSTEM SERVICE	SUMMARY OF QUANTIFICATION FOR PROVISIONING SERVICES
Baseline for the project area per year	
Farming	Hectare area of small scale farmland from NFA land cover data x yield/ha = yield
Grazing of cows	Number of cows per household x Hhds[b] x % of hhds using project area for cow grazing = cow grazing days
Fishing	Boats using Sumbwe Bay x catch rate for Tilapia = Tilapia kg catch
Water	Jerry cans per hhd x (Hhds – Kagulu residents) x % of hhds using the project area = jerry cans
Firewood	Bundles per hhd x Hhds x % of hhds use firewood x % collect from forests x % using the project area = bundles collected
Medicinal plants	Hhds x % disease prevalence x % of hhds use medicinal plants x % using the project area = no. of households that collect medicinal plants
Charcoal	Firings x bags produced per firing = bags of charcoal produced
Timber	Volume per ha of harvestable timber x project area = volume of timber
Poles	Harvestable stem density per ha x project area = volume of stems
Post-construction and for 30 years after construction for the project area per year	
Water	Jerry cans per hhd x (Hhds + population projection) = Jerry cans
30 years after construction for the reforestation area per year	
Firewood	Sustainable harvesting rate of bundles of firewood per ha x reforestation area x biomass that is used for firewood = bundles harvested
Medicinal plants	(Hhds + population projection) x % disease prevalence x % who use medicinal plants x (% collect in baseline – 20%) = no. of households that use medicinal plants
Timber	Harvestable biomass for timber x reforestation area = volume of harvestable timber
Poles	Harvestable stem density per ha x % increase in above ground biomass from baseline x reforestation area = volume of harvestable stems

[a] Data sources in the Supporting Information. [b]Hhds = Households defined as project-affected people (Table 1).

Testing key decisions

We used the aggregate monetary value for provisioning services to test the quantitative impact of the decisions and, for those decisions that could not be modelled or quantified, we discussed them qualitatively (Table 3; Supporting Information). We focused on the decisions concerning the baseline, counterfactual, and the future scenarios. We also considered decisions that affect the value of water provision to the project-affected people. We have included the impact of 10% error in each component. Given the time and logistical restraints of this research, we were unable to assess the sustainability of the different levels of ecosystem service provision.

Table 3: *Sensitivity analysis* for baseline, future scenarios, counterfactuals and water provision, including assumptions for the alternatives scenarios*

KEY DECISION	BASE CASE	ALTERNATIVE SCENARIO	ASSUMPTION FOR ALTERNATIVE SCENARIO
Baseline for project-affected people	Illegal fishing village not included	Fishing village extant in baseline	Assume that the fishing village demolition is due to the project area and the fishing shifts to other areas. Baseline use of the project area and Sumbwe Bay includes the illegal fishing village, so project-affected people increase as well as the number of fishing boats using Sumbwe Bay.
After 30 years scenarios for local natural resource use of the reforestation area by project-affected people	Restricted access to the reforestation area. 2016 baseline use of firewood and medicinal plants	After 30 years – no access to the reforestation area	No access to provisioning ecosystem services for project-affected people, except water provision by NWSC
		After 30 years – full access to the reforestation area	Baseline usage plus population growth rate for grazing, fishing, medicinal plants and charcoal. Double the NFA's estimate for sustainable yield for firewood, timber and poles (Drichi 2002)
		Reduction in use of firewood for external reasons	15% of annual biomass yield for firewood, decline from 25% in the base case
		Reduction in use of medicinal plants for external reasons	Medicinal plants used by 25% of population, reduced from 75% in the base case
Counterfactual for no project scenario	2016 usage	1. 2016 usage + Population growth	Population growth of 2.7% (exc. farming, timber and poles)
		2. 2016 usage with continued encroachment	Encroachment 1% per year increase in farm area, 1% per year decrease in availability of goods (except fishing and grazing)
Water needs of project-affected people	Borehole observed	1. No borehole (as per ESIA)	All project-affected people accessing water from project area
	Piped water provided by NWSC to compensate for loss of access	2. Households have to pay for piped water (NWSC, personal communication)	Each household pay connection and fee per jerry can of water consumed (NWSC tariffs)
Accuracy of quantitative estimates		10% error	Each component increased / decreased by 10%

***** Quantitative scenarios were assessed on the basis of the monetary value of provisioning services

RESULTS

Base case stocks of biodiversity components of natural capital, the flows of ecosystem services and dependencies

For the extent of habitats, we estimated that the project would lead to the loss of 1.5 hectares of tropical high forest, 46 hectares of bush, 7.4 hectares of small-scale farmland and gain of 26 hectares of built-up area and 29 hectares of woodland (Supporting Information). The base case monetary flows of ecosystem services, including both the selected provisioning and regulating services, were 439 UGX million per year for the baseline in 2016, 101 in post-construction (2020) and 278 after 30 years (2050). The base case net loss of monetary flows of ecosystem services was 161 UGX million per year (Supporting Information).

In terms of dependencies, the Plant will require water for abstraction and be dependent on the CFR for water treatment, treatment of wastewater from the plant and erosion prevention.

Sensitivity Analysis

We found provisioning services contributed 94% of the aggregate monetary flow accounts of total ecosystem services delivered in the 2016 baseline (Table 4; Supporting Information).

Baseline

We estimated the 2016 baseline monetary flows of provisioning services was 6 times greater with the illegal fishing village extant, compared to the base case (Table 4).

Scenarios

Changes in the access granted to the reforestation area affected the provisioning services, with no access reducing the monetary value to the project-affected people after 30 years by 11%, compared to the base case. However, this would have positively affected the rate of reforestation, which would increase provision of regulating services. Full access increased the monetary value to project-affected people after 30 years by 4.6 times, however, this would likely negatively affect the stocks of the biodiversity components of natural capital and provision of regulating services.

We found that a decrease in the proportion of households using firewood reduced the monetary flow of provisioning services after 30 years by 4% and a reduction in the proportion of households using medicinal plants decreased the after 30 years scenario by 1% (Table 4).

Counterfactuals

The base case net loss of the monetary flow of provisioning services to project-affected people was 193 UGX million. If population growth was included in the counterfactual, the net loss was 3.9 times greater than the base case and if continued degradation by local communities was included the loss reduced to 0.75 times the base case (Table 4).

Water

The provision of water from the project area and by NWSC contributed 6% of the 2016 baseline monetary value of provisioning services, 100% of the post-construction and 89% of the after 30 years. This illustrates the changes in the provision of individual ecosystem services over the project lifecycle. While carrying out the observations for the NCA, a borehole was observed in the closest village to the CFR, Kagulu, which was not mentioned in the ESIA. The observation was therefore included in the base case, but without it, the 2016 baseline would have been 1.7 times greater (Table 4). If the NWSC decide to charge the local communities for connection to the new water supply, this would reduce the net benefit of the water supply to project-affected people to 73% of the base case (Table 4).

Table 4: *Sensitivity analysis for aggregate monetary flows of provisioning services for the baseline and after 30 years*[a]

		UGX (million)			
		Baseline (2016)	After 30 years (2050)	Net change[b]	Ratio to base case[c]
For Provisioning - overall					
	Base scenario	415	222	- 193	NA
Baseline	Fishing village	2,680	222	-2,458	12.7
Scenario	After 30 years - no access	415	196	-218	1.13
Scenario	After 30 years – full access	415	1,030	615	-3.2
Scenario	Reduction in use of medicinal plants	415	213	-202	1.0
Scenario	Reduction in use of firewood	415	220	-195	1.0
Accuracy	10% +	640.78	370.31	-270	1.4

For Provisioning - water only

Base scenario	24	196	172	NA
No observation of borehole	40	196	156	0.91
Households pay for piped water	24	149	125	0.73

For Counterfactuals

	Counterfactual[d]	After 30 years	Net change	Ratio to base case
Base case (2016 baseline)	415	222	-193	NA
Base case + Population growth	965	222	-744	3.85
Continued degradation of the project area in absence of the project	366	222	-145	0.75

[a] Aggregate monetary flows are used for illustrative purposes, with the individual monetary flows in the Supporting Information

[b] The net change is the difference between the baseline and after 30 years scenario.

[c] The ratio is the difference between the net change for the alternative scenario compared to the base scenario

[d] Reference scenario where no project occurred

DISCUSSION

There are major gaps between the conceptual and operational implementation of project-level NCAs. Project-level NCAs can improve understanding of a project's impacts and dependencies on the biodiversity components of natural capital and ecosystem services compared to that provided by ESIAs (Natural Capital Coalition 2016). However, they require further testing through real-world case studies, to understand how decisions made when constructing the NCA influence its output and to establish guidelines on good practice (eftec et al. 2015; Bolt et al. 2016). Our case study is the first to develop an ex ante NCA of an infrastructure project to inform the design process to deliver and evidence NNL for both biodiversity and people.

Natural Capital Accounts are valuable for decision-making because they make explicit all the potential impacts and dependencies regarding biodiversity, even if they cannot be quantified. As identified in our case study, the project area generates ecosystems services that are not included in the numerical accounts, due to insufficient data or because it would be inappropriate to quantify them. Numerical accounts only ever illustrate a partial account of biodiversity-related human activities and needs (The RSPB 2017).

The numerical accounts are highly dependent on the decisions made when carrying out the NCA and subject to uncertainty. Even small errors can affect the output, illustrated by a 10% error generating 40% increase in the net loss of the monetary flows of provisioning ecosystem services. Therefore, NCAs need to be built on credible and reliable source data.

Ex ante project-level NCAs can be an invaluable decision-making tool for an infrastructure project, rather than purely a set of numerical accounts. Scenario analysis can help identify decisions, assumptions or uncertainties that significantly affect the output of the NCA (Regan et al. 2002; Milner-Gulland & Shea 2017). In our case study, the value of provisioning services was affected by decisions over the level of access to the reforestation area, whereas the uncertainties around the future use of firewood had a more limited effect on the numerical accounts. Natural Capital Accounts can inform decisions on which project option or compensation measures are more fair and sustainable in the long term and prioritise data collection. Projects can use NCAs to evidence their compliance with the mitigation hierarchy, illustrating the project has avoided and minimised the impact on biodiversity and local communities, with offsets as a final resort (Kiesecker et al. 2010).

An ex ante NCA can monitor and evaluate the delivery of NNL, which is rarely conducted in NNL assessments although considered best practice (Maron et al. 2018). No net loss is complicated by the challenges and uncertainties when defining a baseline and counterfactual (Bull et al. 2014). The baseline should accurately represent biodiversity and use by local communities before the project, including illegal activities (IFC 2012c). However, baselines can be subject to uncertainties and political issues, for example, the fishing village. Counterfactuals are dependent on assumptions, with small changes significantly affecting the net loss of the project, as illustrated by this case study. Transparent, evidence-based decisions and multiple counterfactuals under explicit assumptions help to recognize the risks and uncertainties to delivering NNL (Milner-Gulland & Shea 2017; Maron et al. 2018). As the project progresses, the assumptions can be tested to update the NCA and evaluate whether NNL is predicted to be, or has been, achieved.

However, the “no worse off principle” for NNL requires consideration of the well-being of people affected by a project’s losses and gains in biodiversity throughout a project lifecycle (Griffiths et al. 2018). Our case study assessed how the monetary value of selected ecosystem services changed at three stages of the project lifecycle, but not the changes to well-being (Nicholson et al. 2009). We were unable to assess how well-being was affected by the trade-off across services, such as the provision of water at the expense of firewood, or whether those ecosystem services with the highest contribution to well-being were included in the numerical accounts.

Natural Capital Accounts allow consideration of changes to stocks of biodiversity and flows of ecosystem services, as well as the project’s dependencies on biodiversity. These are all fundamental as there are positive associations, conflicts and the potential for unintended feedbacks between their provision (Larrosa et al. 2016). For example, reducing access to the reforestation area by project-affected people could aid prevention of soil erosion, an important regulating service and dependency (Fuwape 2003). However, reducing access affects provisioning services and potentially creates ethical issues. The stocks of the biodiversity components of natural capital are often neglected in NCAs but are important for capturing the full impact of the project (Bolt et al. 2016). The impact of infrastructure on biodiversity has been the focus in conservation literature, but the project’s dependencies on biodiversity are important for achieving sustainable outcomes and are not included in ESIAs or the NNL and Corporate NCA literature (Bolt et al. 2016; The RSPB 2017). Dependencies cannot simply be added to the NNL calculation due to the overlaps and conflicts with regulating and provisioning services. Further research on how to measure and manage the project's dependencies, alongside the stocks and flows of natural capital, could improve the outcomes for people and biodiversity (Natural Capital Coalition 2016).

Our NCA was compiled based on secondary and observational information, to test whether such an approach generates the information needed. Although these provided data to analyse the impact and the sensitivities, there were limitations. Our case study identified a wealth of secondary data, even in a relatively understudied area, which can be used to produce a NCA and help prioritise primary data collection for topics such as well-being. Our study also illustrated the benefit of triangulation of data, such as the observation of the borehole which was not identified in the ESIA interviews (GKW Consult GmbH 2016). However, assumptions had to be made. We assumed no significant change in the stocks of biodiversity components of natural capital or on the number of project-affected people between 2016 and 2018, in order to use the ESIA data and observations within our baseline. We assumed the observation period was representative of the year. We also assumed that valuing provisioning services using the cheapest available alternative was instructive for our purpose. Further details of the assumptions and limitations are in the Supporting Information.

Natural Capital Accounts are useful to design NNL for both people and biodiversity, but many of the NCAs that exist are national-level accounts without any links to individual development projects (Spurgeon 2014). Our study reveals the substantial complexity and uncertainty when undertaking a project-level account, which affected our ability to produce a robust NCA. However, project decisions are made on the basis of ESIAs, which are also subject to many complexities and uncertainties. Further research is required to apply the findings from this case study to larger projects and to inform the use of NCAs at a landscape level, thereby generating further guidance for the implementation of NCAs. An aggregation of best practice is required from ESIAs, Corporate NCAs and the NNL literature. Practical and feasible guidance is important to enable uptake and reduce the chance that paralysing uncertainty will sustain the use of ESIAs (Milner-Gulland & Shea 2017). However, further assessment and peer-reviewed rigour will help acknowledge the limitations and uncertainties within NCAs. The recognition of the issues with ESIAs is more important than ever given the surge of infrastructure projects around the world (Slingenberg et al. 2009). Collaboration is required across industries, governments, and scientists to improve assessments of infrastructure and preserve the biodiversity on which people's lives and livelihoods depend.

ACKNOWLEDGEMENTS

The author is grateful to EJ Milner-Gulland, Julia Baker, Simon Nampindo, Beatrice Kyasiimire and Morena Mills for their advice and supervision of this research project, and to Racheal Nabayinda and Winnie Kayuza for their fieldwork assistance.

SUPPORTING INFORMATION STATEMENT

Structure of ex ante NCA framework (Appendix S1), Case study of Katosi Water Treatment Plant project (Appendix S2), Sensitivity analysis (Appendix S3), Limitations (Appendix S4), and Scope of the ESIA (Appendix S5) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

LITERATURE CITED

BBOP. 2012. Resource Paper : No Net Loss and Loss-Gain Calculations in Biodiversity Offsets. BBOP, Washington D.C. Available from http://bbop.forest-trends.org/guidelines/Resource_Paper_NNL.pdf (accessed June 2018).

Bolt K, Cranston G, Maddox T, McCarthy D, Vause J, Vira B. 2016. Biodiversity at the heart of accounting for natural capital. Cambridge Conservation Initiative, Cambridge, UK. Available from https://naturalcapitalcoalition.org/wp-content/uploads/2016/07/CCI-Natural-Capital-Paper-July-2016-low-res.pdf (accessed June 2018).

Bull JW, Gordon A, Law EA, Suttle KB, Milner-Gulland EJ. 2014. Importance of baseline specification in evaluating conservation interventions and achieving no net loss of biodiversity. Conservation Biology **28**:799–809.

Bull JW, Suttle KB, Gordon A, Singh NJ, Milner-Gulland EJ. 2013. Biodiversity offsets in theory and practice. Oryx **47**:369–380.

Bush G, Nampindo S, Aguti C, Plumptre A. 2004. The Value of Uganda's Forests: A livelihoods and ecosystems approach. Wildlife Conservation Society, Kampala, Uganda.

COMBO. 2016. COMBO Project Launch and Training Workshop in Uganda. COMBO, Kampala, Uganda. Available from http://combo-africa.org/wp-content/uploads/2016/07/COMBO-Project-Launch-Training-Uganda-main-report.pdf (accessed April 2018).

Daily Monitor. 2018, July 27. Army, district chairman clash over eviction of fishermen. Daily Monitor, Kampala, Uganda. Available from http://www.monitor.co.ug/News/National/Army-district-chairman-clash-eviction-fishermen/688334-3975938-rwj97xz/index.html (accessed July 2018).

De Groot R, Kumar P, Van Der Ploeg S, Sukhdev P. 2010. Estimates of monetary values of ecosystem services. Appendix 3. Earthscan, London, UK. Available from https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/ (accessed July 2018).

Diisi J. 2009. National Biomass Study Technical Report 2005. NFA, Kampala, Uganda.

Drichi P. 2002. National Biomass Study Technical Report of 1996-2002. NFA, Kampala, Uganda.

eftec, RSPB, PwC. 2015. Developing Corporate Natural Capital Accounts. eftec, London, UK.

Farber S et al. 2006. Linking Ecology and Economics for Ecosystem Management. BioScience **56**(2): 117-129

Forest Trends, eftec. 2017. No Net Loss of Biodiversity in Corporate Natural Capital Accounting A Summary. Forest Trends and eftec, London, UK.

Fuwape JA. 2003. The Impacts of Forest Industries and Wood Utilization on the environment. World Forestry Congress XII, Quebec City, Canada. Available from http://www.fao.org/forestry/5387/en/ (accessed August 2018).

Gardner TA et al. 2013. Biodiversity Offsets and the Challenge of Achieving No Net Loss. Conservation Biology **27**:1254–1264.

GKW Consult GmbH. 2016. Environmental and Social Impact Assessment Report. GKW Consult GmbH, Kampala Uganda.

Griffiths VF, Bull JW, Baker J, Milner-Gulland EJ. 2018. No net loss for people and biodiversity. Conservation Biology **0**:1–12.

IFC. 2012a. Performance Standard 1: Assessment and Management of Environmental and Social Risks. IFC, Washington D.C.

IFC. 2012b. Performance Standards on Environmental and Social Sustainability. IFC, Washington D.C.

IFC. 2012c. Performance Standard 5: Land Acquisition and Involuntary Resettlement. IFC, Washington D.C.

Kiesecker JM, Copeland H, Pocewicz A, McKenney B. 2010. Development by design: Blending landscapelevel planning with the mitigation hierarchy. Frontiers in Ecology and the Environment **8**:261–266.

Larrosa C, Carrasco LR, Milner-Gulland EJ. 2016. Unintended Feedbacks: Challenges and Opportunities for Improving Conservation Effectiveness. Conservation Letters **9**:316–326.

Laurance WF. 2018. Conservation and the Global Infrastructure Tsunami: Disclose, Debate, Delay! Trends in Ecology and Evolution **33**:8–11.

Maron M et al. 2016. Taming a Wicked Problem: Resolving Controversies in Biodiversity Offsetting. BioScience **66**:489–498.

Maron M, Brownlie S, Bull JW, Evans MC, von Hase A, Quétier F, Watson JEM, Gordon A. 2018. The many meanings of no net loss in environmental policy. Nature Sustainability **1**:19–27.

MEA. 2005. Ecosystems and human well-being: Synthesis. Island Press, Washington D.C.

Milner-Gulland EJ, Shea K. 2017. Embracing uncertainty in applied ecology. Journal of Applied Ecology **54**:2063–2068.

Natural Capital Coalition. 2016. Natural Capital Protocol. Natural Capital Coalition, London, UK. Available from http://naturalcapitalcoalition.org/protocol (accessed March 2018).

Natural Capital Coalition. (2018). Natural Capital Coalition Case Studies. Natural Capital Coalition, London, UK. Available from https://naturalcapitalcoalition.org/category/case-studies/ (accessed August 2018).

Natural Capital Committee. 2013. The State of Natural Capital: First report. Natural Capital

Committee, London, UK. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516707/ncc-state-natural-capital-first-report.pdf (accessed May 2018).

NatureUganda. 2011. The Economic Valuation of the Proposed Degazettement of Mabira Central Forest Reserve. NatureUganda, Kampala, Uganda.

New Vision. 2018. Four arrested over illegal fishing. New Vision, Kampala, Uganda. Available from https://www.newvision.co.ug/print_article/new_vision/news/1463649/arrested-illegal-fishing?print=true (accessed July 2018).

NFA. 2012. Forest Management Plan for Zirimit Central Forest Reserves Management Plan Area. NFA, Kampala, Uganda.

Nicholson E et al. 2009. Priority research areas for ecosystem services in a changing world. Journal of Applied Ecology **46**:1139–1144.

Regan HM, Colyvan M, Burgman MA. 2002. A Taxonomy and Treatment of Uncertainty for Ecology and Conservation Biology. Ecological Applications **12**:618–628.

Slingenberg A, Braat L, Windt H Van Der, Rademaekers K, Eichler L, Turner K. 2009. Study on understanding the causes of biodiversity loss and the policy assessment framework. Report to the European Commission Directorate-General for Environment, ECORYS Research and Consultation, The Netherlands.

Spurgeon JPG. 2014. Comparing Natural Capital Accounting approaches, data availability and data requirements for businesses, governments and financial institutions: a preliminary overview. EU Business and Biodiversity Platform. Available from http://ec.europa.eu/environment/biodiversity/business/assets/pdf/b-at-b-workstream-1-natural-capital-accounting.pdf (accessed June 2018).

TEEB. 2010. Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. Earthscan, London and Washington. Available from www.teebweb.org (accessed June 2018).

Thames Water. 2016. Opportunities and challenges of taking a natural capital accounting approach. CLA, London, UK. Available from https://www.cla.org.uk/sites/.../Natural Capital Accounting WESTLAKE.pdf (accessed August 2018).

The RSPB. 2017. Accounting for Nature: A Natural Capital Account of the RSPB's estate in England. The RPSB, Sandy, UK.

UBOS. 2015. Uganda District Population Projections. Ugandan Bureau of Statistics, Kampala, Uganda. Available from http://catalog.data.ug/dataset/uganda-s-district-population-projections-2015-2020 (accessed June 2018).

UBOS. 2017. Uganda National Household Survey 2016/17. Ugandan Bureau of Statistics, Kampala, Uganda.

UNEP-WCMC, IDEEA. 2017. Experimental Ecosystem Accounts for Uganda. UNEP-WCMC and IDEEA, Cambridge, UK.

UNEP-WCMC, IUCN. 2018. Protected Planet: The World Database on Protected Areas (WDPA). UNEP-WCMC and IUCN, Cambridge, UK. Available from www.protectedplanet.net (accessed May 2018).

Winterbottom B, Eilu G. 2006. Uganda Biodiversity and Tropical Forest Assessment. US AID, Washington D.C.

World Bank. 2016. The Uganda Poverty Assessment Report 2016. World Bank, Washington D.C. Available from www.worldbank.org/uganda (accessed August 2018).

SUPPORTING INFORMATION

Appendix S1 - Structure of ex ante NCA

Table 1: Structure of ex ante NCA for delivering NNL (adapted from eftec et al. 2015; Natural Capital Coalition 2016; Forest Trends & eftec 2017)

	Process	**Key decisions / questions** **Overall question – what are the implications of the decision?**
1. Scope & Purpose	1.1 Define purpose, scope, boundary and timeline of NCA, including baseline and future periods of assessment, direct or indirect impacts	Purpose and scope? Boundary Baseline? Counterfactual? Timeline and scenarios? Project-affected people? Data aggregation? Considerations of well-being Yearly or cumulative benefits?
	1.2 Identify the existing and required data sources. Planning data collection	What data are required? What secondary data exist? What are the gaps? How can the data be filled with primary data collection? What methods of primary data collection will be used?
2. Stocks of Natural Capital	Classify habitats, including extent, condition and spatial distribution	Habitat classification? GIS data? Condition metric?
3. Flows of Ecosystem services	3.1 Identify all potential ecosystem services from these habitats, for local, regional and international communities	Classification of ecosystem service? Who is benefiting from these ES?
	3.2 Filter these ecosystem services to those relevant to the NCA / project	Method for identification of relevant ES? Implications of choice?
	3.3 Classification of ecosystem services into those going to quantify and / or monetise	Method for classification? Implications of choice?
4. Physical flow	Quantify those ecosystem services where sufficient data and appropriate	Method for quantification? Implications of choice?
5. Monetary flow	Monetise those ecosystem services where sufficient data and appropriate	Method for monetization? Implications of choice?
6. Biodiversity metric	Develop and quantify biodiversity metrics	What biodiversity metrics exist? Implications of choice?
7 Maintenance costs	Maintenance costs	What costs are associated with the site?
8 Dependencies	Determine dependencies of the project on natural capital	How to identify dependencies? How to measure them?
9 Criteria for offset	Use accounts to summarise impact and dependencies of project and as criteria to identify potential offset sites	
10 Offset accounts	Repeat steps 2-7 for the offset site and use the combined accounts to assess whether “no net loss” has been achieved	

Literature cited

eftec, RSPB, PwC. 2015. Developing Corporate Natural Capital Accounts. eftec, London, UK.

Forest Trends, eftec. 2017. No Net Loss of Biodiversity in Corporate Natural Capital Accounting A Summary. Forest Trends and eftec, London, UK.

Natural Capital Coalition. 2016. Natural Capital Protocol. Natural Capital Coalition, London, UK. Available from http://naturalcapitalcoalition.org/protocol (accessed March 1, 2018).

Appendix S2 - Case study of Katosi Water Treatment Plant project

Table of contents

Site background and Timeline

The National Water and Sewage Corporation (NWSC)'s Katosi Water Treatment Plant project is an element of The Kampala Water – Lake Victoria Water and Sanitation Project designed to deliver increased volumes of drinking water to the residents of Kampala and surrounding areas. The Katosi Project involves construction within two Central Forest Reserves to build a water treatment plant with a capacity of 160 million litres per day (MLD). Central Forest Reserves are areas of forest or woodland managed by the National Forest Authority under the National Forestry and Tree Planting Act (NFA 2003, 2016). Water abstraction will occur in Lake Victoria and the main water treatment plant will be constructed in the Mwola Central Forest Reserve (CFR) on Lake Victoria. Of this 629 hectare CFR, c.26 hectares will be required for the Water Treatment plant and 29 hectares will be reforested. The water will then flow through pipes along the main road to Nsumba Hill in the Kisakombe Central Forest Reserve, where 9 hectares, out of a total area of 213 hectares, will be used to create reservoirs and storage facilities (GKW Consult GmbH 2016; UNEP-WCMC & IUCN 2018). This is the preliminary project design as set out in the ESIA and a more detailed project design is undergoing development (NWSC, personal communication).

Our case study developed a Natural Capital Account of the biodiversity losses and gains for the proposed Water Treatment project site and reforestation area within the Mwola Central Forest Reserve (CFR). Mwola CFR was gazetted in 1932 and covers 629 hectares along the shore of Lake Victoria (National Forest Authority 2012; UNEP-WCMC & IUCN 2018). The CFR is located in Mukono District and Ntenjeru sub-country, about 34km from Mukono town and South East of Kampala. The communities around the forest reserve are mainly engaged in farming and fishing, with a small proportion engaged in other paid activities such as brick making, basket weaving or shop-keeping. Mukono and the area around the forest reserve have experienced rapid population growth, resulting in increased pressure on land in the area (GKW Consult GmbH 2016).

The forest is used by the local communities for collection of goods permitted by the National Forest Authority including the collection of fresh water, non-timber forest products and firewood, however, there has also been significant encroachment for timber extraction and farming activities (National Forest Authority 2012; GKW Consult GmbH 2016; Kiyingi & Kalanzi 2016). In 2016, a fishing village was also identified within the CFR and proposed project area at Sumbwe Bay, with c.200 households. NWSC found that the fishing village was causing reductions in the water quality of the lake near the proposed abstraction point (NWSC, personal communication). However, in early 2018 the fishing village was demolished and residents told to leave by the Fisheries Protection Unit, as part of the government's project to reduce illegal fishing in Lake Victoria (New Vision 2018; Daily Monitor 2018).

Step 1.1. Purpose and Scope

Purpose

Our case study is a NCA of the Katosi Water Treatment Project's losses and gains in biodiversity to design fair and sustainable NNL outcomes. Within the definition of biodiversity, we have focused on the losses and gains of habitats and the derived ecosystem services.

Scope

We have used a "design freeze" and our NCA is conducted on the basis of the preliminary project plan as outlined in the ESIA in 2016 (GKW Consult GmbH 2016). Therefore, any changes to this preliminary project plan are not reflected in our NCA.

We have developed the accounts for the Water Treatment Plant within the Mwola CFR, focusing on the project site and reforestation area as the area over which NWSC will have stewardship. We estimated that the project area within Mwola CFR will be c. 55 hectares. We have not included any further access routes, the proposed pipeline corridor between the CFRs or the proposed project area within the Kisakombe CFR within our NCA.

We have considered the impacts and dependencies of the project, where dependencies are defined as "a business reliance on or use of natural capital"(Natural Capital Coalition 2016). The impacts are disaggregated into the impacts on the stocks of the biodiversity components of natural capital and the flows of ecosystem services.

Boundary

We have developed the accounts for the direct project footprint within the Mwola CFR, any indirect impacts of the project will not be quantified within the accounts.

Baseline

The baseline is the first point of assessment of the project area and the definition is important as project areas can be subject to outside influences, as was the case for our case study.

For our case study, the baseline is the status of biodiversity in 2016 when the ESIA was conducted. We have not included the Sumbwe Bay fishing village in our the base case baseline as it was disbanded by the Fisheries Protection Unit as part of a wider project to address illegal fishing along the shore of Lake Victoria and their removal would likely to have occurred with or without the Katosi Water Treatment project. (New Vision 2018; Daily Monitor 2018).

Counterfactual

The counterfactual is a measurement by which to assess whether NNL has been achieved. The definition of a counterfactual, whether fixed or dynamic, is widely discussed in the NNL literature (e.g. Bull et al., 2014). Counterfactuals are based on assumptions about the future trends of biodiversity and anthropogenic impacts; the assumptions should be clear and updated as the project progresses (Bull et al. 2014).

For our study, we have used 2016 usage as our base counterfactual, however, we have tested the impact of using other counterfactuals (Appendix S3). A dynamic baseline in this instance could be useful, however, there is significant uncertainty concerning future trends of biodiversity and anthropogenic impacts (Nicholson et al. 2009; Bull et al. 2014; Aiama et al. 2015). There is data on the historic decline in woody biomass from land cover maps and there are concerns that the baseline may have already been affected as residents were initially informed of the proposed project in 2014 (NWSC and NFA, personal communication; Diisi 2009). There have also been a number of Collaborative Forest Management Schemes established around the project area which were potentially not located in the project area due to the impending development (NFA, personal communication).

<u>Timeline</u>

The stocks and flows of natural capital must be assessed at a base scenario and at multiple point in time in the future (Forest Trends & eftec 2017). As is the case for a counterfactual, these future time periods are not observed and therefore rely on assumptions. For our accounts, we have assessed the habitats and derived ecosystem services at the 2016 baseline, post-construction (2020) and after 30 years (2050) (NWSC, personal communication).

The post-construction scenario involves c.26 hectares used for the construction of the Water Treatment Plant and c.29 hectares for the reforestation area, as estimated from the preliminary project plan (GKW Consult GmbH 2016). From the project plan, the Plant will be cleared of vegetation and there will be no access to the reforestation area to allow tree planting and natural regeneration (NWSC, personal communication). The local communities will no longer be able to cultivate crops, graze cattle or access firewood from this area. The NWSC will also restrict access to Sumbwe Bay via the main road to try to sustain the water quality, therefore, fisherman will no longer be able to keep their boats at Sumbwe Bay. The reforestation area would have been planted during this time period but would not have had significant impact on the structure of the forest. We have assumed that the Water Authority will provide access to the piped water for free to the local communities.

The after 30 years scenario would still have the c.26 hectares Plant area. The reforestation program would be completed and the c.29 hectares would be managed to allow restricted access to project-affected people. The local communities would be able to harvest firewood and collect medicinal plants but they will not be able to cultivate crops, graze cattle, burn charcoal or fish from this area as these activities would be deemed detrimental to the forested area or water quality. This level of access and use would be consistent with the NFA's forest management plan (NFA 2012).

<u>Project-affected people</u>

We considered the usage by the communities closest to the proposed project area, in Buwjja and Kagulu up to Ngombere. We also assumed that 50% of those households collected goods from the project area. The impact of both these assumptions was tested in the sensitivity analysis (Appendix S3).

Data aggregation

We have considered yearly flows of ecosystem services and made assumptions that the estimates can be extrapolated to the whole year, a simplifying assumption made due to logistical limitations. We used top down estimates on use of forests by the project-affected people from secondary data. However, if we had conducted interviews or focus groups we would have assessed whether it was appropriate to extrapolate from the sample to the community or across different groups within the community.

Considerations of well-being
We were not able to include well-being in the NCA as we did not conduct interviews or focus groups. The quantification and monetisation of ecosystem services can be useful but potentially the goods that contribute most to the community's well-being may not rank highest in quantified or monetary terms, or do not feature in the accounts as there is insufficient data or it is inappropriate to include them in the physical or monetary flow accounts (Griffiths et al. 2018).

Yearly or cumulative benefits?
With projects and offsets, there can be time lags between the loss of ecosystem services and the benefits from offsets (Griffiths et al. 2018). We estimated yearly flows of ecosystem services, however, cumulative benefits or losses for both the counterfactual and future scenarios may be useful to consider these time scales.

Step 1.2 Data collection

We used the table in Appendix S1 to structure our case study. Due to logistical limitations, our data collection consisted of compiling secondary data and observations. A summary of data collection is included in the main paper, with a summary table below of the secondary data and sources of data used in the study (Table 1).

Table 1: Summary of secondary data used for NCA and the source of the report

Report	Source
GKW Consult GmbH. 2016.Environmental and Social Impact Assessment Report.	NFA & NWSC
NFA's National Biomass Study Land Cover Data (1990 - 2015) NFA	NFA
UBOS's 2014 census and 2016/17 National Household Survey Data	UBOS
Albers A. 2016. Sustainability: availability, distribution and consumption of firewood near Kidepo valley national park.	Online
Bush G, Nampindo S, Aguti C, Plumptre A. 2004. The Value of Uganda's Forests: A livelihoods and ecosystems approach.	WCS
De Groot R et al. 2010. Estimates of Monetary Values of Ecosystem Services.	Online
Diisi J. 2009. National Biomass Study Technical Report 2005.	NFA
Drichi P. 2002.National Biomass Study. Technical Report.	NFA

Heuzé V, Tran G, Archimède H, Régnier C, Bastianelli D, Lebas F. (n.d.). Cassava roots. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO.	Online
Josupeit H. 2004. World Market of Tilapia	Online
Kakuru W, Turyahabwe N, Mugisha J. 2013. Total economic value of wetlands products and services in Uganda.	Online
Kamatenesi-Mugisha M, Oryem-Origa H. 2005. Traditional herbal remedies used in the management of sexual impotence and erectile dysfunction in western Uganda.	Online
Kiyingi I, Kalanzi F. 2016. Economic valuation of proposed sites for the development of a new water treatment plant in Kisakombe and Mwola Central Forest Reserve.	NFA
Kolding J, Zwieten P Van, Manyala J, Okedi J, Mgaya YD, Orach-meza F. 2005. Regional Synthesis Report on Fisheries Research and Management.	Online
Langdale-Brown I, Osmaston HA, Wilson JG. 1964. The vegetation of Uganda and its bearing on land-use.	National Biodiversity and Data Bank
Masiga M, Muramira E, Kaggwa R. 2012. Contribution of Uganda's Forestry Sub-sector to the National Economy: Natural Resource Accounting Approach.	Online
MEA. 2005. Ecosystems and human well-being: Synthesis.	Online
MEMD. 2016. National Charcoal Survey for Uganda 2015.	Online
Moyini Y, Masiga M. 2011. The economic valuation of the proposed degazettement of mabira central forest reserve	National Biodiversity and Data Bank
Mukhtar AA, Tanimu B, Arunah UL, Babaji BA. 2010. Evaluation of the Agronomic Characters of Sweet Potato Varieties Grown at Varying Levels of Organic and Inorganic Fertilizer. World Journal of Agricultural Sciences 6:370–373.	Online
NaFFRI, DiFR, The Catch Assessment National Working Group. 2016. The Fisheries Catch Assessment Survey in the Ugandan waters of Lake Victoria	Online
NAFIS. (n.d.). Harvesting , Utilization & Conservation.	Online
NFA. 2012. Forest Management Plan for Zirimiti Central Forest Reserves Management Plan Area.	NFA
NFA. 2003. The National Forestry and Tree Planting Act.	NFA
NFA. 2012. Forest Management Plan for Zirimit Central Forest Reserves Management Plan Area	NFA
NFA. 2016. Annual Performance Report for FY 2015/16.	NFA
NWSC. (n.d.). NWSC tariffs.	NWSC
Pomeroy D. 2002. Uganda and Ecosystem and Protected Area Characterisation	National Biodiversity and Data Bank
Tabuti JRS, Dhillion SS, Lye KA. 2003. Firewood use in Bulamogi County, Uganda: Species selection, harvesting and consumption patterns.	Online
Thames Water. 2016. Opportunities and challenges of taking a natural capital accounting approach.	Online
UBOS. (n.d.). Uganda District Population Projections	Online
UBOS. 2010. Uganda census of agriculture Crop Area and Production Report	Online
UBOS. 2017. National Population and Housing Census 2014 - Area Specific Profiles Mukono District.	Online
UBOS. 2017. Uganda National Household Survey 2016/17.	Online
UNEP-WCMC, IUCN. 2018. Protected Planet: The World Database on Protected Areas (WDPA)	Online
Wairegi LWI, van Asten PJA, Tenywa M, Bekunda M. 2009. Quantifying bunch weights of the East African Highland bananas (Musa spp. AAA-EA) using non-destructive field observations.	Online
XE.com. (n.d.). USD to UGX Exchange rate.	Online

Step 2. Stocks of Natural Capital

Methodology

Habitats

Extent and spatial distribution
The Natural Capital Asset Register aims to illustrate the extent, condition and spatial distribution of the ecosystems that exist within the proposed project site. From the preliminary project design, description and map within the ESIA, we were able to extract the extent and spatial distribution of the preliminary project design (GKW Consult GmbH 2016). Through the site visits, we were also able to assess these estimates as the NWSC has laid out markers of the proposed project site.

Currently in Uganda, there is no universal method for habitat classification either within scientific study or within the ESIA process (Atacama Consulting, personal communication). From the literature, the two principal methods of classification of habitats in Uganda are Langdale-Brown et al. (1964) Vegetation classification and the National Biomass Study, conducted by the National Forest Authority, which produces national land cover maps (Langdale-Brown et al. 1964; Pomeroy 2002; Diisi 2009; UNEP-WCMC 2016; UNEP-WCMC & IDEEA 2017).

Many surveys use the Langdale-Brown et al (1964) classification as an indicator of the potential vegetation that could exist within the area (Langdale-Brown et al. 1964). During this study, the vegetation of Uganda was mapped at a scale of 1:500,000 and identified 22 plant communities or vegetation types, which were then subdivided to create 86 mapping units (Langdale-Brown et al. 1964). For the purpose of our study, this classification implies that the entire project area as Piptadeniastrum-Albizia-Celtis Medium Altitude forest (Langdale-Brown et al. 1964). Pomeroy et al (2002) reclassified the original Langdale-Brown classifications into 6 categories and under this classification, the entire project area is classified as “Forest” (Pomeroy 2002). However, both these classifications are too broad with too low a resolution to be particularly instructive for the 50 hectare project area, however, for larger projects, these vegetation maps could be used as a starting point for habitat classification.

For our case study, we have based our habitat classification on the National Biomass Study. From the 2015, land cover data from the NFA and project details provided by the ESIA, we were able to map the different habitats within the project area. The NFA’s land cover data used remote sensing Landsat data and the Land Cover Classification System from FAO to produce estimates at a scale of 1:50,000, which were then ground-trothed (Diisi 2009; FAO 2016). Using the semi-automatic classification in QGIS, version 2.18, we estimated the hectare extent of each classification (QGIS 2018).

For the 2016 baseline, we used the 2015 land cover as the baseline of existing habitat. For post-construction, we have assumed that the c.26 hectare Plant area would be converted into built up area and the habitat within the reforestation area would not change significantly within two years.

After 30 years, we have assumed that the Plant will still be 26 hectares of built-up area. We have also assumed that the reforestation area will now be classed as Woodland, converted from Bush due to replanting of indigenous species and restriction of access to local communities. In the National Biomass Study, "to qualify as woodland the average height of the trees must exceed 4 m" which is not currently the case in the Plant or reforestation area before construction (Diisi 2009).

Condition
We have used site visits, the National Forest Authority Forest Management Plan and the ESIA to qualitatively discuss the condition of the proposed project area (NFA 2012; GKW Consult GmbH 2016). We were also able to use historic land cover data from the NFA, in 1990, 2000, 2005 and 2010, to illustrate the change in land cover over this period (Diisi 2009).

Timber

Volume per hectare of standing timber x project area = volume of standing timber in the project area

For the stock of timber in the 2016 baseline, we used estimates from the ESIA for the volume of standing stock for timber, for Grade I, II and III within the project area, for trees with sufficient quality to be harvested and a diameter at breast height (dbh) greater than 20cm (GKW Consult GmbH 2016). We assumed that the density estimates were applicable to the reforestation area as well as the Plant area.

For post-construction, we assumed the same volume of standing stock of timber per hectare as in the baseline and applied this to the reforestation area. We assumed all timber had been cleared from the Plant (NWSC, personal communication).

For after 30 years, we used the estimate for the above ground biomass per hectare for Woodlands from the National Biomass Study (Drichi 2002). We used the same distribution of grades of timber and the same ratio of above ground biomass to timber as found in the ESIA (GKW Consult GmbH 2016). We applied this to the reforestation area to generate the stock of timber.

Poles

Stem density per hectare x project area = volume of stems in the project area

For the baseline, from the ESIA, we obtained estimates of stem density per hectare for trees suitable for harvesting for poles, with dbh 10-20cm and applied this estimate to the project area (GKW Consult GmbH 2016).

For post-construction, we used the same assumption of stem density per hectare and applied this to the reforestation area. We assumed that the Plant area had been cleared of all poles.

For after 30 years, we used the % increase in above ground biomass from the ESIA estimate to the estimate for Woodlands from the NFA and applied this to the stems per hectare estimate in the ESIA and applied this per hectare estimate to the reforestation area (Drichi 2002; GKW Consult GmbH 2016)

Carbon

Area of Land cover x Carbon stored per hectare = Carbon stored in project area per land cover type

For the baseline, we took the area per land cover type within the project area as calculated from the 2015 NFA land cover data and the carbon stored per land cover type estimated in the Mabira Economic Valuation Report (Diisi 2009; NatureUganda 2011).

For post-construction, we applied the same equation as for the baseline for the reforestation area, assuming that the reforestation area had not changed in structure since the baseline.

For After 30 years, we applied the same equation as for the baseline but assumed that the carbon stored per hectare for Woodland was mid-way between Bush and Tropical High Forest, as defined in the Mabira Economic Valuation Report, and applied this to the reforestation area (NatureUganda 2011)

Results

Habitats

Extent

For the baseline, there were 1.5 hectares of Tropical High Forest low stock, 46.0 hectares of Bush and 7.4 hectares of small-scale farmland. Post-construction, there would be 26 hectares of built-up area and 29 hectares of Bush. After 30 years, the 26 hectares of built up area would remain and we have estimated that the reforestation area would be 29 hectares of Woodland, instead of Bush, after planting and restrictions of access. Therefore, in terms of habitat, the project led to the loss of 1.5 hectares of Tropical High Forest, 46 hectares of Bush, 7.4 hectares of small-scale farmland and gain of 26 hectares of built-up area and 29 hectares of Woodland.

***Figure 1**: Map showing the habitats and ecologically sensitive sites for the baseline, post-construction and after 30 years*

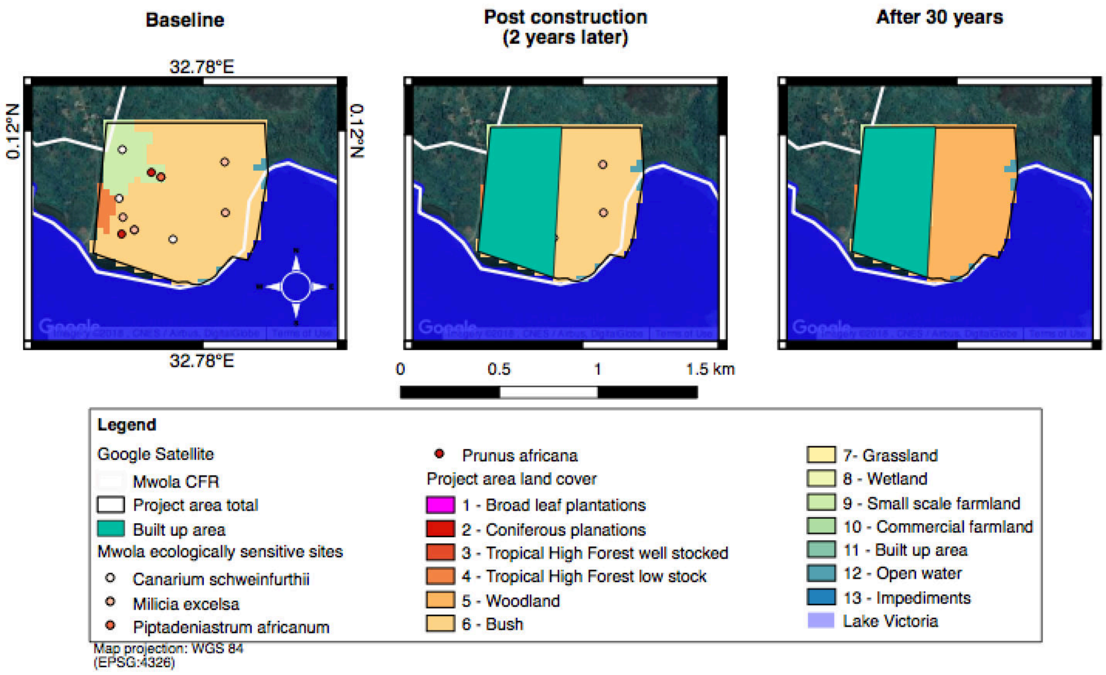


***Table 2:** Natural Capital Stocks using land use classifications from the National Biomass Study*

Land Cover	Units	Baseline (2016)	Post-Construction (2020)	After 30 years (2050)	Net impact ()= Loss + = Gain
Tropical high forest low stocks	ha	1.5			(1.5)
Woodland	ha			29	+29.0
Bush	ha	46.0	29		(46.0)
Small scale farmland	ha	7.4			(7.4)
Built-up area	ha		26	26	+26.0

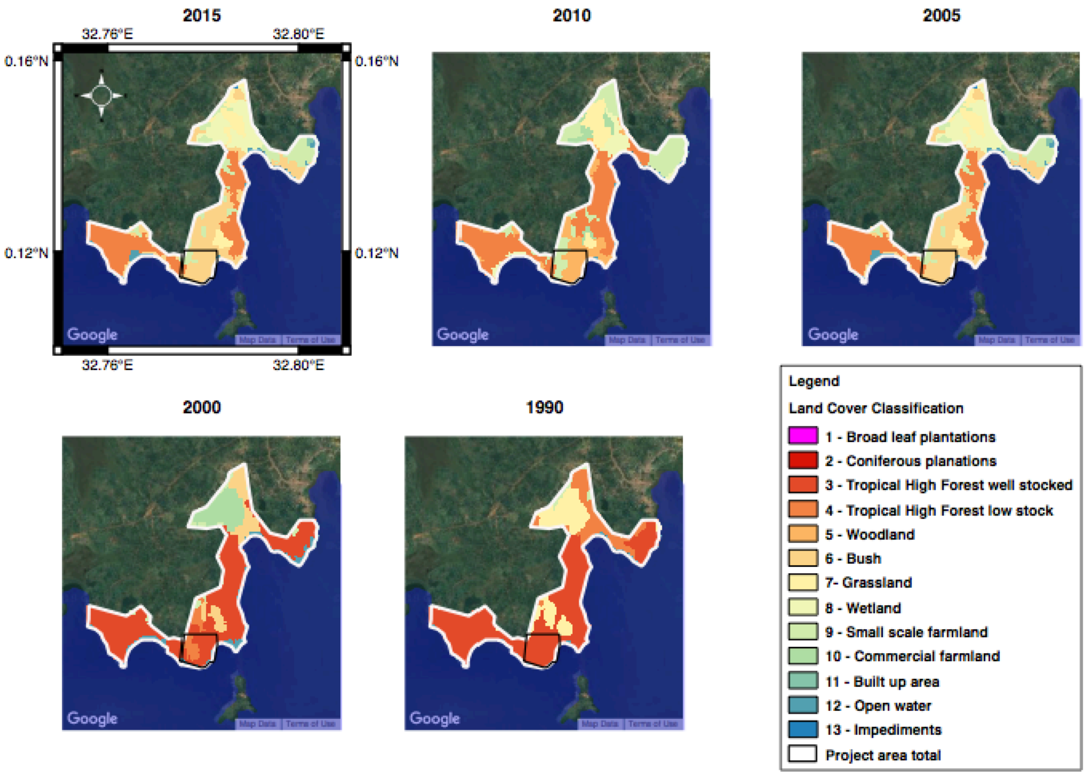
***Table 3:** Stocks of Timber, Poles and Carbon*

Land Cover	Units	Baseline (2016)	Post-Construction (2020)	After 30 years (2050)	Net impact ()= Loss + = Gain
Timber	m^3	1403	740	1114	(289)
Poles	Number	1119	590	908	(211)
Carbon	tC	6,058	3,335	4,481	(1,578)

Condition
From site visits, the National Forest Authority Forest Management Plan and the ESIA, it is clear that this Central Forest Reserve has been severely degraded (National Forest Authority 2012; GKW Consult GmbH 2016). There has been heavy encroachment by the local communities, which has been exacerbated by rapid population growth (GKW Consult GmbH 2016).

From the land cover maps from 1990, 2000, 2005 and 2010 (Figure 2), there has been a decline woody biomass from Tropical Forest Well Stocked in 1990, to Woodland in 2010 to the majority as Bush by 2015 (Diisi 2009).

Figure 2: *Land cover classification for project area within Mwola CFR, from 1990 to 2015*



The degradation and encroachment has led to the Mwola CFR being dominated by trees of low to medium timber value and by perennial crops, including bananas (Musa spp), maize (Zea mays), cassava (Manihot esculenta) and coffee (Coffea robusta)(GKW Consult GmbH 2016).

The ESIA identified 10 ecologically sensitive sites, 8 are within the proposed built-up extent. Prunus africana and Milicia excelsa were reported in the proposed project area and are Vulnerable on the IUCN and National Threatened Species List respectively (Plumptre et al. 2017). The ESIA, through surveys on species richness, found 169 species of vegetation, 63 of butterflies, 13 of dragonflies, 3 of herpetiles, 52 of birds, and 6 species of mammals. However, of the species identified in the proposed project area besides the Prunus africana and Milicia excelsa, there were 5 species protected by the NFA; namely Maesopsis eminii, Cordia africanana, Zanthoxylum gilletii, Piptadeniastrum africanum and Canarium schweinfurthii. Besides these species, all other species that have been evaluated for the IUCN are of least concern. However, there is an issue that a number of species are still data deficit on the IUCN (GKW Consult GmbH 2016).

Step 3. Classification of ecosystem services

Methodology

3.1 List of ecosystem services overall
We used the Millennium Ecosystem Assessment terminology and classification of ecosystem services as this is currently the most widely recognised and understood classification(MEA 2005). For our case study, we constructed a list of potential ecosystem services from forests in Uganda using the ESIA and previous studies both within and outside Uganda (Bush et al. 2004; Forest Europe 2015; GKW Consult GmbH 2016).

3.2 List of ecosystem services relevant to Mwola
From this list, we extracted those that would be relevant in Mwola CFR by identifying all the ecosystem services, either mentioned or quantified, in the ESIA and added any further ecosystem services that were observed during the site visits (GKW Consult GmbH 2016).

3.3 Classification of ecosystem services relevant to Mwola
From the list of relevant ecosystem services to the Mwola CFR, we categorised the ES into i) sufficient data and appropriate to quantify and monetize ii) insufficient data, but appropriate, to quantify and/or monetise iii) inappropriate to quantify and/or monetize, even if data was sufficient. This is an important step as it illustrates that the physical and monetary flow accounts will only be a partial representation of the variety of ecosystem services that are delivered by the proposed project area.

Results

3.1 – 3.3 List of ecosystem services: overall, those relevant and classification Mwola CFR

From the list of total ecosystem services identified that would be relevant, we identified 9 provisioning services that had sufficient data to be quantified and monetised: timber, poles, medicinal plants, farming, fishing, grazing of cows, water, firewood and charcoal. We also identified 5 Regulating services that could be quantified and monetised: carbon sequestration, micro-climate regulation, water purification and waste treatment, air quality regulation and erosion regulation, summarised in table below. Crucially, in comparison to the ESIA, we have included the services provided by the area whether these are conducted legally or illegally, which is consistent with international best practice (IFC 2012c; NFA 2012; GKW Consult GmbH 2016). From site visits, it was observed that the landing site remains an access point to Lake Victoria for the local community including the fisherman, with boats kept near the landing site or stored in the remaining buildings.

Table 4: *Ecosystem services that are relevant to Mwola CFR, those that were covered in the physical or monetary flow accounts and those included in the ESIA*

MA classification		Relevant to Mwola CFR (Y = Yes)	Physical flow account (Y=Yes)	Monetary account (Y=Yes)	ESIA (Y=Yes)	Code
Provisioning	**Timber**	Y	Y	Y	Y	a
	Poles	Y	Y	Y	Y	a
	Hoe/axe handles	Y			Y	b
	Fuel / firewood	Y	Y	Y	Y	a
	Charcoal	Y	Y	Y	Y	a
	Mushrooms	Y			Y	b
	Other Flora	Y				b
	Fauna	Y				b
	Medicinal plants / herbs	Y	Y	Y	Y	a
	Palm leaves	Y			Y	a
	Wild honey					d
	Bark cloth					b
	Clothing					d
	Craft materials / basketry	Y				b
	Thatching materials					d
	Fresh water	Y	Y	Y	Y	a
	Areas for grazing	Y	Y	Y		a
	Crop growing	Y	Y	Y		a
	Fishing	Y	Y	Y		a
	Genetic resources	Y				b
Regulation	Pest regulation					d
	Disease regulation					d
	Health protection					d
	Water regulation					b
	Water purification and waste treatment	Y	Y	Y		a
	Air quality regulation	Y	Y	Y	Y	a
	Carbon sequestration	Y	Y	Y	Y	a
	Micro-climate regulation	Y	Y	Y	Y	a
	Soil protection (erosion regulation)	Y	Y	Y		a
	Pollination	Y				b
	Nutrient cycling	Y				b
	Fish breeding grounds	Y				b
	Amphibian breeding grounds	Y				b
	Natural Hazard protection	Y				b
	Natural Hazard protection	Y				b
Cultural	Spiritual	Y				c
	Cultural	Y				c
	Historical					c
	Ecotourism					d
	Recreation					d
	Sport fishing/hunting					d
	Aesthetic values					b
	Knowledge systems and education	Y				b
Supporting	Soil formation	Y				b
	Biodiversity repository	Y				b

Key	
a	Sufficiently good data and appropriate to quantify and monetize
b	Insufficient data, but appropriate, to quantify or monetise
c	Not appropriate to quantify and / or monetize
d	No evidence that relevant to Mwola CFR

Step 4. Physical flow account

We have based our quantification on the available secondary data and observations.

Provisioning services – for the baseline

Farming

Hectare area x yield/ha/yr = yield/yr for Maize, Matooke, Cassava, Sweet Potatos and Bananas

For the baseline, we used the 2015 area of small-scale farmland from the NFA 2015 land cover maps (Diisi 2009; GKW Consult GmbH 2016; QGIS 2018). From observations, the most prominent crops under cultivation were maize, matooke, cassava, sweet potatoes and bananas. From the Ugandan Census of Agriculture, we obtained estimates of the proportion of the cultivated area used for each crop in the Central region and obtain yield estimates of metric tonnes per hectare per year (UBOS 2010).

Grazing

Cows per household x Households x % taken to the project area per day x days in the year = Cow grazing days

For the baseline, we used the average number of cows per household from the Value of Uganda's Forests Report for Rwenzori as they had a similar proportion of households with livestock as estimated for the project area in the Uganda Census (Bush et al. 2004; UBOS 2017b). From observations, the area around the forest has c.217 households, however, we assumed that only 50% of these would choose to take their livestock to the project area on any given day and that cows are grazed every day of the year.

Fishing

Fishing boats using Sumbwe Bay per day x catch rate for Tilapia x days in the year = kg catch per year from Sumbwe Bay

From observations, the number of fishing boats using Sumbwe Bay per day was estimated and it was observed that the catch all appeared to be Tilapia. We used the average catch rate (kg per boat per day), from the Fisheries Catch Assessment Survey in Lake Victoria

(NaFFRI et al. 2016). We assumed that the week was representative of the rest of the year which is a significant and simplifying assumption.

Water

Jerry cans per household per day x Households x % that use the project area per day x days in the year = Jerry cans per year from the project area

We use estimates of the number of jerry cans per household per day from Kakuru (2013) and assumed this is stable over the year (Kakuru et al. 2013). From observations, there are two boreholes one in Kagulu centre and one between Kagulu and Ngombere. We assumed that the Kagulu residents would use the boreholes as they were closer to their homes. Therefore, from observations we estimated the number of households in Buwjja to be 131 and estimated that 50% of Buwjja residents collect water from the project area.

Firewood

Bundles per household per day x Households x % use firewood x % collect firewood from forests x % collect from the project area x days in the year = Bundles collected from the project area per year

We used estimates for the household usage of firewood per day from Tabuti et al. (2003) and used the estimate of the number of households from observations (Tabuti et al. 2003). From the Uganda National Household Survey 2016/17, we obtained estimates for the Rural population for the proportion of households that use firewood and that collect it from the bush / forest (UBOS 2017a). We estimated that 50% of the households collect firewood from the project area.

Medicinal plants

Households x % to fall sick per month x % who use medicinal plants x % collect from the project area x months in the year = no. of households that use medicinal plants from the project area

We estimated the number of households from observations. Disease prevalence is estimated in the Uganda National Household Survey 2016/17 and we have used the rural estimate for the proportion of people that fall sick per month (UBOS 2017a). We used Kamatenesi-Mugisha & Oryem-Origa (2005)'s estimate of the usage of medicinal plants in Uganda (Kamatenesi-Mugisha & Oryem-Origa 2005). We estimated that 50% of the households collect medicinal plants from the project area.

Charcoal

Firings in the project area per week x Bags produced per firing x weeks in the year = Bags of charcoal produced per year from project area

From observations, we observed the number of firings of charcoal in the project area and from the National Charcoal survey we obtained estimates of the average volume of charcoal produced per firing (MEMD 2016).

Timber
Volume per hectare of standing timber/ harvesting rate x project area = volume of harvestable timber in the total project area per year

From the Ugandan forestry accounts, we obtained estimates that timber is harvested on a 30 year cycle (Masiga et al. 2012). Therefore, we have assumed that the flow of timber is approximately 1/30 of the timber stock in the project area.

Poles

Stem density per hectare / harvesting rate x project area = volume of harvestable stems in the project area per year

From the NFA, we obtained estimates that the felling cycle for poles is approximately 12 years and estimated that 1/12 of the poles in the project area would be harvested every year.

<u>Provisioning services – post-construction</u>

As the Plant area will be cleared and the reforestation area will have restricted access to allow the regeneration, we have assumed that there will be no provisioning ecosystem services derived from the project area, except water. The NWSC will restrict access to Sumbwe Bay in order to maintain the water quality for the plant and therefore the fisherman will need to find an alternative landing site (NWSC, personal communication).

Water

no. of jerry cans used per household per day x (Households + UBOS population growth) x days in the year = Volume of water supplied by NWSC

Post-construction, the NWSC will provide the local communities will access to piped water, including all of the households in Buwjja and Kagulu (GKW Consult GmbH 2016; NWSC, personal communication). We used the estimated population growth rate for Mukono from UBOS population projections and assumed that the provision would apply to the whole village (UBOS 2015).

<u>Provisioning services – 30 years after construction</u>

30 years after construction, we have assumed that the local communities would be able to collect firewood and medicinal plants from the reforestation area and that timber and poles would be harvested. We have assumed that the NWSC would restrict access and use the NFA's estimates of sustainable harvesting rates for wood based products and assumed that the level of medicinal plant usage would be sustainable (Drichi 2002). In the scope of this

case study, we have not considered how the compliance would these limits would be regulated, or how the local communities would source any further requirements for firewood and other products.

Water
no. of jerry cans used per household per day x (Households + UBOS population growth) x days in the year = Volume of water supplied by NWSC

We used the estimated population growth rate for Mukono from UBOS population projections and assumed that the water provision would apply to the whole village (UBOS 2015).

Firewood

Bundles of wood that can be sustainably harvested per hectare x reforestation area x biomass that is used for firewood = Bundles per year of sustainably harvested firewood

The sustainable annual yield of biomass was calculated by the NFA and we have used the estimate for Woodlands and the average weight of a bundle of firewood to calculate the maximum potential number of bundles that could be obtained from the project area (Drichi 2002; Albers 2016). We have also made an assumption that 25% of the biomass will be used for firewood, based on the proportion estimated in the ESIA (GKW Consult GmbH 2016).

Medicinal plants

no. of households x % to fall sick per month x % who treat using medicinal plants x % that obtain medicinal plants from the reforestation area x months in the year = no. of households that use medicinal plants from the reforestation area

We have used the UBOS growth rate to estimate population size in this area (UBOS 2015). We have made the simplifying assumption that the % to fall sick and % who treat using medicinal plants has remained stable from 2016 levels but we have assumed that only a third of the residents will be able to obtain medicinal plants from the reforestation area (Kamatenesi-Mugisha & Oryem-Origa 2005; UBOS 2017a).

Timber

Volume per hectare of harvestable timber per year x reforestation area = volume of harvestable timber in the total reforestation area

We used the NFA estimate of the sustainable harvesting rate of biomass in a Woodland and assumed that 55% of the biomass would be harvestable as timber, as the same proportion applied in the ESIA (Drichi 2002; GKW Consult GmbH 2016). We have used the same distribution of grades of timber as under the ESIA (GKW Consult GmbH 2016).

Poles

Stem density per hectare / harvesting rate x reforestation area = volume of harvestable stems in the reforestation area per year

We used the % increase in above ground biomass from the ESIA estimate to the estimate for Woodlands provided by the NFA. We applied this percentage increase to the stems per hectare per year estimate in the ESIA and multiplied this by the hectare area of the reforestation area (Drichi 2002; GKW Consult GmbH 2016)

Table 5: *Summary table of method for quantifying and valuing provisioning and regulating services, including the data sources*

Ecosystem service	Quantification	Valuation	Data sources
Baseline & Post-construction (except			
Farming	Maize, Matooke, Cassava, Sweet Potatos and Bananas Hectare area x yield/ha/yr = yield/yr	Conversion to market quantity x Market price = Value of crop	NFA land cover data, Ugandan Census of Agriculture, Observations
Grazing of cows	Cows per household x Households x % taken to the project area per day x days in the year = Cow grazing days	Sacks of grass per cow per day x Market price of grass = Value of grazing days	Bush et al (2004), Uganda Census, Observations
Fishing	Fishing boats using Sumbwe Bay per day x catch rate for Tilapia (kg/boat/day) x days in the year = kg catch per year from Sumbwe Bay	Conversion x Market price = Value of fish landed	Fisheries catch assessment survey, Observations
Water	Jerry cans per household per day x (Households – Kagulu residents) x % that use the project area per day x days in the year = Jerry cans per year from the project area	Market price = Value of water collected	Kakuru (2013), Observations
Firewood	Bundles per household per day x Households x % use firewood x % collect firewood from forests x % collect from the project area x days in the year = Bundles collected from the project area per year	Market price = value of firewood harvested	Tabuti et al (2003), Ugandan Household Survey 2016/17, Observations
Medicinal plants	Households x % to fall sick per month x % who use medicinal plants x % collect from the project area x months in the year = no. of households that use medicinal plants from the project area	Average cost of monthly healthcare = Avoided cost of medicinal plants harvested	Ugandan Household Survey 2016/17, Kamatenesi-Mugisha & Oryem-Origa (2005)
Charcoal	Firings in the project area per week x Bags produced per firing x weeks in the year = Bags of charcoal produced per year from project area	Market price = Value of charcoal harvested	Observations, National Charcoal Survey (MEMD, 2016), Observations
Timber	Volume per hectare of standing timber/ harvesting rate x project area = volume of harvestable timber in the total project area per year	Price from ESIA = Value of timber	ESIA, Hassan and Mungatana, 2012), Observations
Poles	Stem density per hectare / harvesting rate x project area = volume of harvestable stems in the project area per year	Market price = Value of poles harvested	ESIA, NFA, Observations
Carbon	Per land cover classification Hectare area x carbon stored per hectare per year = Tonnes of carbon sequestered per year	Price per tonne = Value of Carbon sequestered per year	NFA, Bush et al (2004), Mabira report
Microclimate, air quality, erosion prevention		Minimum value per hectare for tropical forest x Exchange rate = Value of Regulating	De Groot et al (2010)

and water treatment		Service per year	
Post-construction and for 30 years after construction			
Water	Jerry cans per household per day x (Households + UBOS population projection) x % that use the project area per day x days in the year = Jerry cans per year from the project area	Market price = Value of water collected	Kakuru (2013), Observations, UBOS
30 years after construction	Medicinal plants, timber and poles use same equation as 2016		
Firewood	Bundles of wood that can be sustainably harvested per hectare x reforestation area x biomass that is used for firewood = Bundles per year of sustainably harvested firewood	Market price = Value of firewood harvested	ESIA, NFA, Market observations
Medicinal Plants	Households x % to fall sick per month x % who use medicinal plants x (% collect from the project area in baseline – 20%) x months in the year = no. of households that use medicinal plants from the project area	Average cost of monthly healthcare = Avoided cost of medicinal plants harvested	Ugandan Household Survey 2016/17, Kamatenesi-Mugisha & Oryem-Origa (2005), Observations
Timber	Harvestable biomass for timber x reforestation area = volume of harvestable timber in the reforestation area per year	Price from ESIA = Value of timber	ESIA, Hassan and Mungatana, 2012), Observations
Poles	Stem density per hectare / harvesting rate x % increase in above ground biomass in baseline x project area = volume of harvestable stems in the project area per year	Market price = Value of poles harvested	ESIA, NFA, Observations
Microclimate, air quality, erosion prevention and water treatment		1% growth rate from minimum value per hectare for tropical forest x Exchange rate = Value of Regulating Service per year	De Groot et al (2010)

<u>Regulating services – baseline</u>

Carbon

Area of Land cover x Carbon sequestered per year per hectare = Carbon sequestered in project area per land cover type per year

For the baseline, we took the hectare area per land cover type within the project area as calculated from the 2015 NFA land cover data and the carbon sequestered per land cover type per year (Bush et al. 2004; Diisi 2009; NatureUganda 2011).

Microclimate, air quality, erosion prevention and water treatment

We used value benefit transfer per hectare for these regulating services, therefore we do not have a physical flow estimate.

Regulating services – post-construction

Carbon

Area of Land cover x Carbon sequestered per year per hectare = Carbon sequestered in reforestation area per land cover type per year

For post-construction, we applied the same equation as for the baseline, assuming that the reforestation area had not changed in structure between the baseline and post-construction.

Regulating services – after 30 years

Carbon

Area of Land cover x Carbon sequestered per year per hectare = Carbon sequestered in reforestation area per land cover type per year

For After 30 years, we applied the same equation as for the baseline but assumed that the carbon stored per hectare for Woodland was mid-way between Bush and Tropical High Forest and applied this to the reforestation area (Bush et al. 2004; NatureUganda 2011).

Results

Table 6: *Provisioning and Regulation services for Baseline (2016), Post-construction (2020) and After 30 years (2050)*

Physical Flow Account

Ecosystem Service		Units	Baseline (2016)	Post construction (2020)	After 30 years (2050)
Provisioning	Food (Maize)	kg/year	4,582	-	-
	Food (Matooke)		14,928	-	-
	Food (Sweet Potatoes)		4,234	-	-
	Food (Cassava)		4,442	-	-
	Food (Sweet bananas)		145	-	-
	Grazing (cows)	Cows grazing days	8,713	-	-
	Fishing - Tilapia	Kg/ year	10,464	-	-
	Water	20L Jerry cans collected per year	71,723	264,049	582,454
	Firewood	Bundles of firewood per year	7,242	-	1,413
	Medicinal plants	No. of households per year	281	-	414
	Charcoal	Bags/ year	3,360	-	-
	Timber	m^3	47	-	134
	Poles	stems	280	-	227

Regulating	Carbon sequestration	Tonnes / yr	666	290	1958
	Microclimate regulation				
	Air quality regulation				
	Water treatment				
	Erosion prevention				

<u>Step 5. Monetary flow account</u>

Methods

From market observations and secondary data, we constructed yearly monetary flow estimates but have included no discounting in order to minimise any issues of inter-generational equity. We used 2018 market observation prices and an August 2018 exchange rate (XE.com n.d.)

Provisioning services
For the provisioning services, farming, grazing, fishing, water, firewood, poles and charcoal, we used direct market pricing to estimate the value of the cheapest available alternative. We used an average price across the markets nearest to the project area. These values represent the market value (price x quantity) of the goods from the forest and do not represent the additional values, such as any intrinsic value that communities may place on obtaining goods from the forests rather than the market (Farber et al. 2006; Natural Capital Coalition 2016).

For medicinal plants, we used the avoided cost of expenditure on clinics from the UBOS estimate of the average monthly cost on healthcare (Farber et al. 2006; Natural Capital Coalition 2016; UBOS 2017a). For timber, we used the price per cubic metre as estimated in the ESIA (GKW Consult GmbH 2016)

For a number of the provisioning services, conversions were required from the volume of goods that were harvested to the metric used in the local markets. This is a result of using secondary data where the results are often reported in metric quantities whereas the local markets typically sell goods in physical units such as bunches of bananas or a whole fish for tilapia. The conversion estimates were obtained from published literature. For grazing, we estimated the volume of pasture / sacks of grasses that would be required to replace a day of grazing. From observations, it seems that if cows are not grazed they are fed Napier grass and it is estimated that 60kg of grass which would translate to 12kg of dry matter and this would be 2-3 sacks of grass (NAFIS n.d.).

Table 7: *Conversion from metric quantities to metrics used in local markets*

Ecosystem service	Conversion	Data source
Matooke	Kg per bunch	(Wairegi et al. 2009)
Sweet potatos	Kg per bundle	(Mukhtar et al. 2010)

Cassava	Kg per bundle	(Heuzé et al. n.d.)
Sweet bananas	Kg per bunch	(Wairegi et al. 2009)
Tilapia	Kg per fish	(Josupeit 2004)

Table 8: *Market observation results for the average of the 3 closest markets, and the average in Katosi, the closest large market*

Good	Metric	Average Price	N	Median	Standard Deviation	Average price in Katosi	N
Maize	Per Kg	1065	46	900	536	777	11
Matooke	Per Bunch	21246	61	20000	9291	25700	15
Sweet potatoes	Per Bundle	1888	40	2000	310	2000	9
Cassava	Per Bundle	1915	41	2000	294	1944	9
Sweet bananas	Per Bunch	18026	19	19000	6219	21600	5
Grazing of cows	Per Sack	2500	8	2000	756	2600	5
Tilapia	Per Fish	10220	50	10000	4440	10500	6
Water	Per 20L Jerry Can	337	43	300	138	464	6
Firewood	Per Headload	3500	14	3500	1454	2000	2
Charcoal	Per Sack	43990	50	40000	16989	36063	16
Poles	Per Pole	6296	49	6500	2220	13	7346

Regulating services

For carbon, we used estimates of the price per tonnes of carbon sequestered to estimate the value of carbon sequestered in the project area per year (Bush et al. 2004; NatureUganda 2011). For other regulating services, micro-climate regulation, air quality regulation, erosion prevention and water treatment, we used value benefit transfer for tropical forests from De Groot et al. (2010)'s global study (Natural Capital Coalition 2016). For the baseline, we used the minimum value and for the after 30 years scenario, assumed a 1% growth rate from the baseline value to account for the increase in above ground biomass (De Groot et al. 2010).

Results

Table 9: *Monetary flow account for provisioning and regulating services, for the Baseline (2016), Post Constructions (2020) and After 30 years (2050).*

			Monetary Flow Account		
Ecosystem Service		Units	Baseline (2016)	Post Construction (2020)	After 30 years (2050)
Provisioning	Food (Maize)	UGX ('000s) / yr	4,878	-	-
	Food (Matooke)		21,144	-	-
	Food (Sweet Potatoes)		1,903	-	-
	Food (Cassava)		3,271	-	-

	Food (Sweet bananas)		174	-	-
	Grazing (cows)		54,453	-	-
	Fishing - Tilapia		118,826	-	-
	Water		24,185	89,040	196,409
	Firewood		25,346	-	4,944
	Medicinal plants		8,803	-	12,946
	Charcoal		147,820	-	-
	Timber		2,042	-	5,860
	Poles		1,762	-	1,429
Regulating	Carbon sequestration		17,312	7,540	50,895
	Microclimate regulation		2,646	1,452	1,956
	Air quality regulation		2,442	1,340	1,806
	Water treatment		204	112	150
	Erosion prevention		2,239	1,228	1,655

Step 8. Dependency

Methods

We considered the dependencies as defined as "a business reliance on or use of natural capital" during the operational phase of the Plant and used previous studies on Water Treatment Plants to identify potential dependencies of the Katosi project on natural capital (Natural Capital Coalition 2016; Thames Water 2016).

Results

The Water Treatment Plant will be dependent on natural capital, from a consumptive standpoint, the plant will require water for abstraction and from a non-consumptive standpoint, the plant will be dependent on the CFR for water treatment and filtration, treatment of waste water from the plant and erosion prevention.

Literature cited

Aiama D, Edwards S, Bos G, Ekstrom J, Krueger L, Quétier F, Savy C, Semroc B, Sneary M, Bennun L. 2015. No Net Loss and Net Positive Impact Approaches for Biodiversity: exploring the potential application of these approaches in the commercial agriculture and forestry sectors. IUCN, Gland, Switzerland.

Albers A. 2016. Sustainability: Availability, Distribution and Consumption of Firewood near Kidepo Valley National Park. Van Hall Larenstein, University of Applied Sciences,

Leeuwarden, Netherlands.
Bull JW, Gordon A, Law EA, Suttle KB, Milner-Gulland EJ. 2014. Importance of baseline specification in evaluating conservation interventions and achieving no net loss of biodiversity. Conservation Biology **28**:799–809.
Bush G, Nampindo S, Aguti C, Plumptre A. 2004. The Value of Uganda's Forests: A livelihoods and ecosystems approach. Wildlife Conservation Society, Kampala, Uganda.
Daily Monitor. 2018, July 27. Army, district chairman clash over eviction of fishermen. Kampala, Uganda. Available from http://www.monitor.co.ug/News/National/Army-district-chairman-clash-eviction-fishermen/688334-3975938-rwj97xz/index.html (accessed July 28, 2018).
De Groot R, Kumar P, Van Der Ploeg S, Sukhdev P. 2010. Estimates of monetary values of ecosystem services. Appendix 3. Earthscan, London, UK. Available from https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/.
Diisi J. 2009. National Biomass Study Technical Report 2005. NFA, Kampala, Uganda.
Drichi P. 2002. National Biomass Study Technical Report of 1996-2002. NFA, Kampala, Uganda.
FAO. 2016. Land Cover Classification System v3. FAO. Available from www.fao.org/3/a-i5428e.pdf.
Farber S et al. 2006. Linking Ecology and Economics for Ecosystem Management. BioScience **56**:121. Available from https://academic.oup.com/bioscience/article/56/2/121-133/273901.
Forest Europe. 2015. Valuation of Forest Ecosystem Services. Forest Europe, Madrid, Spain. Available from www.foresteurope.org.
Forest Trends, eftec. 2017. No Net Loss of Biodiversity in Corporate Natural Capital Accounting A Summary. Forest Trends and eftec, London, UK.
GKW Consult GmbH. 2016. Environmental and Social Impact Assessment Report. GKW Consult GmbH, Kampala Uganda.
Griffiths VF, Bull JW, Baker J, Milner-Gulland EJ. 2018. No net loss for people and biodiversity. Conservation Biology **0**:1–12. Available from http://doi.wiley.com/10.1111/cobi.13184.
Heuzé V, Tran G, Archimède H, Régnier C, Bastianelli D, Lebas F. (n.d.). Cassava roots. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Available from https://www.feedipedia.org/node/527 .
IFC. 2012. Performance Standard 5: Land Acquisition and Involuntary Resettlement. IFC, Washington D.C.
Josupeit H. 2004. World Market of Tilapia. Globefish, FAO, Rome, Italy. Available from http://www.globefish.org/index.php?id=2185 (accessed August 1, 2018).
Kakuru W, Turyahabwe N, Mugisha J. 2013. Total economic value of wetlands products and services in Uganda. The Scientific World Journal:13. Available from http://dx.doi.org/10.1155/2013/192656.
Kamatenesi-Mugisha M, Oryem-Origa H. 2005. Traditional herbal remedies used in the management of sexual impotence and erectile dysfunction in western Uganda. African Health Sciences **5**:40–49.
Kiyingi I, Kalanzi F. 2016. Economic valuation of proposed sites for the development of a new water treatment plant in Kisakombe and Mwola Central Forest Reserve. NAFFORI, Kampala, Uganda.

Langdale-Brown I, Osmaston HA, Wilson JG. 1964. The vegetation of Uganda and its bearing on land-use. Govt Uganda, Entebbe, Uganda.
Masiga M, Muramira E, Kaggwa R. 2012. Contribution of Uganda's Forestry Sub-sector to the National Economy: Natural Resource Accounting Approach. Page (Hassan RM, Mungatana ED, editors) Implementing Environmental Accounts: Case Studies from Eastern and Southern Africa. Springer Netherlands.
MEA. 2005. Ecosystems and human well-being: Synthesis. Island Press, Washington D.C.
MEMD. 2016. National Charcoal Survey for Uganda 2015. Ministry of Energy and Mineral Development (MEMD), Kampala, Uganda.
Mukhtar AA, Tanimu B, Arunah UL, Babaji BA. 2010. Evaluation of the Agronomic Characters of Sweet Potato Varieties Grown at Varying Levels of Organic and Inorganic Fertilizer. World Journal of Agricultural Sciences **6**:370–373.
NaFFRI, DiFR, The Catch Assessment National Working Group. 2016. FINAL REPORT OF THE FISHERIES CATCH ASSESSMENT SURVEY IN THE UGANDAN WATERS OF LAKE VICTORIA FOR THE MAY 2011 SURVEY PREPARED BY THE CATCH ASSESSMENT NATIONAL WORKING GROUP.
NAFIS. (n.d.). Harvesting , Utilization & Conservation. Available from http://www.nafis.go.ke/fodders/napier-grass/harvesting-utilization-conservation/ (accessed August 1, 2018).
National Forest Authority. 2012. Forest Management Plan for Zirimiti Central Forest Reserves Management Plan Area. Republic of Uganda: Ministry of Water and Environment, Kampala, Uganda.
Natural Capital Coalition. 2016. Natural Capital Protocol. Natural Capital Coalition, London, UK. Available from http://naturalcapitalcoalition.org/protocol (accessed March 1, 2018).
NatureUganda. 2011. The Economic Valuation of the Proposed Degazettement of Mabira Central Forest Reserve. NatureUganda, Kampala, Uganda.
New Vision. 2018. Four arrested over illegal fishing. New Vision. Available from https://www.newvision.co.ug/print_article/new_vision/news/1463649/arrested-illegal-fishing?print=true (accessed July 28, 2018).
NFA. 2003. The National Forestry and Tree Planting Act. The Republic of Uganda, Kampala, Uganda.
NFA. 2012. Forest Management Plan for Zirimit Central Forest Reserves Management Plan Area. NFA, Kampala, Uganda.
NFA. 2016. Annual Performance Report for FY 2015/16. NFA, Kampala, Uganda. Available from http://www.nfa.org.ug/images/reports/2015-16.pdf (accessed July 1, 2018).
Nicholson E et al. 2009. Priority research areas for ecosystem services in a changing world. Journal of Applied Ecology **46**:1139–1144.
Plumptre AJ, Ayebare S, Pomeroy D, Tushabe H, Nangendo G, Mugabe H, Kirunda B, Nampindo S. 2017. Conserving Uganda's Biodiversity: Identifying critical sites for threatened species. WCS, Kampala, Uganda. Available from https://uganda.wcs.org/Admin-Plus/Docustore.aspx?Command=Core_Download&EntryId=33953.
Pomeroy D. 2002. Uganda Ecosystem and Protected Area Characterisation. Makerere University Institute of Environment and Natural Resources (MUIENR), Kampala, Uganda.
QGIS. 2018. QGIS Geographic Information System. QGIS Development Team. Available from

http://qgis.osgeo.org.
Tabuti JRS, Dhillion SS, Lye KA. 2003. Firewood use in Bulamogi County, Uganda: Species selection, harvesting and consumption patterns. Biomass and Bioenergy **25**:581–596.
Thames Water. 2016. Opportunities and challenges of taking a natural capital accounting approach. CLA, London, UK. Available from https://www.cla.org.uk/sites/.../Natural Capital Accounting WESTLAKE.pdf (accessed August 1, 2018).
UBOS. 2010. Uganda Census of Agriculture: Crop Area and Production Report. Uganda Bureau of Statistics, Kampala, Uganda.
UBOS. 2015. Uganda District Population Projections. Ugandan Bureau of Statistics, Kampala, Uganda. Available from http://catalog.data.ug/dataset/uganda-s-district-population-projections-2015-2020 (accessed June 20, 2018).
UBOS. 2017a. National Population and Housing Census 2014 - Area Specific Profiles Mukono District. Uganda Bureau of Statistics, Kampala, Uganda.
UBOS. 2017b. Uganda National Household Survey 2016/17. Ugandan Bureau of Statistics, Kampala, Uganda.
UNEP-WCMC. 2016. Feasibility Study for Biodiversity Accounting in Uganda. UNEP-WCMC, Cambridge, UK.
UNEP-WCMC, IDEEA. 2017. Experimental Ecosystem Accounts for Uganda. UNEP-WCMC and IDEEA, Cambridge, UK.
UNEP-WCMC, IUCN. 2018. Protected Planet: The World Database on Protected Areas (WDPA) [Online]. UNEP-WCMC and IUCN, Cambridge, UK. Available from www.protectedplanet.net (accessed May 23, 2018).
Wairegi LWI, van Asten PJA, Tenywa M, Bekunda M. 2009. Quantifying bunch weights of the East African Highland bananas (Musa spp. AAA-EA) using non-destructive field observations. Scientia Horticulturae **121**:63–72.
XE.com. (n.d.). USD to UGX Exchange rate. XE.com, Newmarket, Canada. Available from https://www.xe.com/currencycharts/?from=USD&to=UGX&view=1M (accessed August 20, 2018).

Appendix S3 - Sensitivity analysis

Methodology

Included in the main report

Baseline – including fishing village

For grazing, firewood, medicinal plants and water, we used the equations for the baseline quantification outlined in Appendix S2 and increased the project-affected people from 217 (131 for water due to Kagulu residents having access to boreholes) to 417 (331 for water provision). For fishing, we estimated that there would be 1 boat per every 3 households in the fishing village and hence the number of fishing boats increased from 4 to 66 per day (Kolding et al. 2005). For charcoal, we estimated that there would be an increase in line with the increase in the households, therefore the number of firings would be 192% of the base case. As the farming values were based on land cover and the timber and poles were based on a harvesting rate of the forest, we did not make assumptions of the impact of the fishing village on these estimates. For the valuation, we used the same monetary valuation as in the base case for each service.

Scenarios - After 30 years – no access to the reforestation area

We assumed that if no access was allowed to the reforestation area, this would result in no provisioning services from the project and reforestation area apart from water provision by NWSC. However, this restriction of access would likely increase the rate of reforestation and regeneration and likely increase the provision of regulating services.

Scenarios - After 30 years – full access to the reforestation area

For grazing, fishing, medicinal plants and charcoal, we used the equations for the baseline summarised in Appendix S2 and increased the number of households, number of firings per week and fishing boats by the projected population growth rate for Mukono (UBOS 2015). In the scope of this study, we have not made an assessment of whether this rate of harvesting would be sustainable. For firewood, timber and poles, we assumed that the rate would be double that of the sustainable rate as estimated for the after 30 years scenario for the base case, summarised in Appendix S2.

Scenarios - After 30 years – Reduction in the use of firewood

For firewood, we used the same equation as in the base case for after 30 years, however, we changed the % of biomass used for firewood down from 25% to 15%. For all other provisioning services, the values were the same as in Appendix S2 for the after 30 years scenario.

Scenarios - After 30 years – Reduction in the use of medicinal plants

For the use of medicinal plants, we used the same equation as used in the base case for medicinal plants after 30 years, however, we changed the % of the population that use medicinal plants down from 75% to 25%. For all other provisioning services, the values were as calculated in Appendix S2 for the after 30 years scenario.

Counterfactuals - 2016 usage + Population growth

For grazing, fishing, firewood, medicinal plants and charcoal, we used the equations for the baseline in Appendix S2 and increased the number of households, number of firings per week and fishing boats by the projected population growth rate for Mukono (UBOS 2015). However, for farming, timber and poles, the values remain as in the 2016 usage as we have not attempted to model the conversion of population growth into farming or timber and pole harvesting. In the scope of this study, we have not made an assessment of whether this rate of harvesting would be sustainable which is a significant limitation.

Counterfactuals - 2016 usage + with continued encroachment

For farming, we used the same equations as summarised in Appendix S2 and assumed there would be a 1% increase in the farm area per year for each crop, from the 2016 baseline assessment. For timber, poles, firewood, medicinal plants and charcoal, we used the equations for the baseline and assumed there would be a 1% p.a. decrease in the availability of these goods.

However, for grazing and fishing, we assumed that in a no project scenario that continued encroachment would not affect the availability of grass for grazing or the availability of fish. These are simplifying assumptions, due to time and logistical limitations.

Water provision – No borehole observation

We used the same equation as summarised in Appendix S2, but used the total number of project-affected people (217) in the calculation, rather than excluding the residents of Kagulu.

Water provision – Connection and access fee charged by NWSC

We used the equation for quantification and monetisation of the flow of water for post construction and for after 30 years as summarised in Appendix S2. However, from the total monetary cost we subtracted the connection fee per household and the cost per litre of water used charged by NWSC under their 2017 tariffs (NWSC n.d.)

Additional sensitivities

Counterfactuals - 2016 usage with continued encroachment, at a faster pace

For farming, we used the same equations as summarised in Appendix S2 and assumed there would be a 2% increase in the farm area per year for each crop from the 2016 baseline. For timber, poles, firewood, medicinal plants and charcoal, we used the equations for the baseline and assumed there would be a 2% per year decrease in the availability of these goods.

However, for grazing and fishing, we assumed that in a no project scenario that continued encroachment would not affect the availability of grass for grazing or the availability of fish.

Water provision - Location of market – Closest market, instead of average of 3 closest

We used the equations for quantification for baseline, post construction and for after 30 years as summarised in Appendix S2. However, for the monetary valuation, we used the average market price from Katosi, the closest market, as supposed to the average of the 3 closest markets, as summarized in Appendix S2.

Water provision – If data collection had been completed in wet season

We used the equations for quantification for the baseline, post construction and for after 30 years as summarised in Appendix S2. However, for the monetary valuation, we used an estimate of the market price for water in wet season which was estimated to be 200 UGX as suppose to the average of our study which was 337, as in Appendix S2.

Water provision – If data collection had been completed in dry season

We used the equations for quantification for baseline, post construction and for after 30 years as summarised in Appendix S2. However, for the monetary valuation, we used an estimate of the market price for water in wet season which was estimated to be 500 UGX as suppose to the average of our study which was 337, as in Appendix S2.

Project-affected people – If only those within 30 minute walking distance

In Appendix S2, the equations for grazing, firewood, water and medicinal plants included the number of project-affected people. We estimated the impact if we used a catchment of the households within 30 minute walking distance. We used the equations in Appendix S2 for the baseline, post construction and after 30 years, but with a catchment of 65 instead of the 217 for the 2016 baseline.

Project-affected people – If only those within 1 hour walking distance

In Appendix S2, the equations for grazing, firewood, water and medicinal plants included the number of project-affected people. We estimated the impact if we used a catchment of the houses within 1 hour walking distance. We used the equations in Appendix S2 for the baseline, post construction and after 30 years, but with a catchment of 136 instead of the 217 for the 2016 baseline.

Project-affected people – use of project area (60%)

In Appendix S2, the equations for grazing, firewood, water and medicinal plants included the proportion of the project-affected people that use the project area on a given day /

month. We estimated the impact if we used 60%, rather than the 50% estimated for the base case. We used the equations in Appendix S2 for the baseline, post construction and after 30 years, but with a proportion of catchment that use the project area of 60%.

Project-affected people – use of project area (40%)

In Appendix S2, the equations for grazing, firewood, water and medicinal plants included the proportion of the project-affected people that use the project area a given day / month. We estimated the impact if we used 40%, rather than the 50% estimated for the base case. We used the equations in Appendix S2 for the baseline, post construction and after 30 years, but with a proportion of catchment that use the project area of 40%.

Table 1: *Summary of sensitivity analysis, including assumptions for the base case and alternatives (those in bold are included in the main report)*

KEY DECISION	BASE CASE	ALTERNATIVE SCENARIO	ASSUMPTION FOR ALTERNATIVE SCENARIO
Baseline for project-affected people	Illegal fishing village not included	Fishing village extant in baseline	Assume that the fishing village demolition is due to the project area and the fishing shifts to other areas. Use of the project area and Sumbwe Bay includes the illegal fishing village, so project-affected people increase as well as the number of fishing boats using Sumbwe Bay.
After 30 years scenarios for local natural resource use of the reforestation area by project-affected people	Restricted access to the reforestation area. 2016 baseline use of firewood and medicinal plants	After 30 years – no access to the reforestation area	No access to provisioning ecosystem services for project-affected people, except water provision by NWSC
		After 30 years – full access to the reforestation area	Baseline usage plus population growth rate for grazing, fishing, medicinal plants and charcoal. Double the NFA's estimate for sustainable yield for firewood, timber and poles (Drichi 2002)
		Reduction in use of firewood for external reasons	15% of annual biomass yield for firewood, decline from 25% in the base case
		Reduction in use of medicinal plants for external reasons	Medicinal plants used by 25% of population, reduced from 75% in the base case
Counterfactual for no project scenario	2016 usage	1. 2016 usage + Population growth	Population growth of 2.7% (exc. farming, timber and poles)
		2. 2016 usage with continued encroachment	Encroachment 1% per year increase in farm area, 1% per year decrease in availability of goods (except fishing and grazing)
		2. 2016 usage with continued encroachment, at a faster pace	Encroachment 2%p.a. increase in farm area, 2%p.a. decrease in availability of goods (all except fishing and grazing)
Water needs of project-affected people	Borehole observed	1.No borehole (as per ESIA)	All project-affected people accessing water from project area
	Piped water provided by NWSC to compensate for loss of access	2. Households have to pay for piped water (NWSC, personal communication)	Each household pay connection and fee per jerry can of water consumed (NWSC tariffs)
Accuracy of quantitative estimates		10% error	Each component increased / decreased by 10%

Water – other	Average market price for 3 closest markets	3. Location of market – Closest market, instead of average of 3 closest	Use the average prices for Katosi (summarized in Appendix S2)
	Value estimate applies to whole year (Average =337)	4. Data collection – wet season	If had taken market observations in wet seasons - Price of water is 200
	Value estimate applies to whole year (Average =337)	4. Data collection – dry season	If had taken market observations in dry season - Price of water is 500
Catchment	Catchment – from project area up to Ngombere (c. 2 hours – 217 households)	Catchment (30 minutes walking distance)	Catchment is 65 households
		Catchment (60 minutes walking distance)	Catchment is 136 households
	50% of catchment use the project area	Use of project area (0.6)	60% of catchment use project area
		Use of project area (0.4)	40% of catchment use project area

***** Quantitative scenarios were assessed on the basis of the monetary value of provisioning services

Results

Table 2: *Summary of sensitivity analysis for aggregate monetary flows of provisioning services for the baseline, post-construction and after 30 years*

For Provisioning - overall	All in UGX (M)					
		Base	Post Construction	After 30 years	Net change	Ratio to base case
	Base scenario	415	89	222	(193)	NA
Baseline	Fishing village	2,680	89	222	(2,458)	12.7
Scenario	After 30 years (no access)	415	89	196	(218)	1.1
Scenario	After 30 years (unregulated access)	415	89	1,030	615	(3.2)
Scenario	After 30 years (Reduction in use of medicinal plants)	415	89	213	(202)	1.0
Scenario	After 30 years (Reduction in use of firewood, use of yield for timber instead)	415	89	220	(195)	1.0
Accuracy	10% +	640.78	143.40	370.31	(270)	1.4
Catchment	Catchment (30 minutes walking distance)	338	25	72	(266)	1.4
Catchment	Catchment (60 minutes walking distance)	371	53	137	(234)	1.2
Catchment	Use of project area (0.6)	437	89	235	(203)	1.0
Catchment	Use of project area (0.4)	392	89	226	(166)	0.9
For Provisioning Water						
	Base scenario	24	89	196	172	NA
Observation	No observation of borehole	40	89	196	156	0.91
Project decision	NWSC make households pay for connection and usage of water	24	68	149	125	0.73
Data aggregation	Closest Market	16	59	131	115	0.7
Data aggregation	Data collected in Wet season	14	53	116	102	0.6
Data aggregation	Data collected in Dry season	36	132	291	255	1.5
For Counterfactuals						
		Counterfactual		After 30 years	Net change	Ratio to base case
Base scenario - 2016 usage		415		222	(193)	
Base scenario + Population growth of 2.7% p.a.		965		222	(744)	3.85
Continued degradation - 1%p.a. decline in availability of goods and 1%p.a. expansion of farming		366		222	(145)	0.75
Continued degradation - 2%p.a. decline in availability of goods and 2%p.a. expansion of farming		340		222	(119)	0.62

Literature cited

Kolding J, Zwieten P Van, Manyala J, Okedi J, Mgaya YD, Orach-meza F, Report F, Salaam DE. 2005. Regional Synthesis Report on Fisheries Research and Management. Lake Victoria Environmental Management Program (LVEMP), Dar es Salaam, Tanzania. Available from https://www.researchgate.net/publication/40118164_Regional_Synthesis_Report_on_fisheries_research_and_management_States_trends_and_processes (accessed August 2018).

NWSC. (n.d.). NWSC tariffs. Available from https://www.nwsc.co.ug/index.php/home-mobile/itemlist/category/44-tarrif (accessed August 2018).

UBOS. 2015. Uganda District Population Projections. Ugandan Bureau of Statistics, Kampala, Uganda. Available from http://catalog.data.ug/dataset/uganda-s-district-population-projections-2015-2020 (accessed June 2018).

Appendix S4 - Limitations

Limitations of NCA in general

There are limitations with NCAs that have been identified in the literature, including that, by definition, the NCA only represents an anthropocentric view of the natural world (Bolt et al. 2016). There are also concerns over how well NCAs are able to represent the natural processes and functions that underpin the production of ecosystem services, which are an important part of natural capital and to the consideration of biodiversity (Natural Capital Committee 2013; Bolt et al. 2016; Natural Capital Coalition 2016).

Limitations of our NCA

There were limitations within our case study. For the counterfactuals, there was limited assessment of the rate of degradation and the sustainable rate of harvesting. Multiple counterfactuals were developed to illustrate the consideration and assumptions required to generate a counterfactual. There were also limitations with our paper that we focused on aggregated monetary flows, but this was for illustrative purposes with the disaggregated flows in the Supporting Information.

There was also a limitation that the observational walk covered approximately 20% of the project site. However, the walk covered the main paths where the majority of activities would likely be conducted. It was very difficult to cover a larger area without disturbing the cultivated areas and we did not believe this would be appropriate. The line of sight was also affected by the time of year, as in June/July it was approaching harvest, so the fields of maize restricted the line of sight.

There were limitations with the NFA's land cover data due to changing methodology (UNEP-WCMC & IDEEA 2017). There were limitations with the use of De Groot et al (2010) benefit transfer for regulating services. These are global estimates for tropical forests and they have a considerable range in each estimate for each ecosystem service (De Groot et al. 2010). Due to the level of degradation within Mwola CFR, we used the minimum value and as there is limited detail on the relation between reforestation efforts and the provision of regulating services we made a simplifying assumption that there would be a 1% growth rate per year from the start of restriction of access and the replanting efforts. We used a single source rather than combine different sources as there can be issues of linguistic uncertainty between different ecosystem services which we wanted to minimise (Regan et al. 2002). The use of international estimates is viewed as a limitation, but there were limited local estimates of the value of these regulating services (Pandeya et al. 2016)

Assumptions

In order to conduct our NCA we also needed to make a number of assumptions which are detailed below. We assumed no significant change between 2016 and 2018 and that the observation week was representative of the year in order to use the ESIA data and observations within our baseline. We assumed there was a uniform catchment and use of the project area across ecosystem services and that using the cheapest available alternative was acceptable for our purpose. We assessed whether the secondary data was representative to the local area using observations and then made assumptions based on this assessment.

Lack of interviews

During study, we faced time and logistical constraints which meant we were not able to complete interviews or focus groups. This had some important implications of our case study, but was also useful. Many ESIAs, on which decisions are made, have very limited time on the ground and therefore, understanding how much of an NCA could be conducted based on secondary data was part of the learnings from the case study. It also identified that observations, such as that of the borehole could be used to inform the questionnaire, to identify differences between perceived use and observed behaviours as well as triangulate findings from other studies.

However, the lack of interviews also meant that we were not able to cover well-being in our case study. The lack of interviews also meant that we were unable to assess the historic changes in use of the project area, which could have given an indication of whether encroachment had already affected the availability of goods.

To address some of the limitations and reduce the number of assumptions required for future NCAs, potentially some of the following questions could be used if interviews or focus groups were going to be conducted:

1) Which ecosystem services contribute the most to the well-being of the community or the household?
2) Does the use of x good change over the year? If so, how?
3) Does the price of good x change over the year? What does it cost at these different times of the year?
4) What proportion of good x do you obtain from the project area?
5) Why do you choose to good x from the project areas vs other areas of forest vs the market?
6) If you were not able to obtain the good from the project area, would you still try to obtain the good? If so, how and where would you obtain the good (e.g. purchase from market, go to a different forested area)?

It would also be useful within NCAs to move beyond the impact of the project on local communities but also develop an understanding of the dependency of the local communities on the project area. For example, if the local communities obtain 90% of their goods from the project area rather than 10%, this would mean the project would have a very different effect on the local communities. This could be an important consideration within Uganda where a large proportion of those out of poverty are still viewed as vulnerable to poverty and changes in their access to goods could affect their well-being (World Bank 2016).

Literature cited

Bolt K, Cranston G, Maddox T, McCarthy D, Vause J, Vira B. 2016. Biodiversity at the heart of accounting for natural capital : Cambridge Conservation Initiative, Cambridge, UK. Available from https://naturalcapitalcoalition.org/wp-content/uploads/2016/07/CCI-Natural-Capital-Paper-July-2016-low-res.pdf (accessed June 1, 2018).

De Groot R, Kumar P, Van Der Ploeg S, Sukhdev P. 2010. Estimates of monetary values of ecosystem services. Appendix 3. Earthscan, London, UK. Available from https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/.

Natural Capital Coalition. 2016. Natural Capital Protocol. Natural Capital Coalition, London, UK. Available from http://naturalcapitalcoalition.org/protocol (accessed March 1, 2018).

Natural Capital Committee. 2013. The State of Natural Capital: First report. Natural Capital Committee, London, UK. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/516707/ncc-state-natural-capital-first-report.pdf (accessed May 1, 2018).

Pandeya B, Buytaert W, Zulkafli Z, Karpouzoglou T, Mao F, Hannah DM. 2016. A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. Ecosystem Services **22**:250–259.

Regan HM, Colyvan M, Burgman MA. 2002. A Taxonomy and Treatment of Uncertainty for Ecology and Conservation Biology. Ecological Applications **12**:618–628.

UNEP-WCMC, IDEEA. 2017. Experimental Ecosystem Accounts for Uganda. UNEP-WCMC and IDEEA, Cambridge, UK.

World Bank. 2016. The Uganda Poverty Assessment Report 2016. World Bank, Washington D.C. Available from www.worldbank.org/ uganda (accessed August 10, 2018).

Appendix S5 - Scope of the ESIA

Table 1: Summary of scope of ESIA (GKW Consult GmbH 2016)

Baseline Environmental Conditions	**Details**
Vegetation	Qualitative description and waypoints of sensitive sites Species richness counts of species, genera and families
Butterflies, Dragonflies, Herpetiles, Birds, Mammals	Species richness, composition and conservation status
Forest Economic Value (For Plant, not reforestation area)	
Timber Poles	Quantitative and Monetised stock - Survey for volume and market price
Charcoal Fuelwood Hoe/axe handles Mushrooms Palm leaves Fresh water	Quantified and Monetised flow - Household Survey for volume and market price. Assumed average annual harvest rate per household and a number of households affected
Herbs	Monetised flow - total number of households and avoided cost per year
Carbon sequestration	Quantified and Monetised stock - above ground biomass and market carbon price
Microclimate regulation Air quality regulation	Monetised - Benefit transfer
Other	
Farming	Mentioned in project description as usage of the area converted from natural vegetation
Fishing	Village identified, but considered as a separate section from rest of the ESIA
Fish spawning and breeding sites for amphibians	Mentioned in qualitative discussion of sensitive sites, not included in impact of project

GKW Consult GmbH. 2016. Environmental and Social Impact Assessment Report. GKW Consult GmbH, Kampala Uganda.