Ecosystem Services 39 (2019) 100987

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Insights into the importance of ecosystem services to human well-being in reservoir landscapes

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ARTICLE INFO

Keywords:
Smallholder farmer
Community-managed reservoirs
Ecosystem services
Social valuation
Human well-being
Sustainable development

ABSTRACT

Smallholder famers in West Africa use multiple ecosystem services (ES) in their day-to-day lives. The contribution that these services make to human well-being (HWB), and therefore to development outcomes, is not well understood. We analyse smallholder farmer perceptions of ES, ecosystem disservices (ED), and their HWB importance around community-managed reservoirs in four semi-arid landscapes in West Africa, using participatory mapping, focus groups and face-to-face surveys. Farmers identified what nature-based benefits (ES) and problems (ED) they perceived across each landscape and rated the importance of each service and disservice for their HWB. Our results indicate that ES make an important contribution to HWB in our study sites. More than 80% of farmers rated benefits from plant-based foods, domestic and agricultural water supplies, biofuel, medicinal plants, and fertile soil, and problems associated with human disease vectors, as of high or very high importance for HWB. Multiple ES were identified as contributing to each dimension of HWB, and ED as detracting from health and material well-being. Perceptions of the importance of several ES and ED varied significantly with socio-economic group, highlighting the need for careful consideration of trade-offs between HWB outcomes and stakeholders in ecosystem management decisions to support sustainable development.

1. Introduction

Ecosystem structure and processes can provide benefits that support human well-being (HWB) (Boyd and Banzhaf, 2007; Fisher et al., 2009; MEA, 2005), for example through pollination of crops, filtration of water pollutants, and provision of plant-based medicinal resources. Ecosystem components can also impact negatively on HWB (Campagne et al., 2018; von Döhren and Haase, 2015), notably by spreading livestock and human pests and diseases. The aspects of ecosystems that impact positively and negatively on HWB are referred to here as ecosystem services (ES) and ecosystem disservices (ED) respectively. The concepts of ES and ED are now fairly consistently applied across ecosystem service science, after a series of pivotal papers clarifying conceptual ambiguities (Boyd and Banzhaf, 2007; Fisher et al., 2009; Wallace, 2007). In contrast, HWB has no standard definition and remains a contested concept (Summers et al., 2012). Income was widely used to measure HWB until attention shifted in the 1990s towards non-economic aspects of well-being, particularly important in development contexts (Sen, 1999). There is now general consensus that HWB is multi-dimensional and that some elements of HWB are universal, such as access to food and shelter, while others are subjective and context-dependent, including happiness and anxiety (Díaz et al., 2015; Schwartz, 1994; Stiglitz et al., 2009). Stiglitz et al. (2009) propose that to inform public policy, both universal and subjective measures of HWB should be considered.

At present, the value of ES for different dimensions of HWB is poorly understood (Olander et al., 2017) and insufficiently captured in wider efforts to improve well-being (Summers et al., 2012). Identifying locally important linkages between ecosystems and HWB has the potential to highlight trade-offs that may exist between potential beneficiaries (Howe et al., 2014) which can facilitate design of ecosystem-based approaches to boost HWB. The Millennium Ecosystem Assessment (MEA, 2005) mapped potential linkages between different ES and dimensions of HWB providing a framework of study. The MEA (2005) views HWB as incorporating freedom of choice and action which stems from sufficient access to material, security, health and social benefits.

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https://doi.org/10.1016/j.ecoser.2019.100987
Received 27 August 2018; Received in revised form 29 July 2019; Accepted 2 August 2019
Available online 14 August 2019

The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) provide a newer conceptual framework for nature-people relations, in which HWB is described as achieving a "good quality of life" and embraces the broad definition of HWB suggested by the MEA (Díaz et al., 2015). However, perceptions of the linkages between ecosystems and HWB and their value can vary between individuals and contexts (Boyd and Banzhaf, 2007), depending on factors such as levels of knowledge and what benefits people value or need (Daw et al., 2016). Ecosystems may only provide HWB benefits to specific groups or at certain times or places (Andersson et al., 2015). For example, the health benefits of medicinal plants may only be important to people who are unwell; income benefits of lowland flooding only important during the cropping season, and; nutrition benefits of wild foods only important in times of household food shortages. Similarly, negative impacts of ecosystems on HWB will vary across stakeholders and space. For example, livestock pests prevalent in lowland areas may be a direct problem only for pastoralists, and malaria vectors to the health of those living near open water.

Identification and disaggregation of the supply and perceived value of ES and ED is important in poverty contexts where community or national level findings can mask household or individual level impacts of ecosystems on a person's well-being (Daw et al., 2011). The way in which people perceive and value ecosystem contributions to HWB influences how these ecosystems are managed (Asah et al., 2014; Hicks et al., 2015; Manfredo et al., 2017). Diverse values amongst stakeholders can impede collective action to manage ES, or result in disjointed actions that have unexpected and sometimes conflicting outcomes (Adger et al., 2009). Here, values refer to "the personal or societal judgement of what is valuable and important in life" (Adger et al., 2009, p. 338). While economic measures of ecosystem benefits dominate valuation studies (Costanza et al., 2014, 1997; de Groot et al., 2012; Hein et al., 2006), these are critiqued for failing to adequately capture biophysical, social or place-based values (Brown, 2013; Carpenter et al., 2009; Cowling et al., 2008; Folkersen, 2018; Kumar and Kumar, 2008; Sherrouse et al., 2011). Moreover, assigning cash values to nature-based sources of well-being is challenging for some services (Barbier et al., 2011), inappropriate in societies with low levels of market interaction (Christie et al., 2012; Folkersen, 2018), and highly sensitive to methodological factors (Schild et al., 2018), pointing to the need for alternative approaches.

Determining the importance individuals assign to an ES is a social valuation approach (Bryan et al., 2010). Assigned values reflect people's perceptions, worldviews, preferences and valuation contexts, and can be shared or vary between individuals (Kenter et al., 2015). While many studies have applied non-monetary approaches to ES valuation, relatively little attention has been given to understanding or quantifying local perceptions of the importance of ES (or ED) for HWB in poverty contexts (Daw et al., 2016) and particularly from the perspective of farmers (Smith and Sullivan, 2014); despite their role as primary stewards of a large share of the world's terrestrial land. Theory suggests that farmers should place a high value on ES because their livelihoods depend on adequate freshwater supplies, soil nutrient cycling, biological pest control and other services that support food, fibre and biofuel production (DeClerck et al., 2017; Swinton et al., 2007; Zhang et al., 2007). Yet farmers, including in rural Africa, are increasingly encouraged to turn to technological and agrochemical solutions to farming challenges which may be eroding their sense of reliance on nature with consequences for farmer perceptions, values and behavior regarding ES.

Landscapes containing community-managed reservoirs in the semi-arid northern Volta basin present an interesting focal point for better understanding farmer perceptions and values regarding ES/ED. Created by damming minor rivers, these reservoirs store runoff and create an environment suitable for year-round fish, crop and livestock production. Without a reservoir, agricultural water supplies are limited to the 4–6 month rainy season for most farmers. The reservoirs are also a source of ED, increasing the prevalence of malarial mosquitoes and water-borne diseases such as Schistosomiasis (Boelee et al., 2009; Kibret et al., 2009; McCartney, 2009). Some farmers may give priority to maintaining reservoir water supplies and associated ES at the expense of managing local land to conserve other ES, and despite the increase in ED. Yet due to individual farmer preferences, access rights and livelihood strategies, ES and ED that are mediated by the reservoir may not hold the same level of importance for the HWB of all farmers. Vast sums of money are invested in the construction, expansion and maintenance of community managed reservoirs to support agricultural production in the region (Venot et al., 2012) yet the ES and ED implications of these reservoirs for local farmers are currently under-researched.

Drawing on methods applied in previous studies to map ES at the community level (e.g. Sinare et al., 2016), eliciting social values for these ES (e.g. Bryan et al., 2010), and comparing values across socio-economic groups (e.g. Iniesta-Arandia et al., 2014; Martín-López et al., 2012), this paper explores farmer perceptions of ES, ED and their importance for HWB in four community-managed reservoir landscapes of West Africa. We focus on three research questions:

1. What are local smallholder farmer perceptions of the ES and ED supplied by different land types (locally meaningful areas of distinct land use and/or land cover) in their landscape?
2. What importance do farmers assign to these ES and ED for HWB, and why?
3. How and why do farmer perceptions of the importance of ES and ED vary with ES/ED type and farmer socio-economic profile?

Answering these questions will help close gaps in knowledge regarding farmer perceptions of ES and ED and the implications of ES and ED provided in reservoir landscapes for HWB outcomes. Understanding farmer perceptions of ES is essential to motivating their participation in sustainable land management (Smith and Sullivan, 2014), while knowledge of how important ES/ED are for different farmer groups in reservoir landscapes can provide insights to donors and policymakers on how to make reservoir investments and landscapes meet the needs of a wider range of farmers.

2. Materials and methods

2.1. Study sites

We selected four agricultural landscapes in seasonally dry portions of the Volta river basin, each containing a small to medium size (0.2–1.8 Mm^3) man-made reservoir around which several communities live and farm. Our study sites included Bidiga and Ladwenda reservoirs in Centre-Est, Burkina Faso, and Binaba and Tanga reservoirs in Upper-East, Ghana (Fig. 1). These sites were selected based on evidence of small-scale irrigated cropland around reservoirs, identified from Google Earth, indicating farming activities and to coincide with sites engaged in a Bioversity International led CGIAR Water Land and Ecosystems project in 2015–2016 in order to facilitate stakeholder engagement. We defined the boundary of each site as the area contained by a ~2 km buffer around the reservoir, its catchment, and downstream irrigation zone, resulting in sites of 32 km^2 (Tanga), 57 km^2 (Binaba), 89 km^2 (Ladwenda) and 109 km^2 (Bidiga).

Ghana's Upper-East region, where Binaba and Tanga sites are located, is one of the poorest in the country with 88% of the population living in the two lowest national wealth quintiles, and 38% of the population having no formal education (Ghana Statistical Service et al., 2015). In contrast, Bidiga and Ladwenda sites in the Centre-Est region of Burkina Faso have a much smaller yet still substantial proportion (29%) of the population in the two lowest national wealth quintiles, while nearly three quarters of the population have no formal education (INSD and ICF International, 2012). While this shows within-country

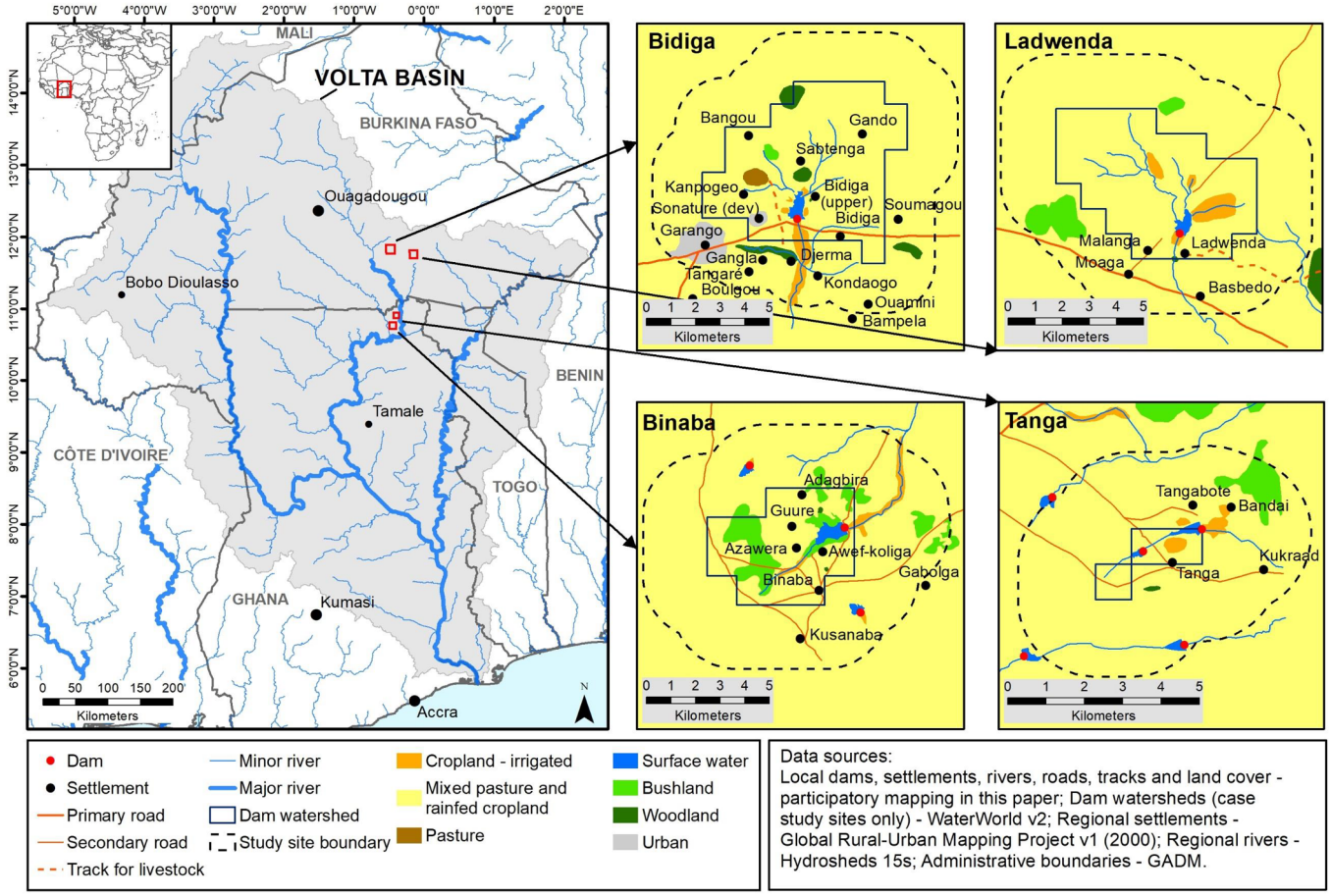

Fig. 1. Location of study sites.

poverty levels are relatively high in the Ghanaian sites, 30% of people are estimated to live in multi-dimensional poverty in Ghana compared to 84% in Burkina Faso showing the stark contrast at a cross-country level (UNDP, 2018). Sites in Ghana are home to the Kusasi people. In Burkina Faso, Bissa people dominate the landscape around Bidiga while at Ladwenda nearly all residents are Mossi, part of the largest ethnic group and prevailing landowners in Burkina Faso. A minority of residents in all four sites are from other ethnic groups, including Dagomba and Bissa in the Ghanaian sites and Fulani, Yarsé and Zaossé in the Burkinabé sites. While sites differ culturally, there are strong similarities in socio-economic and agro-climatic conditions. Households in all sites rely predominantly on subsistence and local market agriculture for their livelihoods. Population densities are low with less than 200 persons per km^2. There are between three (Ladwenda) and ten (Bidiga) small villages within each landscape, comprising clusters of homesteads. Cropped areas are dominated by rainfed cereals (mainly maize, sorghum, millet, rice) and groundnuts, and irrigated rice, maize, small-scale fruit and vegetable production. Livestock roam freely across gently sloping terrain dominated by cropland intermixed with grassland and sparse tree and bush cover. Rainfall is 700–1000 mm per year and bimodal, with mean annual temperatures of ~28 °C (WorldClim V2; Fick and Hijmans, 2017). Each reservoir is situated within 20 km of a small market town.

2.2. Participant selection

We organised focus groups at each site in December 2016. Dam management associations were asked to invite five men and five women from local farming households targeting a cross section of local villages. At some study sites, fewer than five men or women arrived on the day while in others extra people were invited by the association. In total, 46 representatives from 18 villages across the four communities participated in the ES focus group discussions, comprising 27 men and 19 women. Of these, 37 individuals including at least one representative from each of the 18 villages, were available to participate in a follow-up questionnaire survey, ES/ED rating exercise and semi-structured interview on perceptions of the importance of ES and ED to their well-being. Supplementary Material S1 shows the distributions of participants and villages represented per case study.

2.3. Participatory mapping of ecosystem services and disservices

We used a printed 1 m × 1 m aerial image of each study landscape to identify locations where participants perceive ES and ED. Images were obtained from Google Earth. Using this image, participants were familiarized with visible map features, such as roads, towns and rivers, and asked to describe the different land types present and their boundaries. Participants described the vegetation and use of each land type which we later triangulated using observations we collected during transect walks at each site. The transect walks were conducted with a local villager and involved walking around each reservoir at a distance of about 200 m from the reservoir edge, and walking a short way upstream, stopping every 100 m for the villager to describe proximate land types and notable features.

Next, participants identified what benefits (ES) and problems (ED) from nature they associated with each land type identified. For this exercise, we used a large matrix of ES and ED cross-tabulated with land types. Many participants were illiterate and therefore the matrix was designed and completed using pictorial symbols as far as possible. We included 14 ES and 2 ED (Table 1) of potential relevance to the

Table 1
ES, ED and their classifications used in this paper. We use the Common International Classification of Ecosystem Services to determine ES type and classified an ES or ED as mediated by the reservoir if its supply depends heavily on the presence and functioning of the reservoirs in our study sites.

Ecosystem service or disservice	Type	Mediated by reservoir
Food – plant-based	ES-Provisioning	Yes (irrigated crops)
Food – fish		Yes (fisheries)
Food – meat		Yes (livestock watering)
Fodder		No
Water – domestic		Yes (water withdrawals, and reservoir level affects groundwater level)
Water – agricultural		Yes (water withdrawals)
Raw materials (i.e. building materials)		No
Firewood and charcoal		No
Organic fertiliser		No
Medicinal plants		No
Cultural (places for recreation, traditional or spiritual activities)	ES-Cultural	No
Soil nutrient cycling (fertile soil)	ES-Regulation and maintenance	No
Desirable flooding (for agriculture)		Yes (reservoir capacity and management)
Soil moisture retention (between rains or into dry season)		No
Human disease vectors	ED-Ecosystem disservice	Yes (e.g. habitat for mosquitoes)
Agricultural pests		No

Fig. 2. Participatory mapping and ES rating activities. Photos show (a) farmers mapping land types at Binaba, (b) digitized version of land type map produced by participants at Bidiga, (c) a completed matrix of ES and ED (rows) present on each land type (columns) at Bidiga, (d) completed rating from 'No importance' (left) to 'Very high importance' (right) of ES and ED by one participant from Ladwenda.

communities as determined through preliminary fieldwork (observation, informal interviews) in April 2016, and invited participants to indicate any additional services or disservices not listed (none were identified). Groups of 5–10 participants disaggregated by gender discussed and then a facilitator marked on the matrix which ES and ED were available in each land type present in their landscape (see Fig. 2). Men and women were separated for this exercise to ensure equal participation, which is often a challenge in mixed gender groups (Fortmann, 1995). A facilitator introduced each ES and ED to participants, providing examples from the local context. Once the facilitator was confident participants understood the exercise, participants were disaggregated by gender. Each group had a facilitator and a research assistant to translate to and from the local language (Mooré, Bissa or Kusasi) and English. Due to human error, ED and fodder were excluded in the land type mapping exercise at Binaba and Tanga (but included in all other activities).

The groups discussed whether each ES in the matrix is available from a given land type in the Dry Season, Rainy Season or Both Seasons. When consensus was reached, the facilitator marked this information on the matrix.

2.4. Stakeholder values and socio-economic profiles

A subset of 37 focus group attendees who were available to take part in additional research responded to a short questionnaire on their social and economic status and participated in an ES/ED rating exercise (see Supplementary Material S2 for a copy of the questionnaire). While rating and ranking are both valid and robust approaches to capturing individual values (Rankin and Grube, 1980), rating can lead to a narrow distribution of scores and results are subject to variations in individual response styles (Alwin and Krosnick, 1985). However, rating items is generally faster and easier for participants, avoids the problem of interdependency between ranked items, and has the key strength is that it does not force participants to artificially differentiate items (Alwin and Krosnick, 1985). For the rating exercise, we asked participants to individually rate the importance of ES for contributing to, or ED for detracting from, their wellbeing, on a 5-point Likert scale from: 1 – No importance, 2 – Low importance, 3 – Moderate importance, 4 – High importance, 5 – Very High importance, using the question "How important is [X ES/ED] for your well-being?". After two practice runs to ensure understanding, participants were asked to place individual pictorial cards representing each of 14 ES and the 2 ED along the Likert scale, with each participant taking approximately 5 minutes to complete the task. This was followed by a semi-structured interview of around 30 minutes where the participants were asked to explain why they rated each card as they did.

2.5. Explanatory factors behind stakeholder values

2.5.1. Statistical analysis

Kruskal-Wallis is suitable for analysing differences in the distribution of an ordinal response variable across more than two groups using the R stats package (R Core Team, 2018). We used Kruskal-Wallis to test for significant differences between the perceived importance of ED and ES across case study sites, and the dunn.test package in R to apply Dunn's test for stochastic dominance and identify which pairs of communities were significantly different.

We similarly used Kruskal-Wallis to test whether the importance assigned to an ES or ED varied significantly with ES or ED characteristics, and whether the importance varied significantly with stakeholder socio-economic profile. Where differences were significant for factors with more than two groups, we used Dunn's test to identify which groups significantly differed. Table 2 describes the data on ES/ED characteristics and participant socio-economic profiles used in the analysis. We selected socio-economic factors that may explain differences in ES/ED perceptions considered in previous research (Iniesta-

Table 2
Factors used to test hypotheses explaining the variability in importance ratings of ES/ED across participants.

Hypothesis	Factors tested * indicates tested for ES only, not ED	Groups * indicates class boundaries defined by median value	Group sizes (in class order)	Source
H1: Perceived importance of an ES or ED varies significantly with ES or ED characteristics	ES type*	Provisioning, cultural, regulation and maintenance	10, 1, 3	See Table 1
	ED type	Human disease vectors, Agricultural pests	1,1	
	Delivery location	Reservoir-mediated, not reservoir-mediated	6, 8	
H2: Perceived importance of an ES or ED varies significantly with participant socio-economic profile	Age	< 45, ≥45 years*	18, 19	Individual questionnaire responses (Section 2.4)
	Length of time in community	< 34, ≥34 year*	18, 19	
	Gender	Male, female	22, 15	
	Ethnicity	Bissa, Mossi, Kusasi, Minorities (Dagomba, Fulani, Yarsé, Zaossé)	10, 8, 13, 6	
	Occupation	Rainfed and irrigated crop farmer, Rainfed crop and livestock or fish farmer, Rainfed crop farmer and/or business activity, where business activities include work as a seamstress, tailor, takeaway food seller, or shopkeeper	16, 11, 10	
	Household farm area (ha)	< 6, ≥6 *	17, 20	
	Household income	Very low (< 150 Ghanaian cedi or < 25,000 CFA per month) Low (150 to 350 Ghanaian cedi or 25,000 to 50,000 CFA) Moderate (> 350 Ghanaian cedi or > 50,000 CFA)	13, 14, 10	
	Dependency ratio (Number of household dependents ÷ number of household contributors)	< 2.5, ≥2.5*	20, 17	
	Education level	No education Primary or above (including primary, secondary and other formal education)	22, 15	
	Number of times participant too unwell to work in the last year	Never, 1 time, 2 or more times	17, 14, 6	
	Self-assessed life satisfaction	Satisfied (including Satisfied or Very Satisfied), Not satisfied	25, 8	

Arandia et al., 2014; Martín-López et al., 2012) and specific to our case study sites. For example, while age, gender, occupation, education level and income are commonly considered factors, we included ethnicity because of the high ethnic diversity across our study sites, and length of time in the community because reservoirs can attract in-migrants that may have different perceptions of and access to the local landscape compared to autochtones. We included farm area and household dependency ratio as indicators of household wealth in addition to income since many residents in the study sites were thought to have low levels of market interaction. We included life satisfaction and self-assessed health as indicators of respondent well-being, which may affect the importance placed on ecosystems for supporting HWB (e.g. importance ratings may be lower for those who already have high levels of HWB). We grouped participants into similar class sizes for each factor where possible to help ensure the robustness of statistical tests and checked that each pair of variables were independent or only weakly associated using Chi-squared tests. The strength and significance of associations between socio-economic factors, and contingency tables for associated factors, are provided in Supplementary Material S1. We tested the variability in importance ratings across each socio-economic factor for: i) all ES grouped together, ii) all ED grouped together, and iii) individual ES and ED, iv) ES delivery location in relation to the reservoir. Surveys with missing data were excluded from the analyses.

2.5.2. Thematic analysis

We coded and analysed the notes collected during the structured interviews in Nvivo to identify common themes emerging from participant explanations of their reasons for ES/ED importance ratings. We used a grounded theory approach (Denzin and Lincoln, 2000), to avoid forcing responses into predetermined categories.

3. Results

3.1. Distribution of ecosystem services spatially and seasonally

Focus group participants identified between 7 and 11 land types at each study site. Based on similarities in land use and cover, we reclassified some land types to facilitate cross-site comparisons as shown in Table 3.

Participants disagreed, in a few cases, about the linkages between land type and ES. For example, in Tanga there was no consensus on whether and where soil moisture retention or desirable flooding were present in the landscape.

Gender differences in perceived sources or abundance of ES/ED were not statistically significant. Data from female and male focus groups were therefore combined to visualize seasonal variability in the availability of ES/ED from each source. The availability of distinct ES and ED from each land type varied across the four case studies, with between 0 and 9 ES identified in any single land type, and between 0 and 2 ED (Fig. 3). Participants at two study sites identified the highest diversity of ES to be available from bushland, while at the other two sites the highest diversity was found on mixed pasture and rainfed cropland. This result is somewhat expected since mixed pasture and rainfed cropland is the land type that covers the highest fraction of each landscape followed by bushland. In contrast, coverage of permanent pasture (Bidiga only) or woodland is relatively low, and coverage of other land types is variable. Permanent pasture (one study site), irrigated cropland (two sites) and surface water (one site) were identified as the land types providing the fewest ES.

3.2. Importance of ecosystem services and disservices for human wellbeing

3.2.1. Participant importance ratings

Participants most commonly rated ES or ED as of high or very high importance to HWB (Table 4). Our data shows that plant foods, medicinal resources, domestic and agricultural water, firewood and charcoal, and soil nutrient cycling were identified as the most beneficial ES, and the human disease vectors the most problematic ED, based on median importance scores. These six ES and one ED were rated of 'high' (4) or 'very high' (5) importance by over 80% of farmers surveyed including for those with "very low" household incomes and/or an "unsatisfied" level of life satisfaction, which we refer to as underprivileged.

3.2.2. Dimensions of human well-being and other factors motivating importance ratings

From our coded responses of participant motivations for their ES/ED value judgements, we identified a set of common themes relating to the type of human well-being outcomes, and social, institutional and contextual issues affecting these outcomes. We grouped responses into these themes as shown in Fig. 4. In total, 457 (57%) of coded responses related to values participants attributed to specific HWB outcomes, while the remaining 43% were associated with access to or need for an ES, vulnerability to an ED, or appreciation of nature (Fig. 5). At least two ES were associated with each positive HWB outcome and at least one ED or ES with each negative HWB outcome. Negative outcomes from an ES related to, for example, the perception that use of an ES by some people causes problems for others, such as desirable flooding benefiting rice farmers but reducing land available for production of

Table 3
Land types identified across study sites.

Community-identified land type	Identified at which study site				Reclassified land type for cross-site analysis
	Bidiga	Binaba	Ladwenda	Tanga	
Rainfed farmland	X				Mixed pasture and rainfed cropland
Rainfed farmland interchanging with pasture		X	X	X	Mixed pasture and rainfed cropland
Mango plantation interspersed with crops			X		Mixed pasture and rainfed cropland
Irrigated farmland		X		X	Cropland – irrigated
Dry season irrigated farmland	X		X		Cropland – irrigated
Rainy season irrigated farmland	X				Cropland – irrigated
Floodplain farmland			X		Cropland – irrigated
Pasture – temporary	X		X		Mixed pasture and rainfed cropland
Pasture – permanent	X				Permanent pasture
Bush ("Brousse")		X	X	X	Bushland
Forest			X	X	Woodland
Woodland ("Zone de boisement"	X				Woodland
Surface water	X	X	X	X	Surface water
Hills	X				Bushland
Sacred grove	X	X	X	X	Woodland
Homestead	X	X	X	X	Homestead
Urban market	X	X		X	Urban

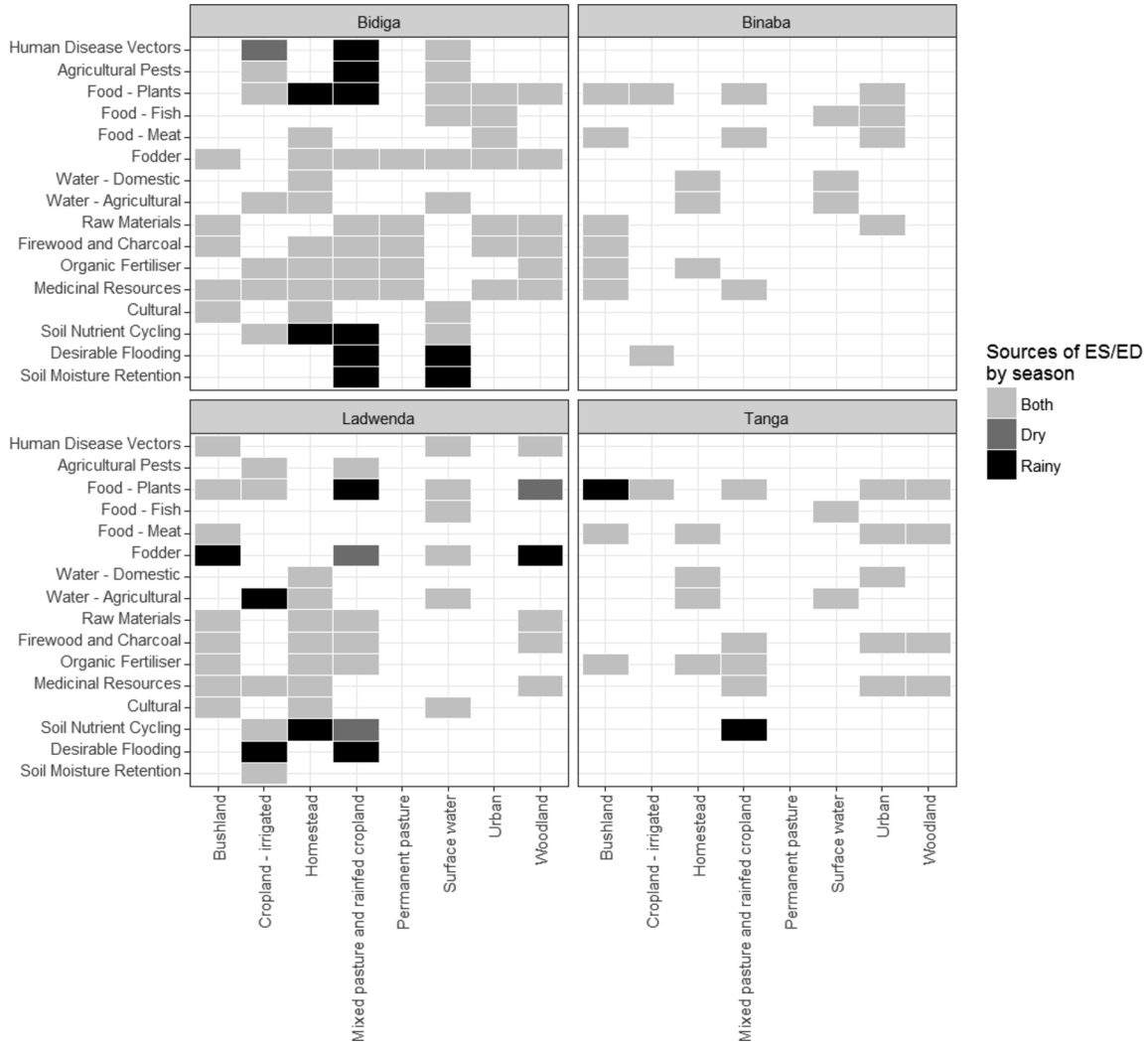

Fig. 3. Sources of ES and ED seasonally, distinguishing ES/ED that are present in "Both" seasons from those present in the "Dry" or "Rainy" seasons only.

Table 4
Distribution of importance ratings participants assigned to each ecosystem service and disservice and median importance values for all participants and underprivileged groups.

ES/ED	n	% participants selecting each importance level					Median importance	Median importance for underprivileged participants (n = 18)*
		Very High (5)	High (4)	Moderate (3)	Low (2)	None (1)		
Desirable Flooding	37	27	22	27	5	19	3	4
Organic Fertiliser	37	43	35	22	0	0	4	4.5
Fodder	37	38	35	24	3	0	4	4
Food – Fish	26	31	31	19	19	0	4	4
Agricultural Pests	37	49	19	11	16	5	4	4.5
Cultural	37	24	30	30	11	5	4	4
Food – Meat	26	19	35	27	8	12	4	3.5
Raw Materials	37	41	24	30	3	3	4	4
Soil Moisture Retention	35	29	26	17	9	20	4	3
Food – Plants	37	86	14	0	0	0	5	5
Medicinal Resources	37	62	22	14	0	3	5	5
Water – Domestic	37	81	14	5	0	0	5	5
Water – Agricultural	37	65	27	8	0	0	5	5
Firewood and Charcoal	37	59	30	5	5	0	5	5
Soil Nutrient Cycling	37	65	24	11	0	0	5	5
Human Disease Vectors	37	73	8	8	5	5	5	5

*Except for Food – Fish and Food Meat (where n = 12), and Soil Moisture Retention (where n = 17).

other crops.

Participants most frequently linked material and health well-being outcomes to ES or ED. Securing stable or improved farm production was the most frequently mentioned material well-being outcome of ES, followed by getting sufficient food, income and finally shelter. Participants valued multiple ES for their contributions to staying

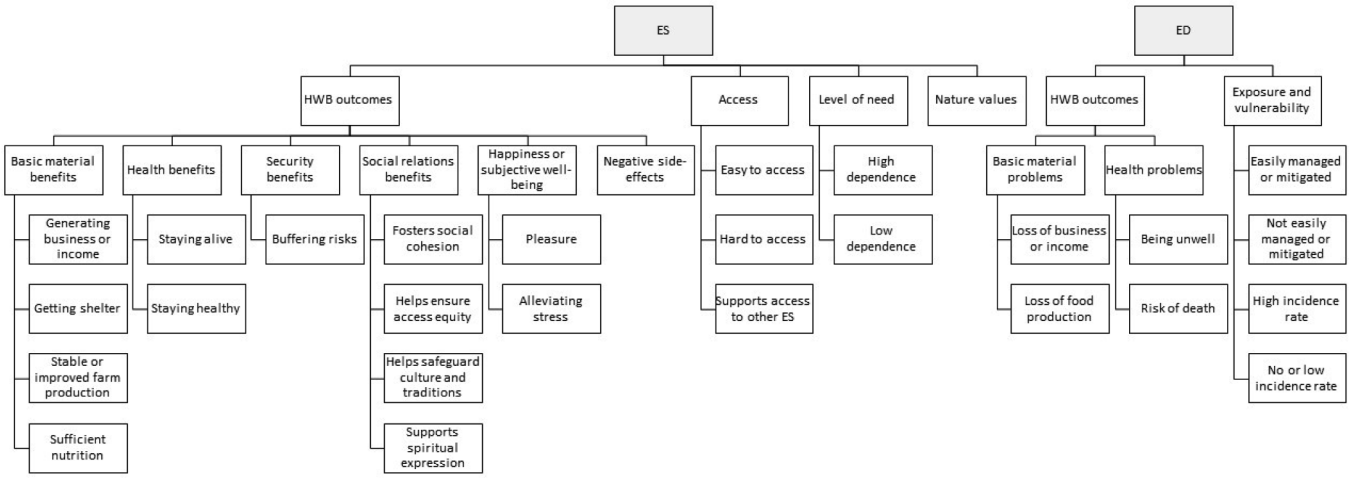

Fig. 4. Coding tree showing themes used to group participant reasons for ES and ED importance ratings.

healthy, with the latter associated with plant foods, fish foods, domestic water and medicinal resources. Cultural services were associated with maintaining social relations, specifically valued for fostering social cohesion, supporting spiritual expression and practices, and helping to safeguard culture and traditions. One Binaba participant who rated cultural services of very high importance explained their inter-generational value: "When children see a place is being conserved for cultural reasons, like a sacred grove, it helps children to be good in the future" (ID: Bin1). Other well-being outcomes motivating importance ratings included security benefits, namely the value of fodder and firewood (associated with livestock and wood sales) in surviving times of hardship, and soil moisture retention in helping buffer crop risks during dry spells. Finally, ES contributions to personal happiness or pleasure motivated importance ratings for some participants, associated with food (plant, fish and meat-based) and cultural services. Regarding food-related services, pleasure in the taste was given as a reason driving ratings, while happiness, fun and stress-relief were associated with cultural services. For example, a Ladwenda participant shared her view that "Space for football, dancing is important. [It] makes us forget [bad] things that have happened" (ID: Lad8), and a farmer from Tanga who placed a very high importance on cultural services explained: "I feel happy when I am in certain places in nature. When you are worried and you go there, you feel better" (ID: Tan11). This contrasts with some participants who placed a lower priority on cultural services for their HWB; one participant from Binaba explained that "The law says these [places in nature] are important areas, but I don't feel they are that important. If they disappeared it would be ok for me." (ID: Bin7). The subjectivity highlights the heterogeneity in the ways ES relate to HWB. For ED, health outcomes ranged from being unwell to risk of death associated with human disease vectors (mosquitoes and flies), while a loss in food production or revenue were mentioned as underpinning HWB importance of agricultural pests. The number of responses relating to HWB outcomes were fairly evenly distributed across the ES and ED, and we used this information to map out which ES and ED farmers associated with different dimensions of HWB (Fig. 6).

Importance ratings for ES were also found to be influenced by level of need and access. The level of need – or dependence on – a service, was mentioned as a factor motivating importance ratings by at least one participant across all ES. A farmer from Tanga who rated meat and fish as of lower importance than plant foods specified, "You can survive without meat or fish. Vegetables are the most important" (ID: Tan7), while a Bidiga farmer explained firewood and charcoal is of moderate importance to him because he uses gas as well as wood to cook so can cope without wood despite its importance for cooking (ID: Bid4). Access

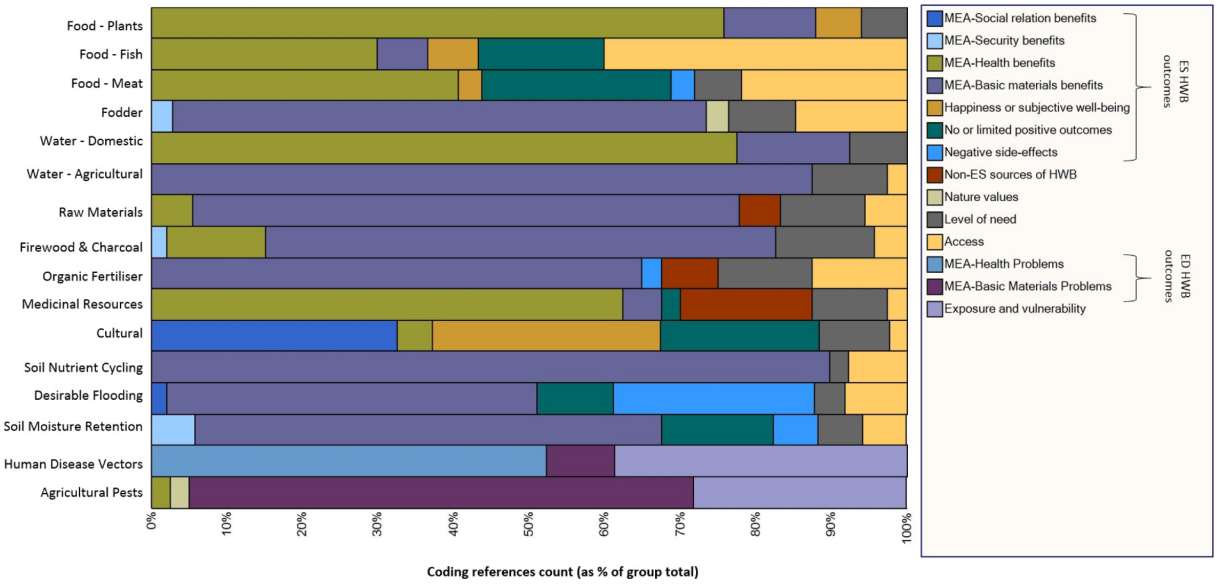

Fig. 5. For each ES and ED, percentage of participant reasons for ES and ED importance ratings related to each theme used to code the responses.

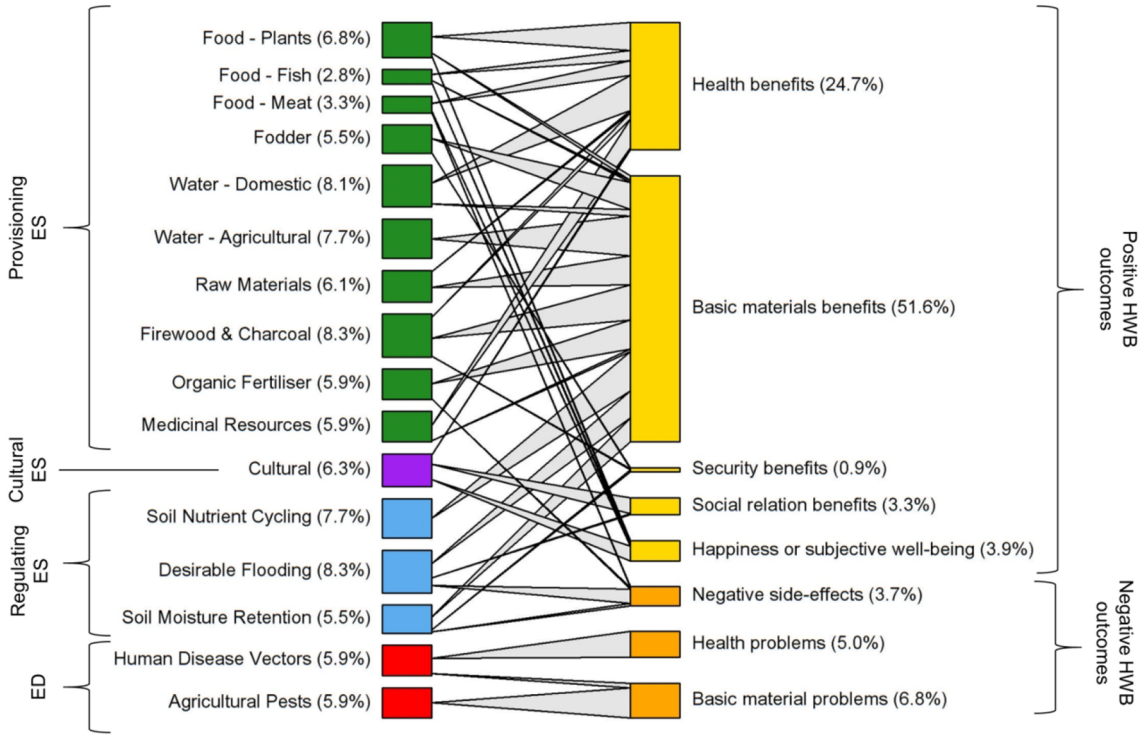

Fig. 6. Perceived linkages between ES/ED and HWB, based on the n = 457 (57%) coded responses which related an ES or ED to specific elements of HWB in participant explanations of their ES/ED importance ratings. The size of the bars reflects the percentage of coded responses related to each ES, ED or HWB outcome, shown in parentheses.

to ES, particularly ease of access, was mentioned by several respondents as a factor determining the importance of ES to HWB, particularly for fish and meat foods, fodder, organic fertilizer and desirable flooding (all mentioned by at least five participants). One farmer from Binaba rated fodder as of low importance because it is easy for them to get, "from the countryside, fields or friends" (Bin7), so it is not highly valued irrespective of its contribution to HWB. Similar explanations were given for firewood for some participants from Ladwenda and Binaba. Conversely, difficulty in accessing natural medicinal resources and organic fertiliser underpinned high importance ratings for several participants, while difficulty accessing meat-based foods because of prohibitive costs was mentioned as a reason for both high and low importance ratings (generally lower importance given by those who have access to what they consider suitable substitutes, such as fish and pulses). Another aspect of access is illustrated by the ratings for cultural services. Several respondents stated they had no time to access these services. A farmer from Bidiga, who considered cultural services to have no importance to HWB, explained; "It's young people who spend time outside for fun, not adults" (ID: Bid7).

With respect to ED, a key factor motivating importance ratings, aside from values associated with specific HWB outcomes, included level of vulnerability to a decline in HWB associated with the disservice. Several participants who rated ED as of low importance for HWB stated this was because the risks are easily mitigated, for example using mosquito nets to prevent exposure to human disease vectors or pesticides to prevent agricultural pests, or if exposed to the risk they are able to recover quickly, e.g. with medical support or purchasing food. In contrast, several participants who rated ED of high importance for HWB mentioned their lack of capacity to mitigate risks or difficulties recovering. For example, a farmer from Binaba who rated human disease vectors as of very high importance explained his family uses mosquito nets but not every person has one because they are "hard to find on the market and no longer distributed for free" (ID: Bin7), while two participants from Ladwenda mentioned the high expenditure associated with malaria treatment leading them to consider human disease vectors a problem of very high importance (ID: Lad5, Lad8). Finally, one participant referenced appreciation of nature and wanting to ensure not only humans benefit from the land as influencing them to give a lower rating for the importance of agricultural pests, with the participant explaining that it is only fair to let birds eat some of the crop to help sustain their populations even if it causes crop damage (ID: Bid5).

3.3. Explanatory factors

3.3.1. Importance ratings vary with ES and ED characteristics

For ES, differences in importance ratings between the four case study sites were significant at the 95% level for Soil Moisture Retention ($p = 0.001$), Food – Fish ($p = 0.011$), Cultural (0.023), and Medicinal Resources ($p = 0.046$), and not significant for any other ES. No more than two out of the six possible pairwise site combinations were significantly different for any single ES. For ED, differences were not significant at the 95% level for Agricultural Pests or for Human Disease Vectors. Given importance ratings for the 2 ED, 10 of the 14 ES, and most pairwise combinations of the remaining 4 ES, were not significantly different across communities, we conducted subsequent statistical analyses using combined data.

Participants across our study sites consistently perceived provisioning services as significantly more important than regulating ($p < 0.001$) or cultural ($p < 0.001$) services, with a median value of *very high* importance assigned to the former, and *high* importance to the latter two groups (see Table 5). Although the median importance of reservoir mediated ES was higher than for ES not mediated by the reservoir, this difference was not statistically significant. In contrast, the perceived importance of ED differed, with Human Disease Vectors considered significantly more important than Agricultural Pests ($p = 0.049$).

3.3.2. Importance ratings vary with participant socio-economic profiles

Participants from the Kusasi ethnic group assigned a higher importance to all ES combined than those from minority ($p = 0.007$) or

Table 5
Statistical differences in participant importance ratings for ES or ED grouped by their defining characteristics. Significant results to the 95% level are indicated by *.

Factor	Groups	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
ES type	ES-Cultural – ES-Provisioning	−3.94	< 0.001*	4 – 5
	ES-Cultural – ES-Regulation and maintenance	−1.52	0.129	4 – 4
	ES-Provisioning – ES-Regulation and maintenance	3.57	< 0.001*	5 – 4
ES relation to reservoir	ES not reservoir mediated – ES reservoir mediated	−1.612	0.107	4 – 5
ED type	Agricultural Pests – Human Disease Vectors	−1.971	0.049*	4 – 5

Table 6
Statistical differences in participant importance ratings for all ES when participants are grouped by socio-economic factors. Significant results to the 95% level are indicated by *.

Factor	Groups	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
Age	< 45 yrs to ≥ 45 yrs old	1.305	0.192	5 – 4
Gender	Female – Male	−0.213	0.832	4 – 5
Education	No education – Primary level or above	0.202	0.840	4 – 4
Ethnicity	Kusasi – Minority	2.695	0.007*	5 – 4
	Kusasi – Mossi	2.242	0.025*	5 – 4
	Bissa – Minority	1.838	0.066	5 – 4
	Bissa – Mossi	1.347	0.178	5 – 4
	Bissa – Kusasi	−0.935	0.350	5 – 5
	Minority – Mossi	−0.523	0.601	4 – 4
Household farm area	< 6 ha – ≥ 6 ha	−0.627	0.535	4 – 5
Household income	1-Very Low – 2-Low	1.428	0.153	5 – 4
	1-Very Low – 3-Moderate	0.703	0.482	5 – 4
	2-Low – 3-Moderate	−0.616	0.538	4 – 4
Household dependency ratio	< 2.5 – ≥ 2.5	2.209	0.027*	5 – 4
Life satisfaction	Not satisfied – Satisfied	−0.239	0.811	5 – 5
Occupation	Rainfed crop farmer and/or business activity – Rainfed and irrigated crop farmer	1.597	0.110	5 – 5
	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	2.782	0.005*	5 – 5
	Rainfed and irrigated crop farmer – Rainfed crop and livestock or fish farmer	1.477	0.140	5 – 5
Self-evaluated health (number of times too unwell to work in last year)	1 time – 2 or more times	−1.201	0.230	4 – 5
	1 time – Never	−1.765	0.078	4 – 5
	2 or more times – Never	−0.105	0.916	5 – 5
Time in Community	< 34 yrs to ≥ 34 yrs	−0.914	0.361	4 – 5

Mossi ($p = 0.025$) groups, as did households with lower dependency ratios ($p = 0.027$). Farmers whose livelihoods center on rainfed crop farming and/or business activities tended to rate ES as of higher importance than farmers focused on rainfed cropping and livestock or fishing activities ($p = 0.005$), although median scores were the same (*very high* importance) for both groups. Differences were not significant across other socio-economic groups (Table 6).

Importance assigned to both ED considered together varied significantly with ethnicity, with minorities tending to assign a higher importance compared to Bissa or Mossi groups ($p = 0.039$ and $p = 0.14$ respectively). However the median importance was *very high* across minority and Bissa groups, and only marginally lower (between *high and very high*) for the Mossi group. Participants with lower levels of self-assessed life satisfaction perceived ED of significantly higher importance than those that were more satisfied (0.030), while the median importance was *very high* for both groups. No other socio-economic factors were associated with statistically significant differences between ED (see Table 7).

Importance ratings for ES whose delivery is or is not mediated by the reservoir indicate that perceptions differ significantly with ethnicity, occupation and household dependency ratio (Table 8). Bissa and Kusasi people rated ES that are not reservoir mediated as of significantly higher importance than was the case for minority or Mossi ethnic groups ($p < 0.05$) while, compared to minority and Mossi groups, Kusasi people rated ES that are reservoir mediated as more important than other ES ($p = 0.002$ and $p = 0.003$ respectively). This points to potential tensions that may arise if either ES group is prioritized over the other in these landscapes. ES that are reservoir mediated were considered more important to households with lower than average dependency ratios compared to those with higher ratios ($p = 0.013$), although within the former group of participants there were also significant differences between ratings for the two ES groups, i.e. some participants with low dependency ratios considered ES that are mediated by the reservoir as significantly less important than other ES ($p = 0.033$). Reservoir-mediated ES were considered more important by participants whose occupations centre on rainfed cropping and/or business activities as opposed to rainfed and irrigated cropping ($p = 0.011$) or rainfed cropping and livestock or fishing ($p = 0.019$). Participants in the rainfed cropping and/or business activities group were also more likely than their counterparts to rate reservoir-mediated ES as of higher importance than non-reservoir mediated ES. This difference across livelihood strategies is surprising; we expected to find that farmers involved in irrigated cropping, livestock or fishing activities would place a higher importance on reservoir-mediated ES than other participants, because their livelihoods center around the community reservoir. These results are likely to be a factor of the relatively high importance the RB group placed on Meat Food, which is classified as reservoir mediated, while other reservoir-mediated ES were rated as of similar importance across occupational groups.

The importance of each individual ES varied significantly between socio-economic groups, with the exception of Firewood and Charcoal, and Organic Material. In particular, ratings for food and water-related ES varied along several socio-economic lines. Individuals who consider themselves healthy – never too unwell to work during the last year –

Table 7
Statistical differences in participant importance ratings for ED when participants are grouped by socio-economic factors. Significant results to the 95% level are indicated by *.

Factor	Groups	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
Age	< 45 yrs to ≥45 yrs old	−1.405	0.160	5 – 5
Education	No education – Primary level or above	0.263	0.792	5 – 5
Ethnicity	Kusasi – Minority	−1.958	0.050	5 – 5
	Kusasi – Mossi	0.807	0.420	5 – 4.5
	Bissa – Minority	−2.061	0.039*	5 – 5
	Bissa – Mossi	0.558	0.577	5 – 4.5
	Bissa – Kusasi	−0.233	0.816	5 – 5
	Minority – Mossi	2.461	0.014*	5 – 4.5
Gender	Female – Male	0.257	0.797	5–5
Household farm area	< 6 ha – ≥ 6 ha	1.606	0.108	5–5
Household income	1-Very Low – 2-Low	−0.713	0.476	5–5
	1-Very Low – 3-Moderate	0.040	0.968	5–5
	2-Low – 3-Moderate	0.704	0.482	5–5
Household dependency ratio	< 2.5 – ≥ 2.5	−1.158	0.247	5–5
Life satisfaction	Not satisfied – Satisfied	2.177	0.030*	5 – 5
Occupation	Rainfed crop farmer and/or business activity – Rainfed and irrigated crop farmer	1.008	0.313	5 – 5
	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	0.262	0.793	5 – 5
	Rainfed and irrigated crop farmer – Rainfed crop and livestock or fish farmer	−0.746	0.456	5 – 5
Self-evaluated health (number of times too unwell to work in last year)	1 time – Never	0.208	0.835	5 – 5
	1 time – 2 or more times	−0.893	0.372	5 – 5
	2 or more times – Never	1.076	0.282	5 – 5
Time in community	< 34 yrs to ≥34 yrs	−1.546	0.122	5–5

placed a higher importance on Plant Foods than participants with poorer health (p = 0.043). This may reflect a keener appreciation and utilization of plant based foods for staying healthy in the former group, who expressed the view that plant foods are the basis for healthy diets and bodies (ID: Bid4, Bin2, Lad11, Tan1) whereas several participants with poorer health focus on the livelihood (ID: Bid6, Lad4) and taste benefits (ID: Bin7, Bit5) of plant based foods as motivating their value judgements. Participants from households with lower than average dependency ratios rated Fish and Meat Foods of significantly greater importance than those with higher dependency ratios (p = 0.006 for fish, p = 0.022 for meat). This may be a result of a greater capacity to access fish and meat among the former group who should have more resources per capita. However, there were no significant differences between Fish and Meat Food ratings across other measures of household wealth, namely household income and farm size, so this result would benefit from further exploration. Interestingly, Bissa and minority ethnic groups rated Fish Foods as less important than their Kusasi counterparts (p = 0.002 and p = 0.029 respectively). Analysis of interview responses indicates this may be because of a heightened appreciation of the health benefits of fish among Kusasi people, with several Kusasi participants explaining that fish makes you “strong” (ID: Bin2, Bin8, Tan2), compared to a tendency for other participants

Table 8
Statistical differences in participant importance ratings for ES whose delivery is or is not mediated by the reservoir, when participants are grouped by socio-economic factors. Only significant results to the 95% level are reported.

Factor	Groups	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
ES not reservoir mediated				
Ethnicity	Bissa – Minority	2.221	0.026	5 – 4
	Bissa – Mossi	2.1	0.036	5 – 4
	Kusasi – Minority	2.139	0.032	4.5 – 4
	Kusasi – Mossi	2.014	0.044	4.5 – 4
ES reservoir mediated				
Household dependency ratio	< 2.5 to ≥ 2.5	2.48	0.013	5–4
Occupation	Rainfed crop farmer and/or business activity – Rainfed and irrigated crop farmer	2.555	0.011	5 – 4
	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	2.348	0.019	5 – 5
All ES grouped by reservoir mediation				
Ethnicity	Minority & ES not reservoir mediated – Kusasi & ES reservoir mediated	−3.065	0.002	4 – 5
	Mossi & ES not reservoir mediated – Kusasi & ES reservoir mediated	−3.011	0.003	4 – 5
Household dependency ratio	< 2.5 & ES not reservoir mediated – < 2.5 & ES reservoir mediated	−2.13	0.033	4 – 5
	≥ 2.5 & ES not reservoir mediated – < 2.5 & ES reservoir mediated	−2.911	0.004	4 – 5
Occupation	Rainfed crop farmer and/or business activity & ES not reservoir mediated – Rainfed crop farmer and/or business activity & ES reservoir mediated	−2.247	0.025	4 – 5
	Rainfed and irrigated crop farmer & ES not reservoir mediated – Rainfed crop farmer and/or business activity & ES reservoir mediated	−2.431	0.015	5 – 5
	Rainfed crop and livestock or fish farmer & ES not reservoir mediated – Rainfed crop farmer and/or business activity & ES reservoir mediated	−3.783	< 0.001	4 – 5

Table 9
Statistical differences in participant importance ratings for single ecosystem services, when participants are grouped by socio-economic factors. Only significant results to the 95% level are reported.

ES	Factor	Groups	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
Food – Plants	Household income	2-Low – 3-Moderate	−1.991	0.046	5 – 5
	Self-evaluated health (number of times too unwell to work in last year)	2 or more times – Never	−2.025	0.043	5 – 5
Food – Fish	Ethnicity	Bissa – Kusasi	−3.034	0.002	2.5 – 5
		Kusasi – Minority	2.183	0.029	5 – 3
	Household dependency ratio	< 2.5 to ≥ 2.5	2.746	0.006	4 – 3
Food – Meat	Occupation	RB – RI	2.133	0.033	4 – 3
	Household dependency ratio	< 2.5 to ≥ 2.5	2.286	0.022	4 – 3
Fodder	Household income	2-Low – 3-Moderate	−2.172	0.030	3 – 4.5
Water – Agricultural	Age	< 45 yrs to ≥ 45 yrs old	2.998	0.003	5 – 4
	Education	No education – Primary level or above	2.280	0.023	5 – 4
Water – Domestic	Occupation	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	2.073	0.038	5 – 5
Raw Materials	Occupation	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	2.078	0.038	5 – 3
Medicinal Resources	Ethnicity	Kusasi – Mossi	3.252	0.001	5 – 3
		Bissa – Mossi	2.570	0.010	5 – 3
	Occupation	Rainfed and irrigated crop farmer – Rainfed crop and livestock or fish farmer–	2.081	0.037	5 – 4
Cultural	Ethnicity	Bissa – Mossi	−2.526	0.012	3 – 4.5
		Bissa – Kusasi	−2.318	0.020	3 – 4
Desirable Flooding	Time in community	< 34 yrs to ≥ 34 yrs	2.439	0.015	4 – 3
	Gender	Female – Male	2.722	0.006	4 – 3
	Occupation	Rainfed crop farmer and/or business activity – Rainfed crop and livestock or fish farmer	3.044	0.002	4 – 2
		Rainfed and irrigated crop farmer – Rainfed crop and livestock or fish farmer–	2.700	0.007	4 – 2
	Household farm area	< 6 ha to ≥ 6 ha	2.541	0.011	4 – 3
	Household income	1-Very Low – 3-Moderate	1.961	0.049	4 – 3
Soil Moisture Retention	Ethnicity	Bissa – Mossi	3.279	0.001	4 – 1
		Kusasi – Mossi	3.014	0.003	4 – 1
		Bissa – Minority	2.713	0.007	4 – 2
		Kusasi – Minority	2.422	0.015	4 – 2

including Bissa and minorities to state that fish is “non-essential” to the diet (ID: Bid1, Bid4, Bid7). Meat was considered more important by farmers with rainfed cropping and business-based livelihoods, compared to those focused on rainfed and irrigated cropping ($p = 0.033$). The former group valued meat for giving “energy” (ID: Bin2, Bin6, Bid8) and preventing illness (Bin2, Bin3, Bid6), while the latter group expressed the view that meat is non-essential for remaining healthy (ID: Tan1, Tan3, Tan7) and often inaccessible due to prohibitive prices (ID: Bid1, Bid2, Tan5, Lad11). Meat tends to be market purchased rather than sourced from the landscape or homestead in the case study sites, so it is also possible that farmers with business activities may have easier access to markets facilitating inclusion of meat in the diet.

Younger people and those with no education valued Agricultural Water significantly higher than older and better educated people ($p = 0.003$ and $p = 0.023$ respectively). Interview responses showed that the former groups consistently mentioned the importance of irrigation water for food consumption at home and particularly during the dry season, and for sustaining livestock through the year, whereas the latter groups, while also valuing agricultural water for its dry season benefits, were more likely to relate this to providing a source of income rather than home food consumption. Desirable Flooding was rated of significantly higher importance by women ($p = 006$) and participants that were relatively new to the community ($p = 0.015$), as well as individuals who have livelihoods based on rainfed cropping with business activities ($p = 0.002$) or irrigated cropping ($p = 0.007$), rather than those based on livestock or fish farming. The latter result is unsurprising since flooding primarily benefits rice cultivation in the study sites. Meanwhile, at Binaba, one participant (ID: Bin7) explained that floodplains are generally divided among women (not men) for farming and this is why they are so important to women farmers at this site. At other sites, women’s perceptions of the production value of flooded areas was generally favorable, highlighting that these areas give a good production particularly for rice (ID: Bid1, Lad10, Lad11, Lad12), whereas men tended to consider these areas as unproductive (ID: Bid4, Bid6, Tan3, Lad6, Tan5). Gender was weakly associated with length of time a participant had spent in the community in our dataset (see Supplementary Material S1). Women were more likely to be newer to the community likely due to local tendencies for women to move into their husband’s household on marriage. As a result, gender may in part explain the divergence in desirable flooding ratings across groups who have spent different lengths of time in the community. However, the latter result may also reflect the increased importance floodplain farming has for migrants, who tend to have less secure land and water access compared to autochthones. Desirable flooding was also rated higher by participants from households with a very low income compared to moderate earners ($p = 0.049$), and those with smaller than average farm holdings ($p = 0.011$). These results may be associated with land access issues and that natural floodplains are more accessible to these groups, and therefore play a more important role in their livelihoods, than areas within the (paid) irrigation scheme.

For individual ED, farmers who had resided longer in the community ($p = 0.010$), or reported lower levels of life satisfaction ($p = 0.039$), considered Agricultural Pests of significantly higher importance for detracting from HWB compared to other participants. This was also the case for minority ethnic groups compared to Bissa or Mossi people ($p = 0.003$ and $p = 0.010$ respectively) and for Kusasi people compared to Bissa ($p = 0.038$). Reasons provided by these groups for giving higher ratings relate primarily to the risk of crop failure due to damage from termites, worms and rodents, while other participants were more likely to consider these problems mitigatable with the use of pesticides. Therefore group differences are likely to reflect different perceptions towards the use of, and levels of access to, pesticides across

Table 10
Statistical differences in participant importance ratings for single ecosystem disservices, when participants are grouped by socio-economic factors. Only significant results to the 95% level are reported.

Factor	Groups	ED	Z-values	P-values (Two-sided)	Median Importance (Group 1 – Group 2)
Agricultural Pests	Time in community	< 34 yrs to ≥34 yrs	−2.569	0.010	3.5 – 5
	Ethnicity	Bissa – Minority	−2.949	0.003	3 – 5
		Bissa – Kusasi	−2.074	0.038	3 – 5
		Minority – Mossi	2.563	0.010	5 – 3.5
	Life satisfaction	Not satisfied – Satisfied	2.065	0.039	5 – 4
Human Disease Vectors	Household farm area	< 6 ha to ≥6 ha	2.028	0.043	5 – 5

participants. In addition, farmers whose livelihoods are more affected by agricultural pests may experience lower levels of life satisfaction, helping explain the difference in importance ratings for groups with different life satisfaction levels. The importance of Human Disease Vectors varied slightly with household farm area ($p = 0.043$), though median values remain *very high* across groups. Tables 9 and 10 present the full list of which ES and ED significantly differed with which socio-economic factors.

4. Discussion

This paper focused on understanding farmer perceptions of ES and ED in four West African landscapes containing community-managed reservoirs, and applying a social valuation approach to assess the importance farmers attribute to ES and ED for maintaining HWB. This is the first paper we know of that investigates farmer perceptions of and values regarding ES and ED in community-managed reservoir landscapes. We show that a diversity of ES and ED are perceived as important for local well-being in these landscapes and explore how and why values for some ES and ED diverge along socio-economic lines. The paper explicitly captures smallholder perceptions of the relationships between specific ES, ED and HWB outcomes in the case study landscapes, helping to close a gap in knowledge regarding context-specific ecosystem contributions to different dimensions of HWB. In this section, we place our findings in the context of other research and use the results to discuss potential implications for local reservoir and ecosystem management.

4.1. Spatio-temporal distribution of ecosystem services and disservices in reservoir landscapes

In our case study sites, farmers identified a diversity of ES supplied by multiple land types, highlighting the multifunctionality of these rural landscapes. This result is consistent with other regionally proximate ES studies (Malmborg et al., 2018; Sinare et al., 2016). Mixed pasture and rainfed cropland or bushland were perceived to provide on average a higher diversity of ES (between 3 and 7 ES) than any other rural land type. Other studies have similarly found that small-scale farmers perceive a wide variety of ES including from agricultural land (Teixeira et al., 2018). Recognition of ES is likely to depend on many factors including culture and tradition, yet in smallholder farming contexts may also be a result of farmers tending to depend less on external inputs and more on the natural ecosystem functions that help co-produce food (Power, 2010; Swinton et al., 2007; Zhang et al., 2007). Urban areas were identified as sources of provisioning ES in three of the case studies, highlighting that some ES are purchased as well as harvested directly from the land. These ES include plant, fish and meat foods, raw materials, charcoal and medicinal resources. Safeguarding natural sources of these products may be less important at some sites for ensuring ongoing local access than safeguarding cultural and regulating ES or those provisioning ES that are not available through markets, such as fodder, freshwater and organic fertiliser. Loss of natural sources of the latter services would likely be harder for farmers to replace.

Seasonal variability in ES and ED supplies was associated primarily with food and water-related ES and ED. This is likely to be due to seasonal fluctuations in surface water availability and flood regimes; low levels of market-interaction leading to high dependency on local, seasonally variable food production, and; the difficulty storing ES through the dry season, e.g. fresh fruit and vegetables, fodder and domestic water. Actions to improve access to ES should therefore include tackling these temporal gaps in supply, such as through improving local ES storage capacities (e.g. vermin-proof food and fodder stores, rainwater harvesting, raising soil moisture storage capacity) and limiting seasonal fluctuations in ES market prices (e.g. meat, fish and vegetables).

4.2. Ecosystem service and disservice importance for human well-being

In our study, plant foods, medicinal resources, domestic and agricultural water, firewood and charcoal, and soil nutrient cycling were consistently considered the most beneficial ES, and the human disease vectors the most problematic ED for achieving HWB outcomes, based on median importance scores. These six ES and one ED were rated of 'high' (4) or 'very high' (5) importance by over 80% of farmers surveyed including for those with the lowest household incomes and/or lowest levels of life satisfaction. The HWB outcomes associated with the six most important ES related predominantly to health and basic materials, including having stable or improved farm production, generating income, staying healthy, and getting adequate nutrition (clean water, sufficient food), while human disease vectors were associated with financial stress, poor health and even death. Bushland (at all four case study sites), woodland (three sites), irrigated cropland (two sites), and surface water (one site) were identified as providing two or more of the six most beneficial ES, while also being identified as sources of human disease vectors at one or more site. This points to a direct trade-off between ES and ED that may need to be taken into account when managing land type extent and configuration to secure ecosystem-based HWB outcomes. It also highlights the value of conserving bushland zones in these reservoir landscapes; loss of bushland would pose a risk to the supply of multiple locally important ES that are connected to health and material benefits for local farmers. The biggest risks to bushland in these landscapes are over-harvesting of firewood, overgrazing, and encroachment of agricultural land. These risks could be mitigated by increasing household use of alternative energy sources combined with facilitating controlled grazing and increasing productivity of existing cropland to help limit further cropland expansion.

Our results showed that provisioning services were perceived as significantly more important than regulating and maintenance or cultural services. This is likely to be because individual perceptions of value tend to be biased towards where there is a simple connection between the ecosystem process and its end-benefit (Costanza et al., 2014). This nonetheless points to a risk that regulating and maintenance or cultural services will be given a lower priority in farmer land management decisions designed to conserve ES, because the benefits they provide are less tangible rather than because the benefits are less important to HWB. ES are often interconnected (Vallet et al., 2018) and loss of a regulating service, such as soil nutrient cycling, may reduce provision or quality of provisioning or other services, such as food

production and firewood provision. Indeed, the interconnectedness of ES and water scarcity in semi-arid areas means that maintaining water-related ES must remain a priority to safeguard supplies of other dryland services (Le Maitre et al., 2007). Discussing the interconnectedness of ES with farmers in the case studies may be useful to identify possible (unexpected) trade-offs between ES and HWB outcomes that could arise from changes to reservoir and land management.

Participant explanations for why they assigned ES/ED importance ratings indicate the ES ratings were primarily a function of the perceived value of the HWB outcome to which an ES makes a contribution and/or; how accessible the ES was to the person, and/or how dependent the person was on the ES for the HWB outcome. In contrast, the perceived value of the HWB outcome and participant level of vulnerability to ED influenced how important the ED was for HWB. This suggests that altering levels of access to and need for ES, and vulnerability to ED, may alter the perceived importance of the contribution ES make to HWB, making these entry points for managing ES for more equitable HWB outcomes. The HWB outcomes associated with the six most important ES related predominantly to health and basic materials, including having stable or improved farm production, generating income, staying healthy, and getting adequate nutrition (clean water, sufficient food). These elements of HWB are high on the agenda of globally agreed development priorities encapsulated in the Sustainable Development Goals (SDG) and our results highlight the contribution ES are making to achieving these goals in our reservoir landscapes. For example, sustainable production of nutritious plant-based foods and regulated agricultural water delivery is helping support farm production and healthy diets, vital to meeting SDG 2 on food security and sustainable agriculture, while supplies of traditional medicinal plants are helping local households stay healthy, essential to achieving SDG 3 on health and ensuring access to affordable medicines. The contribution ecosystems make to HWB is clearly elicited by participants in this study and re-enforces the notion that ES have a fundamental role to play in achieving sustainable development (Costanza et al., 2017; Wood et al., 2018). However, ES and ED are co-produced by ecosystems, infrastructure and society (Boyd and Banzhaf, 2007). Ecosystem management alone will not be enough to ensure HWB outcomes are achieved. It needs to be integrated with management of social, political, and economic interventions to ensure farmers have the capacity and rights to access and use ES, and to mitigate impacts of ED. The reservoirs around which farming activities revolve in our case studies are an example of co-produced freshwater and associated food supplies, whose access is socially mediated and dependent on reservoir governance arrangements.

4.3. Shared and conflicting values

While participants widely considered ES and ED of importance for their HWB, several key value differences emerged along socio-economic lines. For example, Mossi people tended to place a lower value on the importance of both ES and ED compared to other ethnic groups. This may simply reflect cultural differences in how natural resources are valued, or it may be associated with Mossi people having relatively good access to different land types and therefore multiple ES, being primary landowners. In contrast, minorities and Kusasi (for agricultural pests) tended to place a higher value on the importance of ED for detracting from HWB compared to other groups. For minorities, this may be because people have less access to pest mitigation measures, while for Kusasi, who dominate the Ghanaian sites, it is possible that prevalence of agricultural pests is higher in these locations. Future studies would be beneficial to confirm tendencies across ethnic groups and explore possible explanations in more depth.

Our results revealed low levels of agreement among some participants regarding the importance of plant-based foods, meat, fish, agricultural water and desirable flooding which are all ES whose access is mediated by the reservoir. Assigned values for each of these ES were significantly different across two or more socio-economic groups, including household income and self-evaluated health (plant-based foods), ethnicity (fish), household dependency ratio (fish and meat), occupation (meat), age and level of education (agricultural water), gender, occupation, household income, farm area, and time in the community (desirable flooding). Farmers indicated that fish and meat are generally purchased rather than harvested directly from the landscape, despite fish being readily available from the reservoir. Government regulation of fish and meat prices, particularly when these products are produced with water from or sourced directly from the local reservoir, could help provide more even access among households to these foods and minimize potential conflicts or HWB trade-offs related to these ES. However, this would need to be carefully managed to avoid over-consumption of meat or fish. Plant foods, agricultural water and desirable flooding support, or are mediated by, irrigated cropping activities. It is possible that lower levels of agreement for the importance of these ES reflect differing levels of access to irrigable land and water, and/or capacities to turn this access into productive farmland which requires labour, technical and knowledge inputs. Obtaining access to water and irrigable land is likely to become increasingly difficult in the study sites as the youth-heavy population continues to grow while households continue to rely on agricultural livelihoods. Younger and less educated participants, who placed a higher importance on agricultural water for their well-being, may be particularly vulnerable to food shortages if their reservoir water access or supplies are reduced. They may also be susceptible to conflicts with elder, better educated peers who are more likely to be involved in natural resource management decision processes. Appreciation of flooding among relative newcomers to the community, rainfed and irrigated crop farmers, female farmers with small farm areas and very low incomes, may also reflect a high dependence on flood regimes for agricultural water access, i.e. lack of access to motor pumps and other costly water transportation methods. The timing and extent of these flood regimes are part determined by reservoir management, making it important that reservoir managers continue to try and meet the needs of diverse user groups. In general, the significant differences among socio-economic groups regarding the importance of food and water-related ES is likely to be linked to unequal access to these ES, and therefore difficulty realising the HWB benefits, driven by reservoir governance which is subject to all common pool resource management challenges (Ostrom, 1999).

In contrast, there was a high level of agreement (no significant differences) regarding the importance of firewood and charcoal and organic fertilizer among men and women, age groups, people with different occupations, education levels, incomes, farm sizes and ethnicities. Shortages of firewood and organic fertilizer are common concerns among farmers in the study sites. Given their cross-cutting importance for cooking (firewood) and food production (fertiliser), future declines in these ES are likely to have direct negative impacts on local health and material well-being. These risks could be mitigated to some extent by, for example, managed tree planting to increase the availability of fuelwood, and promoting soil conservation agriculture where this is not already in use to improve soil health and reduce demand for organic fertilizer.

4.4. Implications for reservoir landscape management

Generally most ES and both ED were considered important for HWB by farmers in this study. This calls for a holistic approach to reservoir landscape management which seeks to maintain sufficient supplies of a diversity of ES while minimising trade-offs with ED. Future research to identify threats to the contribution local ES make to HWB, and to explore how to decrease negative effects of ED, would help distil actions that could be taken to ensure net positive relationships between ecosystems and HWB in reservoir landscapes. Intensifying crop production by introducing reservoirs is an active national policy in both Burkina

Faso and Ghana, aimed at closing food supply gaps and boosting rural development. The high importance farmers attributed to multiple ES in this study implies natural resource policies in reservoir landscapes should not focus solely on sustainable water management at the expense of other locally valuable resources. Maintaining multiple ES across the landscape could help minimize tensions and potential conflicts that may arise, such as between reservoir users and non-users. This may also help shield the wellbeing of users of reservoir-mediated ES, which will be negatively impacted by future loss or degradation of these ES as reservoirs inevitably dry up seasonally and eventually permanently (Jones et al., 2017). Since agriculture is the dominant land type in each of our cases, a promising option could be to improve ES supplies from local agroecosystems. As agricultural land is already managed or semi-managed, it is also potentially easier to safeguard, enhance and diversify agro-ecosystem functionality to meet ES demand rather than altering management of other land types (DeClerck et al., 2017). This approach empowers farmers as principal land stewards to shape their own landscape futures (Raymond et al., 2016).

Regarding ED, our results reinforce the notion that mitigation measures to reduce the risk of local farmer exposure to vector borne diseases, notably malaria, should be implemented systematically where reservoirs are present in order to minimize serious negative impacts on farmer well-being. These measures may include education on how to protect against mosquitoes and other vectors, provision of mosquito nets, and increasing local habitat for natural predators such as bats and birds.

4.5. Limitations of this study

We collected data on assigned values for ES and ED from a small number (n = 37) of farmers relative to the total number of smallholder households in each case study landscape. We chose to limit the survey to only farmers who had participated in the participatory mapping focus groups to ensure a shared understanding of ES and ED concepts and terminology. In addition the farmers were selected by local gatekeepers who may not have selected the most marginalized households in the landscape. As a result, while our sample is representative of a range of ages, ethnicities, education, and income levels, we may not have captured the full spectrum of viewpoints on the HWB importance of ES/ED among smallholder farmers in these landscapes.

Fewer ES were identified in the participatory ES mapping at the Ghana study sites, Binaba and Tanga. This is likely to reflect methodological errors and limitations, i.e. omission of fodder in the pre-determined ES lists and the quality of the translation, rather than lower on-site ES diversity. We discussed the research concepts in depth with each translator prior to data collection. However the translator assisting at the Ghana sites was less comfortable with ES concepts that the translator in Burkina Faso. Descriptions of more complex ES, such as soil moisture retention and desirable flooding, may not have been as clear for participants at the Ghana sites.

4.6. Future research priorities

The social valuation approach applied here (i.e. using a simple Likert scale and interview) proved effective at accommodating a broad range of interpretations of how to judge the importance of an ES or ED for HWB. While we focused on the relative importance of ES and ED to HWB, several respondents highlighted that sources of well-being not associated with locally available ES/ED – such as purchased medicines and doctors to treat diseases, bottled gas for cooking fuel – were important for their well-being. Future research that includes direct questions to identify the importance of ES-sources of HWB in relation to non-ES sources would help distil the contribution ES can make to overall HWB.

Explicitely including ED into the MEA, IPBES and other frameworks for assessing ES and HWB interactions would help ensure future studies applying these frameworks encompass the full diversity of ecosystem-HWB linkages. Suich et al. (2015) show that many studies of ES-HWB linkages fail to include ED in their analyses, yet our results indicate ED can be of high importance for HWB. These negative impacts of ecosystems on HWB, while acknowledged, should be more clearly elicited in the MEA and IPBES typologies and further researched to provide decision-makers with more complete information on ecosystem-HWB linkages.

5. Conclusions

This study points out that while there is increased attention towards ES, ED and the contribution ecosystems can make to HWB, more work is needed to elicit and integrate insights to inform sustainable development in reservoir landscapes. Our results highlight specific services, including plant-based foods, domestic and agricultural water supplies, firewood and charcoal, medicinal plants, and soil nutrient cycling (ES), and problems arising from human disease vectors (ED), were consistently identified as of high or very high importance for human well-being by many (> 80%) farmers in our case study landscapes. The high importance farmers attributed to multiple ES implies natural resource policies in these reservoir landscapes should seek to maintain multiple ES, and mitigate exposure to human disease vectors, to help minimize tensions and potential conflicts that may arise between reservoir-mediated ES users and non-users. In our study, farmers associated multiple ES with positive health, material, security, social, and happiness outcomes, and ED with negative health and material outcomes. These HWB outcomes are encapsulated in the SDGs, re-enforcing the notion that the contributions ecosystems make to improving HWB should be firmly incorporated into local and national sustainable development planning.

Application of our method in other reservoir landscapes would be valuable to document the spectrum of farmer viewpoints on the contributions ecosystems make to HWB in these contexts in order to draw more general conclusions of where, when and how ES and ED impact on HWB. With sufficient studies it would be possible to identify consistently important ecosystem-HWB linkages across reservoir contexts and provide general guidance on strategies to manage trade-offs between ES, ED and associated HWB outcomes for local farmers in these landscapes. Since local households have the most to gain or lose from changes to ES and ED in their landscapes and are primary ecosystem stewards, assessments of ES and ED that integrate local perceptions and value judgements should be widely deployed to help identify locally appropriate policies and incentives for sustainable ecosystem management and development planning.

Acknowledgements

Ethical approval for this study was obtained from the King's College London Research Ethics Committee (LRS15/62825). This work was supported by the CGIAR Water, Land and Ecosystems research program through the *Targeting agricultural innovations and ecosystem services in the northern Volta basin* project (2015–16), and the UK Economic and Social Research Council and Department for International Development (grant number ES/R002126/1). We thank the research assistants and translators who supported fieldwork activities, in particular Samuel Guug, Désiré Kaboré and Idrissa Ouédraogo. Most of all, we thank the farmers of Bidiga, Binaba, Ladwenda, and Tanga reservoirs for their valuable time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2019.100987.

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