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Farmers' preferences towards water hyacinth control: A contingent valuation study

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ABSTRACT

Lake Tana is the most important freshwater lake in Ethiopia. Besides pressures on water quality resulting from urbanization and deforestation, the invasion of the exotic water hyacinth (*Eichhornia crassipes*) poses new threats to the ecosystem. Water hyacinth, endemic to South America, is widely considered as the world's worst aquatic invasive weed. In 2011, the weed appeared on the northern shores of Lake Tana, expanding in south-eastern direction. The lake area affected by water hyacinth was last estimated in 2015 at 34,500 ha, which equals 16% of the total lake surface. In this research, the benefits of water hyacinth control and eradication for the rural population inhabiting the northern and north-eastern villages bordering Lake Tana, are investigated. In the area, the population largely depends on farming and fishing. An assessment of the total economic benefit of eradication was conducted. The stakeholder-centered approach led to measuring the willingness to contribute in labor and cash terms. Results showed smallholders in the study are willing to contribute over half-a-million euros annually. Costs of management actions can be weighed to the benefits, where further research is needed on the impact on other stakeholder groups. Moreover, wetland management should advance to explore multiple pathways in an integrated approach: water hyacinth control, water hyacinth utilization and sustainable waste water management.

Introduction

According to Anteneh et al. (2014), Lake Tana has been infested with water hyacinth (*eichhornia crassipes*) since 2011. Water hyacinth is an aquatic alien invasive species (AIS), possibly originating from Brazil from where it spread to nearly all of the southern and central American countries. Today, almost all countries between 40°N and 40°S face the threat of infestations on lakes, slowly moving rivers or swamps (Malik, 2007). Water hyacinth is a free-floating plant, known for its rapid reproduction and its tendency for dense mat-formation. Classified as one of the world's most productive plants and worst aquatic weeds (Lowe et al., 2000), eradicating an infestation is extremely challenging. While physical/manual removal often yields temporary reductions in the coverage, biological control is a widely applied solution to effectively reduce infestations. Around Lake Victoria, biological control was responsible for the initial decline of this infestation (Albright et al., 2004). However, after discontinuing these costly programs, water hyacinth remains problematic in Lake Victoria. Biological control has been successful in other African countries, e.g. case studies of Lake Chivero (Zimbabwe), White Nile (Sudan), Southern Benin (De Groote et al., 2003; Irving and Beshir, 1982). In Benin, the biological water hyacinth control was estimated to have outweighed the costs with a 124:1 ratio (De Groote et al., 2003), in South Africa the benefit to cost ratio was calculated at 4.2:1 (Law, 2008).

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Water hyacinth infestations lead to ecological and socio-economic disruptions. In the Lake Victoria basin water hyacinth has been impacting local communities' livelihoods since the late 1980 s. Mailu (2001) described the unfavourable impacts of these infestations: reduction of water quality and availability through increased evapotranspiration, clogging of irrigation canals and hydropower dams, reduction in fish catches and decline of aquatic biodiversity through reduced oxygen and distorted water flow, obstruction of navigation, hindrance on water access for fishermen and livestock, rise of human social conflict and migration through negatively affected agricultural conditions, surge in vector-borne diseases through an increase in the breeding grounds for e.g. mosquitos. The total economic impact was estimated in the order of billions of dollars (Mailu, 2001). Observations of similar disturbances to the livelihood in the northern to north-eastern parts of Lake Tana have been identified in previous research (Anteneh et al., 2014; Anteneh et al., 2015; Dejen et al., 2017; Gezie et al., 2018). Moreover, the strategic location of Lake Tana at the source of the Blue Nile, which flow through several hydroelectric plants (Tesfaye et al., 2016), adds an additional threat of the water hyacinth infestation to the socioeconomic wellbeing of the region. Despite the evidence on the substantial negative economic impact of water hyacinth in other lakes, like Lake Victoria, economic impact was currently not yet subjected for research in the Lake Tana area.

Increased land degradation through overexploitation of the wetland resources and poor waste management have increased the nutrient levels and led to eutrophication of the Lake Tana Basin (Wondie, 2010). These circumstances benefitted the actual outbreak of water hyacinth on the northern shores of Lake Tana. This outbreak was officially recognized in 2011, when a coverage of 4,000 ha was reported. The most recent coverage survey by Anteneh et al. (2015) estimates 34,500 ha of the Lake is affected by water hyacinth. Wondie (2018) identified water hyacinth now as the main threat for wetlands in the north of Lake Tana. Because ecosystem services that are provided by Lake Tana can be described as 'public goods', the use of these services is characterized by non-rivalry and non-excludability (Carson and Mitchell, 1989). As a result of the water hyacinth infestation, these 'public goods' cannot be enjoyed to the maximum. In 2017 and 2018, local awareness of the problem increased drastically through media coverage aimed at informing the public (e.g. BBC News (2018)).

Given the burden that this AIS is putting on the lake's ecosystem, the local economy, social and political structures, and the daily livelihoods of the communities around Lake Tana, management action should be taken. Due to the pervasive nature of the water hyacinth, management actions focus on minimizing the socio-economic and ecological impact (Malik, 2007; Villamagna and Murphy, 2010). There is a need to estimate the damage to local smallholders caused by water hyacinth in order to allow environmental economists to use reliable inputs for future decision-making and ecosystem management. According to Schuyt (2005), a major cause for the failure of wetland management in African countries is the lack of understanding of the economic value of these wetlands. To estimate the current socio-economic impact of the water hyacinth infestation on the local smallholders around Lake Tana, the contingent valuation method (CVM) was applied. Xu et al. (2018) pointed out that local people's perception is rarely considered; hence, this participatory study with direct local stakeholders is preferred. By assessing the value that the local smallholders on the Lake Tana shores assign to a hypothetical water hyacinth removal campaign, the actual socio-economic implications can be estimated. In reporting and explaining these implications on the lake's ecosystems and the people that rely on them, this research aims to provide input for decision-making and local ecosystem management. The results enable cost-benefit analyses and serve to justify the cost of control/eradication measures.

Methods and materials

Study area

Formed 5 million years ago by volcanic activity, Lake Tana is the largest freshwater body in Ethiopia and accounts for approximately 50% of Ethiopia's surface freshwater reserves. It is the source for the Abay river (Blue Nile) which makes up 85% of the total Nile River discharge (Sewnet & Kameswara, 2011). The Lake Tana ecosystem was designated as a 'Biosphere Reserve' by UNESCO in 2015. This Man and Biosphere Reserve program aims at "*improving the overall relationship between people and their environment*" (UNESCO, 2017). Lake Tana is of significant ecological and socio-economic importance (Anteneh et al., 2015).

Lake Tana is located in the Amhara National Regional State in the north-western part of Ethiopia. The lake surface covers between 3000 and 3600 km^2, whereas total lake catchment includes 15,096 km^2 (Setegn et al., 2008). Lake Tana is shallow with a mean depth of 8 m and ranges up to a maximum depth of 14 m (Anteneh et al., 2015). It lies at an elevation of 1800 m above sea level. According to figures of the Ethiopian government, 85% of people in the Amhara Regional State depend on agriculture as the main source of income (Ethiopian Government Portal, 2018). Other main sources of income in the region are trade, fishing, tourism and sand mining (Ethiopian Government Portal, 2018). Poverty and illiteracy levels are high in the rural landscape of the study area. High population growth rates and migration have contributed to the extensive urbanization and augmented direct dependence on the ecosystem services provided by the Biosphere Reserve.

Regarding the water hyacinth infestation, households in the area are expected to participate in regular physical removal campaigns. Water hyacinth infestations follow a cyclical pattern (Ongore et al., 2018) and these campaigns are organized by the local authorities in every district at the end of the rainy season (September-January). The campaigns are organized once or twice a week. As a household of the issuing kebele (the smallest administrative unit in Ethiopia), at least one household member is obliged to contribute. Larger events are organized where people from the wider areas are mobilized. Anteneh et al. (2015) concluded that regardless of the communal efforts of physically removing water hyacinth, the weed remains difficult to control.

The study-area was selected from the "Water hyacinth coverage survey" conducted by Anteneh in 2014 and 2015. Out of five infested districts (or woredas), three were chosen based on severity of infestation, accessibility and recent developments in water hyacinth coverage: Dembiya, Gondar Zuria and Dera. In correspondence with local experts in field research employed at Bahir Dar University, the kebeles suitable for the study were assigned. Development agents were responsible for organizing farmer workshops, sharing insights and good practices and keeping in touch with local communities. Based on the expertise, previous experience and familiarity with certain development agents, the field experts at Bahir Dar University selected possible woredas and kebeles to be surveyed. In each of the three chosen woredas, one kebele was surveyed: Achera Mariam in Dembiya, Lemba Arbayitu in Gondar Zuria and Tana Mitsili in Dera (indicated on Fig. 1). According to Anteneh (2015), the infestation in Tana Mitsili is the most recent and consequently the least severe. On the contrary, Achera Mariam on the northern shore is close to the Megech river mouth, where water hyacinth infestation started in 2011. Lemba Arbayitu was also infested early, the water hyacinth coverage in Lemba Arbayitu is considered the most severe.

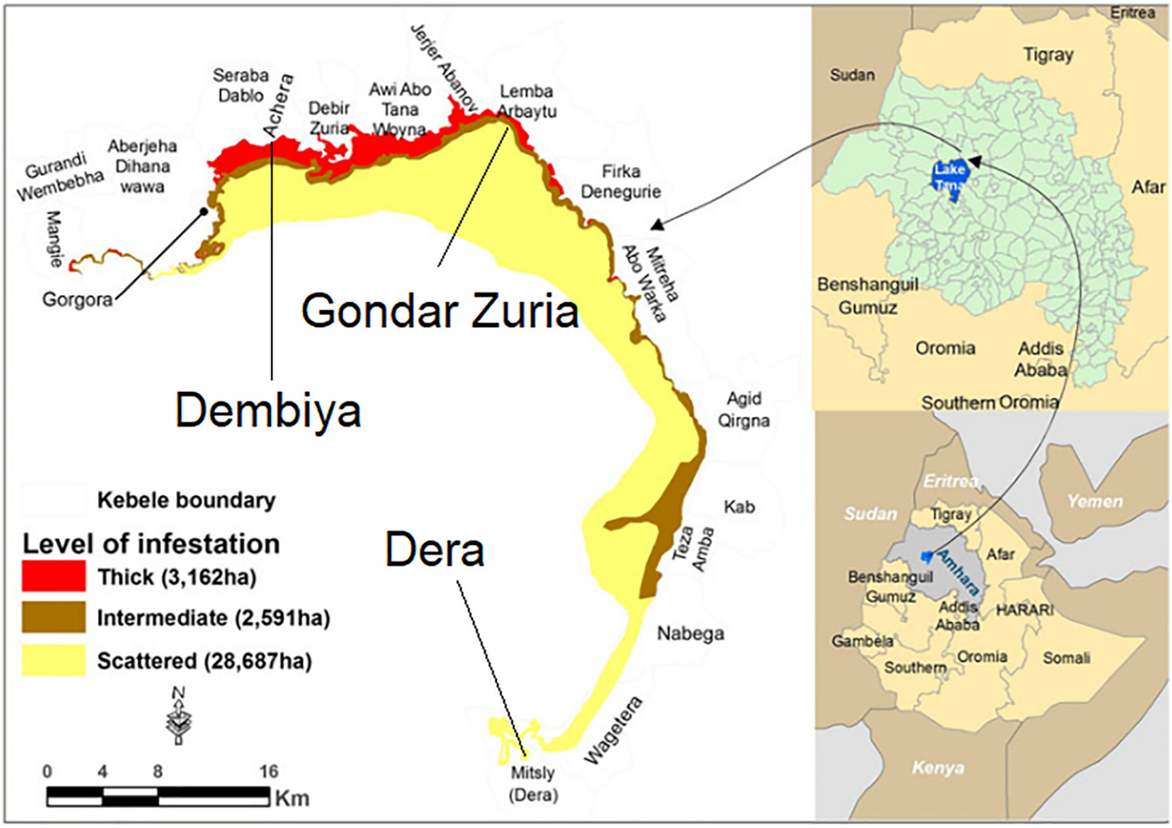

Fig. 1. Map of the Lake Tana water hyacinth infestation, adapted from Dejen et al. (2017).

Valuation method

To estimate the value of the water hyacinth removal, the contingent valuation method (CVM) was applied (Loomis et al., 2000). The CVM is a stated-preference method for economic valuation: surveys are carried out to elicit respondents' willingness to pay and/or willingness to contribute labor (Carson and Mitchell, 1989; Cawley, 2008). Water hyacinth currently is not exchanged in regular markets around Lake Tana (harvested crops are disposed at the shores), making revealed preference methods challenging. Additionally, the vast majority of local households are familiar with the existence and hindrance of water hyacinth and benefit from removal initiatives, which can be defined as a public good. This familiarity stems from the mandatory physical removal campaigns that were mentioned earlier. Another commonly used stated preference method is a choice experiment. However, choice experiments are suited to assess the impact of certain specific attributes on the provision of an environmental good (Holmes et al., 2017), which is not the objective with this study. Lastly, the ability of CVM to not only measure the use value, but also the non-use value, is essential to capturing the 'total economic value'. People might derive utility from the water hyacinth removal campaign, even if they don't and possibly won't use Lake Tana directly, for example out of respect for its spiritual value.

As follows, a contingent valuation survey was carried out to derive the willingness to pay and willingness to contribute labour of local smallholder households under the scenario of water hyacinth control and complete removal. Two scenarios were chosen, because they provide additional insight into the utility that respondents derive from different states of the ecosystem. After all, contingent valuation rested on the implicit assumption that the economic measure of benefit of a good originates from the utility that stakeholders derive from this good.

Data collection

The community surveys were conducted in November 2017. This period coincides with the harvesting season for water hyacinth. From September/October to January – at the end of the rainy season - the weed expands most rapidly. During this period local communities organize campaigns to manually remove the water hyacinth. These manual removal campaigns usually consist of harvesting the water hyacinth plants and piling them up on the shores (picture in Electronic Supplementary Material (ESM) Appendix S1).

The questionnaires were prepared in English and pretested with Amharic translators. Pre-testing took place at a farming conference in Dera woreda. A total of 15 farmers of a village similar to those of the study area (i.e. same woreda and water hyacinth infested shoreline) were surveyed in the presence of Bahir Dar University (BDU) personnel, afterwards the survey was revised to ensure clarity. The revised survey was translated to Amharic. The surveys were all carried out by trained development agents, in the company of local experts and the first author (Van Oijstaeijen, W.). The units of analysis in this study were households living in the kebeles mentioned above. Households are chosen because contributions to public goods are assumed to be made as a household (e.g. current land tax). In the Lake Tana area, the census in 2007 reported that households comprise 5 members on average (Stave et al., 2017). Respondents were chosen randomly within the selected kebeles. The selected kebeles were all situated on the shores of the lake. Inhabitants in these kebeles live from crop production and livestock production. In the region, 80% of the household heads are men and even when the man is not household head (HH), he is still primarily responsible for economic decisions within the household. In consequence of the above reasons, only men were interviewed. Qualitative interviews with women were collected as well.

Questionnaire design

Respondents were first asked some general, introductory questions about their use and appreciation of Lake Tana. Subsequently, enumerators provided the respondent with an information card (ESM Appendix S1). This information card stated the current water hyacinth problem and the threats posed by the issue to the ecosystem (Bräuer, 2003). The information card was read by the enumerator in case of illiteracy. Following the problem statement, the hypothetical market called "The Lake Tana protection program" was defined, before proceeding to the willingness to contribute labor (WTCL) or willingness to pay (WTP) questions. The end of the survey consisted of socio-demographic information questions. In drafting the survey and processing the results, widely accepted guidelines (Arrow et al., 1993) for value elicitation surveys were taken into account.

Three different formats of the survey were designed, dependent on the mean of contributing to "the Lake Tana protection program". The method that would be used by the program to eradicate water hyacinth was not explained. The objective of the study was to obtain the aggregated benefits of water hyacinth control/eradication. Potential distrust towards certain eradication methods could influence the willingness to contribute statement and rather reflect willingness to contribute to the method than for the eradication itself.

In the 'cash money' format, respondents' (n = 76) willingness to pay in terms of a yearly amount of money in Ethiopian Birr (ETB) was asked. In the 'labor' format, respondents (n = 60) expressed their willingness to contribute labor to the program in man-days (8 h of work by an adult man) yearly. In the 'mixed' format, respondents (n = 104) were given the possibility to contribute in cash, in labor, a mix of both or to not contribute at all. Dependent on the answer respondents in the mixed survey provided to this contribution question, a set of contingent valuation questions were asked. Respondents were assigned one of the above three formats (cash money, labor or mixed) randomly. The addition of contribution in terms of labor, contrary to standard contingent valuation studies, had several reasons. First, it was hypothesized that households were not indifferent to contributing in money and labor. Previous studies, introducing both cash and labor contributions in developing countries, found the cash constraint and low valuation of time as main drivers (Kamuanga et al., 2001; Swallow and Woudyalew, 1994; Tilahun et al., 2015). Moreover, in rural Ethiopia, labor markets are very restricted, implying the limited ability of job mobility (Swallow & Woudyalew, 1994; Tilahun et al., 2015). A low willingness to pay does not necessarily imply reluctance towards the program. Household incomes are often inadequate to meet basic needs, so a sole willingness to pay question may not fully reflect the value of the Lake Tana protection program. Secondly, by offering the option, the strength of this assumed preference towards labor contribution can be measured.

Two scenarios for the hypothetical market were developed: a status quo scenario and an improvement scenario. In the status quo scenario, the Lake Tana protection program would keep the level of water hyacinth infestation constant at the current level. In the improvement scenario, the Lake Tana protection program was presented to entail the complete removal of all water hyacinth. The last scenario was merely hypothetical because the complete removal of an infestation is often extremely challenging. Respondents were clearly informed about the form and frequency of the contribution (Carson and Mitchell, 1989).

Polychotomous questions allow the interviewee to receive additional information, while not deviating from the Referendum Format. The fact that it may be superfluous to ask prompting questions, saves the enumerator effort and consequently time (Cameron and Huppert, 1989). In addition, respondents may be uncertain to be explicit about a single point of personal value, but rather have ranges in mind (Cameron and Quiggin, 1994), using intervals can account for this issue. However, the formulation of predefined (as a product of the pilot surveys) intervals may cause anchoring bias. The size and values of the intervals formulated in the actual survey were the result of the pre-tests. The result of offering ranges to choose from is similar to a payment card approach and its processing (Welsh and Poe, 1998).

If a respondent of the mixed survey stated to be willing to contribute a combination of cash and labor, an open-ended question was asked to express the maximum WTP/WTCL. Open-ended questions are often less favored due to the possible occurrence of non-responses and protest zeros (Carson and Mitchell, 1989). In the presence of trained enumerators, this concern was not applicable to this study. After the elicitation of WTP/WTCL in the status quo scenario, respondents proceeded to an identical question on the WTP/WTCL in the improvement scenario. The full survey can be found in ESM Appendix S1.

Econometric specification

The data obtained by the polychotomous question are interval censored. The objective is to formulate a mean WTP/WTCL with confidence intervals. According to Cameron and Huppert (1989), regression models with an interval-censored dependent variable are preferably estimated with an efficient maximum likelihood (ML) function, called 'interval regression' (IR). This is especially relevant when intervals are coarse, which is the case for this study. Another attribute determining the choice of the estimation technique is the amount of zero responses. A tobit regression is preferred when the WTP data contain a high amount of zero bids (O'Garra and Mourato, 2007) and with open-ended data. This was not the case in this study which had only 3.5% zero bids.

For all respondents, a water hyacinth infested Lake Tana yields some utility given by $U(WH_1, S, I, \varepsilon_1)$. With WH a vector for the evolution of infestation (WH_0 equals no infestation, WH_1 is the current state, WH_2 would imply that the lake surface is completely covered), S is the vector of socio-economic characteristics, I represents income and ε denotes randomness in the data. Their utility of a non-infested Lake Tana is given by $U(WH_0, S, I, \varepsilon_0)$. The level of infestation reduces from WH_1 to WH_0. An individual has a willingness to pay Y^* for this environmental improvement such that (Bateman and Willis, 2001):

$$U(WH_1, S, I, e_1) = U(WH_0, S, [I - Y*], e_0)$$

This expression is similar for WTCL if the amount of leisure would be included. L denotes total leisure, Y^* now denotes a bid in labor terms:

$$U(WH_1, P, X, L, e_1) = U(WH_0, P, X, [L - Y*], e_0).$$

Let x_i be the vector that includes the income/leisure stack and the socio-economic characteristics. ε_i is the random term of the individuals' WTP/WTCL, which is assumed to be normally distributed with zero mean and constant error. β is the vector of interval regression coefficients, with $i = 1,\ldots,n$ individuals in the questionnaire sample. Cameron and Huppert (1989) have defined a maximum-likelihood *interval regression*. Such that:

$$Y* = x_i b + e_i$$

In the interval-censored data, the true WTP/WTCL Y^* of a respondent is not expressed as a point value but lies between an upper threshold (t_k) and lower threshold (t_{k-l}) in each interval. Expressed as follows by Whitehead et al. (1995):

$$\Pr\left[Y_i^* \subseteq (t_k, t_{k-l})\right] = \Pr\left[\frac{(t_k - x_i\beta)}{\sigma} < z_i < \frac{(t_{k-l} - x_i\beta)}{\sigma}\right]$$

With $z_i = \frac{x_i\beta}{\sigma}$.

Similarly, Cawley (2008) describes the single likelihood contribution of an individual i with willingness to contribute in the interval [Y_{i1}, Y_{i2}] as:

$$\Pr(Y_{i1} < x_i\beta + \varepsilon_i < Y_{i2})$$

In the survey, people indicating to be willing to pay more /contribute more labor than the maximum-stated amount are asked an open-ended follow-up question to reveal the maximum willingness. In the interval regression, these answers are treated as right-censored in the absence of an upper bound. This likelihood contribution is described as $\Pr(Y_{i1} < x_i\beta + \varepsilon_i)$. The maximum likelihood functions that were used are all estimated with the *intreg* commando in STATA 15. The individual mean WTP/WTCL is estimated using the regression's results. Robust standard errors were used to calculate the 95% CI on the mean WTP/WTCL. The baseline model includes all variables examined in the questionnaire. For the following models, variables were iteratively removed from the baseline model, creating more parsimonious models, to improve interpretability and avoid overfitting. As a mean of control, ordered logistic regressions were run for every model to verify the interval regression's conclusions. For the mixed survey regional differences in responses on the contribution question were examined through a Fischer's Exact test. This is commonly used to examine the relation between two categorical variables when one or more cells have an expected value ≤ 5.

Results

Descriptive analysis

A total of 240 households correctly completed the contingent valuation questionnaire, of which 3.75% stated zero WTP/WTCL. Table 1 provides an overview of the participants' demographics. The exploratory questions in the beginning of the survey revealed that respondents value Lake Tana most importantly for the services it provides supporting crop production (90%) and livestock farming (71%). Other services stated as important are recreation (47%), religion (32%) and fishing (30%).

The regressors utilized for the interval regression are outlined in Table 2 which reports the results for the WTP for the status quo. Because the 'HH is owner of the plot(s)' and 'Main type of agricultural activity' questions both had one very dominant answer, the additional information to the model is dismissible. In the 'Estimated annual off-farm income' the dominance of the first category was due to the high percentage (95%) of zero responses. In the study-area there was little alternative for income but farming; for the modelling only the farm income is counted. The independent demographic variables included in the model are respondents' age, place of living, farming experience, education, water hyacinth conference attendance and (farming) income.

Table 2
Descriptive statistics of survey respondents.

Variable	n	%
Location		
Dembiya	58	24
Gondar Zuria	123	51
Dera	59	25
Age group		
18–24	10	4
25–34	69	29
35–44	73	30
45–54	40	17
55–64	27	11
65+	21	9
Household head is owner of plot(s)	232	97
Farming Experience of household head		
0–5 years	20	8
6–10 years	55	23
11–20 years	59	25
> 20 years	106	44
Main type of agricultural activity		
Crop production	22	9
Livestock	3	1
Mixed	215	90
Estimated annual farm income		
< 10,000 ETB	36	15
10,000–25,000 ETB	89	37
25,001–50,000 ETB	79	33
> 50,000 ETB	36	15
Estimated annual off-farm income		
< 5,000 ETB	227	95
5,000–10,000 ETB	10	4
10,001–20,000 ETB	3	1
> 20,000 ETB	0	0
Highest education of household head		
Can't read and write	138	58
No formal education	58	24
Grades attended	44	18

Willingness to pay

In the status quo scenario respondents expressed their WTP for the water hyacinth infestation remaining at the same level as it is today (Table 3). As can be expected, willingness to pay for the program is positively influenced by the household's income. A household stating to be in a higher income category is estimated to be willing to pay 84.9 ETB more than a household in the lower income category. The sample has an interval regression estimated mean willingness to pay of 440.9 ETB yearly (≈ €(euros) 13.5) for the sta-

Table 1
Definition of regressors utilized in interval regression.

Variables		Description	Mean (SD) (std.err.)
Age	Discrete	Continuous variable in years	41.6 (13.4)
Location	Categorical	1 if respondent lives in Achera Mariam, 2 if respondent lives in Lemba Arbayitu and 3 if respondent lives in Tana Mitsili	
Farming experience	Ordinal	1 if respondent has 0–5 years of farming experience, 2 if respondent has 6–10 years of farming experience, 3 if respondent has 11–20 years of farming experience and 4 if respondent has>20 years of farming experience	3.0 (1.0)
Education	Ordinal	1 if respondent can't read or write, 2 if respondent has no formal education, 3 if respondent has attended formal education	1.6 (0.7)
Local conference attendance	Binary	1 if respondent attended a water hyacinth conference, 0 if not	0.7 (0.4)
(Farming) Income	Ordinal	1 if income is smaller than 10,000 ETB yearly, 2 if income is between 10,000–25,000 ETB yearly, 3 if income is between 25,001–50,000 yearly and 4 if income is over 50,000 ETB yearly	2.5 (0.8)

Table 3
WTP interval regression results for the status quo scenario. The baseline model was defined as the full model (1) which including all regressors. Subsequently, regressors without statistical significance were removed from the estimating model (in columns (2) and (3)), until further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p < 0.05, *** p < 0.01.

Variable	(1)	(2)	(3)
Age	−9.5 (5.1)*	−10.2 (4.7)**	−10.3 (4.8)**
Gondar Zuria	−133.1 (88.0)	−122.1 (83.1)	−124.2 (57.2)**
Dera	−5.1 (92.2)	3.1 (89.8)	
Farming Experience 6–10 years	26.1 (117.4)	24.5 (122.1)	24.08 (121.8)
Farming Experience 11–20 years	161.8 (128.1)	168.7 (128.8)	168.6(129.1)
Farming Experience > 20 years	174.5 (129.6)	176.6 (130.1)	176.6 (130.0)
No formal education	−35.3 (79.5)		
Grades attended	22.5 (82.4)		
Local conference	89.9 (69.0)	97.6 (65.9)	98.0 (65.0)
Income	84.9 (36.2)**	79.2 (34.2)**	79.4 (34.6)**
Constant	247.4 (136.7)*	(140.3)*	252.5 (133.4)**

Table 4
WTP interval regression results for the improvement scenario. The baseline model was defined as the full model (1) which including all regressors. Subsequently, regressors without statistical significance were removed from the estimating model (in columns (2) and (3)), until further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p < 0.05, *** p < 0.01.

Variable	(1)	(2)	(3)
Age	−5.0 (10.3)	−4.6 (9.9)	−4.6 (9.9)
Gondar Zuria	−283.3 (157.6)*	−290.4 (144.1)**	−300.1 (106.9)***
Dera	19.4 (163.0)	13.8 (152.0)	
Farming Experience 6–10 years	−144.7 (162.5)	−147.8 (159.0)	−149.7 (156.2)
Farming Experience 11–20 years	105.8 (203.0)	98.9 (190.7)	98.3 (190.3)
Farming Experience > 20 years	63.9 (213.8)	60.6 (208.2)	60.4 (207.5)
No formal education	21.5 (146.1)		
Grades attended	−1.1 (160.9)		
Local conference	166.5 (129.9)	164.6 (122.5)	166.2 (120.5)
Income	182.5 (75.6)**	185.3 (70.6)***	186.3(71.1)***
Constant	388.4 (205.4)*	391.8 (193.0)**	398.6 (178.0)**

tus quo scenario, with 95% CI [376.8; 505.0] and robust standard error of 32.7. Interval regression coefficient estimates are shown in table 4. The Lake Tana protection program has a mean WTP value of 764.4 ETB yearly (≈ €23.4), with 95% CI [647.2;881.6] and robust standard error of 59.8.

Recurrently, the statistical significance is most prominent for the variables 'Income' and 'Lemba Arbayitu' (Lemba Arbayitu, Gondar Zuria). For the household's income, the relation to willingness to pay is intuitive, and the consistent direction of the estimating coefficients confirms the intuition. For the location Lemba Arbayitu, underlying factors could explain their reduced WTP relative to the other kebeles in the study-area. Expectedly, local households are willing to pay significantly more for the improvement scenario compared to the status quo scenario.

Willingness to contribute labor

Respondents who were interviewed through the WTCL survey stated their willingness to contribute labor in terms of personal man-day labor contribution. The estimations of the interval regression based on the status quo scenario data can be found in table 5. Respondents living in Tana Mitsili, Dera were willing to contribute significantly more man-days of labor compared to the other kebeles. As opposed to the willingness to pay assessment, the attendance of water hyacinth local conferences (positively) influences the WTCL significantly. Model reduction from (1) to (2) in Table 5 entails the removal of the variables Education due to high correlation with other regressors.

The mean WTCL of the sample is 32.6 man-days yearly with 95% CI [29.1; 36.1] and robust standard deviation equal to 1.8. The positive relation between the Farming Experience and the eventual WTCL is logical; respondents with more farming experience are better aware of the influence on the farming activity due to water hyacinth.

For the improvement scenario (Table 6), the same regressors have a significant impact on the model estimation. The positive coefficients confirm the results of the interval regression in the status quo scenario. The mean willingness to contribute labor is estimated at 51.2 man-days yearly, with 95% CI [45.4; 56.9] and a robust standard deviation of 2.9.

Table 5
WTCL interval regression results for status quo scenario. The baseline model was defined as the full model (1) which including all regressors. Subsequently, regressors without statistical significance were removed from the estimating model (in columns (2) and (3)), until further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p < 0.05, *** p < 0.01.

Variable	(1)	(2)	(3)
Age	−0.3 (0.3)	−0.4 (0.3)	−0.4 (0.3)
Gondar Zuria	2.6 (4.0)	3.3 (3.6)	
Dera	8.6 (3.4)***	8.9 (3.4)***	6.8 (3.0)**
Farming Experience 6–10 years	6.4 (6.7)	6.0 (6.6)	5.4 (6.3)
Farming Experience 11–20 years	12.4 (6.9)*	12.3 (7.0)*	11.7 (6.7)**
Farming Experience > 20 years	16.1 (6.7)**	16.6 (6.8)**	16.7 (6.8)***
No formal education	−0.8 (4.1)		
Grades attended	3.6 (6.9)		
Local conference	8.1 (3.3)**	8.0 (3.3)**	7.8 (3.3)***
Income	−2.5 (1.9)	−2.2 (1.8)	−1.8 (2.0)
Constant	23.2 (10.2)**	22.9 (10.2)**	27.5 (6.8)***

Table 6
WTCL interval regression results for improvement scenario. The baseline model was defined as the full model (1) which including all regressors. Subsequently, regressors without statistical significance were removed from the estimating model (in columns (2) and (3)), until further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p < 0.05, *** p < 0.01.

Variable	(1)	(2)	(3)
Age	−0.2 (0.5)	−0.3 (0.4)	−0.3 (0.4)
Gondar Zuria	−3.5 (6.4)		
Dera	7.1 (6.6)	7.7 (6.8)	9.2 (5.7)*
Farming Experience 6–10 years	−0.4 (10.5)	−1.1 (10.6)	−0.7 (10.3)
Farming Experience 11–20 years	11.8 (10.8)	11.6 (11.0)	12.3 (7.2)
Farming Experience > 20 years	12.4 (10.6)	13.3 (10.7)	14.1 (9.0)
No formal education	−1.9 (6.9)		
Grades attended	6.0 (10.1)		
Local conference	14.2 (5.1)***	14.1 (5.3)***	14.2 (5.4)***
Income	0.7 (2.9)	1.3 (2.7)	1.1 (2.8)
Constant	33.0 (14.9)**	31.2 (13.7)**	33.1 (6.8)***

Mixed survey format

In the mixed survey, respondents were first provided with the option to contribute to the Lake Tana protection program in the way they prefer: cash, labor, combination of both, or not contribute at all. The results of these preferences are shown in Table 7.

Mixed survey – cash

For a limited sample size (n = 25) only very strong relationships are demonstrable. However, running the interval regressions on the sample doesn't give enough evidence to reject the null hypothesis of all zero value regressors. Mean willingness to pay for the status quo scenario of the sample is 459.8 ETB yearly, with 95% CI [355.1; 564.4]. For the improvement scenario the mean WTP is estimated at 891.9 ETB per year, with 95% CI [651.1; 1132.8]. The wider intervals result from the small sample size, otherwise these results are similar to the regular willingness to pay format.

Mixed survey – labor

The results from the mixed – labor contribution show that the average willingness to contribute labor is at 28.9 man-days in the status quo scenario, 95% CI of [25.8; 31.9]. In the improvement scenario people or willing to contribute 46.7 man-days on average, with a 95% CI of [41.9; 51.5].

Mixed survey – combination

Respondents who stated to be willing to contribute to the Lake Tana protection program through a combination of cash and labor were given an open question to compose their willingness to contribute bundle. The results are shown in Table 8. The combination in terms of cash was composed from the cash to labor (and vice versa) ratio that resulted from the WTP and WTCL surveys.

Table 7
Mixed survey; choice of contribution.

Contribute	Frequency (%)
Cash	25 (24)
Labor	58 (56)
Mixed	18 (17)
Not contribute	3 (3)

Discussion

The results from the cash and labor surveys indicate that the WTP and WTCL respectively vary in logical ways. For example, the cash survey indicated a higher WTP when a household has more income, both in the status quo and the improvement scenario. In the labor survey, the attendance of water hyacinth conferences positively influences the WTCL, which can be attributed to the deeper knowledge and awareness of the water hyacinth problem in Lake Tana. This supports the face validity of the contingent valuation survey. It is noticeable that the age is negatively correlated with the willingness to pay and – to lesser extent - willingness to contribute labor. This result matches with the general intuition that was obtained by qualitative interviews in the study-area. Youth are more involved in the water hyacinth harvesting programs and are often more connected to the (social) media, where coverage on the issue creates increased awareness resulting in a serious concern about the future of Lake Tana. Thus, they are more committed to restoring the ecosystem balance. The main conclusion from the mixed survey can be drawn from the preference question. Respondents were significantly more inclined to contribute in terms of labor than the other options. With the mixed survey, it was found that respondents deliberately opted to contribute in terms of cash money and had a slightly higher mean WTP. However, the small sample didn't provide reliable evidence.

Including a mixed survey format provided useful insights. First of all, it allowed verification of the results in a realistic market situation where customers have the option to contribute in any way possible. All beneficiaries of a water hyacinth-free Lake Tana have the option to contribute to the current problem in terms of labor, to donate money for research/machines, to combine these previous options or not to contribute in any manner. Secondly, the total

Table 8
Summary of results from the mixed survey.

		Status quo Mean	Improvement Mean
CashMixed		459.8 ETB	891.9 ETB
Labor		28.9 MD	46.7 MD
Mixed	Combination	391.7 ETB + 48.1 MD	855.6 ETB + 65.6 MD
	Combination in terms of cash*	1042.2 ETB	1835.0 ETB
	Combination in terms of labor**	77.1 MD	122.9 MD

Note: * Status quo: 1 MD = 440.9/32.6 ETB, Improvement: 1 MD = 764.4/51.2 ETB. ** Status quo: 1 ETB = 2.6/440.9 MD, Improvement: 1 ETB = 51.2/764.4 MD.

value of the bundles that were stated by people choosing for the combination option were much higher than the values obtained in the regular cash and labor formats.

Different factors may underlie these results; respondents may have misunderstood the combination question and thus consequently overstated their willingness to contribute. Although the enumerators were trained and carefully observed during the survey, it remains that open-ended elicitation questions are more sensitive to enumerator bias than close-ended questions. Another potential explanation for the results of the mixed contribution can be related to anchoring bias. In the cash and labor contribution surveys, the dichotomous question preceding the willingness to contribute question in terms of polychotomous intervals may have caused this anchoring effect. By presenting some monetary value or some amount of man-days to contribute, respondents may have been biased to adjust their true willingness to contribute in the direction of this value. This would imply that the results obtained in the open-ended mixed contribution format are a closer representation of the true value of water hyacinth eradication around Lake Tana with the studied sample. Alternatively, open-ended questions have given evidence to significant overstatement of the actual willingness to pay (Green et al., 1998). Open-ended questions result in increased uncertainty and subsequently in biased statements. Moreover, Bateman et al. (1995) found that positive interests in the conservation of a good may induce strategic overstatement if the respondent believes that this would influence the provision of such a good. While conducting this study, qualitative interviews confirmed that the people in the study-area strongly rely on the natural resources from Lake Tana and are severely negatively affected in their livelihood by AIS. This is a source for strategic overstatement. Additionally, the unrealistic prospect of completely eradicating water hyacinth on Lake Tana may cause a willingness to contribute that is influenced by a short-term view. Respondents may be convinced that profound sacrifices of time/money now will solve the problem within a short time period, leading to unrealistically high contributions if the results would be expanded to medium to long term (>5 years).

A few other factors must be taken into consideration in interpreting the results of this study. First of all, one must understand the cultural context of making contributions to the state. In Ethiopia, the practice of contributing free labor to the state is a longstanding tradition. As opposed to other regions, community work is generally widely accepted within the study area. This cultural context should be taken into account when conducting similar studies. Secondly, the skewed male sample introduces a gender bias. Considering the fact that male household members are obliged to contribute to the ongoing community actions, their willingness to contribute is expected to be higher than those of female household members. However, in opting for contribution as a household for the payment scenario's, which is typically a male's decision in the study area, it was intended to reduce the influence of this sampling bias.

With regard to the cash constraint that was assumed, mixed evidence is observed. Firstly, from the choice of contribution in the mixed survey, it could be interpreted that there is a cash constraint, which impedes on the actual value of the ecosystem to the farmers. On the other hand, the ratio that is observed as a result of the cash format and the labor format can be interpreted as indicating otherwise. For the status quo, it is found that 1 man-day is worth 13.52 ETB and for the improvement scenario this ratio is 14.93 ETB/MD. Similar to Tilahun et al. (2015), the convergence validity can be tested through using the public employers' minimum wage (320 ETB per month) to make the conversion. When taking into account the fact that one month entails 20 to 23 workable days on average, the value of one working day lies within the range of 13.9–16 ETB. Thus, the ratio's that are obtained through the study are not significantly different from the public employers' minimum wages, indicating the absence of the assumption of low valuation of time. It can be concluded that simply assuming that a cash constraint will influence results in developing countries is not realistic. Especially, when the livelihood is directly and drastically affected by the threat, measured WTP may reflect pragmatic value.

Having evidence of the validity of the survey responses, one can extrapolate these findings on the broader population. The study-area consists of three kebeles in three different woredas. Hence, the results are extrapolated on all households in the infested kebeles of these three woredas. In Dembiya seven kebeles are infested (9,834 households), in Gondar Zuria five kebeles are infested (11,129 households) and in Dera one kebele is infested (2,051 households). In total 23,014 households are thus affected in these three woredas. Extrapolating the values of the WTP and WTCL, taking into account the percentage of zero responses, results in aggregative yearly contributions as shown in table 9.

The numbers depicted in table 9 give an indication of the willingness to contribute of some of the direct users of the ecosystem services provided by Lake Tana. It is important to stress that this is not the overall total benefit for a Lake Tana without water hyacinth. Only three out of five infested woredas were considered in the extrapolation. Moreover, contingent valuation studies often describe the influence of distance to the environmental good on the willingness to contribute, implying additional (but diminishing) willingness further away from the lake (Schaafsma et al., 2012; Yao et al., 2014). With 2 to 3 million people living in the Lake Tana Biosphere Reserve and the importance of the ecosystem services the Biosphere provides, many more stakeholders contribute to the total benefits of eradicating the water hyacinth. This stakeholder approach should be complemented by further research into other stakeholder groups. A similar and more recent study in Bahir Dar city with 398 urban households found that households in Bahir Dar are willing to make an aggregated one-time payment of 77,624,226.2 ETB (over 2,5 million euros) (Tesfa, 2019). It is clear that the communal economic weight of the infestation is at a level where action should be undertaken.

From the management perspective, the invasion process of alien plants is to be managed in four sequential strategies: identification, protection, mitigation and adaptation (Vaz et al., 2017). For Lake Tana, the severity of the problem observed and the results of this socio-economic study leave no strategic solution except for adaptation. The water hyacinth is in Lake Tana to stay. The socio-economic impact on local smallholders that was assessed in this study justifies potential management expenditures on the control of the weed. However, as demonstrated by the Lake Victoria case, when biological control programs stop, the weed persists. Currently, it should be noted that the research around Lake Tana is targeted specifically at biological control.

Nevertheless, alternative pathways to sustainably managing this outbreak should be researched locally. Economically viable uses of water hyacinth may create benefit to support local households, turning current threat into opportunities. Exemplary cases in Africa have shown that water hyacinth utilization can become an economically viable alternative by producing biogas, fertilizers, fibers, paper, *etc.* Bénin and Lake Victoria (Güereña et al., 2015;

Table 9
Aggregated yearly willingness to contribute.

	Status quo	Improvement
Willingness to pay (Ethiopian Birr)	9,766,365 (or € 317,678*)	16,932,206 (or € 550,767*)
Willingness to contribute labor (man-days)	750,256	1,178,317

* Based on currency conversion rate in may 2018

Roux, 2019), where water hyacinth was initially experienced as 'an ecological disaster', now give evidence of creating added value from water hyacinth. In Kenya, Biofit Agritech (https://www.biofit.co.ke) profitably produces qualitative livestock feed with water hyacinth as a raw material, having clear socioeconomic benefits: creating employment and enhancing farming efficiency. Greenkeeper Africa (http://www.greenkeeperafrica.com), based in Bénin, has developed a water hyacinth sorbent to remediate oil-based pollutions, benefitting society and environment. In Nigeria, the company Green Energy Biofuels (http://www.gebiofuels.com) specializing in biofuels for cooking stoves, is currently pilot testing with water hyacinth as feedstock and claims promising first results. Such examples prove that initiating or supporting businesses that create a return on investment from water hyacinth is impactful in the short term, which is, given the severity of the implications on the population, highly desirable. Further research should target the readiness and willingness to generate business, identifying actual barriers and pathways to overcome these.

Because the most affected stakeholder group around Lake Tana, currently are local smallholders who are already vulnerable, governments or possibly NGO's should look beyond them to release the burden. Possible management options should advance from the current biological/chemical/mechanical eradication debate and explore integrated approaches, requiring other investments. These (public) investments should be targeted at improved waste water management to reduce the favorable environment for water hyacinth. Infrastructure investments to benefit from the occurrence of water hyacinth, leading to water hyacinth utilization, may provide a sustainable solution to adapt to the newly defined ecosystem. With regard to sustainable ecosystem and resource management, providing the necessary equipment for processing water hyacinth into a productive resource in newly defined business processes may be the strategically opportune decision.

Conclusion

The water hyacinth infestation of Lake Tana, officially recognized in 2011, led to disruptions in the daily lives of those depending on its resources. We provided a stakeholder group approach focusing on local smallholders around Lake Tana to assess the value of water hyacinth control, using the contingent valuation method. The sample size exists of 240 households in the Dembiya, Lemba Arabayitu and Dera woredas bordering the northern to northeastern shores of Lake Tana. Through this participatory approach, the severity of the infestation as perceived by the most affected stakeholder group was put into numbers for the first time. Using interval regressions, we estimated a yearly willingness to pay of 764.4 ETB (€23.4) per household or yearly willingness to contribute labor of 51.2 man-days per household for the eradication of this alien invasive species. Aggregating these results over the study area yields a yearly willingness to pay of over half a million euros or willingness to contribute labor of over one million man-days per year.

These findings support previous qualitative research in a tangible, quantitative approach which can be used as an input to cost-benefit analyses regarding control efforts or alternative solutions. In this study, only the impacts on smallholders were researched; studies on the (potential) impact on other actors is advised for a comprehensive assessment of the total benefits the water hyacinth eradication/control entails. Moreover, using different valuation methods (choice experiments, travel cost methods, etc.) would enhance a complementary and comprehensive overview.

Given the experiences of other water bodies in Africa (e.g. Lake Victoria) and the urgency that is resembled by the numbers in this study, we advise responsible bodies to look beyond the current debate on mechanical/biological/chemical control and advance to explore sustainable solutions in both water-waste management and water hyacinth utilization. After all, the infestation has reached a level where adaptation is inevitable, because previous examples show that eradication is costly, technically difficult and often impossible. Further research is required on the economic damage of the water hyacinth infestation, but also on the pathways to creating socioeconomic benefit from the weed. On top of that, economic implications of water hyacinth on the ecosystem services provided by Lake Tana and the overall economic value of the Lake should be researched to a greater extent, for justifiable and sustainable ecosystem management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2020.06.009.

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