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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.

Keywords: Invasive species; Contingent valuation; Lake Tana; Socio-economic impact; Willingness to contribute labor;

Willingness to pay;

1 Introduction

2

According to Anteneh et al. (2014), Lake Tana has been infested with water hyacinth 3 (eichhornia crassipes) since 2011. Water hyacinth is an aquatic alien invasive species (AIS), 4 5 possibly originating from Brazil from where it spread to nearly all of the southern and central 6 American countries. Today, almost all countries between 40°N and 40°S face the threat of 7 infestations on lakes, slowly moving rivers or swamps (Malik, 2007). Water hyacinth is a free-8 floating plant, known for its rapid reproduction and its tendency for dense mat-formation. 9 Classified as one of the world's most productive plants and worst aquatic weeds (Lowe et al., 10 2000), eradicating an infestation is extremely challenging. While physical/manual removal often yields temporary reductions in the coverage, biological control is a widely applied 11 12 solution to effectively reduce infestations. Around Lake Victoria, biological control was 13 responsible for the initial decline of this infestation (Albright et al., 2004). However, after 14 discontinuing these costly programs, water hyacinth remains problematic in Lake Victoria. 15 Biological control has been successful in other African countries, e.g. case studies of Lake 16 Chivero (Zimbabwe), White Nile (Sudan), Southern Benin (De Groote et al., 2003; Irving & 17 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 18 cost ratio was calculated at 4.2:1 (Law, 2008). 19

20 Water hyacinth infestations lead to ecological and socio-economic disruptions. In the Lake Victoria basin water hyacinth has been impacting local communities' livelihoods since 21 22 the late 1980s. Mailu (2001) described the unfavourable impacts of these infestations: 23 reduction of water quality and availability through increased evapotranspiration, clogging of 24 irrigation canals and hydropower dams, reduction in fish catches and decline of aquatic 25 biodiversity through reduced oxygen and distorted water flow, obstruction of navigation, 26 hindrance on water access for fishermen and livestock, rise of human social conflict and 27 migration through negatively affected agricultural conditions, surge in vector-borne diseases 28 through an increase in the breeding grounds for e.g. mosquitos. The total economic impact was 29 estimated in the order of billions of dollars (Mailu, 2001). Observations of similar disturbances 30 to the livelihood in the northern to north-eastern parts of Lake Tana have been identified in 31 previous research (Anteneh et al., 2014; Anteneh et al., 2015; Dejen et al., 2017; Gezie et al., 32 2018). Moreover, the strategic location of Lake Tana at the source of the Blue Nile, which flow 33 through several hydroelectric plants (Tesfaye et al., 2016), adds an additional threat of the 34 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 LakeVictoria, economic impact was currently not yet subjected for research in the Lake Tana area.

37 Increased land degradation through overexploitation of the wetland resources and poor 38 waste management have increased the nutrient levels and led to eutrophication of the Lake 39 Tana Basin (Wondie, 2010). These circumstances benefitted the actual outbreak of water 40 hyacinth on the northern shores of Lake Tana. This outbreak was officially recognized in 2011, 41 when a coverage of 4,000 ha was reported. The most recent coverage survey by Anteneh et al. 42 (2015) estimates 34,500 ha of the Lake is affected by water hyacinth. Wondie (2018) identified 43 water hyacinth now as the main threat for wetlands in the north of Lake Tana. Because 44 ecosystem services that are provided by Lake Tana can be described as 'public goods', the use 45 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 46 47 the maximum. In 2017 and 2018, local awareness of the problem increased drastically through 48 media coverage aimed at informing the public (e.g. BBC News (2018)).

49 Given the burden that this AIS is putting on the lake's ecosystem, the local economy, 50 social and political structures, and the daily livelihoods of the communities around Lake Tana, 51 management action should be taken. Due to the pervasive nature of the water hyacinth, 52 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 53 54 smallholders caused by water hyacinth in order to allow environmental economists to use 55 reliable inputs for future decision-making and ecosystem management. According to Schuyt 56 (2005), a major cause for the failure of wetland management in African countries is the lack of 57 understanding of the economic value of these wetlands. To estimate the current socio-economic 58 impact of the water hyacinth infestation on the local smallholders around Lake Tana, the 59 contingent valuation method (CVM) was applied. Xu et al. (2018) pointed out that local 60 people's perception is rarely considered; hence, this participatory study with direct local 61 stakeholders is preferred. By assessing the value that the local smallholders on the Lake Tana 62 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 63 64 ecosystems and the people that rely on them, this research aims to provide input for decisionmaking and local ecosystem management. The results enable cost-benefit analyses and serve 65 to justify the cost of control/eradication measures. 66

67

68 Methods and materials

69 *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).

77 Lake Tana is located in the Amhara National Regional State in the north-western part of 78 Ethiopia. The lake surface covers between 3000-3600 km2, whereas total lake catchment 79 includes 15,096 km₂ (Setegn et al., 2008). Lake Tana is shallow with a mean depth of 8 meters and ranges up to a maximum depth of 14 meters (Anteneh et al., 2015). It lies at an elevation 80 81 of 1800 meters above sea level. According to figures of the Ethiopian government, 85% of 82 people in the Amhara Regional State depend on agriculture as the main source of income 83 (Ethiopian Government Portal, 2018). Other main sources of income in the region are trade, 84 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 85 86 migration have contributed to the extensive urbanization and augmented direct dependence on 87 the ecosystem services provided by the Biosphere Reserve.

88 Regarding the water hyacinth infestation, households in the area are expected to participate in regular physical removal campaigns. Water hyacinth infestations follow a 89 90 cyclical pattern (Ongore et al., 2018) and these campaigns are organized by the local authorities 91 in every district at the end of the rainy season (September-January). The campaigns are 92 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 93 94 events are organized where people from the wider areas are mobilized. Anteneh et al. (2015) 95 concluded that regardless of the communal efforts of physically removing water hyacinth, the 96 weed remains difficult to control.

97 The study-area was selected from the "Water hyacinth coverage survey" conducted by
98 Anteneh in 2014 and 2015. Out of five infested districts (or woredas), three were chosen based
99 on severity of infestation, accessibility and recent developments in water hyacinth coverage:
100 Dembiya, Gondar Zuria and Dera. In correspondence with local experts in field research
101 employed at Bahir Dar University, the kebeles suitable for the study were assigned.
102 Development agents were responsible for organizing farmer workshops, sharing insights and

103 good practices and keeping in touch with local communities. Based on the expertise, previous 104 experience and familiarity with certain development agents, the field experts at Bahir Dar 105 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 106 107 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, 108 109 Achera Mariam on the northern shore is close to the Megech river mouth, where water hyacinth 110 infestation started in 2011. Lemba Arbayitu was also infested early, the water hyacinth 111 coverage in Lemba Arbayitu is considered the most severe.

112 Valuation method

To estimate the value of the water hyacinth removal, the contingent valuation method 113 (CVM) was applied (Loomis et al., 2000). The CVM is a stated-preference method for 114 economic valuation: surveys are carried out to elicit respondents' willingness to pay and/or 115 116 willingness to contribute labor (Carson and Mitchell, 1989; Cawley, 2008). Water hyacinth 117 currently is not exchanged in regular markets around Lake Tana (harvested crops are disposed 118 at the shores), making revealed preference methods challenging. Additionally, the vast majority 119 of local households are familiar with the existence and hindrance of water hyacinth and benefit 120 from removal initiatives, which can be defined as a public good. This familiarity stems from 121 the mandatory physical removal campaigns that were mentioned earlier. Another commonly 122 used stated preference method is a choice experiment. However, choice experiments are suited 123 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 124 125 not only measure the use value, but also the non-use value, is essential to capturing the 'total 126 economic value'. People might derive utility from the water hyacinth removal campaign, even 127 if they don't and possibly won't use Lake Tana directly, for example out of respect for its 128 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.

135 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).

142 The questionnaires were prepared in English and pretested with Amharic translators. Pre-143 testing took place at a farming conference in Dera woreda. A total of 15 farmers of a village 144 similar to those of the study area (i.e. same woreda and water hyacinth infested shoreline) were 145 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 146 147 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 148 149 mentioned above. Households are chosen because contributions to public goods are assumed 150 to be made as a household (e.g. current land tax). In the Lake Tana area, the census in 2007 151 reported that households comprise 5members on average (Stave et al., 2017). Respondents 152 were chosen randomly within the selected kebeles. The selected kebeles were all situated on 153 the shores of the lake. Inhabitants in these kebeles live from crop production and livestock 154 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 155 156 household. In consequence of the above reasons, only men were interviewed. Qualitative 157 interviews with women were collected as well.

158 *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.

169 Three different formats of the survey were designed, dependent on the mean of 170 contributing to "the Lake Tana protection program". The method that would be used by the 171 program to eradicate water hyacinth was not explained. The objective of the study was to obtain 172 the aggregated benefits of water hyacinth control/eradication. Potential distrust towards certain 173 eradication methods could influence the willingness to contribute statement and rather reflect 174 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 175 176 amount of money in Ethiopian Birr (ETB) was asked. In the 'labor' format, respondents (n=60) 177 expressed their willingness to contribute labor to the program in man-days (8 hours of work by 178 an adult man) yearly. In the 'mixed' format, respondents (n=104) were given the possibility to 179 contribute in cash, in labor, a mix of both or to not contribute at all. Dependent on the answer 180 respondents in the mixed survey provided to this contribution question, a set of contingent 181 valuation questions were asked. Respondents were assigned one of the above three formats 182 (cash money, labor or mixed) randomly. The addition of contribution in terms of labor, contrary 183 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, 184 185 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 186 187 Woudyalew, 1994; Tilahun et al., 2015). Moreover, in rural Ethiopia, labor markets are very 188 restricted, implying the limited ability of job mobility (Swallow & Woudyalew, 1994; Tilahun 189 et al., 2015). A low willingness to pay does not necessarily imply reluctance towards the 190 program. Household incomes are often inadequate to meet basic needs, ao a sole willingness 191 to pay question may not fully reflect the value of the Lake Tana protection program. Secondly, 192 by offering the option, the strength of this assumed preference towards labor contribution can be measured. 193

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 theform and frequency of the contribution (Carson and Mitchell, 1989).

201 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 202 203 prompting questions, saves the enumerator effort and consequently time (Cameron and 204 Huppert, 1989). In addition, respondents may be uncertain to be explicit about a single point 205 of personal value, but rather have ranges in mind (Cameron and Quiggin, 1994), using intervals 206 can account for this issue. However, the formulation of predefined (as a product of the pilot 207 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 208 209 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.

217 Econometric specification

218 The data obtained by the polychotomous question are interval censored. The objective is 219 to formulate a mean WTP/WTCL with confidence intervals. According to Cameron and 220 Huppert (1989), regression models with an interval-censored dependent variable are preferably 221 estimated with an efficient maximum likelihood (ML) function, called 'interval regression' 222 (IR). This is especially relevant when intervals are coarse, which is the case for this study. 223 Another attribute determining the choice of the estimation technique is the amount of zero 224 responses. A tobit regression is preferred when the WTP data contain a high amount of zero 225 bids (O'Garra and Mourato, 2007) and with open-ended data. This was not the case in this 226 study which had only 3.5% zero bids.

For all respondents, a water hyacinth infested Lake Tana yields some utility given by
U(WH1, S, I, ε1). With WH a vector for the evolution of infestation (WH0 equals no infestation,
WH1 is the current state, WH2 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(WH₀, S, I, ε₀). The level of
infestation reduces from WH₁ to WH₀. An individual has a willingness to pay Y* for this
environmental improvement such that (Bateman and Willis, 2001):

234
$$U(WH_1, S, I, \epsilon_1) = U(WH_0, S, [I-Y^*], \epsilon_0)$$

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

237
$$U(WH_1, P, X, L, \varepsilon_1) = U(WH_0, P, X, [L-Y^*], \varepsilon_0).$$

238 Let xi be the vector that includes the income/leisure stack and the socio-economic 239 characteristics. ε_i is the random term of the individuals' WTP/WTCL, which is assumed to be 240 normally distributed with zero mean and constant error. β is the vector of interval regression 241 coefficients, with i = 1, ..., n individuals in the questionnaire sample. Cameron and Huppert 242 (1989) have defined a maximum-likelihood *interval regression*. Such that:

243
$$Y^* = x_i \beta + \varepsilon_i$$

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 (tk) and lower threshold (tk-1) in each interval.
Expressed as follows by Whitehead et al. (1995):

247
$$\Pr[Y_i^* \subseteq (t_k, t_{k-l})] = \Pr\left[\frac{(t_k - x_i\beta)}{\sigma} < z_i < \frac{(t_{k-l} - x_i\beta)}{\sigma}\right]$$

248 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 [Yi1, Yi2] as:

251 $\Pr\left(Y_{i1} < x_i\beta + \varepsilon_i < Y_{i2}\right)$

252 In the survey, people indicating to be willing to pay more /contribute more labor than the 253 maximum-stated amount are asked an open-ended follow-up question to reveal the maximum 254 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 $Pr(Y_{i1} < x_i\beta + \varepsilon_i)$. 255 256 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. 257 258 Robust standard errors were used to calculate the 95% CI on the mean WTP/WTCL. The 259 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 .

- 266
- 267 **Results**
- 268 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%).

275

276 The regressors utilized for the interval regression are outlined in Table 3 which reports 277 the results for the WTP for the status quo. Because the 'HH is owner of the plot(s)' and 'Main 278 type of agricultural activity' questions both had one very dominant answer, the additional 279 information to the model is dismissible. In the 'Estimated annual off-farm income' the 280 dominance of the first category was due to the high percentage (95%) of zero responses. In the 281 study-area there was little alternative for income but farming,; for the modelling only the farm 282 income is counted. The independent demographic variables included in the model are respondents' age, place of living, farming experience, education, water hyacinth conference 283 attendance and (farming) income. 284

285

286 *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 status 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.

303 Willingness to contribute labor

304 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 305 306 interval regression based on the status quo scenario data can be found in table 5. Respondents 307 living in Tana Mitsili, Dera were willing to contribute significantly more man-days of labor 308 compared to the other kebeles. As opposed to the willingness to pay assessment, the attendance 309 of water hyacinth local conferences (positively) influences the WTCL significantly. Model 310 reduction from (1) to (2) in Table 5 entails the removal of the variables Education due to high 311 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 mandays yearly, with 95% CI [45.4; 56.9] and a robust standard deviation of 2.9.

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.

325 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.

333 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].

338 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.

344 Discussion

345 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 346 347 a household has more income, both in the status quo and the improvement scenario. In the labor 348 survey, the attendance of water hyacinth conferences positively influences the WTCL, which 349 can be attributed to the deeper knowledge and awareness of the water hyacinth problem in Lake 350 Tana. This supports the face validity of the contingent valuation survey. It is noticeable that 351 the age is negatively correlated with the willingness to pay and – to lesser extent - willingness 352 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 353 harvesting programs and are often more connected to the (social) media, where coverage on 354 355 the issue creates increased awareness resulting in a serious concern about the future of Lake 356 Tana. Thus, they are more committed to restoring the ecosystem balance. The main conclusion 357 from the mixed survey can be drawn from the preference question. Respondents were 358 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 359 360 money and had a slightly higher mean WTP. However, the small sample didn't provide reliable 361 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 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 369 370 combination question and thus consequently overstated their willingness to contribute. Although the enumerators were trained and carefully observed during the survey, it remains 371 372 that open-ended elicitation questions are more sensitive to enumerator bias than close-ended 373 questions. Another potential explanation for the results of the mixed contribution can be related 374 to anchoring bias. In the cash and labor contribution surveys, the dichotomous question 375 preceding the willingness to contribute question in terms of polychotomous intervals may have 376 caused this anchoring effect. By presenting some monetary value or some amount of man-days 377 to contribute, respondents may have been biased to adjust their true willingness to contribute 378 in the direction of this value. This would imply that the results obtained in the open-ended 379 mixed contribution format are a closer representation of the true value of water hyacinth 380 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., 381 382 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 383 of a good may induce strategic overstatement if the respondent believes that this would 384 385 influence the provision of such a good. While conducting this study, qualitative interviews 386 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).

393 A few other factors must be taken into consideration in interpreting the results of this 394 study. First of all, one must understand the cultural context of making contributions to the state. 395 In Ethiopia, the practice of contributing free labor to the state is a longstanding tradition. As 396 opposed to other regions, community work is generally widely accepted within the study area. 397 This cultural context should be taken into account when conducting similar studies. Secondly, 398 the skewed male sample introduces a gender bias. Considering the fact that male household 399 members are obliged to contribute to the ongoing community actions, their willingness to 400 contribute is expected to be higher than those of female household members. However, in 401 opting for contribution as a household for the payment scenario's, which is typically a male's 402 decision in the study area, it was intended to reduce the influence of this sampling bias.

403 With regard to the cash constraint that was assumed, mixed evidence is observed. Firstly, 404 from the choice of contribution in the mixed survey, it could be interpreted that there is a cash 405 constraint, which impedes on the actual value of the ecosystem to the farmers. On the other 406 hand, the ratio that is observed as a result of the cash format and the labor format can be 407 interpreted as indicating otherwise. For the status quo, it is found that 1 man-day is worth 13.52 408 ETB and for the improvement scenario this ratio is 14.93 ETB/MD. Similar to Tilahun M. et 409 al. (2015), the convergence validity can be tested through using the public employers' 410 minimum wage (320 ETB per month) to make the conversion. When taking into account the 411 fact that one month entails 20 to 23 workable days on average, the value of one working day 412 lies within the range of 13.9-16 ETB. Thus, the ratio's that are obtained through the study are 413 not significantly different from the public employers' minimum wages, indicating the absence 414 of the assumption of low valuation of time. It can be concluded that simply assuming that a 415 cash constraint will influence results in developing countries is not realistic. Especially, when 416 the livelihood is directly and drastically affected by the threat, measured WTP may reflect 417 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

425 aggregative yearly contributions as shown in table 9.

426 The numbers depicted in table 9 give an indication of the willingness to contribute of 427 some of the direct users of the ecosystem services provided by Lake Tana. It is important to 428 stress that this is not the overall total benefit for a Lake Tana without water hyacinth. Only 429 three out of five infested woredas were considered in the extrapolation. Moreover, contingent 430 valuation studies often describe the influence of distance to the environmental good on the 431 willingness to contribute, implying additional (but diminishing) willingness further away from 432 the lake (Schaafsma et al., 2012; Yao et al., 2014). With 2 to 3 million people living in the 433 Lake Tana Biosphere Reserve and the importance of the ecosystem services the Biosphere 434 provides, many more stakeholders contribute to the total benefits of eradicating the water 435 hyacinth. This stakeholder approach should be complemented by further research into other 436 stakeholder groups. A similar and more recent study in Bahir Dar city with 398 urban 437 households found that households in Bahir Dar are willing to make an aggregated one-time 438 payment of 77,624,226.2 ETB (over 2,5 million euros) (Tesfa, 2019). It is clear that the 439 communal economic weight of the infestation is at a level where action should be undertaken.

440 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., 441 442 2017). For Lake Tana, the severity of the problem observed and the results of this socio-443 economic study leave no strategic solution except for adaptation. The water hyacinth is in Lake 444 Tana to stay. The socio-economic impact on local smallholders that was assessed in this study 445 justifies potential management expenditures on the control of the weed. However, as 446 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 447 448 specifically at biological control.

449 Nevertheless, alternative pathways to sustainably managing this outbreak should be 450 researched locally. Economically viable uses of water hyacinth may create benefit to support 451 local households, turning current threat into opportunities. Exemplary cases in Africa have 452 shown that water hyacinth utilization can become an economically viable alternative by 453 producing biogas, fertilizers, fibers, paper, *etc.* Bénin and Lake Victoria (Güereña et al., 2015; 454 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 (455 https://www.biofit.co.ke) profitably produces qualitative livestock feed with water hyacinth as 456 457 a raw material, having clear socioeconomic benefits: creating employment and enhancing 458 farming efficiency. Greenkeeper Africa (http://www.greenkeeperafrica.com), based in Bénin, 459 has developed a water hyacinth sorbent to remediate oil-based pollutions, benefitting society 460 and environment. In Nigeria, the company Green Energy Biofuels (http://www.gebiofuels.com) specializing in biofuels for cooking stoves, is currently pilot 461 462 testing with water hyacinth as feedstock and claims promising first results. Such examples 463 prove that initiating or supporting businesses that create a return on investment from water 464 hyacinth is impactful in the short term, which is, given the severity of the implications on the 465 population, highly desirable. Further research should target the readiness and willingness to 466 generate business, identifying actual barriers and pathways to overcome these.

467 Because the most affected stakeholder group around Lake Tana, currently are local 468 smallholders who are already vulnerable, governments or possibly NGO's should look beyond 469 them to release the burden. Possible management options should advance from the current 470 biological/chemical/mechanical eradication debate and explore integrated approaches, 471 requiring other investments. These (public) investments should be targeted at improved waste 472 water management to reduce the favorable environment for water hyacinth. Infrastructure investments to benefit from the occurrence of water hyacinth, leading to water hyacinth 473 474 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 475 476 for processing water hyacinth into a productive resource in newly defined business processes 477 may be the strategically opportune decision.

478 Conclusion

479 The water hyacinth infestation of Lake Tana, officially recognized in 2011, led to disruptions 480 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 481 482 hyacinth control, using the contingent valuation method. The sample size exists of 240 483 households in the Dembiya, Lemba Arabayitu and Dera woredas bordering the northern to 484 northeastern shores of Lake Tana. Through this participatory approach, the severity of the 485 infestation as perceived by the most affected stakeholder group was put into numbers for the 486 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.

498 Given the experiences of other water bodies in Africa (e.g. Lake Victoria) and the 499 urgency that is resembled by the numbers in this study, we advise responsible bodies to look 500 beyond the current debate on mechanical/biological/chemical control and advance to explore 501 sustainable solutions in both water-waste management and water hyacinth utilization. After all, 502 the infestation has reached a level where adaptation is inevitable, because previous examples 503 show that eradication is costly, technically difficult and often impossible. Further research is 504 required on the economic damage of the water hyacinth infestation, but also on the pathways 505 to creating socioeconomic benefit from the weed. On top of that, economic implications of 506 water hyacinth on the ecosystem services provided by Lake Tana and the overall economic 507 value of the Lake should be researched to a greater extent, for justifiable and sustainable 508 ecosystem management.

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679 Tables

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681 Table 1

682 Definition of regressors utilized in interval regression.

Variables		Description	Mean (SD)
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 more than 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)

685 686 Table 2

Descriptive statistics of survey respondents.

Variable	n	68%
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

688Table 3. WTP interval regression results for the status quo scenario. The baseline model was defined689as the full model (1) which including all regressors. Subsequently, regressors without statistical690significance were removed from the estimating model (in columns (2) and (3)), until further691reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust692standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p</td>693< 0.05, *** p < 0.01</td>

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	26.1 (117.4)	24.5 (122.1)	24.08 (121.8)
Farming Experience 11-20	161.8 (128.1)	168.7 (128.8)	168.6(129.1)
Farming Experience > 20	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)*	251.0 (140.3)*	252.5 (133.4)**

698Table 4. WTP interval regression results for the improvement scenario. The baseline model was699defined as the full model (1) which including all regressors. Subsequently, regressors without700statistical significance were removed from the estimating model (in columns (2) and (3)), until701further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with702robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p <</th>7030.10, ** 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)**

707 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 <
- **713** 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	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)***

716 Table 6. WTCL interval regression results for improvement scenario. The baseline model was defined717 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

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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	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)***

725 Table 7.Mixed survey; choice of contribution.

Contribute	Frequency (%) 726
Cash	25 (24)
Labor	58 (56)
Mixed	18 (17)
Not contribute	3 (3)

727 Table 8. Summary of results from the mixed survey.

		Status quo	Improvement
		Mean	Mean
Cash		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

728 729 730 Note: * Status quo: 1 MD = 440.9/32.6 ETB, Improvement: 1 MD = 764.4/51.2 ETB. ** Status quo: 1 ETB = 32.6/440.9 MD, Improvement: 1 ETB = 51.2/764.4 MD.

Table 9

732	Aggregated yearly	willingness	to contribute
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	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

Figures Fig. 1



739 Figure captions

Fig. 1: map of the Lake Tana water hyacinth infestation, adaptated from Dejen et al. (2017)

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