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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

3 According to Anteneh et al. (2014), Lake Tana has been infested with water hyacinth
4 (*Eichhornia crassipes*) since 2011. Water hyacinth is an aquatic alien invasive species (AIS),
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
11 often yields temporary reductions in the coverage, biological control is a widely applied
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 Groot et al., 2003; Irving &
17 Beshir, 1982). In Benin, the biological water hyacinth control was estimated to have
18 outweighed the costs with a 124:1 ratio (De Groot et al., 2003), in South Africa the benefit to
19 cost ratio was calculated at 4.2:1 (Law, 2008).

20 Water hyacinth infestations lead to ecological and socio-economic disruptions. In the
21 Lake Victoria basin water hyacinth has been impacting local communities' livelihoods since
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

35 on the substantial negative economic impact of water hyacinth in other lakes, like Lake
36 Victoria, 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,
46 1989). As a result of the water hyacinth infestation, these ‘public goods’ cannot be enjoyed to
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,
53 2007; Villamagna and Murphy, 2010). There is a need to estimate the damage to local
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
63 implications can be estimated. In reporting and explaining these implications on the lake’s
64 ecosystems and the people that rely on them, this research aims to provide input for decision-
65 making and local ecosystem management. The results enable cost-benefit analyses and serve
66 to justify the cost of control/eradication measures.

67

68 **Methods and materials**

69 *Study area*

70 Formed 5 million years ago by volcanic activity, Lake Tana is the largest freshwater body
71 in Ethiopia and accounts for approximately 50% of Ethiopia's surface freshwater reserves. It is
72 the source for the Abay river (Blue Nile) which makes up 85% of the total Nile River discharge
73 (Sewnet & Kameswara, 2011). The Lake Tana ecosystem was designated as a 'Biosphere
74 Reserve' by UNESCO in 2015. This Man and Biosphere Reserve program aims at "*improving*
75 *the overall relationship between people and their environment*" (UNESCO, 2017). Lake Tana
76 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
80 and ranges up to a maximum depth of 14 meters (Anteneh et al., 2015). It lies at an elevation
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
85 levels are high in the rural landscape of the study area. High population growth rates and
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
89 participate in regular physical removal campaigns. Water hyacinth infestations follow a
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
93 administrative unit in Ethiopia), at least one household member is obliged to contribute. Larger
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
106 woredas, one kebele was surveyed: Achera Mariam in Dembiya, Lemba Arbayitu in Gondar
107 Zuria and Tana Mitsili in Dera (indicated on fig. 1). According to Anteneh (2015), the
108 infestation in Tana Mitsili is the most recent and consequently the least severe. On the contrary,
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*

113 To estimate the value of the water hyacinth removal, the contingent valuation method
114 (CVM) was applied (Loomis et al., 2000). The CVM is a stated-preference method for
115 economic valuation: surveys are carried out to elicit respondents' willingness to pay and/or
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
124 (Holmes et al., 2017), which is not the objective with this study. Lastly, the ability of CVM to
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.

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

135 *Data collection*

136 The community surveys were conducted in November 2017. This period coincides with the
137 harvesting season for water hyacinth. From September/October to January – at the end of the
138 rainy season - the weed expands most rapidly. During this period local communities organize
139 campaigns to manually remove the water hyacinth. These manual removal campaigns usually
140 consist of harvesting the water hyacinth plants and piling them up on the shores (picture in
141 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
146 revised to ensure clarity. The revised survey was translated to Amharic. The surveys were all
147 carried out by trained development agents, in the company of local experts and the first author
148 (Van Oijstaeijen, W.). The units of analysis in this study were households living in the kebeles
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 5 members 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
155 household head (HH), he is still primarily responsible for economic decisions within the
156 household. In consequence of the above reasons, only men were interviewed. Qualitative
157 interviews with women were collected as well.

158 *Questionnaire design*

159 Respondents were first asked some general, introductory questions about their use and
160 appreciation of Lake Tana. Subsequently, enumerators provided the respondent with an
161 information card (ESM Appendix S1). This information card stated the current water hyacinth
162 problem and the threats posed by the issue to the ecosystem (Bräuer, 2003). The information
163 card was read by the enumerator in case of illiteracy. Following the problem statement, the
164 hypothetical market called “The Lake Tana protection program” was defined, before
165 proceeding to the willingness to contribute labor (WTCL) or willingness to pay (WTP)

166 questions. The end of the survey consisted of socio-demographic information questions. In
167 drafting the survey and processing the results, widely accepted guidelines (Arrow et al., 1993)
168 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.

175 In the ‘cash money’ format, respondents’ (n=76) willingness to pay in terms of a yearly
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
184 households were not indifferent to contributing in money and labor. Previous studies,
185 introducing both cash and labor contributions in developing countries, found the cash
186 constraint and low valuation of time as main drivers (Kamuanga et al., 2001; Swallow and
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, so 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
193 be measured.

194 Two scenarios for the hypothetical market were developed: a status quo scenario and an
195 improvement scenario. In the status quo scenario, the Lake Tana protection program would
196 keep the level of water hyacinth infestation constant at the current level. In the improvement
197 scenario, the Lake Tana protection program was presented to entail the complete removal of
198 all water hyacinth. The last scenario was merely hypothetical because the complete removal of

199 an infestation is often extremely challenging. Respondents were clearly informed about the
200 form and frequency of the contribution (Carson and Mitchell, 1989).

201 Polychotomous questions allow the interviewee to receive additional information, while
202 not deviating from the Referendum Format. The fact that it may be superfluous to ask
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
208 the actual survey were the result of the pre-tests. The result of offering ranges to choose from
209 is similar to a payment card approach and its processing (Welsh and Poe, 1998).

210 If a respondent of the mixed survey stated to be willing to contribute a combination of
211 cash and labor, an open-ended question was asked to express the maximum WTP/WTCL.
212 Open-ended questions are often less favored due to the possible occurrence of non-responses
213 and protest zeros (Carson and Mitchell, 1989). In the presence of trained enumerators, this
214 concern was not applicable to this study. After the elicitation of WTP/WTCL in the status quo
215 scenario, respondents proceeded to an identical question on the WTP/WTCL in the
216 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.

227 For all respondents, a water hyacinth infested Lake Tana yields some utility given by
228 $U(WH_1, S, I, \epsilon_1)$. With WH a vector for the evolution of infestation (WH_0 equals no infestation,
229 WH_1 is the current state, WH_2 would imply that the lake surface is completely covered), S is
230 the vector of socio-economic characteristics, I represents income and ϵ denotes randomness in

231 the data. Their utility of a non-infested Lake Tana is given by $U(WH_0, S, I, \varepsilon_0)$. The level of
 232 infestation reduces from WH_1 to WH_0 . An individual has a willingness to pay Y^* for this
 233 environmental improvement such that (Bateman and Willis, 2001):

$$234 \quad U(WH_1, S, I, \varepsilon_1) = U(WH_0, S, [I-Y^*], \varepsilon_0)$$

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

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

238 Let x_i 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 $i = 1, \dots, n$ individuals in the questionnaire sample. Cameron and Huppert
 242 (1989) have defined a maximum-likelihood *interval regression*. Such that:

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

244 In the interval-censored data, the true WTP/WTCL Y^* of a respondent is not expressed as a
 245 point value but lies between an upper threshold (t_k) and lower threshold (t_{k-1}) in each interval.
 246 Expressed as follows by Whitehead et al. (1995):

$$247 \quad \Pr[Y_i^* \subseteq (t_k, t_{k-1})] = \Pr \left[\frac{(t_k - x_i\beta)}{\sigma} < z_i < \frac{(t_{k-1} - x_i\beta)}{\sigma} \right]$$

$$248 \quad \text{With } z_i = \frac{x_i\beta}{\sigma} .$$

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

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

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
 255 absence of an upper bound. This likelihood contribution is described as $\Pr (Y_{i1} < x_i\beta + \varepsilon_i)$.
 256 The maximum likelihood functions that were used are all estimated with the *intreg* commando
 257 in STATA 15. The individual mean WTP/WTCL is estimated using the regression's results.
 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,

260 variables were iteratively removed from the baseline model, creating more parsimonious
261 models, to improve interpretability and avoid overfitting. As a mean of control, ordered logistic
262 regressions were run for every model to verify the interval regression's conclusions. For the
263 mixed survey regional differences in responses on the contribution question were examined
264 through a Fischer's Exact test. This is commonly used to examine the relation between two
265 categorical variables when one or more cells have an expected value ≤ 5 .

266

267 **Results**

268 *Descriptive analysis*

269 A total of 240 households correctly completed the contingent valuation questionnaire,
270 of which 3.75% stated zero WTP/WTCL. Table 1 provides an overview of the participants'
271 demographics. The exploratory questions in the beginning of the survey revealed that
272 respondents value Lake Tana most importantly for the services it provides supporting crop
273 production (90%) and livestock farming (71%). Other services stated as important are
274 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
283 respondents' age, place of living, farming experience, education, water hyacinth conference
284 attendance and (farming) income.

285

286 *Willingness to pay*

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

292 to pay of 440.9 ETB yearly (\approx €(euros) 13.5) for the status quo scenario, with 95% CI [376.8;
293 505.0] and robust standard error of 32.7. Interval regression coefficient estimates are shown
294 in table 4. The Lake Tana protection program has a mean WTP value of 764.4 ETB yearly (\approx
295 €23.4), with 95% CI [647.2;881.6] and robust standard error of 59.8.

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

303 *Willingness to contribute labor*

304 Respondents who were interviewed through the WTCL survey stated their willingness to
305 contribute labor in terms of personal man-day labor contribution. The estimations of the
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.

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

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

320

321 *1.1 Mixed survey format*

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

325 Mixed survey – cash

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

333 Mixed survey – labor

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

338 Mixed survey – combination

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

344 **Discussion**

345 The results from the cash and labor surveys indicate that the WTP and WTCL
346 respectively vary in logical ways. For example, the cash survey indicated a higher WTP when
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

353 qualitative interviews in the study-area. Youth are more involved in the water hyacinth
354 harvesting programs and are often more connected to the (social) media, where coverage on
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
359 mixed survey, it was found that respondents deliberately opted to contribute in terms of cash
360 money and had a slightly higher mean WTP. However, the small sample didn't provide reliable
361 evidence.

362 Including a mixed survey format provided useful insights. First of all, it allowed
363 verification of the results in a realistic market situation where customers have the option to
364 contribute in any way possible. All beneficiaries of a water hyacinth-free Lake Tana have the
365 option to contribute to the current problem in terms of labor, to donate money for
366 research/machines, to combine these previous options or not to contribute in any manner.
367 Secondly, the total value of the bundles that were stated by people choosing for the combination
368 option were much higher than the values obtained in the regular cash and labor formats.

369 Different factors may underlie these results; respondents may have misunderstood the
370 combination question and thus consequently overstated their willingness to contribute.
371 Although the enumerators were trained and carefully observed during the survey, it remains
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
381 have given evidence to significant overstatement of the actual willingness to pay (Green et al.,
382 1998). Open-ended questions result in increased uncertainty and subsequently in biased
383 statements. Moreover, Bateman et al. (1995) found that positive interests in the conservation
384 of a good may induce strategic overstatement if the respondent believes that this would
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

387 Tana and are severely negatively affected in their livelihood by AIS. This is a source for
388 strategic overstatement. Additionally, the unrealistic prospect of completely eradicating water
389 hyacinth on Lake Tana may cause a willingness to contribute that is influenced by a short-term
390 view. Respondents may be convinced that profound sacrifices of time/money now will solve
391 the problem within a short time period, leading to unrealistically high contributions if the
392 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.

418 Having evidence of the validity of the survey responses, one can extrapolate these
419 findings on the broader population. The study-area consists of three kebeles in three different
420 woredas. Hence, the results are extrapolated on all households in the infested kebeles of these

421 three woredas. In Dembiya seven kebeles are infested (9,834 households), in Gondar Zuria five
422 kebeles are infested (11,129 households) and in Dera one kebele is infested (2,051 households).
423 In total 23,014 households are thus affected in these three woredas. Extrapolating the values of
424 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
441 in four sequential strategies: identification, protection, mitigation and adaptation (Vaz et al.,
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
447 persists. Currently, it should be noted that the research around Lake Tana is targeted
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

455 give evidence of creating added value from water hyacinth. In Kenya, Biofit Agritech (
456 <https://www.biofit.co.ke>) profitably produces qualitative livestock feed with water hyacinth as
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
461 (<http://www.gebiofuels.com>) specializing in biofuels for cooking stoves, is currently pilot
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
473 investments to benefit from the occurrence of water hyacinth, leading to water hyacinth
474 utilization, may provide a sustainable solution to adapt to the newly defined ecosystem. With
475 regard to sustainable ecosystem and resource management, providing the necessary equipment
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
481 approach focusing on local smallholders around Lake Tana to assess the value of water
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

487 (€23.4) per household or yearly willingness to contribute labor of 51.2 man-days per household
488 for the eradication of this alien invasive species. Aggregating these results over the study area
489 yields a yearly willingness to pay of over half a million euros or willingness to contribute labor
490 of over one million man-days per year.

491 These findings support previous qualitative research in a tangible, quantitative approach
492 which can be used as an input to cost-benefit analyses regarding control efforts or alternative
493 solutions. In this study, only the impacts on smallholders were researched; studies on the
494 (potential) impact on other actors is advised for a comprehensive assessment of the total
495 benefits the water hyacinth eradication/control entails. Moreover, using different valuation
496 methods (choice experiments, travel cost methods, etc.) would enhance a complementary and
497 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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678

679 **Tables**

680

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)

683

684

685 Table 2
686 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

688 Table 3. WTP interval regression results for the status quo scenario. The baseline model was defined
 689 as the full model (1) which including all regressors. Subsequently, regressors without statistical
 690 significance were removed from the estimating model (in columns (2) and (3)), until further
 691 reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust
 692 standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p
 693 < 0.05, *** p < 0.01

694

695

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)**

696

697

698 Table 4. WTP interval regression results for the improvement scenario. The baseline model was
699 defined as the full model (1) which including all regressors. Subsequently, regressors without
700 statistical significance were removed from the estimating model (in columns (2) and (3)), until
701 further reductions negatively influenced the log likelihood. The coefficient estimates are listed, with
702 robust standard errors in parentheses and statistical significance is illustrated with asterisks: * p <
703 0.10, ** p < 0.05, *** p < 0.01

704

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)**

705

706

707 Table 5
708 WTCL interval regression results for status quo scenario. The baseline model was defined as the full
709 model (1) which including all regressors. Subsequently, regressors without statistical significance
710 were removed from the estimating model (in columns (2) and (3)), until further reductions negatively
711 influenced the log likelihood. The coefficient estimates are listed, with robust standard errors in
712 parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p < 0.05, *** p <
713 0.01

714

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)***

715

716 Table 6. WTCL interval regression results for improvement scenario. The baseline model was defined
 717 as the full model (1) which including all regressors. Subsequently, regressors without statistical
 718 significance were removed from the estimating model (in columns (2) and (3)), until further
 719 reductions negatively influenced the log likelihood. The coefficient estimates are listed, with robust
 720 standard errors in parentheses and statistical significance is illustrated with asterisks: * p < 0.10, ** p
 721 < 0.05, *** p < 0.01

722

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)***

723

724 Table 7.Mixed survey; choice of contribution.
725

Contribute	Frequency (%)
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 *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,*
 729 *Improvement: 1 ETB = 51.2/764.4 MD.*

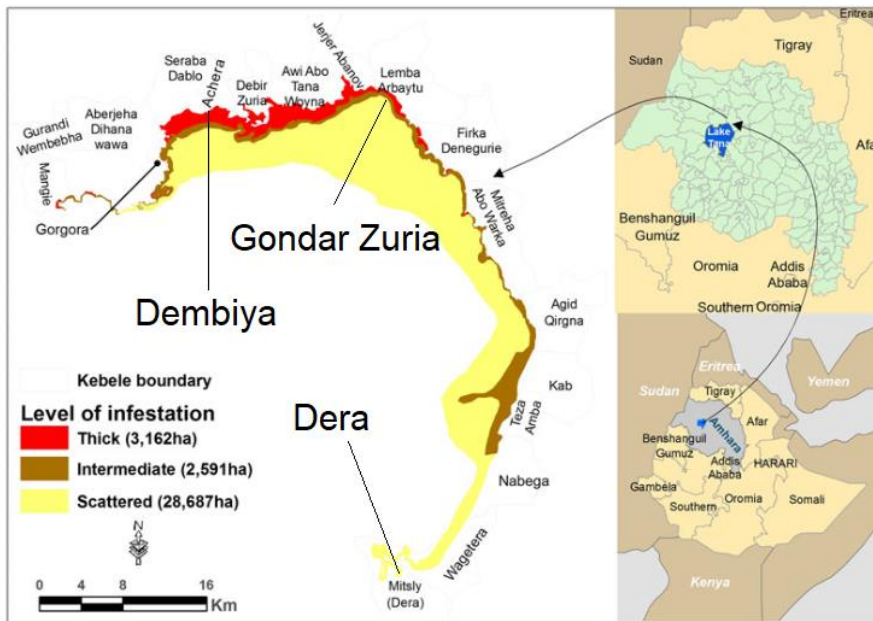
730

731 Table 9
 732 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

733 * Based on currency conversion rate in may 2018
 734

735 **Figures**
736 **Fig. 1**



737

738 **Figure captions**

739

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

740

741

742