The potential of floating macrophytes as feed and phytoremediation resources to improve the environmental performance of giant gourami production in Indonesia: A life cycle assessment

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2 **the environmental performance of giant gourami production in Indonesia: A Life Cycle**

3 **Assessment**

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Abstract

Over the past few decades, Indonesian freshwater aquaculture has intensified, raising many issues on the associated environmental impacts. In this study, a life cycle assessment (LCA) approach was used to assess the environmental performance of Indonesian giant gourami (*Osphronemus goramy*) aquaculture. We compared two contrasting fish production systems: a traditional monoculture (MoC) or a co-culture with the macrophyte *Azolla filiculoides* used as feed alternative to compounded pellets (CoC). Seven impact categories were considered: climate change, eutrophication, cumulative energy demand, land occupation, acidification, net primary production use (NPPU) and water dependence. The potential impacts were calculated in terms of 1 kg of fish produced by the systems and were also expressed in terms of surface area (m^2 of the farm). Monte Carlo analysis was carried out to evaluate uncertainties in the assessed impacts based on data uncertainties for the systems. Results highlighted notable differences between the two production systems. CoC led to less impact relative to climate change, eutrophication and NPPU per kg of fish produced. These differences were even greater when reporting the impacts per surface area. Nonetheless, the main contributors of the seven impact categories remained constant between the two production systems (CoC and MoC). Overall, our findings suggested that using floating macrophytes as alternative feed resources, even in relatively low proportions, can improve the environmental performance of giant gourami production.

Keywords: Agroecology, Asia, Aquaculture, Freshwater, LCA

1. Introduction

With a production of 4.3 million tons of farmed fish in 2020, Indonesia is the third-largest fish aquaculture producer country in the world (FAO, 2022a). Since the government made aquaculture development a national priority in 2009 (Phillips et al., 2015; Rimmer et al., 2013), fish farming has shown the most rapid expansion of all Indonesian agronomic production sectors, with an average annual growth of 9% over the last decade (FAO, 2022b). This sector indeed plays a significant role in the national economy, ensuring food availability and security and improving living standards for rural communities (Rimmer et al., 2013). Excluding seaweed, freshwater fish farming represents 66% of aquaculture production in Indonesia (FAO, 2022b) and relies mainly on small-scale farms, which represent 90% of all fish farms (Maskur et al., 2013). Small-scale fish farmers usually practice aquaculture using low-input and low-level technology (Pouil et al., 2019). Nevertheless, the increasing demand for freshwater aquaculture products has driven a shift from low-intensive traditional culture methods to semi-intensive monoculture production systems. This intensification was accompanied by an increase in the use of commercial fish pellets (Edwards, 2015; Rimmer et al., 2013), involving a decrease in the proportion of non-fed Asian aquaculture by a factor of two since the 2000s (excluding China; FAO, 2022b). Such changes raise many issues on the actual effectiveness of current production systems regarding the use of resources and the associated negative environmental impacts. These negative impacts are further reinforced by the large amounts of solid effluents (faeces, feed wastes) and dissolved nutrients (waste products) discharged resulting from the use of commercial feeds, which contribute to eutrophication of wild aquatic ecosystems. Several freshwater reservoirs in Java, where fed fish farming has proliferated, experienced water quality degradations leading to the occurrence of disease outbreaks and fish death (Rimmer et al., 2013).

57   Indonesian aquaculture must become more sustainable to meet the national demand for

58   aquaculture products and also limit their environmental footprint. Henriksson et al. (2019)

59   evaluated possible interventions and innovations to mitigate environmental impacts related to the

60   growth of Indonesian aquaculture. The authors found that improving feed efficiency for white

61   leg shrimp, common carp and tilapia by 20% witnessed major reductions in environmental

62   impacts. Such interventions imply the design of aquaculture systems that use fewer chemical

63   products and commercial feeds, more renewable resources, and make the best use of ecosystem

64   services without impairing their regeneration. Such systems can be called "ecologically

65   intensive" (Griffon, 2010), having a high level of production per surface area but using

66   ecological processes as much as possible to optimize natural resource use and develop ecosystem

67   services (Bonny, 2011). In recent years, a growing effort has been made worldwide to implement

68   ecological intensification in aquaculture (Aubin et al., 2019), particularly by increasing the

69   complexity of rearing systems using different complementary species as in integrated multi-

70   trophic aquaculture (Jaeger and Aubin, 2018). However, the proof of concept must be enhanced,

71   and comparative studies of different production systems for the same species remain scarce.

72   Among the fish species reared in Indonesia, giant gourami *Osphronemus goramy* is one of the

73   primary freshwater commodities of economic importance due to its high price and local demand

74   (FAO, 2019). With its propensity to consume plant-based feeds, giant gourami is a valuable

75   candidate for low-input aquaculture (FAO, 2019) and for integrating fish production and plant

76   culture. Giant gourami production in Indonesia is mainly located on Java Island (79% of the

77   national giant gourami production; BPS, 2013) and is strongly segmented (FAO, 2019). Rearing

78   takes place in ponds exclusively dedicated to giant gourami or shared with other species

79   (Kristanto et al., 2020). Slembrouck et al. (2018) evaluated *Azolla* as the best candidate among

80 five floating macrophytes species for the ecological intensification of small-scale fish farming in

81 tropical areas. Recently, a study evaluated the feasibility of combining the production of the

82 floating macrophyte *Azolla filiculoides* in giant gourami ponds (Caruso et al., 2021), with the

83 macrophytes being used as an alternative fish feed. Compared with those from a conventional

84 giant gourami monoculture system exclusively based on exogenous commercial feeds (Caruso et

85 al., 2021), the use of *Azolla* proved to be economically advantageous by reducing the amount of

86 commercial pellets used while maintaining a similar growth rate of the fish and biomass gain at

87 the end of the trial. However, this study was not dealing with the environmental impacts of using

88 such alternative production system compared to the conventional monoculture production.

89 A holistic approach is needed when considering the environmental impacts of production

90 practices, and life cycle assessment (LCA) is considered a suitable tool for analysing aquaculture

91 production systems (for review, see Bohnes et al., 2019). LCA is an international standardized

92 method (ISO, 2006) designed to evaluate the global impact of a product or a process on the

93 environment. Such evaluation implies the assessment of all the phases required for or caused by

94 the product's existence; they include raw material uses and energy production, manufacturing,

95 transport and emissions released into the environment at each stage until the product's end of life.

96 Over the last two decades, LCA has been regularly used to assess the environmental impacts of

97 aquaculture production (e.g., Aubin et al., 2006; Medeiros et al., 2017; Mungkung et al., 2013;

98 Yacout et al., 2016). Several environmental impact categories are regularly used to assess

99 aquaculture systems (Aubin et al., 2006; Bohnes et al., 2019; Henriksson et al., 2012;

100 Papatryphon et al., 2004). One advantage of LCA is that it allows different products or systems

101 to be compared using the same functional unit. Despite the usefulness of LCA, there are various

102 limitations to its application. One of the critical challenges is the necessity to incorporate

103 uncertainty in the calculations to produce more robust outcomes (Mendoza Beltran et al., 2018).

104 The present study aimed to assess the potential benefits of ecological intensification in

105 Indonesian fish farming. Thus, our objectives were (1) to evaluate the environmental

106 performances of two production systems of giant gourami aquaculture, with or without the

107 integration of a co-cultured floating macrophyte (*A. filiculoides*) and (2) to identify the sources

108 of uncertainties in the environmental impacts. We hypothesized that the use of *Azolla* as an

109 alternative feed should reduce net primary production use, energy demand and climate change

110 impacts by partially substituting commercial feeds while decreasing eutrophication by improving

111 nutrient recycling (Caruso et al., 2021).

112 **2. Materials and Methods**

113 2.1. Description of the production system

114 2.1.1. Giant gourami production system

115 Although the giant gourami production cycle is not well standardized in Indonesia (Kristanto et

116 al., 2020), its propagation relies on the natural spawning of captive brooders in ponds and

117 includes the seven following production segments:

118 1) The hatchery phase lasts 10 days from egg incubation to 8-9 days after hatching.

119   Larvae are kept unfed during this period.

120 2) The nursery phase lasts until juveniles reach 2 ± 0.5 cm of length (40 days; Prakoso et

121   al., 2019). Tubifex (*Tubifex tubifex*) worms, usually purchased on local markets, are

122   the first and primary food provided during larval rearing (i.e., nursery phase).

123   3)   The pre-growing I stage lasts 150 days until juveniles reach 30 g. Commercial feed

124   (~33% of crude protein) is introduced at the beginning of this segment.

125   4)   The pre-growing II stage, until juveniles reach 180 g (from the "jingo" to the

126   "dampal" stage), is the first stage of the production cycle during which fish are able to

127   eat plant materials (FAO, 2019). This production stage lasts 160 days.

128   5)   The growing phase lasts 120 days. During this phase, fish are fed with commercial

129   pellets and plant materials (mainly giant taro *Alocasia macrorrhizos* leaves). At the

130   end of this production phase, fish of ≤ 500 g are sold, and the biggest fish are selected

131   as future brooders.

132   6)   Brooder selection lasts 210 days, where fish of ≥ 2000 g are sorted by sex and

133   separated. Plant materials become the predominant feed at this stage, and commercial

134   feeds are used as supplements.

135   7)   The egg production period is continuous throughout the year. The average weight of

136   brooders used for egg production is 3.6 kg, and they are usually kept for 10 years of

137   production.

138   Note: all the values used in our analysis are average values gathered from surveys of

139   approximately 40 giant gourami farms (Kristanto et al., 2020).

140   Except for hatchery and nursery phases, usually performed in plastic basins and wooden tanks

141   covered by tarpaulin filled with stagnant water, all the production phases are performed in flow-

142   through systems, mainly in earthen ponds of 300-1000 m^2 in size with gravity-flow water supply

143   system from local reservoirs or upstream aquaculture farms. The production chain for giant

144   gourami is shown in Figure 1.

145   2.1.2. Scenarios of production: experiment details and records

146   The system under study consisted of a typical small-scale Javanese polyculture fish farm where

147   farmers can quickly shift from one species to another to better adapt to the market and the

148   difficulties encountered. Kristanto et al. (2020) underlined that giant gourami is mainly produced

149   by farmers producing other species in variable proportions. Thus, only about 50% of the surface

150   is dedicated to giant gourami rearing. The production capacity is about 2 tons per year. All the

151   production is sold on local markets (< 10 km of the production site). The farm included in this

152   study is located in Bogor district, West Java, in the village of Babakan (-6°28'S; 106°42'E; alt:

153   125 m). The farm size (i.e., 2100 m^2) is in the range typically observed locally (Kristanto et al.,

154   2020). While a non-negligible number of aquaculture farms are located in the peri-urban area in

155   West Java (see Kristanto et al. (2020) for details), our study site is mainly bordered by rice

156   fields.

157   The studied production cycle, which lasts 160 days (i.e., two production cycles per year),

158   consisted in rearing giant gourami from 30 to 180 g of average fresh weight (i.e., from the

159   "jingo" stage to the "dampal" stage). This phase corresponds to the pre-growing stage II

160   described in section 2.1.1 (Figure 1). "Jingo" fish were purchased from the neighbourhood and

161   were stocked at a density of 6 fish m^{-2}.

162   The production system consisted of four earthen ponds, whose size varied between 353 and 482

163   m^2 with depths ranging from 0.46 to 0.55 m. Each pond was equipped with PVC pipes for inlet

164   and outlet water; anti-predator nets held by bamboo poles were placed 1 m from the banks.

165   Ponds connected in series were filled by gravity with water from a reservoir located at <1 km

166   from the farm. Before production, ponds were dried; the bottom was levelled and the banks were

167   consolidated with sediment accumulated during the previous production cycle. Then, unwanted

168   species were removed and the water, transported by gravity from a reservoir located at <1 km

169   from the farm, was limed and fertilized using organic fertilizer (typical composition: poultry

170   manure mixed with rice bran at a 0.5:1 ratio on a dry weight basis; Purnomo et al., 2017).

171   Production takes place in open-flow water (average water renewal 4-8% d^{-1}).

172   Traditionally, giant gourami are reared in a monoculture system (MoC). To evaluate the

173   possibilities of using floating macrophytes for ecological intensification of tropical freshwater

174   fish aquaculture, as suggested by Slembrouck et al. (2018), an experiment was carried out

175   throughout one 160-day production cycle in 2018 to test a new giant gourami rearing system

176   based on co-culture with *Azolla* (CoC). Here, the two production systems (CoC and MoC) were

177   operated as described below.

178   The MoC system fed fish exclusively on commercial extruded pellets of known composition

179   (Table 2). According to fish growth, the daily ration was 3 to 5% of the estimated wet biomass

180   which is slightly higher than what is usually done by farmers (FAO, 2019). The final feed

181   conversion ratio (FCR) reached 2.8. Fertilizer was regularly added to the ponds (equiv. 6 kg m^{-2}

182   per year) to stimulate primary productivity. The annual fish production volumes reached 2 kg m^{-2}

183   in this production system, and mortality was 8% per production cycle.

184   In the CoC system, *Azolla* was cultivated in the space available between the banks and the anti-

185   predator net (80 m^2 of production surface) (Figure 2) in earthen ponds managed as described

186   above with slightly higher use of fertilizer than in the MoC system (i.e., 7.5 kg m^{-2} an^{-1}). Fish

187   were fed for two days with extruded pellets as described above, then one day with *Azolla* at a

188   food ration of 8% of the estimated fish biomass. Such rationing corresponds to the amount of

189   *Azolla* the fish can ingest within 24h. *Azolla*, coming from an initial stock maintained in two 33

190   m^2 tarpaulin tanks, was stocked at an initial concentration of 400 g m^{-2}, and *Azolla* growth was

191   checked every three days (before distribution to the fish). *Azolla* was regularly sampled for

192   chemical analyses (Table 2). During our experiment, stable production of *Azolla* was not met as

193   initially planned, and its production regularly collapsed in the ponds. During the 160-day fish

194   production cycle, only two cycles of *Azolla* production occurred for a total of 40 days of

195   production. A complementary experiment was performed to understand better the limiting

196   factors in the mass production of *Azolla* in ponds (Pouil et al., 2020). That experiment suggested

197   that phosphorus (P) was likely the main limiting factor in *Azolla* production, with an average of

198   0.4 µmol L^{-1} measured in the ponds, with the optimal growth occurring at a concentration of 2.0

199   µmol L^{-1}. In addition, the occurrence of grazing snails (3-4 adult individuals m^{-2}) may reduce

200   *Azolla* production by 35% (Pouil et al., 2020). Thus, we built a scenario based on the

201   extrapolation of the data (i.e., zootechnical and economic performance, chemical analyses)

202   collected when co-culture was effective (i.e., 40 days) for the entire 160-day production period,

203   and uncertainty related to the production of *Azolla* was included in the uncertainty analysis (see

204   Section 2.6). The mortality and the annual fish production volume were comparable to the MoC

205   system (i.e., 2 kg m^{-2}), and the FCR reached 2.1 given the average reduction of ~25% of the

206   extruded pellets used.

207   2.2. Assessment methodology

208   2.2.1. Goal and scope

209   This LCA study followed ISO standards (ISO, 2006) and aimed at evaluating the environmental

210   relevance of ecological intensification of giant gourami culture by integrating a co-culture of

211   *Azolla*, which may provide the ecological services of water depuration and provision of

212   complementary feed for fish. Environmental performances of earthen pond-based production of

213   giant gourami aquaculture were evaluated through: (1) a traditional semi-intensified monoculture

214   system as used in West Java province (MoC), (2) a co-culture production system including

215   *Azolla* (CoC). This study is based on experimental results designed to compare the efficiency of

216   the two rearing systems. The results were expressed per kg of fresh fish and m^2 of surface area.

217   As an additional information, results expressed per kg of protein are also available in the

218   Supplementary Material (Table S1).

219   The system boundaries used in this study were from "cradle to farm gate" (Figure 2). They

220   included the production of capital goods (infrastructure and equipment), the production of

221   organic fertilizers and lime, the production of fish feed (including the production of ingredients

222   from agriculture or fishery sectors), the production of fish juveniles, farm operations (including

223   the local emission of nutrients and pollutants), the use of energy sources, and the transportation

224   of critical inputs (juveniles, fish feed, equipment), and the transport of fish from the farm gate to

225   the local market by motorcycle or small trucks.

226   2.2.2. Life cycle inventory

227   Inventory data for giant gourami fingerling production and brooder management were compiled

228   mainly by collecting the data from fish farms and production centres producing giant gourami

229   fry located in the Bogor and Tasikmalaya regencies (n=37, Kristanto et al., 2020). We also used

230   experimental data from the experiments we performed on giant gourami egg production in the

231   BPPSIGN Center, Tasikmalaya (Arifin et al. 2020; Slembrouck et al., 2019, 2020) and larval

232   rearing in the RIFAFE, Cijeruk (Arifin et al., 2019; Prakoso et al., 2021).

233 The inventory of the experimental phase was recorded during daily on-site monitoring of one

234 entire production cycle from November 2017 to April 2018. The descriptive data concerning the

235 studied sub-system are summarized in Table 1. The inventory covered farm operations, as well

236 as the following processes: production of farm inputs such as energy carriers, fertilizers,

237 juvenile, exogenous feeds (including ingredient production and processing), and farm equipment

238 and infrastructures (i.e., equipment; construction of buildings and breeding infrastructures) and

239 transportation at all stages. Water flow at the outlet of each pond was measured daily to estimate

240 the water balance. The fate of nitrogen (N) and phosphorus (P) was based on a nutrient-balance

241 experiment performed on-site involving chemical analysis of fish, fertilizers, feeds, inlet and

242 outlet water, water and sediment (Pouil et al., 2019). Data for pond gaseous emissions were

243 adapted from the literature. Gaseous fluxes are influenced significantly by factors such as

244 drainage, primary productivity, and the availability of organic matter in aquaculture ponds (Yang

245 et al., 2018). It is important to note that fish production plays a pivotal role in shaping these

246 variables, especially in the context of our pond production systems, where the absence of

247 drainage, the organic fertilization practice, and the provision of commercial feed are key

248 determinants. Denitrification and ammonia volatilization were assumed to be equivalent to

249 17.4% and 12.5% of the N inputs, respectively as found in channel catfish ponds (Gross et al.,

250 2000). Values for methane (CH_4) and nitrous oxide (N_2O) emissions were extracted from Yang

251 et al. (2018) who measured fluxes in semi-intensive shrimp ponds: 3.09 mg m^{-2} h^{-1} and 0.5 μg m^{-1}

252 ^{2} h^{-1} for CH_4 and N_2O emissions, and carbon dioxide (CO_2) fixation in pond sediment was

253 evaluated at 21.56 mg m^{-2} h^{-1} (Yang et al., 2018).

254 Background data (i.e., construction materials, fuel, rearing equipment) were based on the

255 ecoinvent v3.8 database (Wernet et al., 2016) and adapted to the local context. The inventory

256 data for Indonesian electricity production were obtained from EIA (2021). Data on feed

257 production were collected based on detailed reports supplied by the feed manufacturer in which

258 all feed ingredients were quantified while proximate analysis were performed to determine

259 nutritional composition (Table 2). The feed formulations were then validated regarding

260 nutritional constraints according to Guillaume et al. (1999). Data on feed processing were

261 supplemented with detailed information from a local feed producer. The inventory data for local

262 fishmeal production (discarded fish) was collected from a local fishery processing plant

263 dedicated to frozen fish (for export), surimi and fishmeal (Palembang, Sumatra Island). Heat

264 energy from wood wastes was used for fishmeal processing (Mungkung et al., 2013). Inventories

265 for crop-based feedstuffs were adapted from the ECOALIM dataset (Wilfart et al., 2016) to

266 consider transportation to Indonesia. Distances for road and boat transport were estimated using

267 Google Maps®. For organic fertilizer, we used the inventory for poultry manure on the global

268 market available in the ecoinvent v3.8 database while inventory of rice produced in China, from

269 the same database, was used for rice bran considering a mass allocation (Ayer et al., 2007).

270 2.2.3. Life cycle impact assessment

271 Midpoint impact categories were selected based on previous studies and recommendations for

272 aquaculture LCA (Aubin et al., 2009; Bohnes et al., 2019; Papatryphon et al., 2004; Wilfart et

273 al., 2013):

274 • acidification (mol H^+ eq), which aggregates substances that release hydrogen ions into

275   the ecosystem;

276 • cumulative energy demand (CED; MJ), which aggregates the energy used from

277   renewable and non-renewable sources;

278   •   climate change (kg CO_2 eq), which aggregates greenhouse gas emissions;

279   •   eutrophication (kg PO_4^{3-} eq), aggregating nutrient emissions that lead to oxygen

280   depletion, impacting aquatic and terrestrial environments and adding the theoretical

281   oxygen demand (ThOD) calculation for solid wastes from fish farms (Aubin et al., 2009);

282   •   land occupation (m^2 yr) which represents the terrestrial ground area used;

283   •   net primary production use (NPPU, kg C) refers to the use of a net primary producer as a

284   biotic resource in the sense of being unavailable for other purposes, as defined by

285   Papatryphon et al. (2004);

286   •   water dependence (m^3) included the volume of water used in ponds as proposed for

287   aquaculture production systems by Aubin et al. (2009) and the amount of water used in

288   the other production phases.

289 The impact assessment was conducted according to (1) the International Reference Life Cycle

290 Data System (ILCD) method for acidification and climate change, (2) the CML IA method,

291 version 3.06 for eutrophication potential, and land occupation. Total energy use was calculated

292 using the Cumulative Energy Demand method, version 1.10. Calculations were made using

293 SimaPro software 8.5.4.0 (PréConsultants, Amersfoort, The Netherlands). As mentioned earlier,

294 the ecoinvent version 3.8 database was used for background data, and the Agribalyse® database

295 (Koch and Salou, 2014) was used for agricultural machinery, agricultural products and feed

296 ingredients (ECOALIM dataset; Wilfart et al., 2016). For comparison purpose, we also

297 performed the impact assessment using ReCiPe 2016 Midpoint (H) version 1.08 (Table S2 in the

298 Supplementary Material).

299 2.6. Uncertainty analysis

300   The process for determining the uncertainty in the production systems was adapted for primary

301   and secondary data. Among the primary data, the most important source of uncertainties in the

302   CoC system was the production of *Azolla*. Considering the risk of predation and the variation in

303   *Azolla* productivity due to the environmental conditions (light, nutrients) observed in ponds

304   (Pouil et al., 2020), an uncertainty rate of 50% was applied in *Azolla* used as alternative feed in

305   this production system. For other primary data (i.e., other inputs used and fish harvested), the

306   standard deviation of the replicates was used in a normal distribution, as suggested by Medeiros

307   et al. (2017). For secondary data, the pedigree matrix from Ciroth et al. (2016) was used to

308   quantify uncertainty in the values selected from the literature (i.e. ThOD, N volatilization and

309   denitrification and fluxes of CH_4, CO_2 and N_2O). We applied a lognormal distribution to the

310   results generated from the matrix. Monte Carlo (MC) analysis was performed in SimaPro

311   software 8.5.4.0.

312   2.7. Data analysis

313   To compare the CoC and MoC systems while considering uncertainty, we ran 1000 interactions

314   in pairs in an MC analysis. This method indicated the number of times one system had higher

315   impacts than the other. We considered that the two systems differed if one had higher impacts in

316   at least 90% of the runs (Medeiros et al., 2017).

3. Results

318   Figure 3 presents the LCA impacts by category calculated per kg of fish produced (Figure 3A) or

319   by m^2 of the farm (Figure 3B) for the CoC and MoC giant gourami production systems. Overall,

320   we found similar trends regardless of the functional units chosen (i.e., product-based or surface-

321 based). Thus, values presented in the following sections are first provided by kg of fresh fish;

322 values expressed by m^2 are also given in Table 3.

323 3.1. Impact assessment

324 Among the impact categories selected, the MoC system had the highest impacts for all of them

325 except land occupation (Figure 3 and Table 3), with 4.7 ± 0.2 m^2 yr^{-1} being required to produce 1

326 kg of fish in MoC and 4.8 ± 0.3 m^2 yr^{-1} in CoC. The highest differences between CoC and MoC

327 were for NPPU (23-27% less in CoC): the production of 1 kg of fish required 13.8 ± 1.3 kg C in

328 MoC, but the NPPU value of the CoC system was noticeably lower with 9.1 ± 0.9 kg C (i.e.

329 ~25% less NPPU required in CoC). The second largest differences in environmental impacts

330 between the two production systems were for water dependence (12-17% less in CoC) with

331 values of 10.1 ± 3.5 m^3 and 8.7 ± 1.7 m^3 in MoC and CoC, respectively. Similarly, implementing

332 the CoC system reduced eutrophication (i.e., 11-16% less in CoC). Climate change showed a

333 reduction of 10-15% in the CoC with, per kg of fish produced, 6.4 ± 0.3 kg of CO_2 eq compared

334 with MoC where 7.1 ± 0.1 kg CO_2 eq were estimated (Figure 3). Differences between CoC and

335 MoC were less pronounced for the other impact categories. The energy requirements for

336 producing 1 kg of fish from the ponds were slightly reduced in the CoC, with 130 ± 7 MJ vs 139

337 ± 4 MJ for MoC (i.e. 7-11% less in CoC; Figure 3). The gain provided by CoC in acidification

338 was comparable, with values of 0.14 ± 0.01 mol H^+ eq for CoC and 0.15 ± 0.01 mol H^+ eq for

339 MoC, equivalent to an impact reduction of 6-11% (Figure 3).

340 Contributions of the rearing system components (energy, exogenous feeds,

341 equipment/infrastructures, farm operations, fertilizers, fish inputs and transport) varied according

342 to the impact category and to the system (Figure 3 and Table 3). Overall, the ranking of the

343   different contributors among the seven impact categories remained constant between the two

344   production systems (CoC and MoC). Results presented in Figure 3 show that for eutrophication

345   and water dependence, farm operations contributed the most to the impacts (81-82% and 52-

346   58%, respectively), and the second largest contributor for these impact categories was fish inputs

347   (11-13% and 42-48%, respectively). For NPPU, climate change and CED, exogenous feeds were

348   the main contributors (83-86%, 37-45% and 31-40%, respectively), followed by fish inputs (14-

349   17%, 20-22% and 18-19%, respectively) and/or fertilizers (15-21% for climate change and 27-

350   35% for CED; Figure 3). For acidification, the main contributors were ranked as follows: 32-

351   34% for fish inputs, 30-32% for farm operations and 15-19% for exogenous feeds, accounting

352   for ~80% of the total acidification. Interestingly, land occupation was mainly driven by

353   fertilizers (49-60%) and exogenous feeds (28-38%; Figure 3).

354   3.2. Uncertainty analysis

355   Uncertainty analysis qualifies data according to their origin, considering the uncertainties linked

356   to the production of macrophytes in the CoC and including the variabilities observed between

357   ponds in the LCA. Considering a threshold beyond which the two systems differed if one had

358   higher impacts in at least 90% of the MC runs, there were notable significant differences

359   between the two production systems. The analysis showed that CoC leads to less impact relative

360   to climate change, eutrophication and NPPU on a production basis (per kg of fish produced;

361   Figure 4A). The differences are even more marked on a farm surface basis (per unit area (m^2);

362   Figure 4B), where, in this case, CED was also significantly lower in the CoC.

363   **4. Discussion**

364   4.1. Product-based vs area-based LCA approach

365   The functional unit is the basis of comparison in LCAs and influences allocation decisions at the

366   farm gate (Henriksson et al., 2012). Here, we used a descriptive product-based functional unit

367   (kg of fish) that is appropriate for comparisons between studies (Bohnes et al., 2019). Van Der

368   Werf et al. (2020) highlighted the interest in combining product-based and area-based LCA

369   when studying agricultural systems that provide a broad range of ecosystem services. For

370   instance, although organic agriculture generally emits fewer pollutants per unit of land occupied

371   than conventional agriculture (an area-based approach), it may have higher impacts per unit of

372   product (e.g., land occupation, eutrophication and acidification). Thus, we also expressed the

373   environmental impacts using an area-based functional unit (m^2 of farm), an original approach in

374   LCA aquaculture studies (Bohnes et al., 2019; Henriksson et al., 2012). Our results show that the

375   choice of the functional unit did not result in significant differences in environmental impacts for

376   the LCA impact categories considered. Nevertheless, even if the conclusions remain similar

377   comparing the two production systems (CoC and MoC), a greater difference between the

378   systems was observed using the area-based functional unit for the following impact categories:

379   acidification, CED and NPPU.

380   4.2. Comparison of production systems

381   The responses in environmental impacts between the two studied production systems differed

382   according to the impact category considered. The two systems remained similar considering land

383   occupation and water dependence, although CoC showed slightly lower impacts for the latter

384   category. Using CoC as an alternative to MoC was expected to reduce land utilization by

385   decreasing the quantity of extruded pellets used. Nevertheless, the beneficial effects of reducing

386   exogenous feed were attenuated by the higher quantity of organic fertilizer from the intensive

387   poultry production system and rice culture (Purnomo et al., 2017) for *Azolla* production in CoC.

388   Such results highlight the need to better control the origin and the quantity of fertilizers used for

389   pond fertilization.

390   Between the two production systems, the differences observed in acidification, CED, climate

391   change eutrophication and NPPU were mainly explained by the lower use of exogenous feed in

392   CoC (-25% on average per kg of fish produced). Our study confirms previous investigations

393   highlighting that feed production is the major contributor to different impact indicators in semi-

394   intensive aquaculture production systems (e.g., Wilfart et al., 2013; Yacout et al., 2016). The

395   difference reflects the high impact of feed production, from the extraction of raw materials up to

396   manufacturing processes, which require large amounts of energy and resources (Ghamkhar and

397   Hicks, 2020). The processing of feed is by far the highest contributor to NPPU. Such results are

398   in accordance with Mungkung et al. (2013), who pinpointed feed production as the unique

399   contributor to NPPU (100%) in Indonesian tilapia-carp production systems. In addition to its

400   predominant environmental impact, fish feed has a significant economic impact on the

401   aquaculture farm because some ingredients are imported, which is frequently the case for small-

402   scale fish farming practised in Indonesia (Slembrouck et al., 2018).

403   The importance of FCR, and hence of extruded feeds in general, has been highlighted by

404   numerous LCA aquaculture studies. In literature reviews, Aubin (2013) and Bohnes et al. (2019)

405   have concluded that feed production is the primary source of environmental impacts. In the

406   present study, FCR for commercial pellets was relatively high in giant gourami compared with

407   other omnivorous species like carp and tilapias (Fry et al., 2018).

408   In small-mouthed fish like giant gourami, uneaten feeds can represent 30% of the feed supplied

409   (Bosma and Verdegem, 2011; Van Der Meer et al., 1997; Verdegem, 2013). In giant gourami,

410 Pouil et al. (2019) suggested that a significant proportion of the nutrients in pond sediments

411 comes from uneaten commercial pellets. Nevertheless, FCR can be improved in the co-culture

412 system (2.1 vs 2.8 for CoC and MoC, respectively) by using *Azolla* as a partial alternative feed

413 resource. Here, we assumed that the improvement of FCR, calculated for commercial feeds, in

414 CoC is related to the changes in feeding practices. The alternance between feeding with *Azolla*, a

415 less nutritive resource, and commercial pellets may contribute in reducing the quantity of

416 uneaten feed in particular. Indeed, Narimbi et al. (2018) also found very high FCR (6.4) in daily-

417 fed GIFT tilapia while FCR was six times lower in weekly-fed fish suggesting wastage of feed

418 when fish were daily fed. Lower FCR decreases the amount of feed delivered as well as the

419 excess nutrients released in the water, influencing eutrophication.

420 Eutrophication is a primary concern among farmers and local populations due to the risks for

421 water quality in reservoirs (Mungkung et al., 2013). A broad range of eutrophication potential

422 has been reported in the literature for different aquaculture systems (i.e., 0.01 to 0.3 kg PO_4 eq

423 per kg of fish; Ghamkhar et al., 2021; Medeiros et al., 2017; Mungkung et al., 2013; Pelletier and

424 Tyedmers, 2010; Yacout et al., 2016). The differences in eutrophication between MoC and CoC

425 can be identified through the nutrient concentrations measured in the water outlet with a notable

426 decrease in P released from the CoC ponds (Table 1). Here, the differences in eutrophication is a

427 consequence of the lower FCR in the CoC system that limits the impacts related to the farm

428 operations (i.e. reducing on-farm nutrient emissions). Indeed, the nutrient emissions resulting of

429 biological activity of fish, is the major contributor to eutrophication (see, e.g., Mungkung et al.,

430 2013; Wilfart et al., 2013), and is driven by the quality and the amount of feeds used.

431 Interestingly, our results regarding the contribution of exogenous feeds in acidification and

432 climate change differ from the literature. Indeed, in previous studies, exogenous feeds explain 64

433   to 95% of the acidification potential observed in different aquaculture pond systems, including

434   Indonesian intensive tilapia monoculture (Pelletier and Tyedmers, 2010) or tilapia-carp

435   polyculture (Mungkung et al., 2013) and Egyptian intensive and semi-intensive tilapia

436   monoculture (Yacout et al., 2016). Similarly, most LCA aquaculture studies, carried out in

437   production systems that are sometimes very different from fertilized ponds, report that feeds are

438   drivers of climate change (Bohnes et al., 2019; Wilfart et al., 2023). In this study, we found a

439   relatively low contribution of exogenous feeds to acidification (15-18%), with fertilizers and fish

440   inputs contributing to more than 40% of the total acidification. A similar trend was observed for

441   climate change, where fertilizers and fish inputs explain 35-43% of the impacts, with exogenous

442   feeds also accounting for ~40%. Such findings can be explained by the origin of the organic

443   fertilizer (i.e., poultry manure mixed with rice bran; Purnomo et al., 2017), a co-product from

444   intensive agriculture used in large quantities in our production systems. Furthermore, the fish

445   used in this experiment, as described in Section 2.1.1, are already six months old, meaning that

446   their own production also required exogenous feeds and other inputs, which explains their

447   significant contributions to the estimated global impacts on our production systems. Such

448   findings differ from LCAs performed in aquaculture systems where the fish inputs are based on

449   younger life stages (eggs or larvae for example).

450   Recent studies reported that one of the leading production constraints in the Indonesian

451   aquaculture sector, in addition to the dependence on imported feed ingredients (Henriksson et al.,

452   2017), is energy sources (Henriksson et al., 2019, 2017). Previous studies have also pointed out

453   that energy consumption during fish feed production is one of the significant contributors to

454   CED (e.g., Mungkung et al., 2013; Pelletier and Tyedmers, 2010; Yacout et al., 2016). Overall,

455   the estimated CED are comparable to other semi-intensive aquaculture production systems. For

456 instance, Yacout et al. (2016) found 238 MJ eq per kg of fish produced in an Egyptian Nile

457 tilapia (*Oreochromis niloticus*) semi-intensive production system, compared with a tilapia

458 intensive production system being almost fivefold more efficient in energy use, with 53 MJ eq

459 per kg of fish production than a semi-intensive system. In this study, we found that ecological

460 intensification performed in the CoC could also significantly improve energy efficiency in giant

461 gourami pond production.

462 4.3. Origins of the uncertainties

463 The uncertainty in this study was similar to other LCA aquaculture studies (Dekamin et al.,

464 2015; Medeiros et al., 2017). Nevertheless, comparisons between studies remain challenging due

465 to the heterogeneity in the studied systems and rearing practices and the origin of the data. Here,

466 we compared similar production systems, except for including *Azolla* in the CoC system as a

467 partial alternative to extruded pellets. However, the stable production of this floating macrophyte

468 was more challenging than expected and inadequate in the present experiment, presumably due

469 to the predation by snails and nutrient deficiency (Pouil et al., 2020). Nevertheless, the scenario

470 built for CoC, designed based on experience gained in the production of *Azolla* on this farm

471 (Caruso et al., 2021), made it possible to estimate uncertainties related to the exogenous feed

472 gain in the implementation of such a production system. The uncertainties related to *Azolla*

473 production mainly affect the impact categories in which exogenous feeds contribute strongly.

474 Therefore, unsurprisingly, we observed higher variability in the CoC systems for NPPU, climate

475 change, CED and, to a lesser extent, land occupation.

476 In addition to *Azolla* production, the other sources of uncertainties for all impact categories

477 include variability among the two replicates of each system, the inherent variability already

478   accounted for in the ecoinvent database and the assumptions made for mass-balance modelling.

479   Interestingly, most of the data we recorded from the replicates of the two systems were, overall,

480   comparable. There was a relatively high uncertainty on water dependence, particularly for the

481   MoC system. Indeed, the ponds used, connected in series and fed by the same river, experienced

482   fluctuating flows during the production cycle. Although this only had a minor effect on fish

483   production, the water inputs in the study were highly variable, especially for MoC.

484   Nutrients (N and P) fluxes can be an important source of uncertainties in LCA aquaculture

485   studies. Here, most of the data used were extracted from chemical analysis of each compartment

486   included in the production systems (i.e. water, feeds, fertilizer and fish), and the N and P

487   quantities stored in sediments were taken from Pouil et al. (2019) that gives nutrient budgets in

488   the same ponds with an MoC system of giant gourami. Assuming the occurrence of *Azolla* in the

489   CoC was not drastically affected by particulate N and P in sediments (related to uneaten feed,

490   faeces, plankton sedimentation, dead fish, etc.), the overall N and P values we used in the study

491   are reliable. Digestibility determines the fate of nutrients and the amounts of nutrients in the

492   water column (digestible wastes) and sediment (non-digestible wastes) (Medeiros et al., 2017).

493   Here, we calculated ThOD, an interesting parameter to refine the impacts related to

494   eutrophication as suggested by Aubin et al. (2009), using digestibility values for protein,

495   carbohydrates, lipids, ash and fibre. Only protein digestibility values have been found for giant

496   gourami in literature (Andriani et al., 2019). Thus, other digestibility information (i.e. fat,

497   carbohydrates, ash, P) came from an experiment based on Nile tilapia, another omnivorous

498   species (Schneider et al., 2004). This lack of data in the literature reduces the accuracy of the

499   estimates. However, the release of nutrients (N and P) from the two production systems was

500 derived mainly from chemical analysis allowing a relatively accurate determination of the
501 nutrient budgets.

502 Gaseous emissions to the atmosphere were the parameters with higher uncertainties in the
503 pedigree matrix. The processes considered were denitrification and ammonia volatilization,
504 which directly influence eutrophication. Denitrification and ammonia volatilization rates were
505 based on Gross et al. (2000), a reference cited in some LCA aquaculture studies (e.g., Medeiros
506 et al., 2017; Wilfart et al., 2013). This reference indicates a loss of roughly 40% of N inputs
507 through these processes in channel catfish ponds. Nevertheless, in the literature, variability in N
508 emissions in the air from aquaculture ponds is huge. For instance, NH_3 volatilization represents
509 ~1% to total N input in feed for snakehead and bighead carp polyculture ponds (Hou et al.,
510 2018), but NH_3 volatilization is equivalent to 10-66% of the N input in feed in shrimp ponds
511 (Dien et al., 2018; Li et al., 2019; Lorenzen et al., 1997; Páez-Osuna et al., 1999). Such
512 differences can be explained by the variety of the pond aquaculture systems studied, with diverse
513 locations, species and rearing practices. Overall, these discrepancies highlight the need to
514 consider such uncertainties of these processes in aquaculture LCA studies.

515 Other sources of uncertainties qualified through the pedigree matrix were the emissions of CH_4
516 and N_2O and the CO_2 fixation in the ponds. Indeed, high variability of such emissions is
517 expected in aquaculture ponds: reported pond emissions to air vary from 0.01 to 20 mg CH_4 m^{-2}
518 h^{-1} and 1 to 252 µg N_2O m^{-2} h^{-1} (Kosten et al., 2020; Yang et al., 2022; Yuan et al., 2019).
519 Interestingly, high greenhouse gas (GHG) emissions from aquaculture ponds have been reported
520 in some studies during the culture period (Chen et al., 2016, 2015; Datta et al., 2009), suggesting
521 the importance of including them in LCA. In our analysis, we used values from Yang et al.
522 (2018), which include measurements during the culture and non-culture period of Chinese

523   shrimp polyculture and earthen carp ponds based on a stocking density comparable to that in our

524   study and a semi-intensive production strategy. Overall, we hypothesized that the presence of

525   *Azolla* in the CoC system has no significant impact on CH_4 and N_2O emissions from the ponds.

526   Nevertheless, some sources suggest that *Azolla* plays a role in these flows. For example, previous

527   studies have shown that *Azolla* application in flooding rice paddy can either increase (Chen et al.,

528   1997; Ying et al., 2000) or have no influence or decrease (Ali et al., 2015; Kimani et al., 2018;

529   Liu et al., 2017; Singh and Strong, 2016) CH_4 and N_2O emissions from rice soils. Similarly,

530   *Azolla* can also contribute to CO_2 sequestration in ponds (Hamdan and Houri, 2022).

531   Nevertheless, despite the discrepancy between these studies associated with the difficult

532   comparison between rice paddies and aquaculture ponds, we considered the assumption

533   reasonable. The overall conclusions of this study would not change if pond GHG emissions were

534   excluded, but we include them in the LCA we performed given their importance to climate

535   change, as previously suggested by Medeiros et al. (2017).

536

537   **5. Conclusion**

538   The development of Indonesian freshwater pond aquaculture in recent years has shifted from

539   low-intensity traditional culture methods to monoculture production systems, with increasing

540   intensification accompanied by the use of commercial feed pellets. Here, for most of the impact

541   categories investigated, the co-culture system (CoC) with *Azolla* appeared to be more efficient

542   than the semi-intensive monoculture (MoC) of giant gourami *O. goramy*. The observed

543   improvements can be directly related to reducing the use of commercial pellets and a better

544   control of the origin of the fertilizer used for enriching the ponds. Overall, we found that

environmental performances for giant gourami production can be enhanced by using floating macrophytes as an alternative feed resource, even in relatively low proportions. Nevertheless, the production of this macrophyte species has still to be optimized to enhance its efficiency for use as a feed supplement while the economic repercussions of a shift to a production system based on co-culture with *Azolla* have to be investigated.

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813   **Figure captions**

814

815   **Figure 1.** Schematic view of the production chain of semi-intensive giant gourami aquaculture.

816   Weights and size provided are means are average values gathered from surveys of approximately

817   40 giant gourami farms (Kristanto et al., 2020).

818

819   **Figure 2.** System boundaries for giant gourami (A) monoculture (MoC) and (B) co-culture
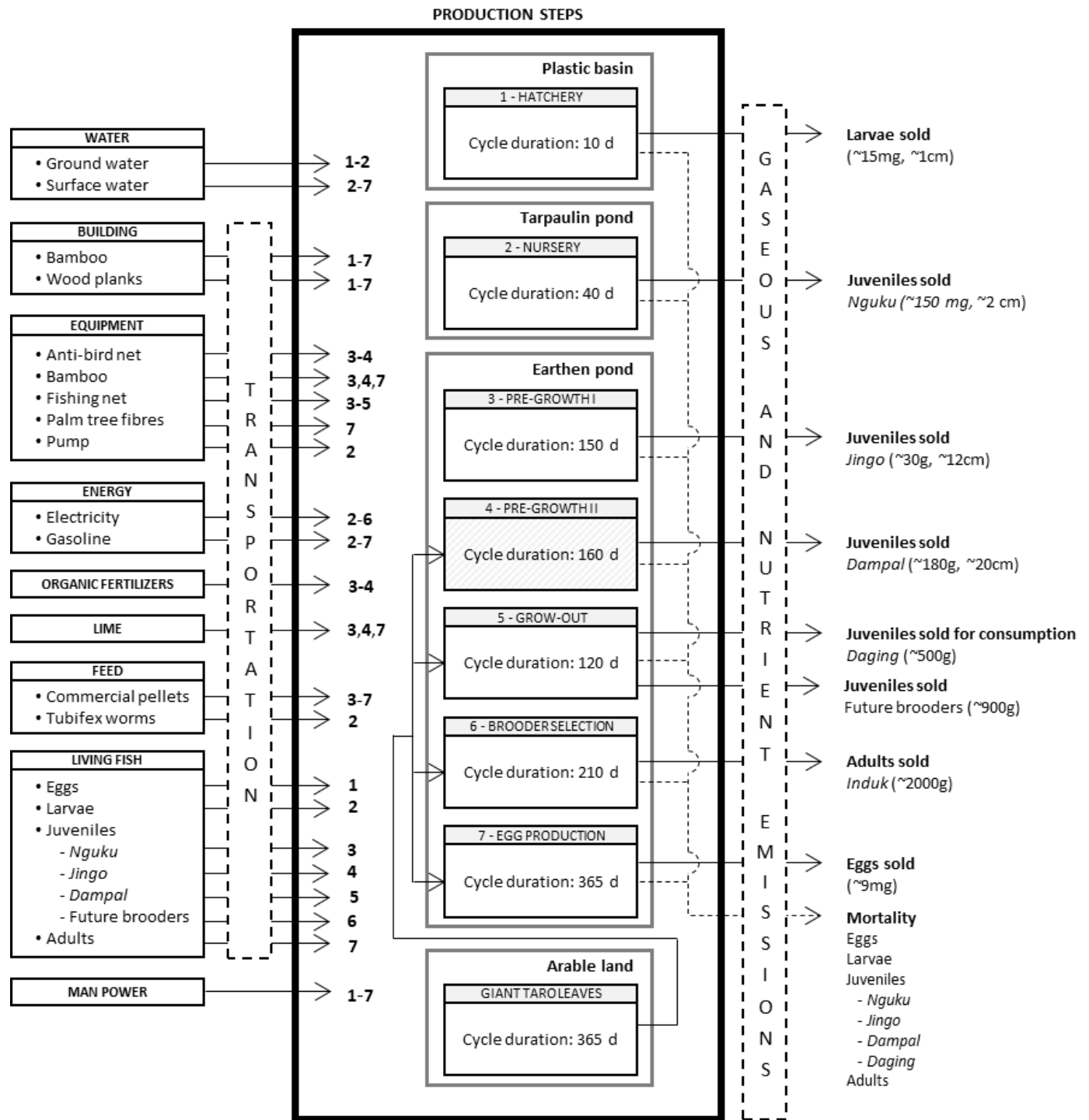
820   (CoC) production systems.

821

822   **Figure 3.** Contribution of each input or production step in environmental impacts per (A) kg of

823   fish and (B) m^2 of the farm in traditional giant gourami monoculture (MoC) and co-culture with

824   the floating macrophyte *Azolla filiculoides* (CoC) systems. CED: cumulative energy demand;
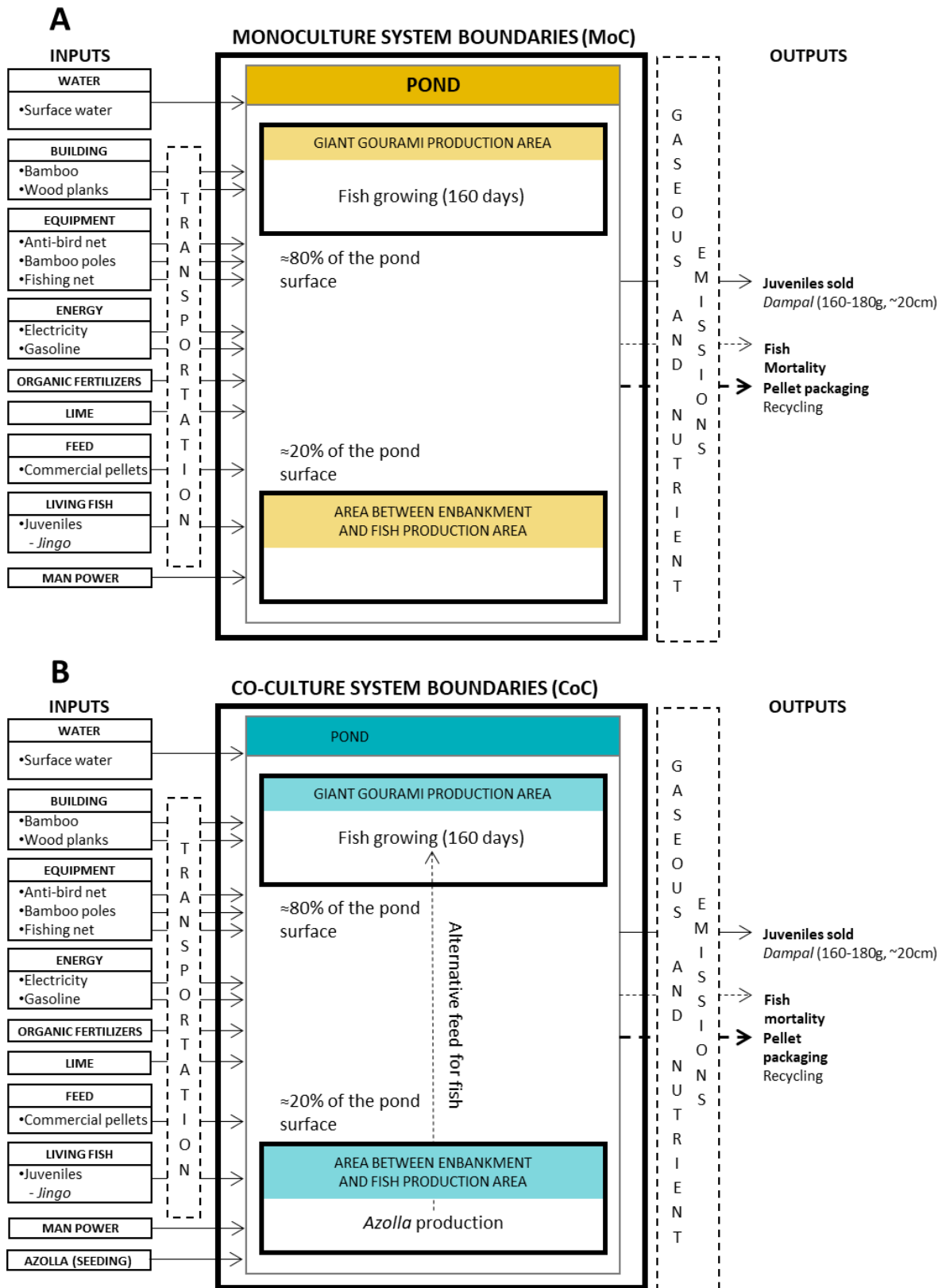
825   NPPU: net primary production use.

826

827   **Figure 4.** Uncertainties in the environmental impacts per (A) kg of fish and (B) m^2 of the farm

828   in the traditional giant gourami monoculture system (MoC) and the co-culture system with the

829   floating macrophyte *Azolla filiculoides* (CoC) for each impact category. Asterisks denote

830   significant differences between the two production systems. We considered that the two systems

831   differed if one had higher impacts in at least 90% of the runs. CED: cumulative energy demand;
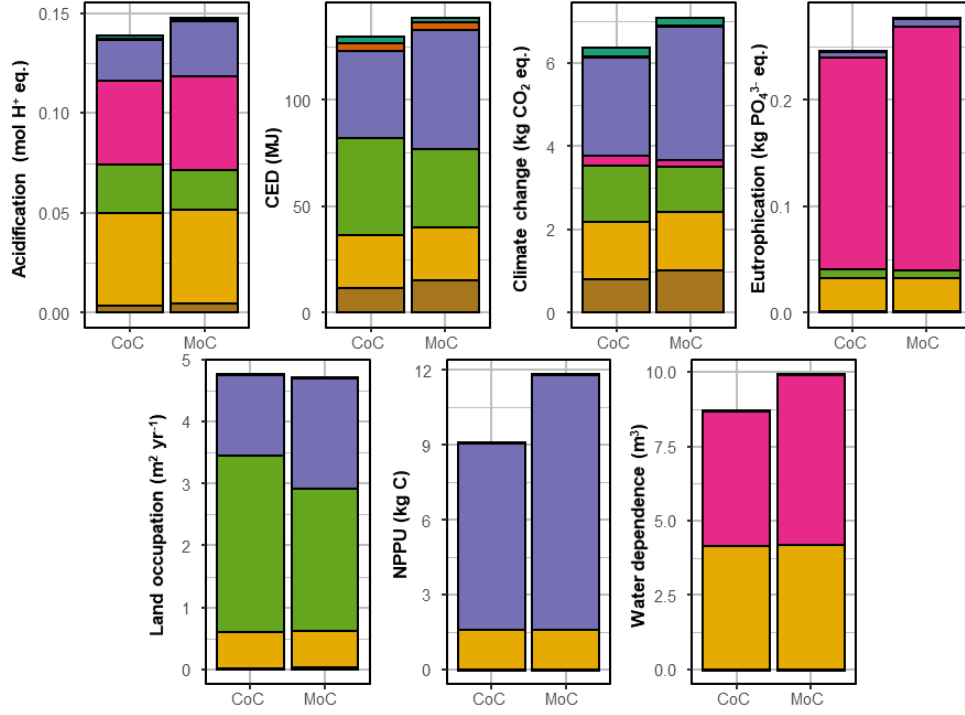
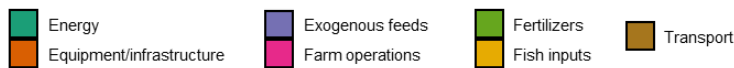832   NPPU: net primary production use.

833   **Figure 1**

834 **Figure 2**

A - per kg of fresh fish

B - per m² of farm

Energy
Equipment/infrastructure
Exogenous feeds
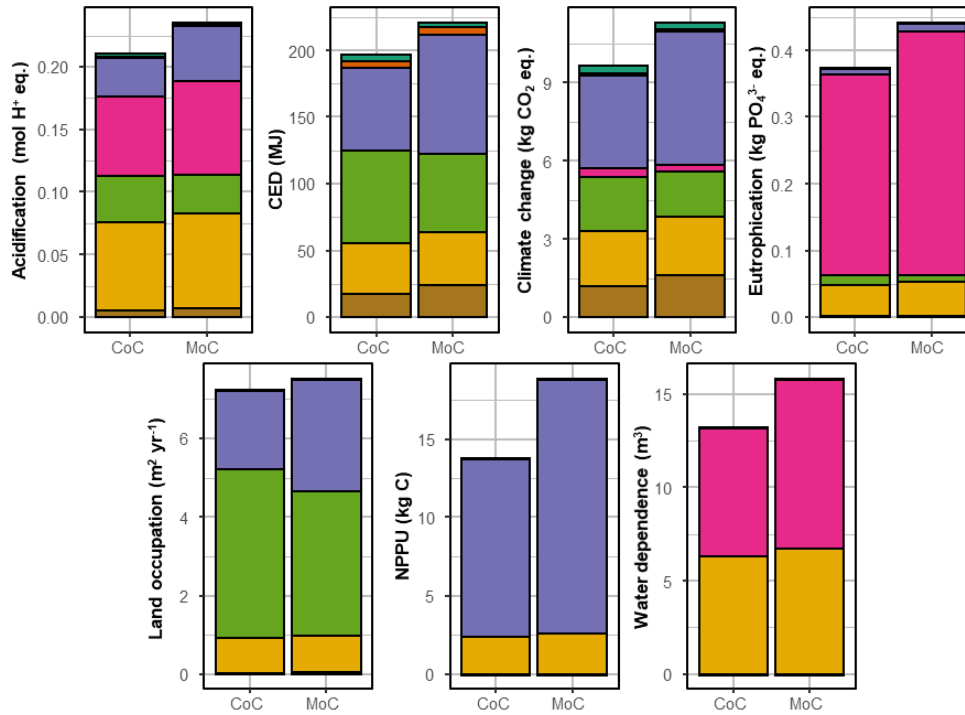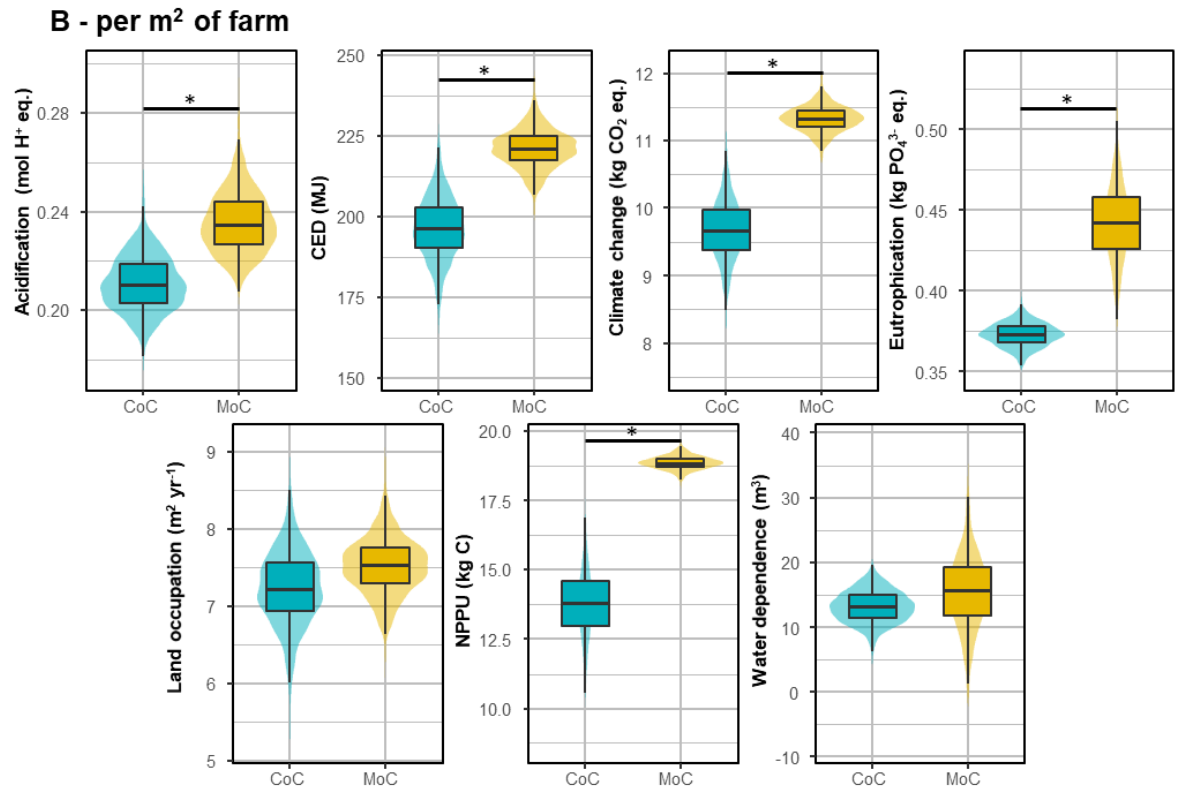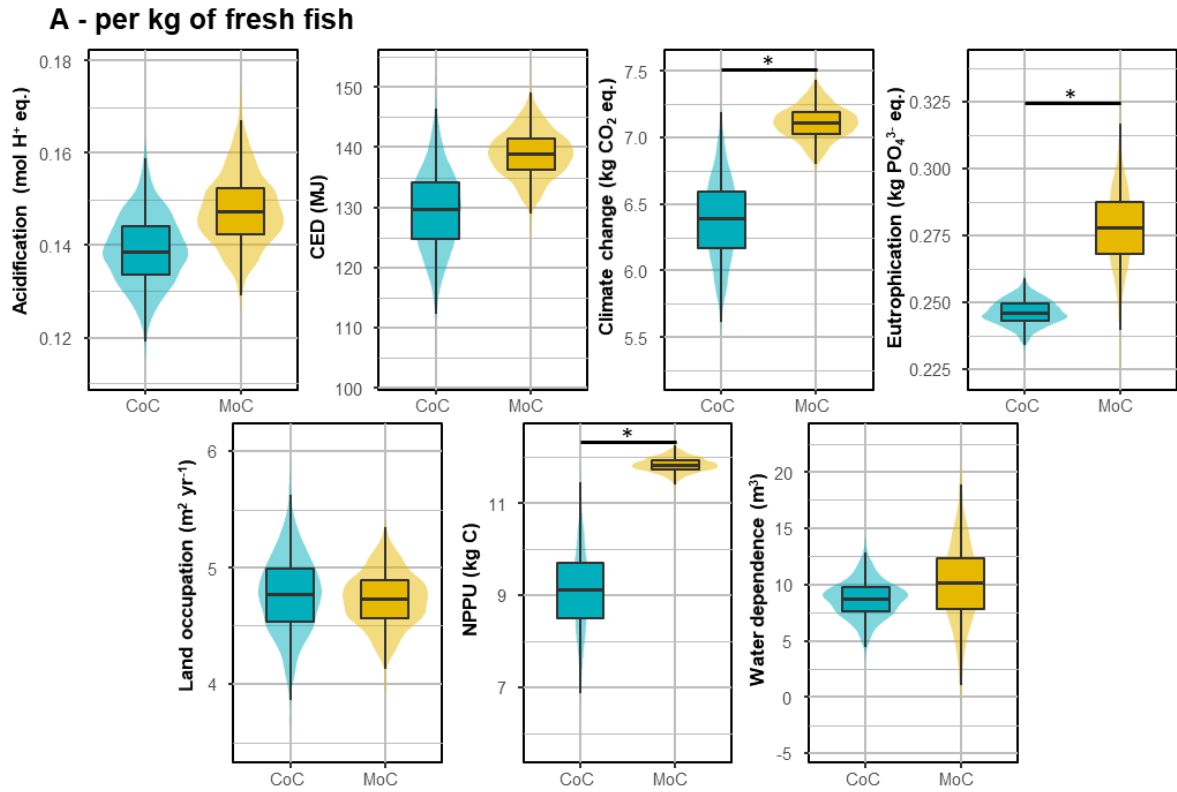Farm operations
Fertilizers
Fish inputs
Transport

835   **Figure 3**

A - per kg of fresh fish

B - per m² of farm

836   **Figure 4**

837 **Table 1.** Pond characteristics, rearing performances and electricity and water consumption used

838 in the LCA of the monoculture (MoC) and the co-culture with the floating macrophyte *Azolla*

839 *filiculoides* (CoC) of giant gourami (mean ± 1 standard deviation).

	CoC	MoC
Pond characteristics and inputs		
Surface (m^2)	771	840
Depth (m)	0.5	0.5
Rearing structures	earthen ponds	earthen ponds
	tarpaulin tanks	
Equipment	PVC pipes	PVC pipes
	bamboo pools	bamboo pools
	anti-predator nets	anti-predator nets
	fishing net	fishing net
	happas	
Fertilizers (kg)	5802 ± 580	5020 ± 502
Pellets (kg)	2874 ± 302	3811 ± 59
Azolla (kg)	2848 ± 1424	-
Rearing performances		
Initial body weight (g)	29 ± 6	28 ± 5
Fish stocking density (fish m^{-2})	6	6
Stocked fish biomass (kg yr^{-1})	274	297
$FCR_{pellets}$ (wet weight)[1]	2.1	2.8
Final body weight (g)	193 ± 52	183 ± 39
Fish productivity (tonne ha^{-1} yr^{-1})	19.9	19.6
Energy and water inputs		
Electricity consumption (kWh yr^{-1})	422	403
Water (m^3 yr^{-1})	6985 ± 2544	9425 ± 5863
Nutrient releases from water		
N (mg L^{-1})	1.4 ± 0.5	1.5 ± 0.4
P (mg L^{-1})	0.167 ± 0.258	0.026 ± 0.031

840 [1]$FCR_{pellets}$ = feed conversion ratio, considering only the commercial feed (extruded pellets) and

841 calculated as the ratio between the amount of distributed pellets (kg) and the biomass gain (kg)

842 over the production cycle

843   **Table 2.** Ingredients and composition values of the feeds (n = 5 and n = 30 samples analysed for

844   pellets and *Azolla*, respectively) used in monoculture (MoC) and co-culture with the floating

845   macrophyte *Azolla filiculoides* (CoC). Except for moisture, composition values are expressed on

846   a dry matter basis.

Composition (%, Mean ± SD)	Extruded pellets	*Azolla filiculoides*
Moisture	7.95 ± 0.49	92.06 ± 1.17
Proteins	32.72 ± 0.23	20.29 ± 5.47
Lipids	5.29 ± 0.17	1.76 ± 0.61
Carbohydrates	47.29 ± 0.25	50.89 ± 4.72
Ash	10.01 ± 0.36	11.49 ± 1.75
Fibres	4.70 ± 0.20	15.58 ± 3.03
Phosphorus	1.47 ± 0.12	0.25 ± 0.13
Ingredients (% [origin])		
Fish meal	10 [Chili]	
Fish meal	11 [East Java]	
Soybean meal	15 [Argentina]	
Meat and bone meal	10 [Australia]	
Wheat bran	20.5 [Australia	
Rice bran	25 [West Java]	
Fish oil	2 [East Java]	
Plant oil	2.5 [Banten/West Java]	
Choline chloride	0.5 [China]	
Premix vitamin	2 [China]	
Premix mineral	1.2 [China]	
Butylated hydroxytoluene (BHT)	0.3 [Central Java]	

857   **Table 3.** Results of the Monte Carlo analysis (n = 1000) applied to the two production systems: monoculture (MoC) and co-culture with the

858   floating macrophyte *Azolla filiculoides* (CoC) for each impact category. We considered that the two systems differed if one had higher impacts

859   in at least 90% of the 1000 runs (see values in bold in the last column).

Functional unit	Category	System	Median	Q1 (25%)	Q3 (75%)	Mean	SD	MoC > CoC (%)
Fish weight (kg)	**Acidification (mol H$^+$ eq.)**	CoC	0.139	0.134	0.144	0.139	0.007	
		MoC	0.147	0.142	0.152	0.148	0.008	78.8
	Cumulative energy demand (MJ)	CoC	129.787	124.828	134.099	129.565	6.653	
		MoC	138.986	136.27	141.493	138.897	3.889	88.6
	Climate change (kg CO$_2$ eq.)	CoC	6.394	6.165	6.595	6.383	0.306	
		MoC	7.108	7.027	7.191	7.109	0.125	**98.4**
	Eutrophication (kg PO$_4^{3-}$ eq.)	CoC	0.246	0.243	0.25	0.246	0.005	
		MoC	0.278	0.268	0.287	0.278	0.014	**98.3**
	Land occupation (m^2 year)	CoC	4.773	4.538	4.989	4.766	0.328	
		MoC	4.732	4.569	4.888	4.728	0.236	46.5
	Net primary production use (kg C)	CoC	9.123	8.489	9.714	9.116	0.87	
		MoC	11.833	11.731	11.949	11.837	0.157	**100**
	Water dependence (m^3)	CoC	8.791	7.609	9.732	8.708	1.659	
		MoC	10.255	7.808	12.345	10.117	3.484	64.4
Farm surface (m^2)	**Acidification (mol H$^+$ eq.)**	CoC	0.21	0.203	0.219	0.211	0.011	
		MoC	0.235	0.227	0.244	0.236	0.013	**93.8**
	Cumulative energy demand (MJ)	CoC	196.47	190.368	202.691	196.505	9.813	
		MoC	221.05	217.39	224.814	221.098	6.095	**97.9**
	Climate change (kg CO$_2$ eq.)	CoC	9.672	9.378	9.97	9.674	0.453	
		MoC	11.327	11.204	11.443	11.323	0.19	**100**
	Eutrophication (kg PO$_4^{3-}$ eq.)	CoC	0.373	0.368	0.378	0.373	0.007	
		MoC	0.442	0.426	0.458	0.442	0.024	**99.9**
	Land occupation (m^2 year)	CoC	7.227	6.937	7.562	7.237	0.48	
		MoC	7.529	7.292	7.751	7.52	0.374	67.9
	Net primary production use (kg C)	CoC	13.827	12.958	14.584	13.793	1.275	
		MoC	18.864	18.708	19.016	18.864	0.237	**99.9**
	Water dependence (m^3)	CoC	13.168	11.37	14.957	13.165	2.463	
		MoC	15.663	11.911	19.249	15.519	5.814	64.0