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1 **Survey on egg and fry production of giant gourami (*Osphronemus goramy*):**

2 **Current rearing practices and recommendations for future research**

3
4 **Running head: Egg and fry production of giant gourami**

5
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19

20 **Abstract**

21 Giant gourami (*Osphromenus goramy*) is one of the main freshwater fish of economic
22 importance in Indonesia. Although this species has been reared for decades, particularly in the
23 province of West Java, and naturally spawns in captivity, the availability of fry is still a
24 limiting factor in aquaculture. Research efforts on giant gourami aquaculture are however
25 limited, and do not always address the difficulties encountered by fish farmers. The objectives
26 of the present study were to provide the first description of giant gourami egg and fry
27 production and highlight the main problems faced by farmers through targeted questionnaires
28 and interviews. Our results show that the production of this species from egg to juveniles is
29 highly segmented and there are currently no clear and standardized production methods.
30 Farming practices vary greatly from one fish farmer to another. Climate factors (such as rain
31 and temperature), proximity to urban areas and the availability and quality of food are
32 identified by the main limiting factors for egg and fry production. Based on a SWOT analysis,
33 we explore possible approaches to improve giant gourami aquaculture in Indonesia. The
34 present study provides guidance for future research.

35

36 Keywords: Giant gourami, Indonesia, Larval rearing, Small-scale aquaculture, SWOT
37 analysis

38 1 INTRODUCTION

39 With a production of 3 million tons of farmed fish in 2015, Indonesia is the third largest
40 freshwater fish aquaculture producer country after China and India (FAO, 2017). Aquaculture
41 production has shown the most rapid expansion among all Indonesian agronomic production
42 sectors, with an average annual growth of 7% (FAO, 2017) after the government made
43 aquaculture development a national priority in 2009 (Philips et al., 2015; Rimmer, Sugama,
44 Rakhmawati, Rofiq, & Habgood, 2013). Freshwater fish farming, which represents 67% of
45 aquaculture production in Indonesia (FAO, 2017), uses traditional production systems mainly
46 based on traditional practices (Edwards, Little, & Yakupitiyage, 1997). This sector plays a
47 significant role in the Indonesian economy, ensuring food availability, household food
48 security and improving living standards for rural communities (Rimmer et al., 2013). In
49 Indonesia, 3.34 million fish farmers practice aquaculture (FAO, 2018), but with a low
50 national productivity (i.e. 1.48 t/farmer) compared with other Asian countries (1.72 t/farmer
51 in Asian countries excluding Indonesia and China; FAO, 2018). This low production output is
52 especially true for freshwater fish aquaculture, which is mainly carried out in small-scale
53 farms, often associated in small groups called “kelompok”, which represent more than 90% of
54 all fish farms (Maskur, Rina, & Hamid, 2013).

55 Among the freshwater fish produced in Indonesia, the giant gourami (*Osphronemus goramy*
56 Lacepède, 1801) is one of the main local species of economic importance. Its annual
57 production was over 119,000 t in 2014 and had grown exponentially over the previous 15
58 years (FAO, 2017). This fish has become one of the main species being farmed and is in great
59 demand in the food aquaculture industry (Amornsakun, Kullai, & Hassan, 2014a). Giant
60 gourami is particularly promising in view of its air-breathing capacities and its diet with a
61 strong vegetarian component (Slembrouck et al., 2018), thereby lowering feeding costs.
62 Furthermore, international institutions are promoting the production of local species in

63 aquaculture (FAO, 2016; Ross, Martinez Palacios, & Morales, 2008; Saint-Paul, 2017), a
64 trend that is backed by the Indonesian government, which adopted the concept of “blue
65 growth” for aquaculture in 2014 (Tran et al., 2017).

66 Although the giant gourami is an interesting species in view of current Indonesian aquaculture
67 guidance, the rise of its production has slowed for various reasons. Due to its traditional
68 production practices based on empirical know-how, there are still gaps in knowledge on
69 several aspects of the biology of this species, particularly for the juvenile life-stages (Arifin,
70 Prakoso, Kristanto, Pouil, & Slembrouck, 2019). One of the main impediments in giant
71 gourami aquaculture is ensuring a regular supply of fry (Slembrouck et al., 2019). Giant
72 gourami is a species able to reproduce spontaneously in captivity. Currently, fry typically
73 come from natural spawning events and are reared in outdoor ponds in stagnant water
74 conditions. Their availability for farmers is generally low and highly variable (Arifin, At-thar,
75 & Nafiqoh, 2013; Budi & Supriyadi, 2015; Etoh, Putra, & Carman, 2011; Nafiqoh &
76 Nugroho, 2013) and should be improved through more reliable production methods
77 (Amornsakun et al., 2014a; 2014b). Nevertheless, the improvement of rearing techniques
78 requires significant research efforts that are not currently undertaken (Prakoso et al., 2019). In
79 addition, to be effective, research efforts should focus on the difficulties faced by fish
80 farmers, and these should be clearly identified before undertaking scientific investigations.

81 For the above-mentioned reasons, giant gourami aquaculture is currently very poorly
82 characterized. This study was therefore initiated (1) to describe the status of giant gourami fry
83 production practices in the province of West Java through questionnaires administered to
84 local fish farmers and an assessment of the strengths, weaknesses, opportunities and threats
85 (SWOT analysis) and (2) to provide some recommendations to guide future research on this
86 species.

87

88 **2 MATERIALS AND METHODS**

89 2.1 Selected study areas

90 Giant gourami production is mainly located on Java Island (79% of the national giant gourami
91 production; BPS, 2013). The production cycle of this species, presented in a simplified view
92 in Figure 1, is highly segmented and there are many market stages (Sarah, Widanarni, &
93 Sudrajat, 2009). This segmentation can reasonably be attributed to the slow growth of this fish
94 and the difficulties encountered in the production chain (FAO, 2019). In this study, we
95 focused on the most critical production stages: from broodfish management to the production
96 of fry called “nguku” (length:1.5-2.5 cm; name used by farmers and corresponding
97 approximately to the width of a thumbnail; Adida, 2014). On this basis, our analysis focused
98 on West Java. A west-east gradient was considered with major production areas near Bogor in
99 the west and Tasikmalaya in the east so as to best capture the different rearing practices of fry
100 gourami (Figure 2). An extensive field-based “rapid reconnaissance” (Hernandez et al., 2018)
101 was then carried out to identify the major clusters of giant gourami aquaculture in the selected
102 areas with the help of the Local Animal Husbandry and Fisheries Service in the Bogor area
103 and through the West Java Center for the Development of Giant Gourami Culture (BPPSIGN)
104 in the Tasikmalaya area. The sample for the survey was drawn using purposive stratified
105 random sampling because fish farming is concentrated in certain districts, and a nationally
106 representative sample was not financially feasible (Hernandez et al., 2018).

107

108

[Figure 1 is here]

109

110 2.2 Establishment of questionnaires and interview process

111 A detailed questionnaire targeting fish farmers involved in gourami egg and fry production
112 was prepared to evaluate the variability of spawning methods and efficiency, hatching success

113 and larval performance during the nursery production of giant gourami and to identify
114 associated limitation factors. Survey questionnaires were divided into 14 categories of
115 questions:

116 A-B. Farm location and description: Information about the location, the size of the production
117 farm, and then the type and size of the rearing structures.

118 C. Farmer presentation: Experience of the fish farmer, age and education level.

119 D-E. Farmed fish description (giant gourami and other species): List of the species reared (in
120 addition to giant gourami), giant gourami strains reared.

121 F-G. Broodfish maintenance and spawning conditions: Number of broodfish, sex-ratio, water
122 renewal, feeding strategy, pond fertilization, type and size of the rearing and spawning
123 structures, problems faced.

124 H-I. Egg production results: Number of spawning events per month, number of eggs
125 collected, incubation conditions, quality and viability of the eggs (estimated from the
126 proportion of white-dead eggs generally observed in spawns).

127 J. Larval rearing up to the “nguku” stage: Larval rearing structure description, duration, water
128 renewal, temperature, first food intake, feeding strategy, survival rates, problems faced.

129 K-L. Perception of limitations for fry production: Farmer’s opinion about the main problems
130 limiting spawning and larval rearing of giant gourami.

131 M. Information needs of fish farmers: Gaps in knowledge identified by the farmer.

132 N. Economy and market: Information regarding selling prices and marketing of fry: market
133 location and type of customers.

134 The questionnaire, originally written in English and translated into Indonesian, included 142
135 questions (multiple-choice questions, textual and numerical questions), both on qualitative

136 and quantitative aspects of the production. The 2-h questionnaire was completed through an
137 individual interview carried out at each production site except for nine farmers who
138 completed the questionnaire during a technical internship at the Tasikmalaya training center.
139 Two people were present during the interviews to introduce the objectives and ensure that
140 each question was understood. When necessary, the questions were translated into the native
141 language (Sundanese). In addition to the questionnaire, field measurements of water quality
142 (temperature, pH, dissolved oxygen, conductivity, turbidity) were taken in the rearing
143 structures. Participation in this study was entirely voluntary. A total of 35 independent
144 farmers, four farmers organized as “kelompok”, and two training centers were interviewed
145 between May and November 2016.

146

147 2.3 Data analysis

148 Initial data processing was performed to identify ambiguous responses or deviations from
149 observed trends and some farmers were contacted again in March 2017 for clarification
150 and/or confirmation.

151 Quantitative data (i.e. area of farms, area of rearing structures, number of employees, number
152 of spawners) were plotted to provide a first visual examination of possible relationships
153 between variables. Based on this first examination, linear regressions were then used to test,
154 among other things, the relationship between farm size and number of employees and egg
155 production by number of brooders per farm.

156 Since assumptions of normality and homogeneity of variances were unable to be achieved, the
157 size of the farms was compared according to their level of proximity to urban areas (“low”,
158 “medium” and “high”) using non-parametric Kruskal-Wallis test followed by a Siegel and
159 Castellan test (Siegel & Castellan, 1988). The size of the farms was also compared between

160 the two production strategies observed (i.e. farms dedicated to gourami production and
161 multispecies farms) using non-parametric Mann–Whitney U test.

162 A Chi-square test (χ^2) was used to define statistical differences in the farmer's responses for
163 the most sensitive larval production stages.

164 The level of significance for statistical analyses was set at $\alpha = 0.05$. All statistical analyses
165 were performed using R freeware version 3.3 (R Development Core Team, 2016).

166

167 **3 RESULTS AND DISCUSSION**

168 3.1 Production chain of giant gourami fry

169 Despite a production rate of more than 100,000 t per year, there is very little information
170 available in the scientific literature regarding the rearing techniques for the giant gourami.

171 The objective of the following section was therefore to provide new insight into the
172 production chain of giant gourami fry based on the answers from the surveyed Indonesian

173 farmers. The answers provided by training centers were sometimes used for comparison. In
174 most cases, percentage data are associated with the number of respondents, question-

175 dependent, and are indicated in parentheses. Unless otherwise stated, values are means \pm SD.

176 Studied locations of production farms are indicated in Figure 2.

177

178 [Figure 2 is here]

179

180 3.1.1 Fish farmers and production site description

181 The interviewed fish farmers were 24 to 80 years old (47 ± 14 years, $n=38$) and skilled in
182 giant gourami aquaculture (14 ± 11 years of experience, median: 10 years, $n=39$). Most

183 farmers (87%) started giant gourami aquaculture as a vocational retraining. The family and/or

184 training centers are the main ways for learning this occupation for most respondents (84%,

185 n=25). The education level was variable with 31% of fish farmers having attended primary
186 school (called Sekolah Dasar or SD), 25% junior high school (Sekolah Menengah Pertama, or
187 SMP), 39% high school (Sekolah Menengah Atas or SMA), whereas 5% (n=2) had post-
188 secondary degrees.

189 Overall, farm altitudes ranged from 110 to 540 m above sea level with lower elevations for
190 farms in the northern part of Bogor. In Java Island, aquaculture is often located in peri-urban
191 areas (Pribadi & Pauleit, 2016). Thus, 20% (n=6) of farms were located in the middle of
192 dwellings or in direct contact with a few dwellings, whereas 47% (n=14) of the farms
193 surveyed were in an area with limited urban development (> 100 m from production ponds)
194 and 33% (n=10) are in an intermediate situation, with houses nearby but in a relatively open
195 environment (e.g. houses close to one side of the farm and countryside on the other side).
196 Farm size ($3811 \pm 2963 \text{ m}^2$, median: 2679 m^2 , n=38) is significantly lower (Kruskal-Wallis
197 test, $p < 0.01$) in urban or developed areas, and most of the largest farms were located in open
198 areas (Table 1).

199

200 [Table 1 is here]

201

202 This survey revealed that giant gourami fry were not mainly produced by farmers focusing on
203 this species: 32% of the respondents (n=12) produce only giant gourami and a large majority
204 of farms (68%, n=26) also produce other species in variable proportions (Figure 3). This is a
205 typical characteristic of Javanese small-scale freshwater fish farming where farmers can
206 quickly shift from one species to another to better adapt to the market and the difficulties
207 encountered, conferring a greater resilience for this type of production system. In the
208 interviewed farms, the most important species reared for human consumption were non-native
209 species (Figure 3). These results reflect the national production statistics very well (i.e. 1.1 Mt

210 of tilapias, 0.72 Mt of African catfish and 0.46 Mt of common carp; FAO, 2017), also
211 indicating that giant gourami is the major local fish species produced (FAO, 2017).

212 [Figure 3 is here]

213

214 Interestingly, farms specifically dedicated to the production of giant gourami were
215 significantly smaller (Mann–Whitney U test, $p < 0.01$) than multispecies farms. These
216 quantitative observations support the fact that giant gourami aquaculture was mainly practiced
217 in small-scale fish farms. The rearing structures larger than 100 m^2 were mostly earthen
218 ponds. However, for smaller structures, 54% of the respondents ($n=21$) reported having
219 between 8 and 100% of their earthen ponds constructed with concrete banks. The number of
220 production ponds per farm varies from 3 to 85 (16 ± 15 ponds, median: 12 ponds, $n=39$). The
221 water supply to the ponds was mainly provided by surface water (55% of the respondents,
222 $n=21$) while drilling water was the water source for the ponds in 24% of the farms ($n=9$).
223 Interestingly, all the farms located in the most developed areas ($n=6$) receive only surface
224 water potentially increasing the risk of exposure to anthropogenic contaminants and,
225 therefore, the risk of disease and mortality for fish through the deterioration of the water
226 quality, although this relationship was not statistically demonstrated.

227 Overall, there were an average of two employees per farm in addition to the farmer (2.0 ± 1.2 ,
228 $n=37$). The number of employees was not significantly related to farm size, although the
229 absence of employees was observed only in the smallest farms.

230

231 3.1.2 Broodstock management and selection

232 It can be difficult to characterize the different strains of giant gourami reared in Indonesia
233 because their vernacular names vary according to localities. Currently, more research is being
234 done to improve strain characterization (Azrita & Syandri, 2015; Nuryanto, Amalia, Khairani,
235 Pramono, & Bhagawati, 2018). Interviewed farmers ($n=38$) reported that they own between
236 one and four different strains of broodfish. The strains used vary according to farm location.

237 In Tasikmalaya, the “Galunggung” strain (Arifin et al., 2017) is clearly dominant (presence in
238 all farms monitored). In the Bogor district, the situation is more complex. Although there is a
239 dominant strain called “Bastar” (Nuryanto et al., 2018) used by 68% of farmers (n=15), other
240 strains coexist and are used in variable proportions.

241 In most cases, broodfish or future broodfish are purchased from other fish farmers, usually in
242 the vicinity (86%, n=32). Nevertheless, 46% of the interviewed farmers reported that they
243 produced, at least partially, their own future broodfish. The number of broodfish kept on
244 farms ranged from 12 to 200 (70 ± 48 broodfish, median=50 fish, n=36) without any
245 significant relationship with the total surface of the farm. Characteristics of the broodfish used
246 are summarized in Table 2.

247

248 [Table 2 is here]

249

250 The stocking density in spawning structures varies between 0.02 and 0.75 fish m⁻² with an
251 average of 0.17 ± 0.15 fish m⁻² (median: 0.13 fish m⁻², n=30). In training centers, values were
252 0.15 to 0.20 fish m⁻². The standard values were one fish for 5-6 m² maintained in one to four
253 ponds in open-flow or regularly changed water conditions, although there were a few
254 exceptions. Water quality measurements taken in broodstock ponds suggested that, for the
255 various measured parameters, values are generally within the recommended range (SNI,
256 2006) except for temperature. Indeed, we found that temperature exceeded the recommended
257 value of 30.0°C during the day in 75% of the measurements recorded (Table 3).

258

259 [Table 3 is here]

260

261 The average pond size used for reproduction varied from 24 to 1100 m² (median: 300 m²,
262 n=33). There were two strategies for egg production: (1) the broodfish were maintained
263 together in a common pond (78%, n=32) or (2) the broodfish were maintained in
264 compartmentalized ponds (10%, n=4) where there was only one male per compartment with a
265 variable number of females (strategy mainly used in Central Java Province). According to the
266 fish farmers, the main advantages of using compartments were to avoid aggression between
267 males and to facilitate broodstock management.

268 Although 100% (n=11) of fish farmers using ponds with concrete banks provided broodfish
269 with supports for nest building, this was not always the case when earthen ponds were used
270 for egg production. For instance, 11 out of 26 farmers (42%) did not provided nest supports;
271 in these cases, the fish build their nests in bank crevices, most often dug by fish farmers.
272 Other fish farmers (58%) provided nest supports most often made of braided bamboo strips.
273 Interestingly, the number of spawning supports did not correlate with the number of broodfish
274 used. Although nest supports were not used systematically, all fish farmers provided various
275 materials for the construction of nests, mainly palm tree fibers (97%), used alone or in
276 combination with plastic fibers (75%), dry grass (25%) or coconut fibers (20%).

277 Farmers usually drain spawning ponds on average every 7 ± 8 months (median: 6 months,
278 range: 1-36 months, n=27) to clean the pond and/or change the broodfish. In most cases, the
279 fish are kept in egg production structures throughout the year. Nevertheless, some farmers
280 (9%, n = 3), trained by BPPSIGN, reported that they separated males and females for 1 month
281 for a resting period and fed them with pellets enriched with fermented soybean, poultry egg
282 yolk or vitamin E to replenish their energy reserves before starting a new three-month egg
283 production period.

284 The male-to-female (M:F) ratio of broodfish was independent of the strains and ranges from
285 1:2 to 1:9 (Figure 4). Nevertheless, 61% of the farmers use sex-ratios of 1:3 and 1:4 (i.e.

286 values close to the recommendations of the interviewed training centers and the Indonesian
287 National Standards; SNI, 2000a; 2000b). Farmers generally use more females than males to
288 minimize spawning disturbances due to the aggression of males, and optimize utilization of
289 the production surface. Based on BPPSIGN, selling prices for mature broodfish (~2 kg) were
290 USD 4.6 kg⁻¹ (i.e. ~USD 9.2 per individual, based on an exchange rate of USD 1 =
291 IDR 14,102) and USD 6.9 kg⁻¹ (i.e. ~USD 13.8 per individual) for males and females,
292 respectively, whereas immature future broodfish (~700 g) were sold at USD 3.5-4.6 kg⁻¹ (i.e.
293 ~USD 2.5-3.2 per individual). Thus, for economic reasons, broodfish were often purchased
294 young and immature. In these conditions, sex identification uncertainties were possible (see
295 below), and thus explained the most uneven sex-ratios, often unwanted. For example, one
296 farmer (excluded in Figure 4) reported a sex-ratio of 3 males for 1 female resulting from sex
297 identification errors of immature broodfish.

298

299 [Figure 4 is here]

300

301 According to fish farmers, the minimal size and age for using fish for reproduction were $1.9 \pm$
302 0.5 kg (median: 2.0, range: 1.0-3.0 kg, n=34) and 3.6 ± 1.9 years (median: 3.0 years, range:
303 1.5-10 years, n=34), respectively. Average values were close to the recommendations issued
304 by the BPPSIGN training center. Farmers exchanged their broodfish when they reached an
305 average age of about 10 years, but some of them kept their broodfish until they died (three
306 farmers indicated that they owned broodfish of 20 years or older). The sexing of mature and
307 future broodfish was a challenge in giant gourami aquaculture. In the absence of dedicated
308 tools, sexing and assessment of sexual maturity were mainly based on external observations.
309 To provide guidance for farmers, the Indonesian National Standard (SNI, 2000b) listed
310 several morphological criteria that could be used for sexing males and females. According to

311 SNI (2000b), mature males have a marked hump on the upper part of the head and a
312 thickening of the lower jaw. Females can be identified by black pigmentation at the base of
313 their pectoral fins. In addition to these criteria, fish farmers used other morphological and
314 behavioral criteria to try to improve sexing success in giant gourami. Among them, body
315 shape, caudal fin shape and specific behavior during handling could be objectively
316 determined. The most subjective criteria were not described here. In a recent study,
317 Slembrouck et al. (2019) demonstrated that observations of the hump on the forehead,
318 thickening of the lower jaw, and the pigmentation on the pectoral fin (not for light color
319 phenotypes) were highly reliable for sexing (about 95% success). Nevertheless, to be
320 efficient, observations of the selected criteria should be carried out using objective scales. The
321 use of the intraovarian cannulation technique was the most accurate sex identification method
322 but required specific cannula and skill which make it unfeasible for most small-scale farms
323 (Slembrouck et al. 2019). Authors also recommended confirming the sex of selected future
324 brooders after they reached sexual maturity. This study also revealed that the criteria often
325 used by fish farmers do not improve sex identification success.

326 Broodfish feeding consisted mainly of giant taro leaves (*Alocasia macrorrhizos*, 92% of the
327 farmers, n = 34 and the training centers). In some cases (16%, n=6), it was the only food used.
328 Commercial pellets (floating pellets in 80% of the cases, 30 ± 4 % of proteins) were used by
329 43% of the fish farmers (n=16). Feeding strategies varied greatly among farmers using pellets:
330 69% feed the broodfish every day (n=11, daily ration of 1% of the biomass), 19% every two
331 days (n=3) and 12% only once a week or less (n=2). Interestingly, commercial pellets were
332 always combined with plant food (mainly giant taro leaves). Only one farmer declared using
333 homemade feed (molasses, yeast, fermented cassava, soy waste, rice bran, fishmeal). Some
334 other food types (such as snails and several plant species, see Table 4) were used when the

335 main feeds were not available or because they were perceived as useful supplements in
336 improving the quality of the eggs.

337

338 [Table 4 is here]

339

340 Broodfish mortality occurred frequently for 58% of the interviewed farmers (n=21) and
341 disease was mentioned in 64% of the interviews (n=25). The main disease agents identified
342 by the fish farmers were ectoparasites such as *Lernaea* sp. (n=9), fungi (n=4), *Argulus* sp.
343 (n=2) and bacteria such as *Aeromonas* sp. (n=2). In addition to disease, 58% of the farmers
344 (n=21) also observed other causes of broodfish mortality such as aggressiveness (especially
345 for males, n=19), water quality (n=6), handling (n=5), animal predation (n=6). In addition,
346 surrounding noise (spontaneously mentioned by 25% of farmers, such as motorbikes,
347 firecrackers, etc.) was considered as an important factor of stress likely to cause broodfish
348 mortalities.

349

350 3.1.3 Natural spawning

351 The giant gourami reproduces spontaneously in the spawning ponds. Once a pair is formed, a
352 nest made of vegetable material is constructed, mainly by the male. Soon after oviposition and
353 egg fertilization, the male closes the nest and guards the progeny. Almost 100% of the
354 interviewed farmers checked the nest every day (median: 1 d, range: 0.5-7 d) in the ponds.
355 The interviewed training centers checked nests daily or every two days. Nest closure and the
356 presence of eggs and an oily film on the surface were the main indicators for identifying the
357 presence of a spawn. Most of the interviewed farmers (91%, n=29) observed seasonality in
358 reproductive intensity.

359 In Bogor and its vicinity, the dry season (from March to September) was given as the best
360 season for egg production and August appears to be the best month for spawning for 68% of
361 the interviewed farmers (n=15). In Tasikmalaya, where the dry season was less marked
362 (Climate Data, 2019), there was no clear seasonality reported in egg production. In the
363 absence of sufficiently reliable data (particularly in egg counts), it was difficult to estimate
364 seasonal changes in fish fecundity. On average, fish farmers estimate that, in their aquaculture
365 conditions, a female spawns about every 3 months (from 1.6 to 12 months), whereas the
366 minimum time interval between two successive spawns of a same female is 0.8 ± 0.9 month
367 (median: 0.8 months or 24 days, n=32). Our experimental data, obtained in another study on
368 hundreds of spawns collected in controlled conditions, corroborate farmer affirmations with
369 the highest observed mean spawning frequencies of 0.2-0.5 spawns per female per month
370 (depending on experimental situations) and the minimum time interval seen between two
371 successive spawns of the same female is 20 days (authors, unpublished data). For the majority
372 of the farmers interviewed (55%, n=21), egg production remained stable over recent years and
373 only 11% (n=4) mentioned decreases mainly attributed to pond instability or broodfish
374 mortality. These results, limited to a small number of fish farmers, indicate that in the
375 province studied, the production of gourami eggs does not appear to have degraded.

376

377 3.1.4 Egg production: from the nest to vitelline resorption

378 Egg management after egg-laying varies among interviewed farmers. Nevertheless, the
379 majority (87%, n=33) collected the nests within 24 h after spawning and incubated eggs in
380 dedicated structures. However, 13% of fish farmers declared that they harvest the larvae
381 hatched in the ponds. Most of the time, the farmers estimated the number of eggs per nest
382 (92%, n=35) and this number ranged from 1500 to 8500 eggs (4369 ± 1670 , median: 4500;
383 Table 5). Based on an average weight of 3 kg for females, the relative fecundity can be

384 roughly estimated at 1500 eggs kg⁻¹ (Table 5), a figure in accordance with data provided by
385 the SNI (2000a, 2000b). The results concerning the viability of the eggs were very variable:
386 76% (n=28) of the interviewed farmers indicated a viability of 80-90% and 19% of the
387 farmers provided viability rates of 50-90%, in accordance with the two training centers
388 (viability rates of 80-90%). Nevertheless, 72% of the interviewed farmers (n=28) indicated
389 that they collected, at least once, a completely unviable spawn (all eggs opaque and whitish).
390 The main reasons given to explain the variability in egg viability were mainly related to the
391 season, water quality, broodfish feeding and fungus development on eggs. Most farmers
392 (90%, n=35) eliminated dead eggs before or at the beginning of incubation. Interestingly,
393 42% of the interviewed farmers sell at least a part of their own egg production to other giant
394 gourami farmers (selling prices USD 3.3 ± 0.6 for 1,000 eggs, based on an exchange rate of
395 USD 1 = IDR 14,102).

396

397 [Table 5 is here]

398

399 The vast majority of fish farmers (n=32, 91%) incubated eggs in stagnant water contained in
400 20 to 50-L black plastic basins. The control of environmental conditions is very limited
401 during the incubation step. Nevertheless, incubation usually took place in a covered place to
402 protect eggs and larvae from rain. For the majority of fish farmers, it is temperature that
403 mainly affects the results of this rearing phase. Based on farmers' declarations, the incubation
404 time of gourami eggs varied between 2 and 4 days (median = 2.8 d, average ± SD: 2.7 ± 0.7 d,
405 n = 30). Post-hatch larvae were kept in the incubation structure (usually black basins) for 6 to
406 15 days (median = 9.5, average ± SD: 9.4 ± 2.4 d, n=34) before being transferred to larval
407 rearing structures. Usually, during this period, larvae were not fed and water was not renewed.
408 In 100% of the cases, larvae were transferred to the larval rearing structures when they were

409 able to swim actively (the “berenang” stage) and sometimes after complete yolk-sac
410 resorption (i.e. after 14-15- day post hatching at 25-30°C; Morioka, Vongvichith,
411 Phommachan, & Chantasone, 2013).

412

413 3.1.5 Larval rearing: from larvae to “nguku” fry

414 The time for the first feeding of larvae was highly variable, between 3.5 and 21 days post-
415 harvest (dph), according to the farmer (10.5 ± 4.5 dph, median: 9.5 dph, n=34). The first
416 feeding was done at 10-12 dph for the two training centers (i.e. before the complete vitelline
417 resorption, Morioka et al., 2013). Nevertheless, Morioka et al. (2013) indicate that feeding
418 begins earlier in laboratory-reared larvae (5 dph at 25-30°C). Other observations showed that
419 giant gourami larvae were able to eat brine shrimp nauplii (*Artemia* sp., authors’ unpublished
420 observations) and *Moina* nauplii (Amornsakun et al., 2014b) after 3 dph at 27-28°C and 4 dph
421 at 28-30°C, respectively. Approximately 8 dph at 28-30°C were needed for the larvae to be
422 able to feed on tubifex (*Tubifex tubifex*, Arifin et al., 2019). This latter live prey was the main
423 first food used (72% of the interviewed farmers, n=28) and other fish farmers used *Moina* sp.,
424 brine shrimp nauplii, natural plankton, poultry egg yolk or commercial powdered fish feed as
425 first feed. In most cases (74%, n=26), farmers did not change feed between the first feeding
426 and the “nguku” stage. During this rearing period, fish were usually fed in excess. All the
427 feeding strategies reported are summarized in Figure 5. The difficulty or the irregularity of
428 supply in natural prey, particularly in tubifex, was considered as a limiting factor for
429 successful larval rearing by 15% (n=5/34) of the fish farmers.

430

431

[Figure 5 is here]

432

433 For 86% (n=32) of fish farmers surveyed, larval rearing was done in one step up to the
434 “nguku” stage (i.e. 1.5-3.5 cm of total length, 2.0 ± 0.6 cm, median: 1.8 cm, n=24). Fish
435 farmers explained this rearing practice by the sensitivity of giant gourami larvae to handling.
436 However, a minority of them (14%) changed larval rearing and pre-growing structures (type
437 and/or size) one or more times with the increase of fish size until “nguku” production. Survey
438 results revealed that there were six types of larval rearing structures. However, the two
439 structures mostly used were tarpaulin tanks (39%, n=15) from 2 to 36 m² and concrete tanks
440 (31%, n=12) from 10 to 100 m².

441 In these rearing structures, the water level ranges from 15 to 50 cm (28 ± 8 cm, n=35) as was
442 the case in the two training centers. Two-thirds of the interviewed farmers (66%, n=23) reared
443 larvae in stagnant water with occasional water renewals. Other farmers (34%, n=12) used low
444 continuous water flow. Water aeration was not a usual practice in giant gourami larval rearing
445 (33% of the surveyed farmers).

446 Most of the surveyed farmers (70%) did not protect the larval rearing structures against the
447 sun or rain. Considering the low water level, it was likely that abrupt temperature variations
448 occur. Among 39 farmers, only five (13%) claim to measure the temperature during the larval
449 rearing and the pre-growing periods. Some on-site continuous measurements with data
450 loggers revealed that the daily temperature variation can range from 26 to 33°C in the
451 Tasikmalaya area and from 26 to 40°C in the Bogor area (Table 3). Up to the “nguku” stage,
452 fish were reared in traditional fish farms at a density ranging from 111 to 714 fish m⁻² ($337 \pm$
453 170 fish m⁻², median: 306, n=20), whereas the BPPSIGN uses and recommends an initial
454 stocking density of 300 fish m⁻².

455 At the end of this rearing phase (i.e. up to the “nguku” stage), reported survival rates vary
456 between 59% and 98% ($75 \pm 12\%$, median: 75%, n=23; Table 6). Such values were probably
457 optimistic and may reflect the best situation. According to fish farmers, the age at the “nguku”

458 stage appears highly variable and ranges from 30 to 98 days (47.9 ± 15.3 d, median: 43.5 d, n
459 = 36; Table 6). The two interviewed training centers indicated that 60 to 62 d were needed to
460 obtain “nguku”-stage fry. Interestingly, no relationship was found between size or age at the
461 “nguku” stage and the initial fish stocking density. Final selling prices for “nguku” fry
462 indicated by farmers interviewed were USD 2.7 ± 0.9 for 100 fish, based on an exchange rate
463 of USD 1 = IDR 14,102).

464 During larval rearing, 92% of the interviewed farmers (n=35) reported frequent mortalities of
465 giant gourami larvae. Among them, 77% (n=27) indicated that mortalities were common
466 during this production phase. Five farmers (14%) even state that mortalities sometimes
467 affected 100% of the stock farmed. From the 31 responses regarding the most sensitive stage,
468 we noted that the “gabah-kuaci” stage (15-25 dph) was the most sensitive (χ^2 , $p < 0.001$).

469 Meteorological conditions (temperature and rain) were considered as the major causes of
470 mortality by a large majority of farmers (68% of them, n=23). Heavy rains were frequently
471 mentioned.

472 The water quality (i.e. pollution of water inflow or by dead prey, etc.) was the second main
473 factor of larval mortality cited by 35% of farmers (n=12). It is clear that giant gourami larval
474 rearing can be significantly improved through better control of the rearing conditions
475 (protection against climatic variations, monitoring water quality and temperature). In this
476 sense, covering the basins to protect them from rainwater and carrying out incubation in tanks
477 less prone to temperature variations was a minimum recommendation to improve giant
478 gourami larval rearing.

479

480

[Table 6 is here]

481

482 3.2 Main problems faced and guidance for research

483 Limiting factors in egg and “nguku” production identified by fish farmers are shown in Figure
484 6. Meteorological factors were the main limiting factors in breeding for 50% of the farmers
485 (n=17). In particular, they considered that rain events led to a reduction in spawning
486 frequency and increased the occurrence of diseases for broodfish (38%, n=13). Interestingly,
487 meteorological factors, and more specifically rain, were also considered as the main source of
488 problems for larval rearing (cited by 68% of the farmers, n=23; Figure 6). However, it
489 remained unclear whether rain acted as a direct or indirect disrupter. Generally, rainfall causes
490 large temperature variations during this rearing phase and results showed almost few farmers
491 control the temperature in their farm structures (see Section 3.1.5).

492 Other factors were less cited by the interviewed farmers. Thus, surprisingly, problems with
493 water quality and pollution were only mentioned by a few farmers for both egg production
494 (12% of the farmers, n=4) and larval rearing (15%, n=5). Nevertheless, our water quality
495 measurements showed non-negligible proportions of values outside the recommended ranges
496 (temperature, dissolved oxygen, pH, Table 3) which suggests potential risks for larval rearing.
497 Interestingly, noise (natural, such as from thunderstorms, or from nearby human activities)
498 was also considered as an important stressor both for broodfish (47% of the interviewed
499 farmers, n=16) and larvae (21%, n=7).

500 Thus, all the information collected and the high variability in broodfish management by fish
501 farmers indicated the need for examination of the effects of biotic (e.g. sex-ratio, fish stocking
502 density, frequency of fish resting periods, etc.) and abiotic (e.g. size of breeding structures,
503 feed, meteorology, etc.) factors on sexual activity and the reproductive success of giant
504 gourami. Such investigations may become priority topics because, paradoxically, available
505 scientific literature in this field is currently rare. Nutrition and disease (especially parasites,
506 see Section 3.1.2) also required specific research efforts. In addition, the effects of external
507 disturbances such as natural noise or nearby human activities have not been documented and

508 information is missing regarding their potential effects on spawning and egg production
509 results.

510 To overcome the difficulties encountered during larval rearing up to the “nguku” stage
511 (Figure 6), this rearing phase could be performed in closed hatcheries and ideally in a
512 thermoregulated recirculating system. This type of system would also protect fry from
513 predators and may provide better control over water quality, disease and noise, also cited as
514 limiting factors. Nevertheless, this type of system requires dedicated infrastructure and incurs
515 additional costs that cannot be covered by most traditional fish farmers alone. In addition, the
516 implementation of such technology requires support through technical training provided to
517 fish farmers. These constraints make the generalization of the closed-circuit hatchery for the
518 giant gourami complex and not necessarily adapted and accessible to all producers. These
519 constraints should be considered in the research objectives for aquaculture of this species.
520 Thus, research efforts should also be directed to better determine the environmental
521 requirements of giant gourami eggs and fry, and the best conditions (with priority on the
522 effects of water quality and especially temperature) for larval rearing and how to adapt them
523 to traditional farms. In parallel, research on nutrition of juvenile giant gourami stages should
524 be conducted to help address the food supply problems faced by farmers and optimize larval
525 rearing performances (growth and survival).

526

527 [Figure 6 is here]

528

529 As complement to the main limiting factors identified by farmers, the two training centers
530 also listed the need to work on the genetic selection of broodfish and the nutrition from larvae
531 to adults. In addition to these topics that can be addressed through scientific research, the
532 training centers underlined the importance of improvement in production tools, better

533 monitoring of the sector by authorized institutions (monitoring of farming practices and
534 rationalization of selling prices), and better training for fish farmers.

535

536 3.3 SWOT analysis of giant gourami fry production

537 A SWOT analysis considers the strengths and weaknesses of the internal operating
538 environment (in this case, defined as the production of giant gourami fry) and the potential
539 opportunities and threats from the external operating environment that may affect the sector
540 (such as customers, markets, government policy, etc.; Leigh, 2009; Rimmer et al., 2013).
541 Thus, based on the results of the surveys and on current knowledge regarding the giant
542 gourami fry production chain, a SWOT analysis was carried out and is summarized in Table
543 7.

544

545 [Table 7 is here]

546

547 The SWOT analysis and the surveys showed that the production of fry of giant gourami in
548 West Java Province, Indonesia had many strengths. This species had high heritage value and
549 was one of the main freshwater commodities in Indonesia (Slembrouck et al., 2018). The
550 market was therefore generally stable, with relatively high prices although they showed some
551 variation throughout the year. In addition, the production of giant gourami fry can be carried
552 out using low inputs and low technology. The species can reproduce naturally in the rearing
553 structures, allowing for relatively easy egg production on most small-scale farms. There were
554 no particular difficulties for first feeding during larval rearing, one of the main bottlenecks
555 generally faced in fish culture (Hamre et al., 2013), because the larvae have large vitelline
556 reserves and oil globules (Baras et al., 2018). The production of giant gourami fry was highly
557 integrated in local agrosystems. One of the best examples was broodfish feeding: in most

558 cases it was based on on-site production of planted terrestrial macrophytes such as giant taro
559 leaves.

560 Nevertheless, as highlighted in this study, the production of giant gourami fry currently
561 suffers from a lack of standardization of production techniques. The production of this
562 relatively slow-growing fish with low fecundity, especially compared with other non-native
563 farmed fishes, was therefore variable and uncertain. Most fish farmers requested training, and
564 had few technical and financial resources, which further limited their ability to optimize their
565 production. As highlighted by the fish farmers' experience, the production of gourami
566 depends greatly on environmental conditions and is potentially threatened by diseases. In
567 addition, freshwater quality and its availability are among the major problems on Java Island
568 and affects aquaculture production. Giant gourami farming relies to a high degree on the farm
569 environment. Thus, to allow the expansion of aquaculture of this species, solutions should be
570 provided to limit the strong dependence between farming practices and the environment.

571 However, giant gourami aquaculture can benefit from several opportunities. For instance,
572 there are increasing incentives from international institutions such as FAO and the Indonesian
573 government to develop the aquaculture of local species (FAO, 2016; Tran et al., 2017).
574 Therefore, in this context, the authorities are more inclined to support aquaculture of this
575 species. Research programs should investigate the requirements for broodfish and juvenile
576 stages to improve the efficiency of egg production methods and larval rearing techniques, to
577 completely domesticate this species (Teletchea & Fontaine, 2014). One of the strengths of the
578 organization of the aquaculture sector in Indonesia is the existence of assistance and training
579 services for fish farmers (called Penyuluh Pertanian Lapangan) and national production
580 standards (SNI) that are tools for potentially more rapid dissemination of scientific research
581 results among fish producers.

582

583 **4 CONCLUSION**

584 This study is, to our knowledge, one of the first to describe in detail the commercial
585 production of giant gourami (*Osphronemus goramy*) fry in Indonesian aquaculture. The
586 production of this species, highly prized on the local market, constitutes high added value for
587 small fish farmers in West Java and contributes to the improvement of their living conditions.
588 The development of this production holds promises but requires an increase in research
589 efforts on the basic biology of this species which, despite more than a century of breeding, is
590 not completely domesticated. Based on our analysis of the main bottlenecks, highlighted from
591 on-farm surveys, we recommend first focusing further research on the influence of climate
592 variables on zootechnical performance. In a second time, nutrition research should be
593 performed both to improve reproduction success of broodfish and also to provide reliable
594 alternatives to tubifex in fry production. On the longer term, improvements in reproduction
595 control would be needed particularly for selection programs.

596

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603

604 **CONFLICTS OF INTEREST**

605 The authors declare that they have no conflict of interest.

606

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738

739 **FIGURE LEGENDS**

740

741 **FIGURE 1** Representative production cycle of giant gourami *Osphronemus goramy* in West
742 Java (Indonesia; modified from FAO, in press). The present study focuses on the phases from
743 broodfish management up to nursery fry production (the “nguku” stage).

744

745 **FIGURE 2** Locations of the giant gourami farms considered in this study (i.e. 35 independent
746 farmers, four farmers members of a “kelompok” and two training centers) in West Java
747 province.

748

749 **FIGURE 3** Occurrence (%) of the fish species (other than giant gourami) reared in the
750 studied multispecies farms. Local species reared for human consumption are indicated in
751 white and non-native species in black.

752

753 **FIGURE 4** Sex-ratios (male:female) used by interviewed farmers for giant gourami egg
754 production.

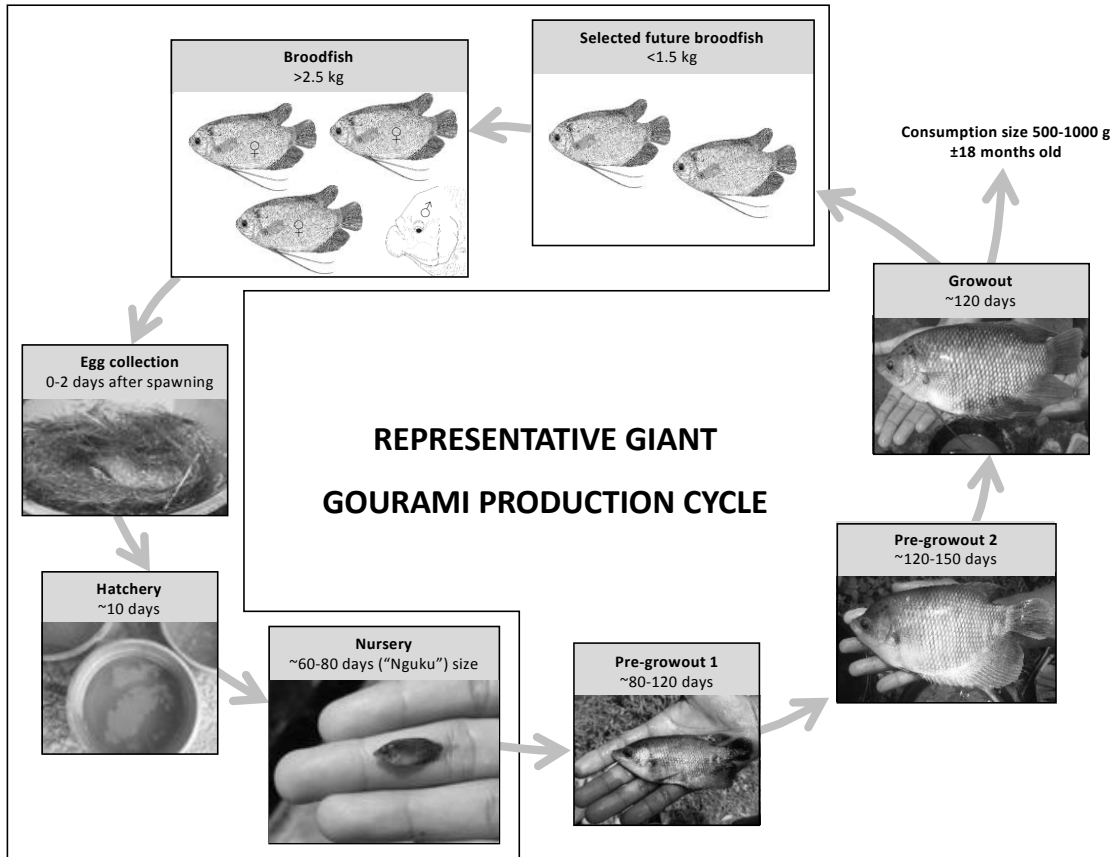
755

756 **FIGURE 5** Feeding strategies for giant gourami from the first feeding (10.5 ± 4.5 dph) to the
757 “nguku” stage (47.9 ± 15.3 dph). The duration of each feeding period was normalized to take
758 into account the variability of rearing time among farmers.

759

760 **FIGURE 6** The main limiting factors identified by farmers in egg and fry production of giant
761 gourami.

Production phases considered in the present study



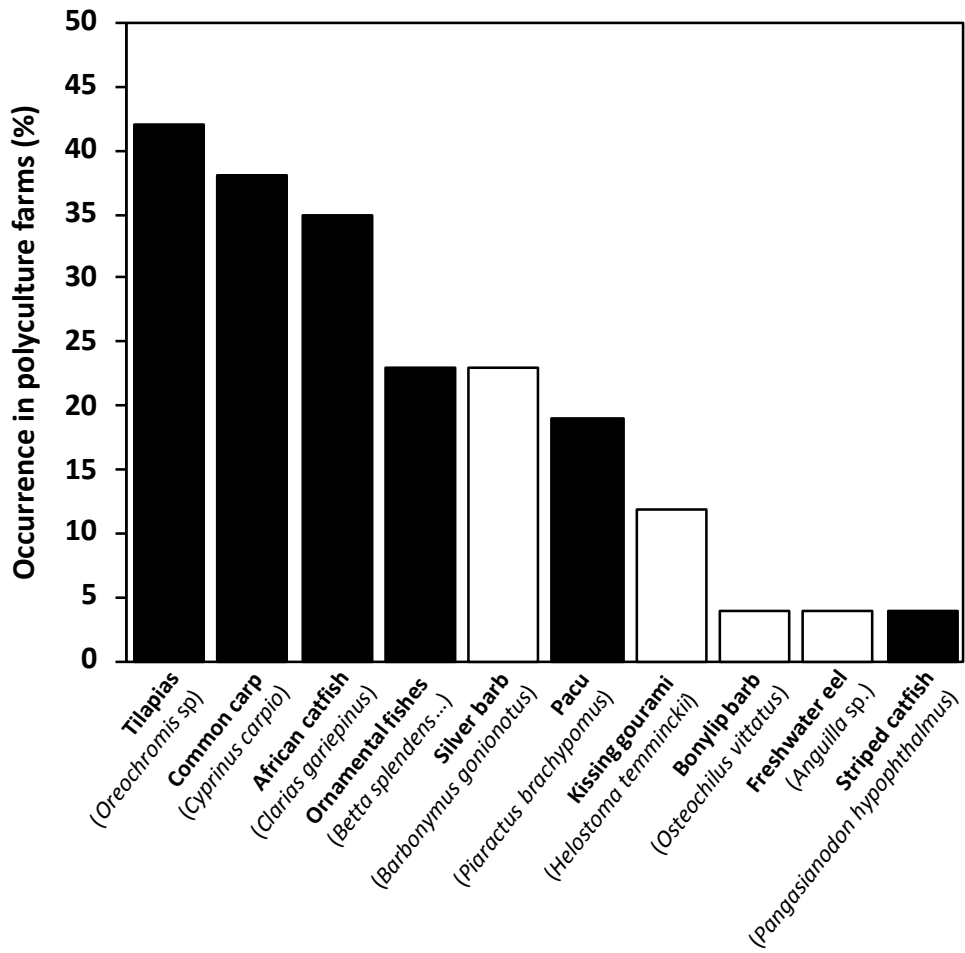
762 **FIGURE 1**

763



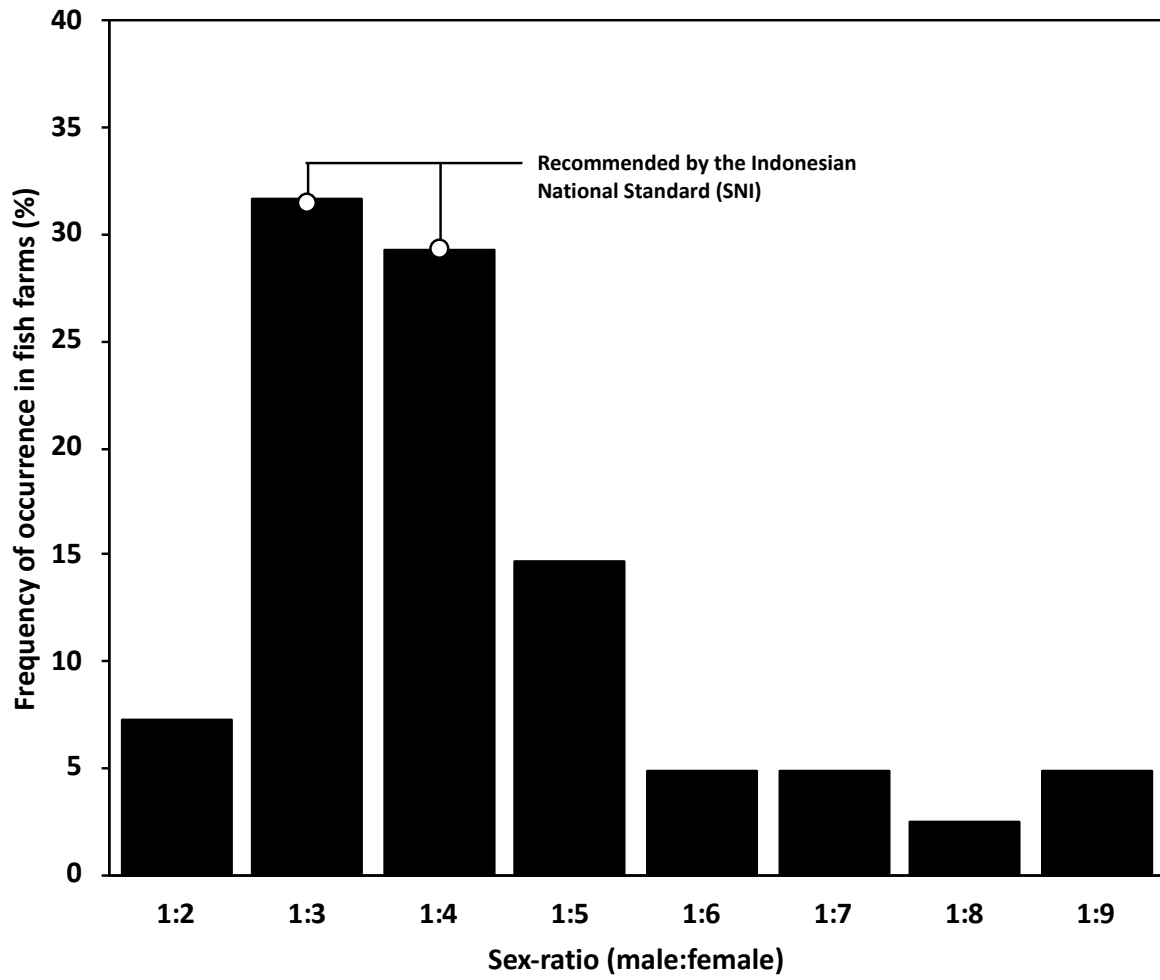
764 **FIGURE 2**

765



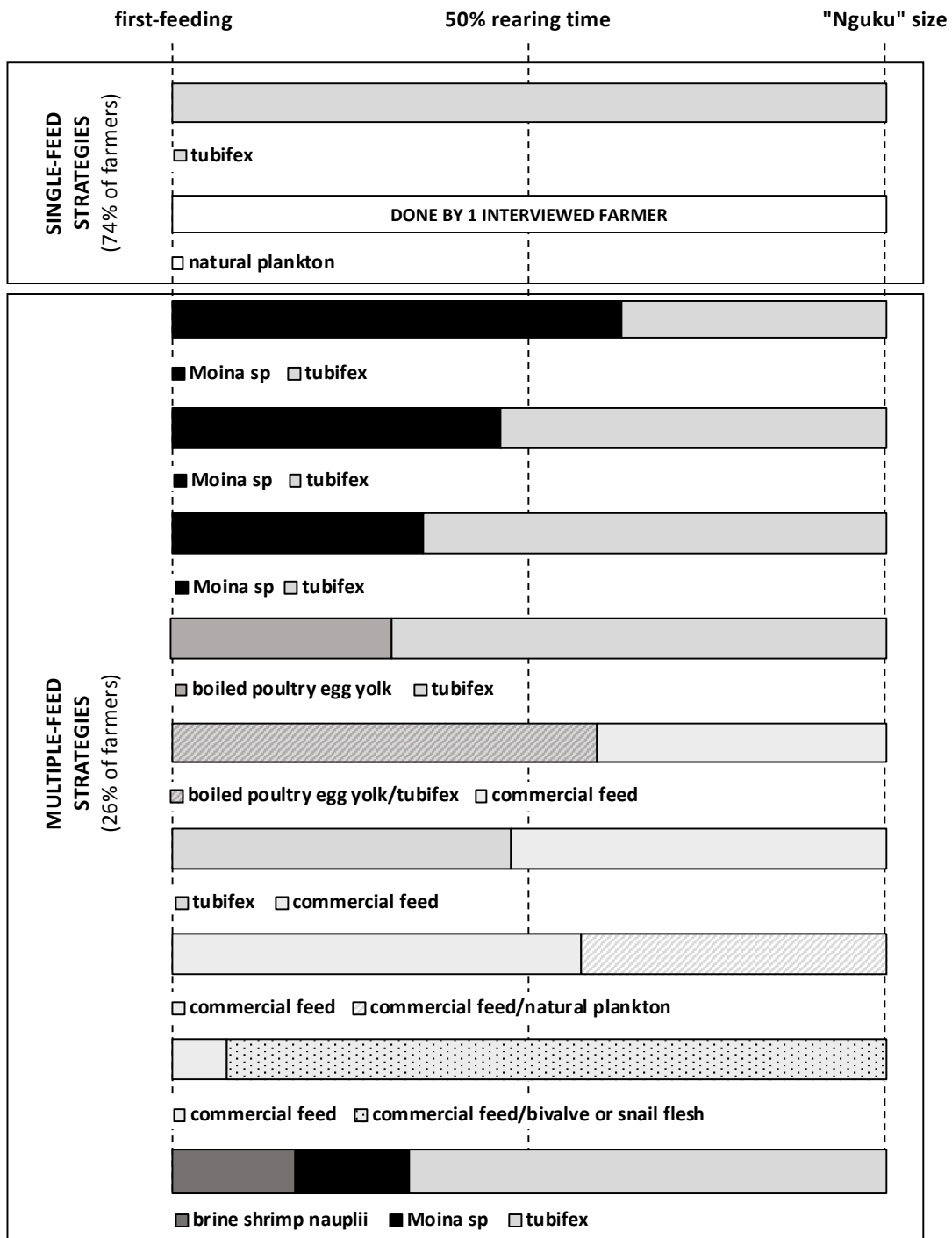
766 **FIGURE 3**

767



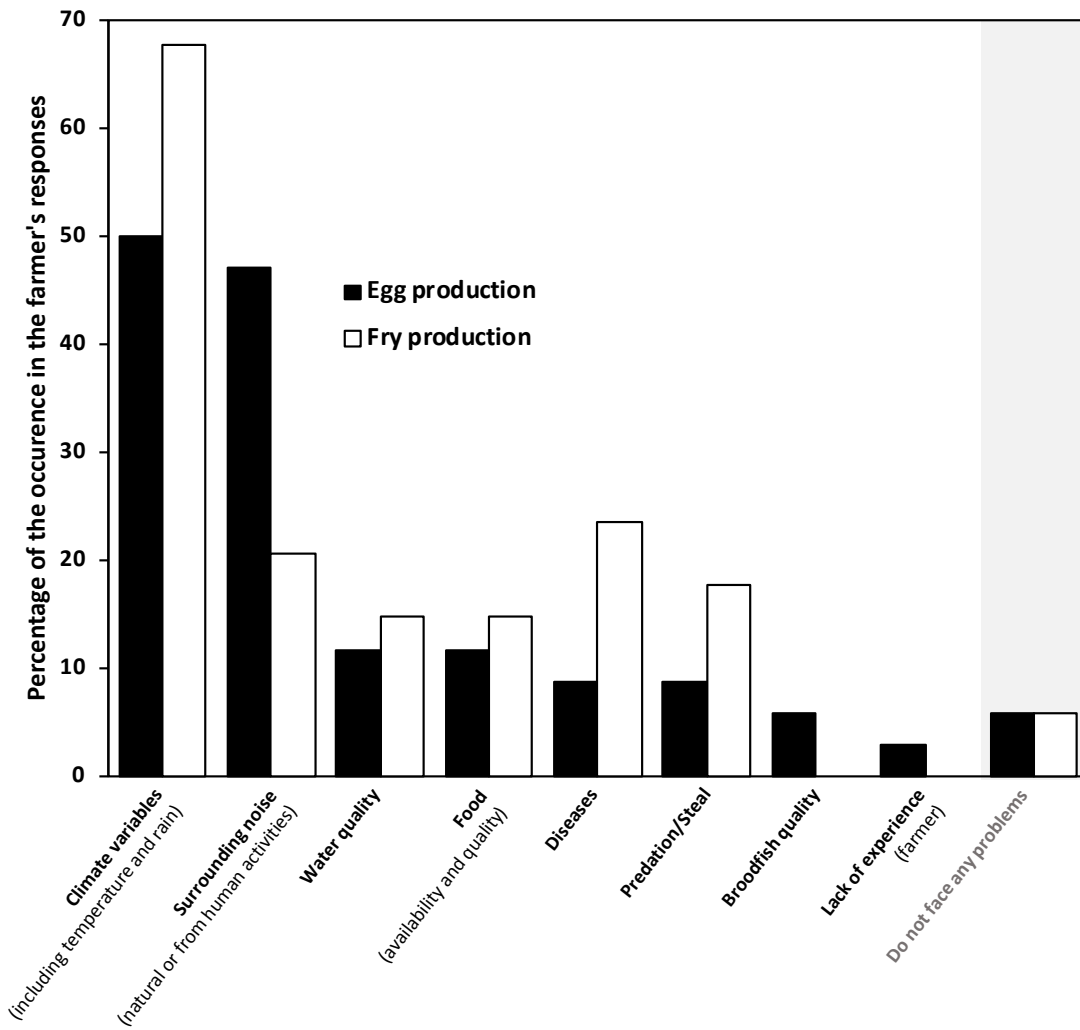
768 **FIGURE 4**

769



770 **FIGURE 5**

771



772 **FIGURE 6**

773

774 **TABLE 1** Main characteristics of the giant gourami production sites in West Java province

Characteristics	Fish farms (n=35-39)	Training centers (n=2)
Proximity to developed areas (% of the production sites)	<ul style="list-style-type: none"> • high: 20% • medium: 33% • low: 47% 	<ul style="list-style-type: none"> • low: 100%
Altitude (m)	110-540	88-480
Surface of the farm (m ²)	3,811 ± 2,963	25,000-29,000
Type of ponds	<ul style="list-style-type: none"> • concrete pond • earthen pond • earthen pond with concrete banks 	<ul style="list-style-type: none"> • earthen pond • earthen pond with concrete banks
Number of ponds	16 ± 15	79-106
Giant gourami rearing only (% of the production sites)	32%	100
Origin of the water used	<ul style="list-style-type: none"> • surface water: 55% • drilling water: 24% • mixed water: 21% 	<ul style="list-style-type: none"> • surface water: 100%

775 Note.

776 Kelompok (fish farmer groups) were excluded for the surface of the farms and the number of

777 ponds

778 **TABLE 2** Management of giant gourami broodfish in the interviewed farms (n=30-39)

Origin of the broodfish (% of the farms)	Number of broodfish per farm	Stocking density (fish m ⁻²)	Type of spawning structure (% of the farms)	Spawning pond size (m ²)	Minimal weight of broodfish (kg)	Minimal age of broodfish (years)	Age of broodfish at replacement (years)
<ul style="list-style-type: none"> • purchased (100%) • on-farm production (46%) 	70 ± 48	0.17 ± 0.15	<ul style="list-style-type: none"> • communal pond (91%) • compartmentalized pond (11%) 	24-1100	1.9 ± 0.5	3.6 ± 1.9	10.2 ± 4.5

779 Note.

780 The total proportions for the type of spawning structure is slightly higher than 100% because

781 farmers can use both communal and compartmentalized ponds on the same farm.

782 **TABLE 3** Summary of water quality parameters measured in the broodstock ponds (n=39)
 783 and juvenile rearing structures (n=47) between 8:15 AM and 6:30 PM during fish farmer
 784 surveys

Parameters	Observed ranges	Recommended ranges	Comments
Broodstock ponds (n=39)			
Temperature (°C)	24.6-34.7	25.0-30.0 (SNI, 2006)	49% measurements > 30.0°C 26% measurements > 32.0°C
Dissolved oxygen (mg L ⁻¹)	0.4-16.3	> 2.0 (SNI, 2006)	10% measurements < 2.0 mg L ⁻¹
pH	5.8-9.5	6.5-8.5 (SNI, 2006)	10% measurements < 6.5 1 extreme value at 9.5
Conductivity (µS cm ⁻¹)	37-289	-	-
Turbidity (NTU)	3-134	> 50 (Seim et al., 1997)	43% measurements > 50 NTU
Fry rearing structures (n=47)			
Temperature (°C)	27.1-39.9	29-30 (SNI, 2000a)	60% measurements > 30.0°C 30% measurements > 32.0°C
Dissolved oxygen (mg L ⁻¹)	3.4-12.5	> 5 (Boyd & Tucker, 1998)	30% measurements < 5 mg L ⁻¹
pH	7.2-9.8	6.5-8.0 (SNI, 2000a)	47% measurements > 8
Conductivity (µS cm ⁻¹)	24-1,242	-	1 extreme value at 1242 µS cm ⁻¹
Turbidity (NTU)	1-282	> 50 (Seim et al., 1997)	28% measurements > 50 NTU

785 Notes.

786 Potential risks related to low dissolved oxygen are age-dependent because the labyrinth organ
 787 begins to develop in fry aged 30 dph and air-breathing behavior is first observed after 35-40
 788 dph (Morioka, 2013).

789 One interviewed fish farmer adds lime and salt during larval rearing in undetermined quantity,
 790 which explains the extreme values observed for conductivity and pH.

791

792 **TABLE 4** Feeds and feeding strategy for giant gourami broodfish in the production site

793 (n=41)

Types of feeds	Occurrence in the broodfish diet (% of farms)	Comment
Main feeds		
Giant taro leaves (<i>Alocasia macrorrhizos</i>)	92	main feed for giant gourami broodfish, 16% of the farmers used only this feed
Compounded pellets	41	mainly floating pellets (80%), proteins: 30 ± 4 %, usually $\leq 1\%$ of the biomass/day
Other feeds		
Taro leaves (<i>Colocasia esculenta</i>)	16	alternative to giant taro leaves
Snails flesh	11	-
Papaya leaves	5	-
Cassava leaves	5	-
Others macrophytes	22	including terrestrial and aquatic macrophytes (leaves, seeds, all plants), sometimes used as medicinal plants

794

795 **TABLE 5** Summary of the egg production results in giant gourami production (n=31-38)

Incubation practice (% of the farms)	Egg count estimation (% of the farms)	Number of eggs in a spawn	Estimated relative fecundity (egg kg ⁻¹)	Number of spawning events female ⁻¹ month ⁻¹ (in high season)	Egg viability (%)
<ul style="list-style-type: none"> • in dedicated structures: 87% • in broodfish ponds: 13% 	<ul style="list-style-type: none"> • yes: 92% • no: 8% 	4,369 ± 1,670	~1,500	0.30 ± 0.23	50-90

796

797 **TABLE 6** Summary of fry production (up to the “nguku” stage) results in giant gourami
 798 production (n=23-37)

Rearing structures (% of the farms)	Size of the rearing structures (m ²)	Stocking density (larvae m ⁻²)	Estimated survival rate (%)	Size at the “nguku” stage (cm)	Age at the “nguku” stage (d)
<ul style="list-style-type: none"> • tarpaulin tank: 39% • concrete tank: 31% • plastic tank: 10% • others: 10% 	2-100	337 ± 170	75 ± 12	2.0 ± 0.6	47.9 ± 15.3

799 Note.

800 Reported values for survival rates are probably optimistic and may reflect the best situation.

801 **TABLE 7** Summary SWOT table for egg and fry giant gourami production in West Java
 802 province, Indonesia.

Strengths	Weaknesses
<p>Species</p> <ul style="list-style-type: none"> • High heritage value • Large vitelline reserves, oil globules • Capable of aerial respiration • Strong vegetarian component 	<p>Species</p> <ul style="list-style-type: none"> • Low fecundity • Low growth performance • Brood fish are difficult to sex
<p>Practices</p> <ul style="list-style-type: none"> • Low-inputs aquaculture • Strongly integrated into local agrosystems • Natural reproduction 	<p>Practices</p> <ul style="list-style-type: none"> • Limited technical resources • High variability in production methods • Lack of training for farmers
<p>Economy/Market</p> <ul style="list-style-type: none"> • Market stability • High selling prices 	<p>Economy/Market</p> <ul style="list-style-type: none"> • High costs of commercial feed • Competition with non-native species • High purchase prices of broodfish
Opportunities	Threats
<ul style="list-style-type: none"> • National support for aquaculture of local species • Promotion of ecological intensification • Improvement of fish farmer training through extension services • Potential improvement in fry availability and zotechnical performance 	<ul style="list-style-type: none"> • Occurrence of disease • Water quality deterioration • Increasing costs of production

803