

Characterizing shrimp-farm production intensity in Thailand: beyond technical indices

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1 **Characterizing shrimp-farm production intensity in Thailand: Beyond technical**
2 **indices.**

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46 **Abstract**

47
48 This study examines shrimp farmer behaviour in relation to production intensity along the
49 eastern coast of the Gulf of Thailand, and its embeddedness in the wider socio-economic
50 context of shrimp farming households. The integrative agent-centred (IAC) framework was
51 used as a basis for designing a structured survey to collect semi-quantitative data for a range
52 of explanatory variables that potentially drive shrimp farmer behaviour. The results show that
53 shrimp farming intensity is associated with a combination of technical (e.g. farm area, pond
54 size, stocking density and production), economic (shrimp selling price, production costs and
55 farm revenue), social (e.g. farm operating years, the use of family labour, engagement in
56 shrimp farming and with other shrimp farmers), and ecological factors (e.g. farmer reliance
57 on natural pond productivity, and constraints brought about by environmental change and
58 fluctuations in productive areas). In addition, the results indicate that a number of external
59 and internal socio-economic factors are related to the decision to adopt a certain level of
60 production intensity, including training received on farming practices, access to technical
61 equipment, proportion of total income from shrimp farming, season-specific changes in
62 production, risk perception, and subjective culture (social norms and roles). This study
63 therefore illustrates that levels of shrimp farming intensity are in fact an indicator of a
64 diversity of socio-economic conditions and behavioural choices, which need to be targeted by
65 sustainability policies differentially and beyond the technical sphere. In showing this, we

66 conclude that national standards aimed at achieving aquaculture sustainability should be
67 designed to reflect the diversity needed to support such a diverse sector, and should be
68 adjustable to better represent different socio-economic contexts.

69
70

71 **Keywords:** shrimp aquaculture; farming intensity; farmer behaviour; sustainability

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74 **1. Introduction**

75 *1.1. Shrimp farming sustainability*

76 With the continued downward trend in the overall state of the world's marine fish
77 stocks (Pauly and Zeller, 2016), the aquaculture sector increasingly plays a major role in
78 meeting the ever-growing human demand for fish and other aquatic products (FAO, 2018;
79 Belton et al., 2014; Hall et al., 2011a). Total worldwide aquaculture production reached about
80 80 million tonnes in 2016, estimated to be worth USD 232 billion (FAO, 2018). Globally,
81 aquaculture supports livelihoods and contributes to food and economic security by delivering
82 sources of animal protein, nutrients, and income (Belhabib et al., 2015; Smith et al., 2010;
83 Godfray et al., 2010).

84 However, aquaculture is often associated with environmental sustainability issues.
85 Major environmental issues have been documented since the 1990s. These include
86 widespread destruction and conversion of coastal ecosystems (Alongi, 2002; Richards and
87 Friess, 2016; Valiela et al., 2001), direct loss of fisheries and coastal biodiversity (Naylor et
88 al., 1998, 2000, 2009; Diana, 2009; Polidoro et al., 2010), salinization of groundwater and
89 transformation of agricultural land (Cardoso-Mohedano et al., 2018), high rates of natural
90 resource consumption (Boyd and McNevin, 2015), eutrophication of coastal waters and
91 disease outbreaks (Naylor et al., 1998, 2000; Herbeck et al., 2013), and large fish meal and
92 fish oil requirements which has put direct pressure on wild fish stocks (Tacon and Metian,
93 2008). Environmental changes have also led to negative consequences for coastal
94 communities, including displacement and loss of local livelihood, increased vulnerability to
95 flooding, and loss of many essential services provided by intact ecosystems (Primavera,
96 1997, 2006; Neiland et al., 2001; Paul and Vogl, 2011). In response, there have been calls for
97 more sustainable aquaculture production (FAO, 2016a).

98 Thailand first developed national certification standards for aquaculture production in
99 the late 1990s, and currently, three state-initiated certification standards exist, including the

100 Good Aquaculture Practice (GAP), Code of Conduct (CoC) and, most recently, the GAP-
101 7401 (Samerwong et al., 2018). These standards set requirements for shrimp producers aimed
102 at improving farming practices, environmental integrity and social responsibility, and
103 mitigating problems of disease, which presents a significant risk to producers across farm
104 intensity types, from the small-scale family operations to the highly intensive corporate-run
105 farms (Cock et al., 2015).

106 While Thai state-initiated standards attempt to be inclusive across producers of
107 varying intensity and capability, two crucial issues can be identified as challenges for the
108 promotion of sustainable aquaculture. First, policy-makers have had difficulties in tailoring
109 sustainability policies and strategies to match the diversity of aquaculture farming systems.
110 For example, on the rise of sustainability certification and quality standards, Bush et al.
111 (2013) argue that while such schemes contribute towards the development of more
112 sustainable production, they have significant limitations due to the complex, context-
113 dependent social issues concerning aquaculture production, which are often overlooked. As a
114 result, many small-scale producers are excluded from these strategies due to, for example, the
115 costs or resources needed to follow the standards (Kusumawati et al., 2013), and so they are
116 often pushed out of global value chains (Bush et al., 2013). Second, there are important gaps
117 in understanding of behaviour among aquaculture producers at the farm-level regarding their
118 production intensity (Bush et al., 2010). Actions taken by producers affect social, economic,
119 and ecological conditions and can thus influence the overall sustainability of aquaculture
120 production. A better understanding of farmer behaviour in relation to their production
121 intensity is therefore central for designing measures that can effectively promote more
122 sustainable aquaculture (Bush et al., 2010).

123 In policies such as the above-mentioned sustainability standards, as well as in
124 research, shrimp aquaculture production intensity is often approached as a technical issue.
125 Yet, shrimp farms are shown to be embedded within a socio-economic landscape
126 (Vandergeest et al., 2015; Bush et al., 2010; Joffre et al., 2015, Bottema et al., 2018). Thus,
127 we hypothesize that levels of production intensity also correspond to different farm socio-
128 economic profiles that are not captured by technical indexes alone. Production intensity
129 should be considered in terms of a combination of technical indices of production embedded
130 within a broader socio-economic context. To reiterate: consideration of the complexity of
131 shrimp farmer behaviour and the wider socio-economic perspective of aquaculture
132 production matters when we think about promoting sustainability through certification
133 standards or other measures: standards may fail because they only take the technical aspects

134 into account and fail to appreciate the socio-economic context in which those technical
135 aspects are embedded (Kusumawati et al., 2013; Bush et al., 2013; also see Bottema et al.,
136 2018).

137 This study builds on earlier literature on farmer behaviour related to shrimp farming.
138 It applies the integrative agent-centred framework (Feola and Binder, 2010) to examine
139 drivers influencing shrimp farmer behaviour in relation to production intensity along the
140 eastern coast of the Gulf of Thailand, and its embeddedness in the wider socio-economic
141 context of shrimp farming households. The study was guided by the following two questions:
142 i) which socio-economic factors are related to distinct levels of shrimp farming intensity?,
143 and specifically, ii) which socio-economic factors matter in the decision to adopt a certain
144 level of production intensity?

145 The paper continues with an overview of shrimp farming in Thailand and its
146 relevance in relation to the above research gaps, and a brief overview of the study site. We
147 then bring together literature on the characterisation of shrimp farming intensity types and
148 farmer behaviour. This is followed by an overview of the research methodology and
149 presentation of the results from the case study. Finally, we discuss the key findings in relation
150 to the wider aims of the study.

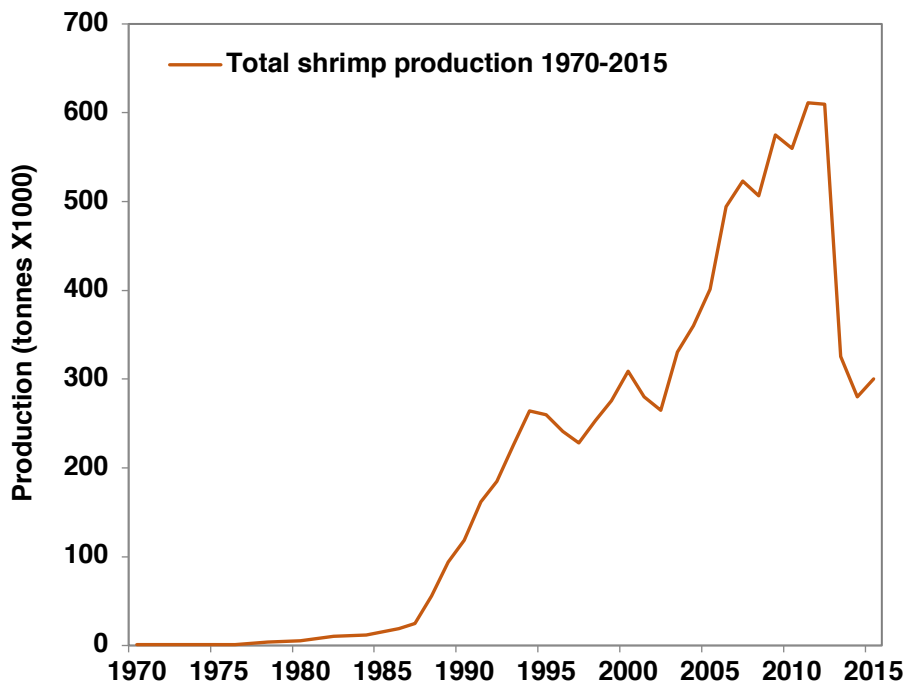
151

152 *1.2. Shrimp aquaculture in Thailand*

153 Shrimp farming has been a traditional livelihood practice on coastal landscapes in
154 Thailand for centuries, but the character of coastal shrimp culture has changed dramatically
155 over the past half century. Production of Penaeid shrimps, which account for around 80% of
156 total shrimp production, has increased rapidly, from less than 24, 000 t in 1950 to over 600,
157 000 t in 2012 (FAO, 2016b; Figure 1), with production from around 23, 800 shrimp farms
158 along the coast (Department of Fisheries, 2018). However, total shrimp production dropped
159 from over 600, 000 t in 2012 to 325, 000 t in 2013 (FAO, 2016b). This was the latest of many
160 abrupt social-ecological dynamics: boom and bust periods driven by disease epidemics in
161 cultured shrimp (Flegel, 2012; Leaña and Mohan, 2012), coupled with negative biophysical
162 changes and ecological feedbacks, and a year-on-year drop in market price for shrimp (Lebel
163 et al., 2002; Hall, 2011b; Huitric et al., 2002; Barbier and Cox, 2004; Piamsomboon et al.,
164 2015).

165 Shrimp farming in Thailand has previously been characterised as being very intensive
166 compared to other Southeast and South Asian countries (Lebel et al., 2002; Kumar and Engle,

167 2016). However, aquaculture practices have been changing rapidly (Henriksson et al., 2015),
168 and currently there is a diversity of farms of different sizes that operate in the landscape at
169 different production intensities side-by-side. This present research therefore captures current
170 shrimp farming diversity in the face of this rapid change and aims to better understand the
171 socio-economic landscape of shrimp production systems.
172



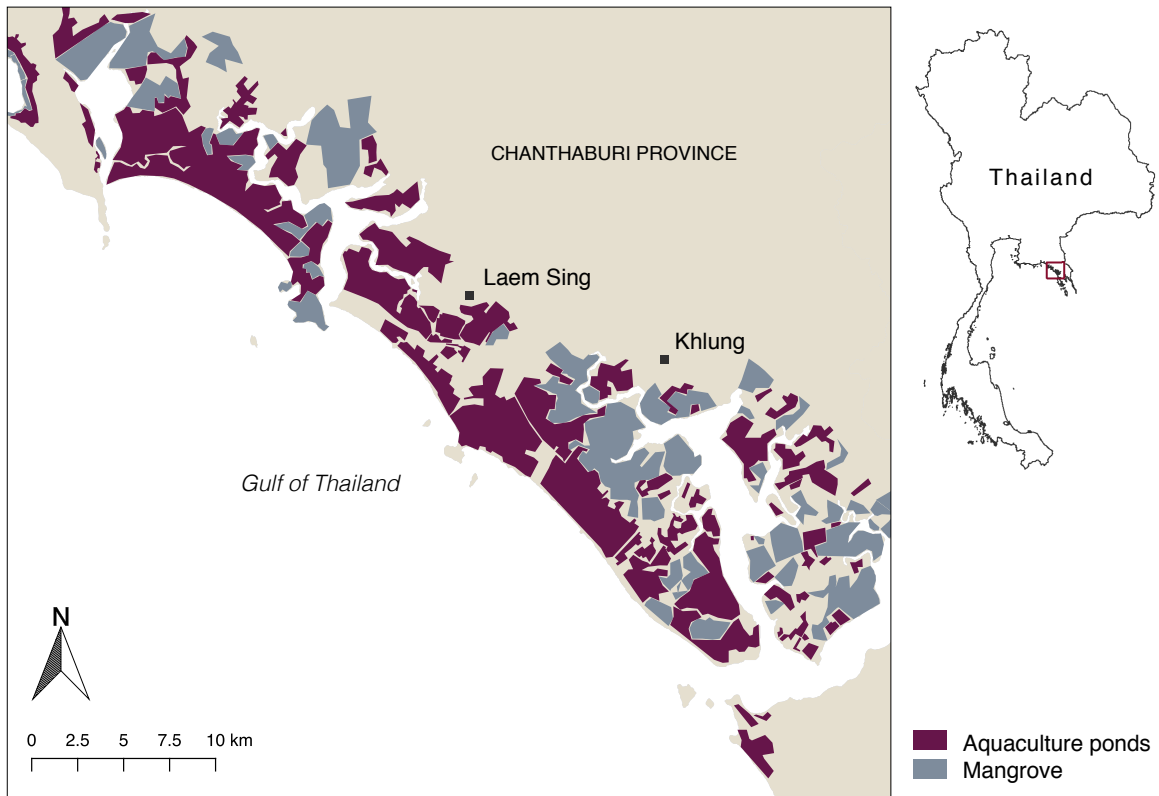
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174 **Figure 1. Production of cultured brackish water shrimp in Thailand from 1970 – 2015.** Source: FAO
175 FishStatJ.
176

177 This study was conducted in the sub-districts of Khlung and Laem Sing, Chanthaburi
178 Province, on the eastern coast of the Gulf of Thailand (12.61° N, 102.10° E; Figure 2). The
179 coastline of Chanthaburi stretches 68 km across four coastal districts; Na Yai Am, Tha Mai,
180 Laem Sing, and Khlung. The region is characterized by its diversity of coastal habitats,
181 including extensive seagrass beds, tidal mudflats, and mangrove forests (Janetkitkosol et al.,
182 2003). However, large areas of mangrove forest were cleared and converted in Chanthaburi
183 during the 1980s and 1990s to make space for aquaculture, with remaining mangroves only
184 occurring in narrow fringes. Behind the mangrove fringe, there are many shrimp farms, rice
185 fields, and fruit orchards.

186 Chanthaburi is a relevant area for this study because for decades it has been one of the
187 largest shrimp-producing provinces in Thailand (Hazarika et al., 2000; Department of
188 Fisheries, 2018), yet the region has been hit by severe social-ecological fluctuations since

189 2013 driven by disease epidemics in shrimp and negative environmental change
190 (Piamsomboon et al., 2015).

191
192
193



194
195 **Figure 2. Map showing the study area location in the Districts of Laem Sing and Khlung, Chanthaburi**
196 **Province, on the Gulf of Thailand coast.**
197

198 Intensive shrimp culture along Chanthaburi's coastline began in the 1980s and
199 expanded at a dramatic rate through the 1990s and 2000s (Hazarika et al., 2000). In 2012,
200 there were around 2120 shrimp farms in Chanthaburi, covering 6758.72 ha in area and
201 producing over 60 000 t of shrimp (Department of Fisheries, 2018). Two Penaeid shrimps
202 (*Litopenaeus vannamei* (Whiteleg shrimp) and *Penaeus monodon* (Black tiger shrimp)) are
203 the main cultured shrimp species in the region, with *L. vannamei* accounting for over 80% of
204 total shrimp production (FAO 2016b). Shrimp production in Chanthaburi has declined
205 sharply in recent years, mainly due to widespread viral outbreaks in shrimp, such as acute
206 hepatopancreatic necrosis disease (AHPND) and hepatopancreatic microsporidiosis (HPM)
207 (Putth and Polchana 2016), and subsequent global shrimp price volatility has permitted
208 increased production and export from other countries such as China, Indonesia, and Vietnam

209 (Wanasuk and Siriburananoon, 2017). In Chanthaburi, shrimp production dropped from
210 around 61 500 t in 2012 to 33 900 t in 2013. Production of shrimp remained at 33 700 t in
211 2015, indicating that the industry has not recovered in this region (Department of Fisheries,
212 2018), and many aquaculture ponds have recently been abandoned (Piamsomboon et al.,
213 2015).

214 What is left from these ecological, social and economic changes is a landscape with
215 persisting environmental issues and a diversity of farming intensities and corresponding
216 livelihood strategies, including large-scale intensive shrimp farms designed to maximise
217 production, and many independent small- to medium-scale farms. Given that shrimp
218 production is highly important for economic development in Thailand, and the demand for
219 shrimp from international markets is projected to increase (FAO, 2016c), policy makers are
220 now confronted with the challenge of directing shrimp farmers away from environmental
221 destruction, and towards more sustainable production systems (Bush et al., 2010; Bush and
222 Marschke, 2014; Joffre et al., 2015). Following the most recent crash of the shrimp industry
223 in Thailand in 2013, the government updated their national certification standards in an
224 attempt to improve environmental conditions and regain credibility in the global market.
225 However, the uptake of these new standards has been limited due to their demanding
226 requirements, leading scholars such as Samerwong et al. (2018) to question their
227 inclusiveness and effectiveness.

228

229 *1.3. Characterization of shrimp farming diversity*

230 Different shrimp culture systems can be classified based on how similar or dissimilar
231 they are to one another with regards to one or more variables related to technical, economical,
232 ecological, geographical, or social aspects of production (Shang, 1981). In terms of culture
233 production intensity, global shrimp aquaculture has been characterized as either (i) extensive,
234 (ii) semi-intensive, or (iii) intensive, reflecting a scale from low to high intensity (Tidwell
235 2012). However, these classes can vary between countries and regions (Primavera, 1993,
236 1998; Dierberg and Kiattisimkul, 1996).

237 Farm intensity types are most commonly defined using technical variables related to
238 farm size, stocking density, feed rate, or rate of fertilizer application, or economic
239 performance indicators, such as yield and income (FAO, 2018; Deb, 1998; Dierberg and
240 Kiattisimkul, 1996; Islam et al., 2005; Stevenson et al., 2007; Joffre and Bosma, 2009). To
241 date, there has been a wealth of literature on technical aspects of different shrimp aquaculture

242 systems, in terms of quantitative descriptions of farm size, pond management methods,
243 resource use, production outputs, and economic analysis (for example, Stevenson et al., 2007;
244 Kongkeo, 1997; Boyd et al., 2016, 2017, 2018; Boyd and Engle, 2017; Engle et al., 2017;
245 Thakur et al., 2018; Islam et al., 2005). Technical analysis at the farm-level is important
246 because it derives data which can be used to assess and reduce negative impacts of
247 aquaculture and to guide more sustainable management practices (Boyd et al., 2017). In a
248 farm-level survey from Thailand and Vietnam, for example, Boyd et al. (2017) concluded
249 that, per ton of shrimp produced, intensive shrimp production systems are more efficient, use
250 fewer resources, and result in less impact on the environment compared to more extensive
251 shrimp production systems.

252 On the other hand, however, classifying culture systems using technical variables
253 alone has its limitations. Firstly, it is difficult to classify polyculture systems based on
254 production indices such as yield and feed rate because different species have different growth
255 rates and feeding behaviour. In addition, farm size, which is sometimes used in classification
256 criteria, does not consistently relate to production intensity because small farms and large
257 farms can be managed at a similar level of intensity (Vandergeest et al., 1999; Engle et al.,
258 2017). Furthermore, while the social-ecological costs of aquaculture have been well
259 documented (Primavera, 1993, 1997), typologies based on technical variables do not account
260 for the social and ecological factors influencing production intensity. Technical indices of
261 production should therefore be complemented with information on the socio-economic
262 context of production (Bush et al., 2013).

263

264 *1.4. Shrimp farmer behaviour*

265 To be able to attempt to steer the sector towards environmentally, economically and
266 socially sustainable configurations, it is important to understand the decisions behind the
267 diversity of farm intensities (e.g. see Bush and Marschke, 2014; Bush et al., 2010; Joffre et
268 al., 2015b, 2019; Nguyen et al., 2018). Shrimp farmers are key actors within the system,
269 therefore a comprehensive understanding of shrimp farmer behaviour¹ is crucial for guiding
270 pathways towards sustainability (Bush et al., 2010).

271 A series of social, ecological, epidemiological, and regulatory factors have been
272 shown to influence the behaviour of aquaculture producers regarding their production system
273 and farm management (Joffre et al., 2015; Ahsan and Roth, 2010; Bush and Marschke, 2014;
274 Ha et al., 2012a; 2012b; Kusumawati et al., 2013; Tendencia et al., 2013). At the macro-

275 scale, Hall (2004) discusses the social processes that have influenced shrimp farmer
276 behaviour at the regional level across countries in Southeast Asia, namely; 1) government
277 programs and State support for shrimp farming expansion in Thailand and Indonesia, 2)
278 corporate involvement in training, research and the building of farm infrastructure (such as
279 Charoen Pokphand Group (C.P.) in Thailand), 3) the role of collective farmer action to
280 reduce problems, such as regulating water systems in Thailand and Indonesia, and 4) the
281 influx of new shrimp producers in Java which destabilized traditional farm systems.

282 At the farm-level, much of the research on aquaculture farmer behaviour to date has
283 focused on risk² perception and management, for example in relation to disease or climate-
284 related risks (Chitmanat et al., 2016; Lebel et al., 2016; Lebel and Lebel, 2018). In Denmark,
285 for example, Ahsan and Roth (2010) identify that mussel farmers perceive and manage risks
286 based on a combination of market factors (future price and demand for mussels), regulatory
287 drivers (changes in government regulations), and bio-physical factors (weather and water
288 conditions). Lebel et al. (2016) show that fish farmers in northern Thailand adopt short-term
289 and medium-term adjustments to production to manage climate-related risk, such as seeking
290 new information, and altering aeration, feeding rate, and stocking.

291 Other studies of aquaculture farm-level behaviour explore how producers collaborate
292 in relation to risk perception, attitude and adoption (Ahsan, 2011; Joffre et al., 2018, 2019; Le
293 Bihan et al., 2013). Some studies (Bush et al., 2010; Joffre et al. 2015; Bottema et al., 2018)
294 explore shrimp farmer social structures in relation to the embeddedness of farms within a
295 landscape, and how the extent to which farms are integrated into the landscape depends on
296 both physical and social factors. Bush et al. (2010) for example, suggest that aquaculture
297 farmers operating intensive 'closed' systems are less likely to adopt collective strategies for
298 risk management compared to farmers operating extensive 'open' systems, who are more
299 likely to self-organise. In contrast, Bottema et al. (2018) compare stocking behaviours and
300 risk management strategies across two shrimp farm intensity types ('closed' intensive shrimp
301 and grouper farmers in Thailand and 'open' integrated mangrove shrimp (IMS) and extensive
302 shrimp farmers in Vietnam), and explore how individual aquaculture farmers interpret and
303 manage environmental risks and how their ability to deal with risk relates to farmer-farmer
304 social relations. Bottema et al. (2018) show that collective action between farmers to mitigate
305 risks depends on shared social experiences.

306 Other literature explores the influence of policy and risk perception on the adoption of
307 certain aquaculture farming practices, such as those aimed at conservation or climate change
308 mitigation (Joffre et al., 2015, 2018; Nguyen et al., 2018). For example, studies on shrimp

309 producers have looked at factors influencing the adoption of more ‘mangrove-friendly’
310 integrated mangrove-shrimp systems (IMS). In Vietnam, for instance, Joffre et al. (2015)
311 identified that shrimp farmers shift from extensive production systems to IMS systems based
312 on a combination of drivers which influence farm profitability and disease risk, such as bio-
313 physical drivers (the role of mangroves in pond management) and those related to the value
314 chain and regulatory framework. Nguyen et al. (2018) explored factors influencing the
315 adoption of IMS systems among shrimp farmers in Vietnam, which they relate to social
316 dynamics such as learning through various media.

317 While this literature has contributed importantly to the understanding of aquaculture
318 and aquaculture producers, questions still remain as to how individual decisions are made on
319 the micro-scale, across different shrimp farming intensities in Thailand. In particular there are
320 gaps in knowledge of how internal social and psychological processes, such as expectations,
321 risk perception and subjective culture, interact with external technical, biophysical, and
322 economic factors to influence shrimp aquaculture adoption behaviour in Thailand.

323 This study therefore builds on findings from other contexts and countries by analysing
324 shrimp farming diversity along the coast of Thailand with the aim to understand the factors
325 involved in farmer behaviour in relation to production intensity, including technical, social,
326 economic and ecological drivers.

327 In sum, the case of Thailand is illustrative of a situation in which (i) there is diversity
328 of farming intensities, (ii) policy has had difficulties to promote sustainable aquaculture, also
329 because (iii) there is a knowledge gap in understanding farmer behaviour in relation to
330 production intensity.

331

332 **2. Materials & methods**

333 *2.1. Data collection and theoretical framework*

334 Exploratory field work was first implemented in October 2016, where a series of
335 semi-structured interviews were conducted with stakeholders from the local to national scale.
336 These interviews helped gain background information on current and historical shrimp
337 farming patterns, and the scale of shrimp farming in Chanthaburi Province. Each of the
338 interviewees had knowledge of the study area due to their occupation and/or place of
339 residence. Interviewees included private individual shrimp farmers ($n = 12$), a local shrimp
340 farming cooperative official, village heads ($n = 2$), Provincial representatives from the local

341 government Mangrove Management Unit ($n = 2$), and representatives from the government
342 Department of Marine and Coastal Resources in Bangkok ($n = 6$).

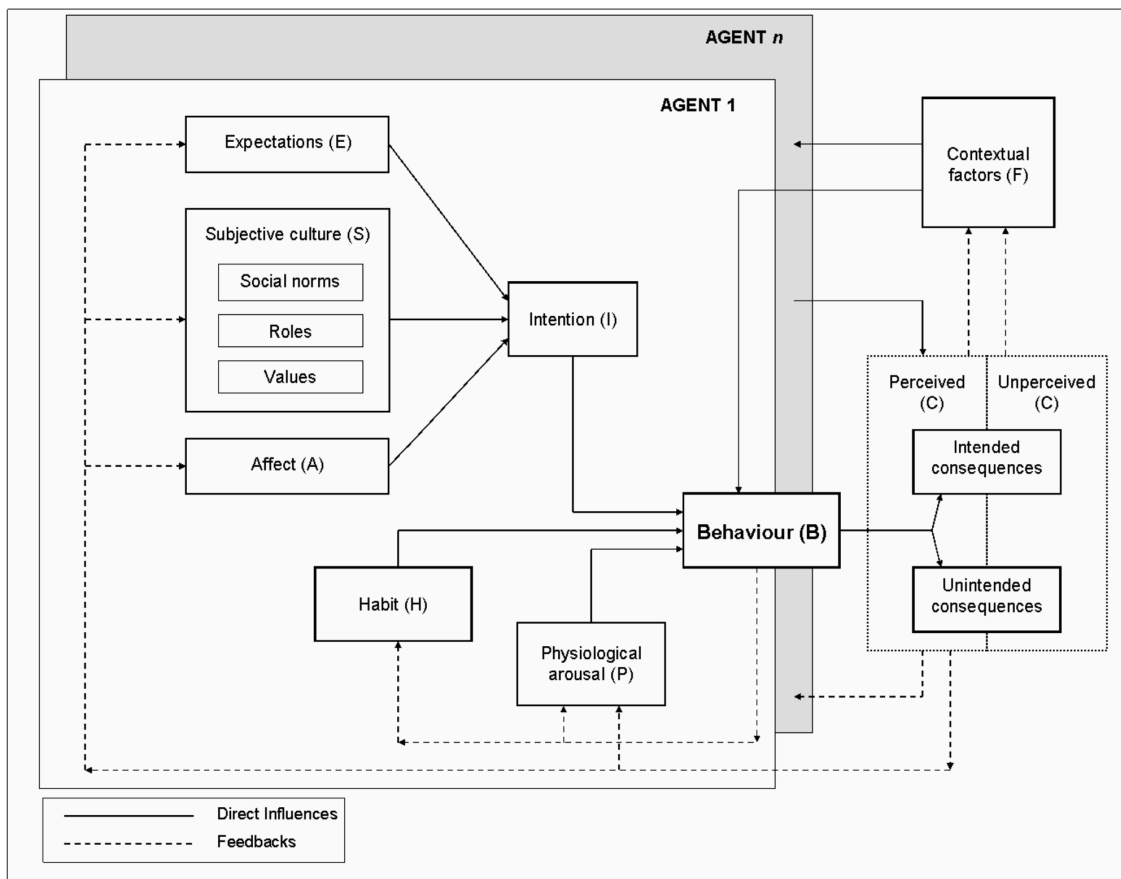
343 Following exploratory field work, the integrative agent-centred (IAC) framework
344 (Feola and Binder, 2010) was used as a basis for designing a structured survey to collect
345 semi-quantitative data for a range of explanatory variables that potentially drive shrimp
346 farmer behaviour in Chanthaburi Province. The IAC framework's general components
347 (Figure 3) were first associated to the variables which were potentially influencing the
348 studied behaviour. Such association was based on a literature review and the knowledge of
349 the study area gained through the exploratory field work. The variables were then
350 operationalized to be measured through semi-structured interviews (Supplementary Material).

351 The adoption of behavioural theory was consistent with the theoretical approach
352 which is most commonly adopted in the aquaculture literature (see literature review above).
353 In addition, a focus on behaviour maintains deliberate decisions at the forefront of the
354 analysis, in contrast to competing approaches such as livelihood or social practice theory; we
355 considered a focus on deliberate adoption decisions to be essential for the present study.

356 Moreover, while the IAC framework allows to maintain such focus on farmer
357 decisions, it also allows to situate them in the wider socioecological context (Feola and
358 Binder, 2010). Thus, this framework responds to some common limitations of behaviour
359 frameworks, and particularly (i) the lack of an explicit and well-motivated behavioural
360 theory; (ii) the lack of an integrative approach (i.e. one which includes a diverse range of
361 psychological, social and economic factors); and (iii) the inability to capture feedback
362 processes between agents' behaviour and system's dynamics (Feola and Binder, 2010). As
363 such, the IAC framework enabled us to investigate farmer adoption behaviour as it is
364 embedded in a particular socioecological context which includes social networks and power
365 relations, and in the face of cross-scale/-level pressures which vary over time, such as those
366 observed in Chanthaburi Province (see Introduction).

367 Finally, the IAC framework has previously been fruitfully used to study farmer
368 behaviour in relation to production intensity in agricultural systems (Feola and Binder 2010;
369 Feola and Binder 2010b) and was thus deemed suitable for supporting the research design for
370 this study. The IAC framework is based on: (i) an explicit and well-motivated behavioural
371 theory; (ii) an integrative approach; and (iii) feedback processes between agents' behaviour
372 and system's dynamics. The questions in the survey corresponded to different classes of
373 behavioural drivers outlined in the IAC framework (Figure 3). These included: Contextual
374 factors (i.e. facilitating conditions or barriers), Habit (the frequency of past behaviour),

375 Expectations (beliefs about the outcomes, their probability and their value), Subjective
 376 culture (social norms, roles, values), and Affect (the feelings associated with the act). Each of
 377 the behavioural drivers were measured through one or more questions in the survey (see
 378 Supplementary Material).
 379
 380



381
 382 **Figure 3. The IAC Framework (Feola and Binder, 2010).**
 383
 384

385 To enable consistency in the data across study sites of Khlung and Laem Sing, and to
 386 make the timeframe as close as possible to the survey time, the questions referred to specific
 387 timeframes of either one production cycle, one year, or two years, as relevant depending on
 388 the question. The survey design aimed to generate data from shrimp farmers working across a
 389 range of shrimp farm intensity types, from low-intensity traditional polyculture systems to
 390 more technologically advanced intensive shrimp monoculture, so that data could be
 391 compared across farm management intensity categories.

392 Fieldwork was conducted between February and May 2017. A total of 102 shrimp
 393 farmers and farm workers were surveyed. Respondents were selected to provide a wide

394 geographical cover across the survey area, and a relevant sample of the shrimp farmers in the
395 area, avoiding biases associated with particular locations and shrimp farm sizes. Respondents
396 were sought systematically by visiting farms and houses along the coastal Province area, and
397 through snowball sampling (Goodman, 1961). All surveys were conducted on an individual
398 shrimp farmer basis to ensure that the responses reflected personal information. In 6 of the
399 102 cases, the owner of the shrimp farm did not live on the farm, or was only present
400 occasionally, and therefore the farm operator was interviewed instead. These surveys were
401 subsequently removed from the sample.

402

403 2.2. Data analysis

404 In order to characterize the socio-economic context of farmers farming at different
405 levels of intensity and to be able to then compare the behaviour of shrimp farmers across
406 farm intensity types, survey respondents were first classified into farm intensity types based
407 on technical similarity within groups with regard to production intensity. Survey data were
408 used to characterize the socio-economic (including demographic and market related) factors
409 associated with each level of farming intensity (Table 1). Three production intensity proxy
410 variables were used to define farm intensity type: ‘shrimp yield (kg ha crop)’, ‘shrimp
411 stocking density (PL m²)’, and ‘number of shrimp crops produced per year’. The grouping of
412 farms under each of the three key variables was based on FAO farm type classifications
413 (extensive ‘low intensity’, semi-intensive ‘medium intensity’, and intensive ‘high intensity’)
414 for the two principal brackish water shrimp species cultured in the study region, *P. monodon*
415 (Black tiger shrimp; FAO, 2018c) and *L. vannamei* (White shrimp; FAO, 2018b). We chose
416 to classify shrimp farms in the present study based on FAO farm type classifications because
417 this is a globally standard classification system which is recognised in aquaculture policy.
418 Therefore, through our subsequent analysis of adoption behaviour and socio-economic
419 differences, we would be better able to demonstrate that groups of aquaculture farmers are
420 more diverse than considered in current aquaculture policy.

421 For the three production intensity proxy variables, the minimum and maximum values
422 for each species were first calculated separately for each individual pond. Minimum and
423 maximum values were then assigned to one of the three production intensity classifications
424 (‘low’, ‘medium’, or ‘high’ intensity). Where minimum and maximum values fell between
425 two intensity categories (for example, minimum = ‘medium intensity’ and maximum = ‘high
426 intensity’), then the mean of the variable was used. If ponds of a farm fell in more than one of

427 the intensity categories (for example, 5 ponds for ‘high intensity’ and 1 pond for ‘medium
428 intensity’), then the farm was allocated to the modal farm type (i.e. ‘high intensity’ in the
429 example).

430 Following identification of the three farm intensity types, survey responses which
431 related to the internal and external behavioural drivers (Figure 3) were compared between
432 farm intensity types. Where differences in responses were found between farm intensity
433 types, the significance level of the difference was statistically tested using the non-parametric
434 Kruskal-Wallis (K-W) H test, followed by the Dunn post hoc multiple comparisons test,
435 where appropriate. Drivers that were found to be statistically different were treated as the
436 determinants of adopting a particular shrimp farming production intensity. All statistical
437 analysis was performed using the software R. Differences at the 0.05 level were considered
438 significant.

439

440 **3. Results**

441 *3.1. Shrimp farm intensity types*

442 This study shows that three distinct farmer profiles /socio-economic configurations
443 and livelihood structures correspond to each distinct production intensity level (low, medium,
444 and high). Descriptive statistics on the different socio-economic-technical variables of farm
445 intensity types are presented in Table 1.

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Table 1. Descriptive statistics on different socio-economic-technical variables of farm intensity types, including shrimp farmer demographic variables, technical (production related) variables, labour/farm organisation variables, and disease occurrence across the three sampled farm intensity types (low, medium, and high).
Values are mean±1SD and range in parenthesis.

Type of factors	Variable	Farm intensity type		
		Low	Medium	High
Demographic	Number of farmers	50	27	19
	Gender (% of farmers):			
	<i>Male</i>	64	78	100
	<i>Female</i>	36	22	0
	Age	55 ± 10 (29-78)	50 ± 10 (28-72)	49 ± 12 (31-70)
	Highest education level (% of farmers):			
	<i>None</i>	18.0	0.0	0.0
	<i>Primary</i>	54.0	67.0	68.4
	<i>Secondary</i>	20.0	19.0	10.5
<i>College/university</i>	8.0	15.4	21.1	
Socio-economic	Farm ownership status (% of farmers):			
	<i>Owner</i>	76.0	78.0	63.2
	<i>Leased</i>	6.0	22.0	36.8
	<i>Government entitlement (tenure)</i>	18.0	0.0	0.0
	Farm operating years	32 ± 17 (6-100)***	17 ± 9 (1-40)	17 ± 12 (3-50)
	Farm helpers (persons/ha)	0.3 ± 0.3 (0-1.3)**	1.4 ± 2.2 (0-10.9)	2 ± 2.5 (0-10.4)
Technical (farm and ponds)	Farm area (ha)	11.2 ± 7.8 (1.6-38.4)	2.9 ± 3.6 (0.2-16.0)	3.8 ± 4.8 (0.4-16)
	Total pond area (ha)	10.9 ± 8.0 (1.0-38.4)***	2.2 ± 2.8 (0.2-12.8)	2.6 ± 2.7 (0.4-9.4)
	Number of ponds	1.2 ± 0.9**	4 ± 7 (1-40)	5 ± 5 (1-16)
	Average pond size (ha)	10.3 ± 7.1 (0.5-32)***	0.56 ± 0.23 (0.24-1.12)	0.56 ± 0.17 (0.32-0.86)
	Species cultured (No.)	4 ± 1 (1-5)***	1.1 ± 0.5 (1-3)	1 ± 0.2 (1-2)
Technical (production)	<i>L. vannamei</i> yield (mean)	28 ± 33 – 36 ± 41***	2288 ± 2144 – 2587 ± 2256***	6119 ± 3793 – 6767 ± 3928***

451

	<i>L. vannamei</i> yield (range)	0.3 - 188	0 - 9375	0 - 12500
	<i>P. monodon</i> yield (mean)	33 ± 59 – 37 ± 62	157 ± 65 -185 ± 104	4337 ± 2789 – 4716 ± 2139 ***
	<i>P. monodon</i> yield (range)	0.3 - 260	84.4 – 291.7	2272.7 – 5625
	<i>L. vannamei</i> SD (PL/m ²)	0.3 ± 1.3 (0-8) ***	38 ± 20, 6-94 ***	63 ± 17 (31-94) ***
	<i>P. monodon</i> SD (PL/m ²)	1.4 ± 2.5 (0-13) ***	12 ± 10 (1-20) ***	45 ± 12 (31-54) ***
	<i>L. vannamei</i> crops/yr.	1 ± 0.1 (1-2) ***	2.3 ± 1 (1-4)	2.5 ± 0.5 (2-3)
	<i>P. monodon</i> crops/yr.	1.1 ± 0.2 (1-2) ***	2.3 ± 1 (2-3)	2.5 ± 0.5 (2-3)
	Fish and crustacean yield†	95.2 ± 200.2 ***	27.2 ± 118.8	0.0
	Feed rate (kg/ha/crop)	0.8 ± 4.3 (0-30) ***	314 ± 251 (0-960) ***	714 ± 464 (184-2,138) ***
	Feed added (% farms)	6	96.3	100
Economic /market	<i>L. vannamei</i> selling price (mean)	127 ± 43 – 141 ± 52	136 ± 38 – 159 ± 40	164 ± 42 – 189 ± 51 ***
	<i>L. vannamei</i> selling price (range)	60-300	60-255	90-300
	<i>L. vannamei</i> sold (%)	75.3 ± 35 – 83.6 ± 37	87.6 ± 27.7 – 92 ± 28	89.1 ± 25 – 93.4 ± 25.5
	<i>P. monodon</i> selling price (mean)	434 ± 164 – 598 ± 111 ***	310 ± 269 – 310 ± 269	277 ± 197 – 280 ± 193
	<i>P. monodon</i> selling price (range)	150-700	120 - 500	130-500
	<i>P. monodon</i> sold (%)	80.4 ± 34 – 86.4 ± 35	85.7 ± 0 – 100 ± 0	91.7 ± 14 – 100 ± 0
	Farm production cost (mean)	31.8 ± 38.6 ***	535 ± 1022 **	790.9 ± 1131.6
	Farm production cost (range)	1 – 201.5	9.5 - 4800	65 - 4800
	Farm revenue	20 ± 46 – 45 ± 140	752 ± 1140 – 872 ± 1335 ***	1955 ± 2525 – 2263 ± 2739 ***
Disease	Disease outbreaks (no./2 yrs.)	2.3 ± 1.6 (0-7)	3.8 ± 4.4 (0-24)	3.5 ± 3.6 (0-16)
	Disease free farms (% /2 yrs.)	12	7.4	5.3

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Significant difference between farm intensity types: ***0.001, **0.01 (Kruskal-Wallis test with the Dunn post hoc test).

Yield is measured in kg/ha/crop, Value is measured in THB/kg, Farm production costs and revenue is presented in 1,000THB per crop. SD = Stocking density.

†including fish sp., crab sp., and shrimp species other than *P. monodon* and *L. vannamei*.

457 **Farm intensity type 1: 'low intensity'.** *Low intensity* farms comprised the largest sampled
458 group (52% of the sample). On average, these farms had been operating for significantly
459 longer than *medium* and *high intensity* farm types ($p < 0.05$). Around one fifth of the farms
460 were located on government owned land which was allocated for use under the government's
461 'Entitlement' policy. Under this policy, abandoned or reclaimed intensive shrimp farms built
462 in areas previously occupied by mangrove forest are allocated to local people for aquaculture
463 use. These farms were located within government conservation areas where restrictions are
464 made on the use of machinery for pond maintenance. Without maintenance, the old pond
465 dikes can gradually erode, resulting in one large aquaculture area, rather than a number of
466 individual ponds. As a result, mean pond size was significantly larger by around 4-5 times
467 compared to other farm intensity types ($p < 0.001$), and the number of ponds on these farms
468 was significantly lower ($p < 0.05$). Family members normally assist with day to day running
469 of *low intensity* farms, and additional labour is hired only for less frequent work, such as
470 pond harvesting. As a result, the labour input per hectare of *low intensity* farms was
471 significantly lower than other farm intensity types ($p < 0.001$).

472 Almost 100% of the *low intensity* farms were polyculture systems with around 60% of
473 mean total aquaculture yield from culturing species of fish, crab, and other less commercial
474 important shrimp species. The mean number of aquaculture species cultured was significantly
475 higher than on other farm intensity types ($p < 0.001$). Furthermore, stocking density of *L.*
476 *vannamei* and *P. monodon*, and the mean number of crops of these species per year, was
477 significantly lower than on other farm intensity types ($p < 0.001$).

478 Most of the *low intensity* farms produced shrimp on the basis of natural productivity
479 in the pond. The methods practiced are typical of extensive polyculture production, whereby
480 shrimp, along with fish and mud crab (*Scylla serrata*) species, enter the ponds through
481 natural tidal inflow to the ponds. Wild species trapped in the ponds are raised with little to
482 none commercial feed inputs, and the produce is harvested frequently throughout the year
483 when they have attained a marketable size. As a result, average production costs on *low*
484 *intensity* farms were significantly lower than on other farm intensity types ($p < 0.001$).
485 Furthermore, only 6% of farmers reported using commercial feed, and this was at rates
486 significantly lower than other farm intensity types ($p < 0.001$).

487 Approximately 75-85% of shrimp yield from *low intensity* farms is sold, which is
488 around average across farm intensity types. Of particular note, however, was that the mean
489 selling price of *P. monodon* was significantly higher compared to *medium* and *high intensity*
490 farms ($p < 0.001$). This is likely to be because the shrimp are growing in larger, less densely

491 stocked ponds thus enabling them to grow to a larger size, and because *low intensity* farmers
492 select larger, more valuable shrimp to sell.

493 Some of the *low intensity* farmers reported being constrained by environmental
494 change and environmental quality. For example, due to problems such as pond dike erosion
495 and increasing costs of pond maintenance. Because one fifth of these farms are located within
496 government conservation areas, farmers are faced with production constraints and
497 fluctuations in the productive areas. Around 75% of *low intensity* farmers reported that they
498 had observed erosion to the dykes of over 50% of ponds on their farm. As the ponds
499 gradually fill in with sediment, the total surface area of the farm reduces.

500 Shrimp farming was not the primary income source for the majority of *low intensity*
501 farmers. Only 40% of farmers stated that all or most of their income is from shrimp farming,
502 and 48% stated that very little or none of their income is from shrimp farming. Some of these
503 farmers operate on a part-time or casual basis, sometimes for subsistence use only, or to
504 provide supplementary income i.e. farmers have primary employment elsewhere but keep a
505 small number of ponds active but on a less intensive scale.

506 Around 73% of the *low intensity* farmers reported that they had reduced the amount of
507 shrimp produced in the past two years, 12% had increased the amount, and 16% had not
508 changed the amount produced. 49% of farmers stated that they had reduced the number of
509 species produced and 8% had increased the number of species.

510

511 **Farm intensity type 2: ‘medium intensity’.** *Medium intensity* farms comprised 28% of the
512 total sample. Farm operating years, mean pond size, and the number of hired labour used on
513 these farms was similar to that observed on *high intensity* farms ($p > 0.05$). Whereas, pond
514 stocking densities of both *L. vannamei* and *P. monodon* were significantly higher than on *low*
515 *intensity* farms but significantly lower than on *high intensity* farms ($p < 0.001$). Furthermore,
516 production of *P. monodon* was significantly lower than on *high intensity* farms ($p < 0.001$).

517 The majority of *medium intensity* farms specialised in the production of *L. vannamei*
518 and, although mud crabs and fish species were sometimes cultured as secondary species, the
519 total yield from species other than *P. monodon* and *L. vannamei* accounted for less than 1%
520 of the total production, which was significantly lower than that produced on *low intensity*
521 farms ($p < 0.001$). On some polyculture farms, farmers reported that they stock higher-value
522 shrimp and crab species, but fish that are raised were recruited from the natural tidal waters.

523 Production costs on *medium intensity* farms were considerably variable, reflecting the
524 heterogeneity in management within this farm intensity type. Use of commercial feed was at
525 rates significantly higher than *low intensity* farms ($p < 0.001$), but significantly lower than on
526 *high intensity* farms ($p < 0.01$). Whereas, farm return on *medium intensity* farms was
527 significantly lower than *high intensity* farms ($p < 0.001$), but not significantly different to *low*
528 *intensity* farms ($p > 0.05$). Around 70% of *medium intensity* farmers stated that all or most of
529 their income was from shrimp farming, and 20% stated that very little comes from shrimp
530 farming. *Medium intensity* farms have had the highest number of disease outbreaks over the
531 past 2 years. However, disease occurrence was not significantly different across all farm
532 intensity types ($p = 0.09$). Around 46% of *medium intensity* farmers reported that they had
533 reduced the amount of shrimp produced in the past two years, 30% had not changed the
534 amount, and 23% had increased the amount. 27% had increased the number of species
535 produced, 11% had reduced the number of species, and 61% had not changed the number of
536 species produced.

537 **Farm intensity type 3: 'high intensity'**. *High intensity* farms comprised the smallest
538 sampled group (20% of sample). These farms contained the highest average number of ponds
539 and maximum pond size did not exceed 1 ha across farms. Average farm area was slightly
540 larger than *medium intensity* farms but significantly smaller than *low intensity* farms ($p <$
541 0.05). Total area of ponds in use made up around 68% of total farm area. The further 30%
542 comprised either ponds that were currently left unused, or ponds that were used for water
543 management, which is common practice in highly intensive shrimp farming systems.
544 Chemicals and treatment ponds were used to control water quality, and to remove predators
545 from the water before PL are stocked.

546 Almost 100% of the *high intensity* farms sampled were monoculture systems
547 specialising in *L. vannamei* production, with *P. monodon* being the only other secondary
548 species. Mean production and stocking densities of *L. vannamei* and *P. monodon* was
549 significantly higher compared to all other farm intensity types ($p < 0.001$). Whereas, mean
550 number of *L. vannamei* and *P. monodon* crops per year was significantly greater than *low*
551 *intensity* farms ($p < 0.001$), but similar to *medium intensity* farms.

552 Feed was added to *high intensity* ponds at rates significantly higher than other farm
553 intensity types ($p < 0.001$). The intensive shrimp farms were often linked to large shrimp feed
554 producing companies, such as C.P. (Charoen Pokphand) Group, which is one of the world's
555 leading producers of shrimp and shrimp feed and a major supplier of shrimp feed and shrimp

556 post larvae (PL) to intensive shrimp farmers in the study area. On *high intensity* shrimp
557 farms, the ponds were managed in a very controlled way. For example, a cycle of a specific
558 number of days (usually 90) following feed tables to attain shrimp of a certain size and
559 weight at the end of the crop cycle.

560 Like on *medium intensity* farms, production costs were highly variable on *high*
561 *intensity* farms suggesting that management practices varied greatly. Although production
562 costs were on average not significantly higher than on *medium intensity* farms ($p > 0.05$),
563 *high intensity* farms generated significantly greater return than any other farm intensity type
564 ($p < 0.001$). The average selling price for *L. vannamei* was higher than on other farm
565 intensity types. Whereas, *P. monodon* produced on *high intensity* farms sold for a relatively
566 low price which may reflect differences in either the quality or size of shrimp sold, or who
567 the shrimp were sold to. Similar to *medium intensity* farmers, nearly three quarters of *high*
568 *intensity* farmers stated that all or most of their income came from shrimp farming, with less
569 than 20% stating that shrimp farming contributed very little to their total income.

570 Around 44% of the *high intensity* farmers reported that they had reduced the amount
571 of shrimp produced in the past two years, whereas 27% said they had increased the amount of
572 shrimp produced. 83% of high intensity farmers stated that they had not changed the number
573 of species produced over the same period, the rest (16%) had decreased the number of
574 species.

575

576 3.2. Farmer behaviour (production intensity)

577 Based on the IAC framework, we understand farmer adoption behaviour (here:
578 production intensity) as the result of decisions that are influenced by a set of internal and
579 external, symbolic and material, individual and social factors (Figure 3). All variables
580 considered in the IAC framework (see Supplementary Information) were tested for
581 significance in driving behaviour, but we report here only the significant ones. This analysis
582 helps to distinguish which factors influence the decision to adopt a certain level of production
583 intensity.

584 Shrimp farmers of the three farm intensity types differed significantly in relation to
585 eight key variables considered by the IAC framework. This included **contextual** (external
586 socio-economic and production) factors (such as training received on farming practices,
587 access to the technical equipment needed to farm shrimp intensively, proportion of total
588 income from shrimp farming, and season-specific changes to their production), as well as

589 internal factors related to **subjective culture** (social norms and roles) (such as what shrimp
590 farmer believes other farmers think about their adoption of a particular production intensity,
591 how often shrimp farmer follows advice from other farmers, pond stocking considerations,
592 level of care for the environment, and perception of a ‘good shrimp farmer’), and
593 **expectations** (perceived risks associated with intensive shrimp farming). A summary of the
594 key findings in relation to these interactions is presented below.

595
596 **Contextual factors (socio-economic).** We found that shrimp farmers who operated *low*
597 *intensity* farms were less likely to have received training from private and/or government
598 agencies, compared to *high* ($p = 0.017$) and *medium intensity* ($p = 0.008$) farmers. A
599 significant difference was also observed in terms of technical equipment access, with a higher
600 proportion of *high* and *medium intensity* farmers having access to equipment, compared to
601 *low intensity* farmers ($p < 0.0001$). *Low intensity* farmers were also found to have more
602 diverse income sources and a significantly lower proportion of these farmers relied solely on
603 income from shrimp farming ($p = 0.012$). Whereas, farmers whose income depended 100%
604 on shrimp farming were significantly more likely to operate *high intensive* farm systems ($p =$
605 0.012).

606
607 **Contextual factors (production).** *Medium* and *high intensity* farmers were more likely to
608 engage in season-specific changes to their production, such as modifying shrimp stocking
609 during the monsoon onset. A significantly higher proportion of these farmers stated *season* is
610 a primary factor considered before stocking shrimp, compared to *low intensity* farmers (high:
611 $p = 0.020$, medium: $p = 0.025$; Figure 4a). Whereas economic factors, such as *production*
612 *costs* and *money available and potential loss of money* were shown to be important stocking
613 considerations among *low intensity* farmers.

614
615 **Subjective culture (social norms).** Social dynamics, such as information networks and
616 conformity with the descriptive norm, also played a role in defining farming intensity levels.
617 For example, *medium intensity* farmers were significantly more likely to have received advice
618 from other shrimp farmers regarding their production ($p = 0.0001$), suggesting that other
619 farmers are a source of information to base production decisions on. On the contrary, *low*
620 *intensity* farmers appeared to have weaker social networks, that is they were significantly less
621 likely to have received advice from the government ($p = 0.0001$) or other farmers ($p = 0.008$)
622 on their farming practices. In addition, when asked how other farmers perceive their

623 production intensity, *low intensity* farmers were significantly more likely to give a neutral
624 response (i.e. not negative or positive), compared to *medium* ($p = 0.046$) and *high* ($p = 0.006$)
625 intensity farmers. These findings indicate that *low intensity* farmers' decisions on production
626 are made on a more individual basis and are less influenced by external actors.

627

628 **Subjective culture (roles).** A sense of care for the environment among *low intensity* farmers
629 was reflected in the way these farmers perceived the status of a “good shrimp farmer”. For
630 example, 22% of *low intensity* farmers considered *care for the environment* as a main trait,
631 and a significantly higher proportion of *low intensity* farmers believed that *no chemical use* (p
632 = 0.0009) and *farming on the basis of nature* ($p = 0.044$) were important characteristics
633 (Figure 4b). These findings illustrate that production decisions of *low intensity* farmers are in
634 part rooted in perceptions of how farming affects the natural environment. Whereas,
635 decision-making based on learning from experience was more important to *high intensity*
636 farmers, who were significantly more likely to regard this as characteristic of a “good shrimp
637 farmer” ($p = 0.013$).

638

639 **Expectations.** Farmer intensity types were also differentiated with respect to their perception
640 of the consequences of intensive farming, illustrated by differences in risk perception.

641 Although 62% of all farmers across intensity types believed *disease outbreak* to be a primary
642 risk factor, *medium* and *high intensity* farmers were significantly more likely to perceive *low*
643 *quality shrimp post-larvae (PL)* as a main risk (high: $p = 0.012$, medium: $p = 0.023$).

644 However, this perceived risk was not apparent among low intensity farmers. Instead, a higher
645 proportion of *low intensity* farmers considered *high production cost* to be a main risk factor,
646 indicating that their production choices could be in part based on limiting potential cost to the
647 household. The risk *losing money* through intensive shrimp farming was regarded highly
648 across all farmer intensity types (>75% of farmers; Figure 4c).

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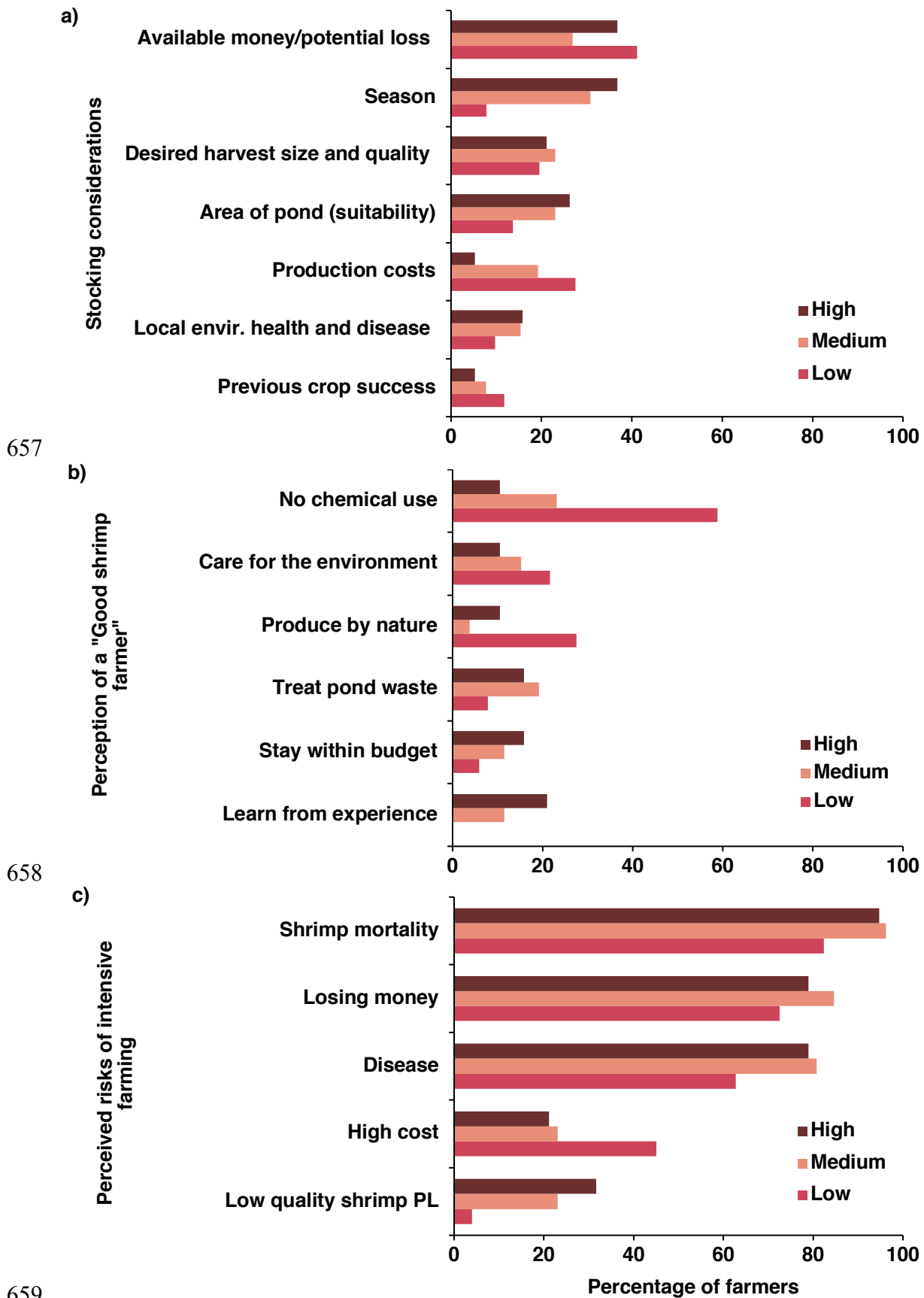
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661 **Figure 4. Shrimp farmer a) pond stocking considerations, b) perceptions of a "good shrimp farmer", and**
 662 **c) perceived risks of intensive farming.** Data shows the percentage of farmers of low (n = 50), medium (n =
 663 27) and high (n = 19) farm intensity type that gave each response.

664 4. Discussion and conclusions

665 This study investigated shrimp farming diversity and farmer behaviour in two coastal
666 districts of Chanthaburi Province, Thailand. The study aimed to answer two research
667 questions: i) which socio-economic factors are related to distinct levels of shrimp farming
668 intensity?, and specifically, ii) which socio-economic factors matter in the decision to adopt a
669 certain level of production intensity? Here we discuss the study's findings in relation to these
670 two questions and reflect on the implications of these findings for the promotion of
671 sustainable shrimp farming in Thailand.

672 Three types of shrimp farms were identified in the study area, defined by their
673 production intensity (low, medium, and high), and socio-economic factors. While different in
674 their technical dimensions, this study shows that farm intensity types also differ in terms of
675 socio-economic factors: shrimp farming intensity is associated with a combination of
676 technical (e.g. farm area, pond size, stocking density and production), economic (shrimp
677 selling price, production costs and farm revenue), social (e.g. farm operating years, the use of
678 family labour, engagement in shrimp farming and with other shrimp farmers), and ecological
679 factors (e.g. farmer reliance on natural pond productivity, and constraints brought about by
680 environmental change and fluctuations in productive areas). However, some differences
681 between farm intensity types are shown to be stronger than others. For example, medium and
682 high intensity farms were more similar in terms of farm operating years, labour use, pond
683 area, number of ponds, pond size, species cultured, and shrimp crops produced. Whereas,
684 they were shown to be substantially different in terms of other technical production and
685 economic/market variables, such as feed rate, shrimp selling price, and farm revenue. In
686 addition, we demonstrate that low intensity farming is much more socio-economic and
687 technically distinct from medium and high intensity farming related not only to stocking
688 density, yield, and crops produced but also to variables such as labour use, species cultured
689 and harvesting strategy. The results also demonstrate substantial within-group diversity in
690 medium intensity production itself related, for example, to number of ponds, fish and crab
691 yield, production costs, and farm revenue. We therefore suggest that future studies consider
692 applying multivariate techniques such as cluster analysis to identify a more detailed division
693 of shrimp farm intensity types than the one adopted in this study (e.g. see Johnson et al.,
694 2014; Kumar and Engle, 2017; Engle et al., 2017).

695 This study has illustrated that farming at a certain production intensity is much more
696 than a technical decision, but instead farms and farmers are embedded within a broader socio-

697 economic context. This supports earlier work by scholars such as Bush et al. (2010), Joffre et
698 al. (2015), and Bottema et al. (2018), who have explored shrimp farmer social structures in
699 relation to the embeddedness of farms within a landscape. Bush et al. (2010) and Vandergeest
700 et al. (2015), for example, argue that a farms' socio-economic embeddedness relates to its
701 level of physical interaction with the surrounding environment, which influences farm
702 management decisions (Waite et al. 2014).

703 Shrimp farming in Thailand has previously been presented as being very high-
704 intensive production orientated (Lebel et al., 2002; Kumar and Engle, 2016), with
705 considerably less diversity, compared to other Southeast and South Asian countries like
706 Vietnam, Bangladesh or Indonesia, where there is greater dependence on varying degrees of
707 lower-intensity extensive production systems (Belton and Azad, 2012; Jespersen et al., 2014;
708 Joffre et al., 2015; Nguyen et al., 2018). In 2002, for instance, Lebel et al. (2002) described
709 Thailand's shrimp farming industry as being dominated by high intensity farming systems.
710 Yet, this study found that a large proportion of shrimp farms in Chanthaburi were low
711 intensity farms, indicating that shrimp farming in this area has evolved over the past 15 years
712 towards more lower intensity production. Our findings may support a recent study by Engle
713 et al. (2017), who report that shrimp farming in Thailand lacks long-term profitability due to
714 economic losses resulting from disease epidemics coupled with increasing land and capital
715 costs.

716 This study also enabled identification of a number of external and internal socio-
717 economic factors related to the decision to adopt a certain level of production intensity. This
718 included external contextual factors, such as training received on farming practices, access to
719 technical equipment, proportion of total income from shrimp farming, and season-specific
720 changes in production, along with internal factors, such as expectations (risk perception) and
721 subjective culture (e.g. how often shrimp farmers follow advice from other farmers, level of
722 care for the environment, and perceived traits of a 'good shrimp farmer'). Two of these
723 factors warrant further discussion.

724

725 *4.1. Social networks and risk management*

726 First, high intensity farmers were not likely to engage in farmer-farmer interactions.
727 This supports previous work by Bush et al. (2010) who suggest that aquaculture farmers
728 operating intensive 'closed' systems are less likely to adopt collective strategies for risk
729 management compared to farmers operating extensive 'open' systems, who are more likely to

730 self-organise. In contrast, social networks and farmer to farmer interactions were more
731 frequent among medium intensity farmers. Collaboration among medium intensity farmers
732 appeared to be important for risk management and building trust, as the following statement
733 from one farmer shows, “it’s important to have a good relationship with surrounding farmers
734 because sometimes they contaminate ponds”. While another farmer explained that,
735 “neighbouring farmers consult with each other to solve problems together”. Similarly, other
736 studies have shown that farmer to farmer interactions can influence decisions on production
737 and risk management (Adger, 2003; Bottema et al., 2018; Hoque et al., 2018; Ahsan, 2011;
738 Joffre et al., 2018; Le Bihan et al., 2013), and can lead to the development of trust and the
739 exchange of knowledge (Berkes and Folke, 2002). Bottema et al. (2018), for example, found
740 that communication and information sharing about disease and other environmental risks
741 among neighbouring aquaculture farmers in Thailand and Vietnam, was perceived by the
742 farmers to be an important component of risk management.

743

744 *4.2. Economic and cultural factors*

745 Second, this study illustrates that a combination of economic and cultural factors
746 matter in the decision to adopt a certain level of production intensity. For instance, among
747 low intensity farmers, there was a sense of pride in being recognized as producers who care
748 for the environment, and these farmers were more likely to perceive caring for the
749 environment as a trait of a ‘good shrimp farmer’. This suggests that subjective culture plays a
750 role in the adoption of low intensity farming. Greater care for the environment among low
751 intensity farmers, compared to high or medium intensity farmers, could be a reflection of
752 higher dependency on a healthy natural environment, given that low intensity farming relies
753 on natural pond productivity. On the other hand, high intensity farmers were more likely to
754 perceive a ‘good shrimp farmer’ as being one who uses their own experience in farm
755 management decisions.

756 Regarding economic factors, production costs and potential loss of money were
757 shown to be particularly important stocking considerations among low intensity farmers,
758 indicating that financial capital was a factor driving the decision to adopt low intensity
759 production. Our results conform with another study of shrimp producers in Thailand by Engle
760 et al. (2017), who show that the ability of farmers to shift to more intensive production
761 practices depends on the farm’s access to sufficient capital, experience, and knowledge.
762 Similarly, in Bangladesh (Bunting et al., 2017), rising costs of shrimp production and greater

763 exposure to debt cycles has driven farmers away from adopting technology for intensive
764 production.

765

766 *4.3. Policy implications*

767 Finally, in emphasizing the heterogeneity that exists among shrimp farms and shrimp
768 farmer behaviours in Thailand, our analysis challenges the effectiveness and accessibility of
769 the most recent national certification standards for aquaculture in this country (GAP-7401).
770 Whilst these standards aim to improve the sustainability of shrimp production, through
771 reducing production risks, and improving social and environmental conditions, they fail to
772 recognise the diversity of the sector and the different socio-economic contexts for different
773 levels of farming intensity, as highlighted in the present study. For many farmers, the
774 adoption of GAP-7401 standards involves high costs and labour requirements (Samerwong et
775 al., 2018) that do not correspond to the family-based labour model adopted by many low and
776 medium intensity farmers, nor their socio-economic context. Even high intensity farmers,
777 they often stated that government guidance on production was too general or difficult to
778 follow and did not account for the variability among farming practices, and so if taken on
779 board it was done so and adapted to their own individual context. One farmer, for instance,
780 stated that, “there are many government regulations and they’re not always realistic, so
781 farmers have to modify them”. This confirms key findings in the same region (Samerwong et
782 al., 2018), where Thai shrimp farmers were shown to value their own experience and
783 methods for tackling disease problems, rather than external advice, which has constrained
784 their willingness to adhere to Good Aquaculture Practice (GAP) standards.

785 While we recognise that the effect of a relatively small sample size of shrimp farmers
786 interviewed in this study is a potential limitation to fully understanding the complexity of
787 shrimp farmer adoption behaviour, our analysis has illustrated substantial diversity among
788 aquaculture farms and farmers in Chanthaburi and therefore makes an important contribution
789 to the scientific and societal debate on aquaculture standards. Thus, we emphasise that
790 national aquaculture standards should be designed to reflect the diversity needed to support
791 such a diverse sector: to achieve sustainability in shrimp farming, policies and certification
792 standards should be adjusted (or adjustable) to different socio-economic contexts.

793

794

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808
809 **Footnotes**

810 ¹The term “behaviour” refers in this paper to an action or a series of actions. An “action”, or “social action”, refers to a series of
811 acts enacted by a social actor, selected among possible alternatives, on the basis of a plan which can evolve in the course of
812 the action itself. The social action aims at a goal, given a situation or context shared also by other actors who can react, and by
813 norms, values, means, and physical objects, which the actor considers, to the extent he/she disposes of information and
814 knowledge (adapted from Gallino, 1993). “Social action” and “behaviour” are distinguished from “decision-making”, which refers
815 to the cognitive “process of making a selective intellectual judgment when presented with several complex alternatives
816 consisting of several variables, and usually defining a course of action or an idea” (from the Online Medical Dictionary:
817 <http://www.mondofacto.com/dictionary/>).

818
819 ²The term “risk” refers in this paper to ‘a state of uncertainty where some of the possibilities involve a loss, catastrophe, or other
820 undesirable outcome’ (Hubbard, 2014).

821
822
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1077 **Supplementary Material**

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1079 **Table 1. List of the questions used in the survey conducted with shrimp farmers in Chanthaburi**
 1080 **Province, and how the questions relate to specific components of the IAC Framework.**

Component of IAC Framework	Factor to measure	Survey question
Contextual factors (socio-economic)	Age	
Contextual factors (socio-economic)	Level of education	What is your highest educational level reached?
Contextual factors (socio-economic)	Member of a shrimp farmer group (frequency of attendance to meetings)	Are you a member of a Shrimp Farmers' Group?
Contextual factors (socio-economic)	Received training on farming practices from research group or shrimp farmer group	Have you received formal training and/or technical assistance in shrimp farming?
Contextual factors (socio-economic)		Do you have access to the technical equipment needed to farm shrimp intensively?
Contextual factors (socio-economic)	Size of shrimp farm (area)	What is the size of your farm (rai)? What was the land used for before the shrimp ponds were built?
Contextual factors (socio-economic)	Number of shrimp ponds	How many ponds are on the farm? How many of these ponds did you use in the last harvest? For how many years have the ponds been in use? Of the ponds used in the last harvest, please indicate for each pond: Area of pond (rai) What products were produced (e.g. shrimp, fish.) Pond stocking density (no. per pond)

Contextual factors (socio-economic)	Total annual production of shrimp	How many crops of shrimp did you produce in the past 12 months? The last time you harvested your ponds, what was the total weight of your harvest (kg)?
Contextual factors (socio-economic)	Average farm labour units (people/year)	In the past 12 months, did anyone help you with the running of the farm?
Contextual factors (socio-economic)	Land ownership status	Are you the owner of the shrimp ponds or are they leased?
Contextual factors (socio-economic)	Annual operating costs:	The last time you harvested your ponds, what was the cost of producing the harvest (baht)?
Contextual factors (socio-economic)	Access to credit/investment capital	Do you have access to credit to assist you with running the farm?
Contextual factors (socio-economic)	Level of outstanding debt	Do you currently have any debt from shrimp farming?
Contextual factors (socio-economic)	Annual income	What proportion of your total income normally comes from shrimp farming?
Contextual factors (production)	Location of shrimp farm	What is the location of your shrimp farm? (indicate on map)
Contextual factors (production)	Seasonal weather conditions	During the rainy season, do you change the amount of shrimp you stock in your ponds?
Contextual factors (production)	Disease frequency on shrimp farm	How many times did your shrimp farm experience disease outbreaks in the last 2 years?
Contextual factors (production)	Shrimp mortality due to disease outbreak	The last time you harvested your ponds , approximately what proportion of your shrimp survived?
Contextual factors (production)	Frequency of erosion of pond dykes	Have you observed erosion of the pond dykes on your farm?
Habit	Number of years as intensive/extensive shrimp farmer	How long have you been farming shrimp? Has the amount of shrimp that you produce changed over the past 2 years? Has the number of different products that you produce (e.g. shrimp, fish) changed over the past 2 years?
Expectations	Perceived risks	Are there any risks associated with intensive shrimp farming?
Expectations	Expected market demand	At the start of the last production cycle , did you expect the market demand for shrimp to:
Expectations	Perception of shrimp prices	At the start of the last production cycle , what price did you expect to sell your harvest for? (baht/kg)
Expectations	Perception of price of shrimp	At the start of the last production cycle , did you expect the market price for shrimp to:
Expectations	Perceived impact of shrimp farming on water quality	If you increased the amount of shrimp you produce in your ponds, how do you think this would impact on the water quality in the ponds?
Expectations	Perceived impact of shrimp farming on soil quality	If you increased the amount of shrimp you produce in your ponds, how do you think this would impact the soil quality in the ponds?
Expectations	Whether shrimp farmer expects a reduction in shrimp disease if	If you increased the amount of shrimp you produce in your ponds, how do you think this would affect the survival rate of shrimp?

	shrimp farm intensity is reduced/increased	
Subjective culture - social norms	How shrimp farmer is perceived by others	Is the opinion of _____ about the amount of shrimp you produce per pond important to you? Your spouse/family Other shrimp farmers Your local Shrimp Farmer group Research groups/aquaculture experts The government Environmental groups What do you think _____ thinks about the amount of shrimp you produce per pond?
Subjective culture - social norms	Social conflict	What do you think _____ would think if you increased the amount of shrimp you produce per pond?
Subjective culture - social norms	How often shrimp farmer follows advice from others	How often do you follow advice from _____ regarding the amount of shrimp you stock in your ponds?
Subjective culture - social norms	Perception about production intensity of other shrimp farmers	At the start of a production cycle, what are the three most important things that you consider when deciding on how many shrimps to stock in your ponds?
Subjective culture - social norms	Perception about the intensity of other shrimp farms	Do most shrimp farmers in this area stock shrimp in their ponds at the same density as you? Do most shrimp farmers in this area produce the same number of crops per year as you?
Subjective culture - roles	Status of shrimp farmer	What are the 3 most important aspects to being a good shrimp farmer?
Subjective culture - roles	Care for the environment	<i>"The health of the coastal environment is important to me".</i> How much do you agree with this statement?
Subjective culture - values	Religion	What is your religion?
Physiological arousal	Feelings associated with shrimp farming	Do you enjoy farming shrimp at this level of intensity?

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