Aquaculture 495 (2018) 912–918

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

The role of small-holder seed supply in commercial mariculture in South-east Asia

Mardiana E. Fachry[a], Ketut Sugama[b], Michael A. Rimmer[c,*]

[a] Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, Indonesia
[b] Agency for Marine and Fisheries Research and Development, Centre for Fisheries Research and Development, Jakarta, Indonesia
[c] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Queensland, Australia

ARTICLE INFO

Keywords:
Small-scale hatcheries
Capture-based aquaculture
Seedstock
Milkfish
Grouper

ABSTRACT

Countries in South-east Asia are significant producers of aquacultured products and production is increasing. Seedstock for mariculture are provided from both wild capture ('capture-based aquaculture') and hatchery rearing ('full-cycle aquaculture'). Collection of Palinurid lobster pueruli and juveniles is currently the sole source of seedstock for aquaculture. Other mariculture commodities, such as milkfish (*Chanos chanos*) and groupers (Family Serranidae, Sub-family Epinephelinae) are supported by a combination of wild-caught and hatchery-reared seedstock. Mariculture in South-east Asia is typified by low levels of vertical integration, and a high proportion of 'small-scale' hatcheries. In Indonesia, small-scale hatcheries are clustered in two main areas: Buleleng Regency in northern Bali and Situbondo in East Java, with small-scale hatcheries comprising 95% and 88% of hatcheries in each area respectively. Fingerling production from these hatcheries is considerable, with 7.3 million grouper and 2.5 billion milkfish fingerlings exported from Bali in 2016. Although several studies have quantitatively evaluated the benefits of small-scale hatcheries to local communities, scant attention has been paid to their regional impact. As an example, much of the global production of around 1 million tonnes per annum of milkfish is supported by fingerling production by small-scale hatcheries in Bali. Despite this acknowledged success, disease remains an ongoing problem for small-scale hatcheries with operators of grouper hatcheries in Bali categorising mortality and financial losses as 'medium' to 'high'. A survey of small-scale hatcheries showed that biosecurity is poor and fish health management approaches are based on previous experience. Factors impacting these approaches include purchaser focus on price at the expense of quality, and limited numbers of hatchery staff with any formal aquaculture training. The impact of disease outbreaks remains a weakness for small-scale hatcheries, and consequently a weakness for the mariculture industries dependent on these as a seedstock source.

1. Introduction

Asia has been the source of around 89% of world aquaculture production of fish for human consumption in the past two decades (FAO, 2016). China remains the major producer of farmed seafood with an estimated 62% of global production, but South-east Asian countries are now also making a substantial contribution to the global total with Indonesia, Viet Nam and other South-east Asian countries contributing 5.8%, 4.6% and 4.3% respectively; a total of 14.7% of global aquaculture production (FAO, 2016).

Freshwater and brackishwater aquaculture both have a long history in South-east Asia, for example in Indonesia where Javanese law from around 1400 prescribed punitive measures against those who stole from freshwater or saltwater ponds (Rabanal, 1988; Schuster, 1952). However, mariculture (defined as culture in the sea) is of more recent origin. This paper reviews and discusses the role of small-holders in seedstock supply to mariculture in South-east Asia, in relation to both capture-based aquaculture (using wild-caught seedstock) and full-cycle aquaculture (using hatchery-reared seedstock). The paper provides some original data on the extent of the small-holder contribution to mariculture seedstock supply in South-east Asia, and discusses some aspects of long-term sustainability of seedstock supply in relation to disease and biosecurity in small-scale hatcheries.

2. Materials and methods

Data on the numbers of hatcheries in Buleleng Regency, Bali, and Situbondo, East Java, were obtained from the respective Provincial

* Corresponding author.
E-mail address: mrimmer@usc.edu.au (M.A. Rimmer).

https://doi.org/10.1016/j.aquaculture.2018.06.076
Received 30 December 2017; Received in revised form 25 April 2018; Accepted 25 June 2018
Available online 26 June 2018
0044-8486/

Fisheries Agencies (Dinas Kelautan dan Perikanan Provinsi). Conversion of price data from Indonesian Rupiah (IDR) to United States Dollars (USD) was done using a nominal rate of IDR 13,000 = USD 1.00.

Data on hatchery knowledge of disease and attitudes to biosecurity were obtained from a study of hatcheries in Gerokgak Sub-district, Buleleng Regency, Bali, carried out during the period October 2015 to January 2016. A questionnaire was used to interview 17 hatchery managers, selected from a pool of 57 hatcheries in that area. The questionnaire was divided into six sections, covering: baseline information (10 questions), production process (10 questions), fish health and disease (16 questions), biosecurity practices (23 questions) and staffing and education (3 questions).

3. Seedstock from wild capture

3.1. Finfish

Capture fisheries are still an important source of seedstock for culture of some marine and brackishwater finfish species. Aquaculture of milkfish *Chanos chanos* in coastal ponds has traditionally been supported by trapping wild fry in brackishwater ponds, then allowing them to grow out to harvestable size (200–500 g) using 'traditional' extensive methods (Schuster, 1952; Sudradjat and Sugama, 2010a). In Indonesia the fry capture season is typically associated with the twice-yearly shift in prevailing wind direction associated with the monsoon seasons (Sudradjat and Sugama, 2010b). Captures are highest immediately prior to and after the full and new moons, which is associated with spawning of milkfish adults during the quarter moon periods (Sudradjat and Sugama, 2010b). As in the case of other fry fisheries, there is substantial inter-annual variability in catches (Sudradjat and Sugama, 2010b), and in the Philippines there appears to have been a long-term decline in the availability of milkfish fry (Marte, 2010). Total annual catches of milkfish fry are estimated at 1.5 billion and 1 billion per annum for Indonesia and the Philippines respectively (Marte, 2010; Sudradjat and Sugama, 2010b).

Grouper (Subfamily Epinephelinae, Family Serranidae) are variously sourced from capture fisheries and hatcheries. A range of grouper species belonging to the genera *Epinephelus, Plectropomus, Cephalopholis, Aethaloperca, Cromileptes*, and *Hyporthodus* may be sourced from wild capture (Rimmer and Glamuzina, in press). Other estuarine and marine species are also supplied mainly through wild capture, particularly the mangrove red snapper *Lutjanus argentimaculatus*. Although these fisheries are categorised as 'fry' fisheries, in many areas they catch a range of sizes including larger sub-adults. For example, a study in Flores, Indonesia, using 'gango' traps caught juvenile groupers averaging 13.6 cm total length (Mous, Sadovy, Halim, and Pet, 2006). However, in Aceh, Indonesia, similar passive traps catch juvenile *Epinephelus* spp. (mainly *E. coioides*) at about 2–3 cm TL (Komarudin, Rimmer, Islahuttaman, and Bahrawi, 2010).

In Indonesia, there is relatively little overlap between grouper seed supply from wild fisheries and from hatchery production. Although fry of several grouper species are captured, the main grouper sourced from wild capture is *E. coioides* (Komarudin et al., 2010; Sadovy, 2000) and this species is rarely produced in Indonesian hatcheries. One reason is the price differential for this relatively low-value grouper. Wild-caught *E. coioides* fingerlings (1.5–2.0 cm TL) are sold from brackishwater pond nurseries at IDR 300–1700 per fish (Komarudin et al., 2010), whereas Indonesian hatcheries sell fingerlings of other *Epinephelus* spp., such as *E. fuscoguttatus*, for about IDR 1500–2000 per fish. Because the wild-caught *E. coioides* fry sell for a lower price, there is little incentive for hatcheries to produce this species.

In Taiwan Province of China (PoC), lower-value species may be produced using lower-cost larval rearing systems, particularly 'outdoor' (i.e. concrete or earthen ponds about 0.3–0.5 ha) systems for larval rearing (Liao, Su, and Chang, 2001; Rimmer, 1998; Su, Su, Tseng, and Liao, 2008). Although these 'outdoor' systems are less reliable than 'indoor' production systems, the outdoor system is popular for family-run farms because of the low technology required and lower input costs (Rimmer, 1998; Su et al., 2008). They are particularly popular in the south of Taiwan PoC where weather conditions are more favourable for outdoor larval rearing (Su et al., 2008). Production from these systems can be substantial: Su et al. (2008) cite an example of commercial production of 3 million *E. coioides* fingerlings from 5 to 6 crops (April to October) using three 0.3 ha larval rearing ponds, supported by nine 450 m^2 rotifer production ponds and nine copepod production ponds ranging from 1 to 4 ha each.

3.2. Tropical spiny lobsters

Aquaculture of tropical spiny lobsters (Family Palinuridae) has been undertaken in Viet Nam, Malaysia, Singapore, Indonesia and Cuba, although lobster farming has virtually ceased in all these countries except Viet Nam (Priyambodo, Jones, and Sammut, 2015) and Malaysia. Despite a decade of research targeting the development of hatchery-rearing techniques for Palinurid lobster production, wild-caught lobster pueruli remains the sole source of seedstock for tropical lobster aquaculture (Jones, 2015; Priyambodo et al., 2015).

In Viet Nam *Panulirus ornatus* dominates puerulus catches (Dao and Jones, 2015). Annual catches of this species are highly variable, ranging from about 1 million to > 3 million per annum (Dao and Jones, 2015). The other species commonly caught in large numbers, *Panulirus homarus*, shows less annual variability with catches ranging from 500,000 to about 1.3 million per annum (Dao and Jones, 2015). Collection of lobster pueruli and juveniles is undertaken over an extensive area of the Viet Nam coastline, from central (Da Nang) to south coast (Binh Thuan) provinces (Dao and Jones, 2015). Ninety-five percent of the lobster seed sold to collectors were at puerulus (transparent) stage and the remaining 5% were pigmented juveniles (Dao and Jones, 2015).

Dow and Jones (2015) note that lobster seedstock collection is very attractive to poor coastal villagers in Viet Nam because the economic returns are high but risks are relatively low because the seedstock are quickly sold on to dealers who in turn sell to the grow-out farms. First sale price for pueruli or juvenile lobsters (*P. homarus* and *P. ornatus*) caught in Lombok ranged from IDR 2000 to 10,000 (USD 0.15 to 0.77) each in 2012–13 (Bahrawi, Priyambodo, and Jones, 2015). Prices paid in Viet Nam for *P. ornatus* were substantially higher, ranging from USD $3 to $9 each between 2005 and 06 and 2010–11, increasing to USD $12 to $14 in 2013–14 (Dao and Jones, 2015).

In Indonesia, lobster seedstock collection is dominated by catches from Lombok (Bahrawi et al., 2015; Priyambodo et al., 2015). Initially, catches in Lombok were small with negligible numbers of pueruli reported in 2005–06 and 2006–07 (Jones, Long, Hoc, and Priyambodo, 2010). However this increased rapidly and in 2008–09 > 600,000 puerulus (mostly *Panulirus homarus*) were captured (Jones et al., 2010). By 2012–13 the numbers of pueruli captured had increased dramatically with 440,000 and 2.6 million *P. homarus* and 256,000 and 408,000 *Panulirus ornatus* captured in 2012 and 2013 respectively (Bahrawi et al., 2015). A survey of lobster seed collection in Java, Lombok and Sumbawa in 2015–16 indicated that the total catch of lobster pueruli and juveniles in these locations was around 100 million per annum (C.M. Jones, pers. comm. 2017).

4. Seedstock from hatchery production

Hatchery production systems in Asia range from small-scale (sometimes termed 'backyard') hatcheries to large complex hatcheries that may form part of vertically-integrated production operations. The term 'small-scale' is usually applied to hatcheries that do not hold broodstock; whereas hatcheries with broodstock are termed 'complete' hatcheries. The term 'small-scale' is something of a misnomer because these hatcheries can have tens or even hundreds of larval rearing tanks.

In many cases, hatchery operators have started out with relatively small numbers of rearing tanks and regularly add tanks to increase their production. Small-scale marine finfish hatcheries operate throughout Asia, including Indonesia, Malaysia, Thailand, the Philippines, Viet Nam and China (Sim et al., 2005).

Throughout Asia, vertical integration of hatchery production, nursery rearing and grow-out phases is still the exception rather than the rule. In Taiwan PoC, there can be up to 4 separate farms involved in aquaculture production: a broodstock farm that provides the eggs/larvae, a larval rearing farm that rears the larvae to about 3 cm in length, a nursery farm that further rears the fish to 6–9 cm, and a grow-out farm that rears the fish to market size (Rimmer, 1997).

In Indonesia, there is a similar separation of production phases for grouper aquaculture. An estimated 8–10% of grouper fingerlings produced by Indonesian hatcheries are directly exported after leaving the hatchery at around 2–3 cm TL. Around 60–80% are transported to North Sumatra, Aceh or northern Java (Lamongan) for nursery culture. In nursery culture, hatchery-reared fingerlings as well as those caught from the wild are cultured in *hapa* nets in shallow brackishwater ponds for around 45 days (Komarudin et al., 2010). Grouper introduced to the nursery culture system at around 2–3 cm TL (the preferred size provided by hatcheries) are grown out to 7–10 cm TL (the preferred size for stocking in sea cages) (Komarudin et al., 2010). Most of the grouper harvested from nursery systems in Aceh and North Sumatra are exported (via Medan) to China, Malaysia, the Philippines, Singapore, Taiwan PoC, Thailand and Viet Nam. Only about 10–20% are used for grow-out within Indonesia.

5. Small-scale hatcheries in Indonesia

In Indonesia, small-scale hatcheries are clustered in two main areas: in Buleleng Regency in northern Bali and in the Situbondo area of East Java. Both Buleleng and Situbondo hatcheries produce grouper fingerlings, but only Buleleng is a major production area for milkfish fingerlings. Data from Buleleng Regency indicate that there are 347 hatcheries comprising 17 'complete' hatcheries with the remainder (95%) categorised as 'small-scale' (Table 1). Together all 347 hatcheries have around 5000 larval rearing tanks. The complete hatcheries have a total of 73 broodstock tanks, most of which contain milkfish broodstock.

A separate survey of hatcheries in the Situbondo (East Java) area in 2015–16 indicated that 60 of 68 hatcheries (88%) were small-scale, i.e. had 4–5 production units, (Table 2), while only 4 were categorised as 'medium' (5–10 units) and another 4 as 'large' (> 10 units). Of the 68 hatcheries surveyed, 42 produced only grouper in 2015–16 while 26 produced both grouper fingerlings and shrimp seedstock.

Small-scale hatcheries are notable for their simple and low-cost construction and operations. Siar, Johnston, and Sim (2002) surveyed 11 hatcheries in northern Bali and found that establishment (capital and fit-out) costs for 10 of these (each with 2 to 12 larval rearing tanks) ranged from USD 4550 to USD 15,750, while the 11th hatchery (with 16 larval rearing tanks) had establishment costs estimated at USD 107,000. Pomeroy, Sugama, Slamet, and Tridjoko (2006) estimated the capital costs of establishing a small (2 × 10 m^3 larval rearing tanks) hatchery at USD 3258.

Table 1
Number of small-scale (i.e. without broodstock) and 'complete' (i.e. with broodstock) hatcheries, number of larval rearing tanks and number of broodstock tanks, in villages in Buleleng Regency, Bali, Indonesia.

Village	No. hatcheries		No. tanks	
	Small-scale	Complete	Larval rearing	Broodstock
Banyupoh	87	1	1066	4
Pemuteran	11	2	152	12
Penyabangan	121	7	1919	17
Sanggalangit	10	1	142	2
Musi	55	1	861	4
Gerokgak	27	4	593	30
Celukan Bawang	2	0	27	0
Patas	17	1	225	4
Total	330	17	4985	73

Table 2
Number of hatcheries in the Situbundo area, East Java, categorised as small (< 5 units), medium (5–10 units) and large (> 10 units) and their potential annual production of grouper fingerlings.

Category	Small	Medium	Large
No. units	< 5	5–10	> 10
No. hatcheries	60	4	4
Production (fish per cycle)	10,000–70,000	30,000–60,000	100,000–200,000

Table 3
Physical characteristics of hatcheries surveyed in northern Bali; frequency and percentage (in brackets) shown.

Hatchery area (ha)	< 0.1	0.1–0.5	0.5–1.0	1–3
	3 (19%)	8 (50%)	2 (13%)	3 (19%)
Number of larval tanks	10–20	21–50	51–90	
	8 (50%)	6 (37%)	2 (13%)	
Volume of larval tanks (m^3)	< 10	11–20	21–30	
	2 (13%)	10 (63%)	4 (25%)	
Number of nursery tanks	0	1–10	11–50	51–300
	4 (25%)	2 (13%)	8 (50%)	2 (13%)
Number of sand filters	0	1	2	4
	5 (29%)	8 (47%)	3 (18%)	1 (6%)

Our 2015 survey of hatcheries in northern Bali showed that most (81%) are < 1 ha in area, and 69% are < 0.5 ha (Table 3). Half of the hatcheries surveyed had only 10 to 20 larval rearing tanks, ranging in size from 9 to 30 m^3 (Table 3). Seventy-five percent of hatcheries had dedicated nursery tanks (Table 3) which ranged in size from 2 m × 2 m up to 4 m × 6 m.

Water is pumped from adjacent inshore coastal waters. Only 50% of the hatcheries surveyed had a storage reservoir. The main form of filtration used in these hatcheries is the gravity sand filter (Sim et al., 2005; Sugama et al., 2012). About half the hatcheries surveyed had only a single gravity sand filter, while about a quarter had multiple filters (Table 3).

Most hatchery production is of the tiger grouper *Epinephelus fuscoguttatus*, the hybrid grouper 'cantang' ♀ *Epinephelus fuscoguttatus* × ♂ *Epinephelus lanceolatus*, and the hybrid grouper 'cantik' ♀ *Epinephelus fuscoguttatus* × ♂ *Epinephelus polyphekadion*. In recent years the demand from grow-out farms has shifted from a high proportion of tiger grouper to increased demand for the two hybrid groupers. This trend is not limited to Indonesia, but is more broadly reflected in other Asian countries that farm grouper (Rimmer and Glamuzina, in press). Reasons for this preference are the faster growth of hybrid groupers in comparison with the parental stocks (Sugama, Muzaki, Permana, and Haryanti, 2014) and farmer perception that hybrid grouper are more resistant to disease (Rimmer and Glamuzina, in press). In addition, small number of the humpback grouper *Cromileptes altivelis* and the leopard coralgrouper *Plectropomus leopardus*, are produced by these hatcheries.

Our survey results indicated that more hatcheries were producing the two hybrid groupers than tiger grouper (Table 4), reflecting the increasing popularity of hybrid groupers for grow-out. Typical production is 10,000–100,000 fingerlings per cycle (Table 4), with typically 5 cycles per annum. One notable aspect is the low price paid for grouper fingerlings, equivalent to USD 0.14 to USD 0.35 for a 3 cm TL fingerling (Table 4).

Table 4
Hatchery production data for Buleleng hatcheries surveyed for this study. Production data is for grouper fingerlings 2–3 cm TL.

Species	Tiger	Cantang	Cantik
No. hatcheries producing	5 (29%)	15 (88%)	9 (53%)
Production (fish per cycle)	20,000–100,000	10,000–100,000	15,000–125,000
Price per cm (IDR)	IDR 600–1000	IDR 600–1500	IDR 600–1500

6. Local impacts of small-scale hatcheries

Small-scale hatcheries are recognised as contributing to local economic and social development. Direct benefit is provided through employment of local people in hatcheries (Siar et al., 2002). A recent study estimated that there were 4000–5000 people employed directly in hatcheries in northern Bali (Hiruy, Murphy, Lewis, and Fudge, 2016). In addition to direct employment in the hatcheries, indirect employment is provided through construction and expansion of hatcheries, provision of input supplies (feed, chemicals, etc.) and employment in the value chain, for example as brokers who on-sell or export fingerlings (Siar et al., 2002). In Buleleng Regency one estimate of indirect employment concluded that about 20% of the local population was involved in hatchery production in some way (Heerin, 2002). This area is believed to have the highest employment rate in Indonesia (Hiruy et al., 2016). A range of broader social and economic impacts have also accrued from the success of small-scale hatcheries, such as increased land values and improved educational opportunities due to higher incomes (Hiruy et al., 2016).

7. Global impacts of small-scale hatchery production

To examine the broader impacts of small-scale hatchery production, we use two examples from Indonesia: grouper and milkfish.

7.1. Grouper

Worldwide, an estimated 47 grouper species and 15 hybrids are cultured (Rimmer and Glamuzina, in press). Groupers are sourced both from wild capture (at various sizes from post-larvae through to subadults) and from hatcheries. The exact proportion of fish sourced from wild capture is uncertain (Rimmer and Glamuzina, in press; Sadovy et al., 2003) but the rising contribution of hybrid groupers to live fish markets (Ferdouse, 2014; Sadovy, 2013) suggests that full-cycle aquaculture is now the dominant source of seedstock because hybrid groupers can only be produced from artificial propagation.

Taiwan PoC and Indonesia are probably the two main suppliers of hatchery-reared grouper fingerlings, although there is significant hatchery production in Viet Nam, Thailand and the Philippines. Traditionally, Taiwan PoC has been a dominant supplier of grouper fingerlings with estimated production ranging from around 40 to 65 million fingerlings per annum in the period 2001 to 2006 (Chang, Chiu, and John, 2008).

Total production of grouper seedstock, including hybrids, from hatcheries in northern Bali in 2015 was around 6 million fingerlings. An estimated 80–90% of those were exported to neighbouring countries including Singapore, Malaysia, Thailand, Viet Nam, Taiwan PoC and China.

7.2. Milkfish

As noted earlier, the two main areas with large numbers of small-scale hatcheries in Indonesia are Buleleng Regency in northern Bali and Situbondo in East Java. Grouper fingerlings are produced in hatcheries in both areas, but milkfish fingerlings are produced mainly by Balinese hatcheries. The 347 hatcheries in the Buleleng area produce about 2.5 billion milkfish fingerlings per annum.

Table 5
Annual exports of milkfish and grouper fingerlings from Denpasar airport, Bali. Data provided by the Agency for Fish Quarantine, Quality Control and Fisheries Product Safety, Denpasar, Bali.

Species	2014	2015	2016
Milkfish fry	1,460,765,000	2,007,944,000	2,467,337,750
Grouper fry	5,486,246	6,141,353	7,272,310

Denpasar airport is the main port for export of milkfish fingerlings from Indonesia, so export data (Table 5) provide some insight into the role of small-scale hatcheries more broadly. Exports of milkfish fingerlings increased from around 1.5 billion in 2014 to 2.5 billion in 2016 (Table 5). Most (70–80%) are exported to the Philippines, with small numbers exported to Japan, Malaysia, Singapore, Thailand and Viet Nam.

8. Disease issues in tropical marine finfish hatcheries

Disease is widely recognised as a significant issue affecting production in tropical marine finfish hatcheries (Bondad-Reantaso, Humphrey, Kanchanakhan, and Chinabut, 2000; Harikrishnan, Balasundaram, and Heo, 2011; Nagasawa and Cruz-Lacierda, 2004; Sugama and Koesharyani, 2017). Following a regional survey of diseases in grouper aquaculture, Bondad-Reantaso et al. (2000) listed a range of diseases which they classified as viral, bacterial, infections caused by parasites, infections caused by monogeneans, nutritional and environmental. While some of these diseases have been reported only for the grow-out stage, most have been reported for various stages of the life cycle, including the larval and nursery stages.

Despite their acknowledged importance, there is little specific information regarding the impacts of particular diseases, the links between various disease syndromes and other factors (such as environment or nutrition), or even the overall impact of disease on hatchery production. The study reported here attempted to obtain information on the latter aspect, i.e. the impact of disease on grouper hatchery production, as well as hatchery operators' attitudes to disease prevention (particularly hatchery biosecurity) and treatment.

8.1. Occurrence of disease in grouper hatcheries

Hatchery operators reported viral diseases as the main fish health problem in grouper hatcheries. Other disease issues reported were related to parasites and skin injuries. Viral diseases were recognised by changes in fish colour and behaviour, particularly lethargy of affected fish.

Most hatchery operators reported the frequency of occurrence of disease as 'medium' (Table 6). However, the impacts of disease outbreaks were viewed differently. Hatchery operators categorised disease-related mortality fairly evenly between 'high' and 'medium', with only one hatchery operator indicating that they had 'low' mortality (Table 6). The financial impacts of this mortality were also mainly categorised as 'high' and 'medium' (Table 6).

Table 6
Hatchery operators' perceptions of frequency of occurrence, level of mortality due to disease and consequent financial loss in grouper hatcheries surveyed for this study; frequency and percentage (in brackets) shown.

Disease impacts	High	Medium	Low
Occurrence	2 (13%)	10 (63%)	4 (13%)
Mortality	8 (47%)	8 (47%)	1 (6%)
Financial loss	8 (47%)	8 (47%)	1 (6%)

Table 7
Responses to questions regarding fish health management practices by hatchery operators in Bali; frequency and percentage (in brackets) shown.

Practice	Yes	No
Restrict entry of visitors	2 (12%)	15 (88%)
Take off or change shoes	3 (18%)	14 (82%)
Provide footbath	4 (24%)	13 (76%)
Wash hands	9 (53%)	8 (47%)
Disinfect vehicles	5 (29%)	12 (71%)
Share equipment	4 (24%)	13 (76%)
Chlorinate water	10 (59%)	7 (41%)
Use UV/other treatment	4 (24%)	13 (76%)
Surrounding hatcheries using hygienic practices	4 (24%)	13 (76%)
Pre-treatment of effluent	0	17 (100%)

8.2. Hatchery facilities and procedures

Hatchery operators were asked a number of questions regarding fish health and biosecurity practices in place in their hatcheries. Only 12% of hatcheries restricted access by visitors (Table 7). Only 18% of hatcheries required that staff and visitors change shoes before entering the hatchery, and only 24% provided footbaths. Fifty-three percent of hatcheries required hand washing and 29% percent disinfected vehicles. Twenty-four percent of the surveyed hatcheries shared equipment with other hatcheries; in all cases these were seawater pumping and supply systems, and aeration systems. Seventy-six percent of hatcheries felt that the surrounding hatcheries were not using hygienic practices.

The most common form of water treatment was chlorination (59% of hatcheries). Four hatcheries (7%) used UV filtration (Table 7) (although in one case that we observed this was a home-made installation that would have had negligible effect). All the hatcheries surveyed cleaned their tanks, floor and equipment between batches of fish, with many (59%) using chlorine. All hatcheries disposed of waste water by directly draining it to the sea.

The main sources of technical information regarding hatchery procedures (71%) were from staff of IMRAD Gondol (the local government research and development institute), followed by the hatchery owner (18%) and equipment/input suppliers (12%). Another aspect of small-scale hatcheries is the lack of formal aquaculture education and training. Of the 17 hatcheries surveyed, only 2 (12%) had staff with formal education in aquaculture. Seven hatcheries (41%) had provided staff with procedural training (not specific to fish health and biosecurity) either onsite or at IMRAD Gondol.

8.3. Disease outbreak management

Seventy-one percent of hatcheries separated apparently diseased fish from healthy fish, while 17% treated sick fish with formalin. During a disease outbreak, most (53%) hatcheries contacted the owner, other technical staff in the hatchery (35%), or the local research institute (12%).

After a disease outbreak, 82% of hatcheries depleted the affected tanks, and 12% sterilised with chlorine. Most hatcheries disposed of dead fish by burying (59%) or burning (35%).

9. Discussion

Small-holder seedstock supply, either from capture fisheries or from hatcheries, is an important feature of the landscape of aquaculture in many South-east Asian countries. In many areas seedstock supply can make an important contribution to poverty reduction in coastal communities.

For example, a census of lobster seedstock collectors in Lombok indicated that there were 556 lobster seedstock fishers operating in 2013–14 (Bahrawi et al., 2015). Total revenue from catches of lobster pueruli and juveniles during 2013 was IDR 17.4 billion (equivalent to around USD 1.34 million) (Bahrawi et al., 2015), giving an average income per fisher of IDR 31.3 million (USD 2400) or IDR 2.6 million per month (USD 200). Indonesia's poverty line at this time was set at IDR 302,735 (about USD 23) per month (Aji, 2015). Clearly, income derived from lobster seedstock fishing could lift many (in not all) of these households well above the poverty line.

Prior to the Indonesian government's ban on collection of lobster seedstock in 2015, most of these pueruli and juveniles were being exported to other South-east Asian countries, particularly Viet Nam. They thus provided not only an export industry for Indonesia, but supported livelihoods for coastal villages involved in lobster aquaculture in Viet Nam. In January 2015, the Indonesian Minister for Marine Affairs and Fisheries issued a decree limiting the legal capture sizes of lobsters (*Panulirus* spp.), mud crabs (*Scylla* spp.) and swimming crab (*Portunus pelagicus*) with a size limit on lobsters of > 8 cm carapace length. Although presumably intended to reduce the impacts of recruitment overfishing, one impact of this size limit was to make the trade in lobster pueruli and juveniles illegal. To date, the impact of this legislation on coastal communities in Indonesia has not been evaluated.

At local scale, small-scale hatcheries make an important contribution to the social and economic well-being of coastal communities, as outlined above, primarily through direct and indirect employment (Heerin, 2002; Hiruy et al., 2016; Siar et al., 2002).

The scale of production of marine finfish juveniles from these hatcheries suggests that the social and economic impacts are more broadly felt throughout the Asia-Pacific region. Total global production of milkfish in 2015 was around 1 million tonnes and Indonesia (63%) and the Philippines (35%) were the major producers (FAO, 2017). Both Indonesia and the Philippines consume nearly all the milkfish that they produce and in both countries milkfish is an important contributor to food security amongst coastal communities (Liao and Leaño, 2010). Indonesia for some time has been the major producer of milkfish fingerlings, substantial numbers of which are exported to the Philippines. As noted earlier, most of this production is from small-scale hatcheries in northern Bali. Production of groupers from aquaculture is an order of magnitude smaller than for milkfish, with an estimated 155,000 t of production in 2015 (FAO, 2017). As seedstock for grouper aquaculture are sourced from wild-capture fisheries and from hatchery production (Rimmer and Glamuzina, in press), both small-holder fishers and small-scale hatchery operators continue to be important component of grouper aquaculture supply chains.

Although small-scale hatcheries make a substantial contribution to livelihoods and food security at a regional level, they are subject to a range of threats, including the impacts of disease. The key features of small-scale hatcheries is that they are inexpensive to construct and relatively simple to operate. Although these features make them accessible to people in poorer coastal communities, they also tend to restrict the implementation of effective biosecurity and fish health protocols.

Viral nervous necrosis (VNN) and iridovirus were reported as the main diseases affecting grouper hatcheries in Bali. VNN is caused by a *Betanodavirus* within the family Nodaviridae and has been reported from all continents except South America (Rodger, 2016; Shetty, Maiti, Shivakumar Santhosh, Venugopal, and Karunasagar, 2012). Clinical signs of the disease include reduced appetite, emaciation, colour change (darkening), abnormal (whirling or cork-screwing) swimming pattern, neurological dysfunction, exophthalmia, swim bladder hyperinflation, anorexia and apparent blindness (Rodger, 2016; Shetty et al., 2012). VNN outbreaks may result in heavy mortality, up to 90–100% (Rodger, 2016). Of the viruses in the family Iridoviridae, *Megalocytivirus* is the most significant in terms of economic impact, and is reported to have affected a wide range of tropical and temperate marine fish species (Rodger, 2016). Mortality rates vary but can be up to 90% in red sea bream (*Pagrus major*), rock bream (*Oplegnathus fasciatus*) and grouper species (Rodger, 2016).

Nakai et al. (2009) note that the main mode of transmission of the nervous necrosis virus (NNV) is through influent and rearing water, and via utensils, vehicles, and human activity. Hick, Schipp, Bosmans, Humphrey, and Whittington (2011) documented repeated outbreaks of VNN at an Australian hatchery and noted that transmission of the virus between segregated and biosecured areas of the hatchery occurred and may have been due to the presence of fish subclinically infected with large quantities of viral particles, or through breakdown in biosecurity measures. There is evidence of vertical transmission of VNN from broodstock to larvae via the eggs, and this is usually controlled by washing eggs in ozone-treated seawater before they are stocking in the larval rearing tanks (Nakai et al., 2009; Su, Tseng, Su, and Liao, 2001).

While there are numerous publications on the occurrence of viral, bacterial and parasitic diseases in groupers, to date there has been no effective epidemiological evaluation of the major diseases of grouper in the various culture phases. Such studies would dramatically increase our knowledge of the economic impacts of disease on grouper aquaculture (Harikrishnan et al., 2011). In the absence of detailed epidemiological studies, approaches to reduce the incidence and extent of VNN outbreaks in hatcheries are based on improved biosecurity to reduce the chance of vertical and horizontal transmission of the virus. These approaches, adapted from Nakai et al. (2009), Hick et al. (2011) and Rodger (2016), can be summarised as:

- Adoption of basic biosecurity approaches (foot bath, hand washing, physical separation of facilities, restricted access by staff, etc.).
- Sterilization of water coming into the hatchery.
- Treatment of spawned eggs with ozone prior to stocking in larval rearing tanks.
- Batch ('all-in, all-out') production followed by disinfection of the hatchery between batches.
- Monitoring populations for sub-clinical infections prior to disease outbreaks.
- Exclusion of incidental species that may act as carriers.
- Disinfection of the hatchery following a disease outbreak.

In regard to the hatcheries surveyed in this study, adoption of these approaches was limited. The majority of hatcheries did not implement effective biosecurity procedures (Table 7). Some sterilization of water using chlorine was carried out by some hatcheries, but this was generally for water used for microalgal and rotifer production (to reduce the incidence of competitors such as protozoans) rather than a procedure to control viral outbreaks. None of the hatcheries surveyed used ozone treatment of eggs to control potential vertical transmission of VNN. Monitoring of fish for disease was done by hatchery operators, but clinical diagnoses were rarely sought because of the additional cost of polymerase chain reaction (PCR) testing.

Many small-scale hatcheries line the shore of north-western Bali (Heerin, 2002) and their intake and outlet systems are usually close together. None of the hatcheries surveyed treated effluent prior to disposal to coastal waters, and most had only simple gravity sand filter pre-treatment systems. Consequently, it is likely that any disease outbreaks result in transmission of pathogens between adjacent hatcheries in the water effluent and supply systems.

In summary, many of the small-scale hatcheries surveyed were significantly impacted by disease outbreaks, nominating fish mortality and the resultant financial impacts as 'medium' to 'high' (Table 6). Despite this, most hatcheries had poor implementation of biosecurity protocols that may reduce the incidence and severity of disease outbreaks, particularly with regard to VNN. The reasons for this response are likely related to the cost of implementation of biosecurity procedures and the education status of the hatchery staff.

Because of the large number of hatcheries producing seedstock, there is intense competition for purchasers. An additional pressure on the hatcheries is that many farms focus on price rather than quality when purchasing batches of fingerlings. Together, these two aspects cause a focus on fingerling price, which in turn forces hatchery operators to adopt low-cost practices. There are costs (either in terms of infrastructure requirements or staff operations) associated with biosecurity implementation and small-scale hatcheries are reluctant to adopt any practices that impose additional costs. Improving the performance of these small-scale hatcheries will first require convincing purchasers that there are economic advantages to buying better quality or specific-pathogen-free seedstock, since it is the purchasers who will need to absorb the increased costs associated with effective fish health management in small-scale hatcheries.

10. Acknowledgments

Components of this research have been funded by the Australian Centre for International Agricultural Research (ACIAR) under projects FIS/97/73, FIS/2002/077 and FIS/2010/101. The authors gratefully recognize ACIAR's long-term support of sustainable development of finfish mariculture in the Asia-Pacific region. We thank Mrs. Suko Ismi for assistance with the hatchery survey and information regarding hatchery production in Indonesia; and Mr. Wahyudin P. Sasmita for assistance in interviewing hatchery managers. We thank our University of Sydney colleagues Prof. Richard Whittington, Dr. Paul Hick and Dr. Joy Becker, for their input to the hatchery survey questionnaire and Dr. Navneet Dhand for assistance with the survey design, data analysis and ethics approval for this study. We also thank Ir. Dwi Haryanto for providing the information on small-scale hatcheries in Situbondo, and the head of the Buleleng District Department of Marine Affairs and Fisheries and Mr. Usama Umar Al Hadadi (Pak Oye), Secretary of the Bali Seed and Mariculture Association, for data on hatcheries in Bali. We thank Dr Clive Jones (James Cook University, Australia) for providing unpublished estimates of lobster puerulus catches in Indonesia. The hatchery attitudinal study was undertaken under University of Sydney Human Ethics approval for the project 'Health and production survey of marine finfish hatcheries and grow-out farms', project number 2015/035. We also thank the organizers of the 'Larvi2017' conference for the opportunity to present and publish these results.

References

Aji, P., 2015. Summary of Indonesia's Poverty Analysis. ADB Papers on Indonesia No.04. Asian Development Bank, Metro Manila, Philippines.

Bahrawi, S., Priyambodo, B., Jones, C., 2015. 2.1 Census of the lobster seed fishery of Lombok. In: Jones, C.M. (Ed.), Spiny lobster aquaculture development in Indonesia, Vietnam and Australia. Proceedings of the International Lobster Aquaculture Symposium held in Lombok, Indonesia, 22–25 April 2014. ACIAR Proceedings No. 145. Australian Centre for International Agricultural Research, Canberra, pp. 12–19 285 pp.

Bondad-Reantaso, M.G., Humphrey, J., Kanchanakhan, S., Chinabut, S., 2000. Development of a Regional Research Programme on Grouper Virus Transmission and Vaccine Development (APEC FWG 02/2000). Report of a workshop held in Bangkok, Thailand, 18–20 October 2000. Asia-Pacific Economic Cooperation, Fish Health Section of the Asian Fisheries Society, Aquatic Animal Health Research Institute, Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Chang, C.-Y., Chiu, C.-C., John, J.A.C., 2008. Chapter 12 - Prophylaxis for iridovirus and nodavirus infections in cultured grouper in Taiwan. In: Liao, I.C., Leaño, E.M. (Eds.), The Aquaculture of Groupers. Asian Fisheries Society, World Aquaculture Society, Fisheries Society of Taiwan, National Taiwan Ocean University, pp. 207–224.

Dao, H.T., Jones, C., 2015. 2.2 Census of the lobster seed fishery of Vietnam. In: Jones, C.M. (Ed.), Spiny lobster aquaculture development in Indonesia, Vietnam and Australia. Proceedings of the International Lobster Symposium held in Lombok, Indonesia, 22–25 April 2014. ACIAR Proceedings No. 145. Australian Centre for International Agricultural Research, Canberra, pp. 20–26 285 pp.

FAO, 2016. The State of World Fisheries and Aquaculture. Food and Agriculture Organisation of the United Nations, Rome.

FAO, 2017. FishStatJ, a Tool for Fishery Statistics Analysis. FAO Fisheries and Aquaculture Department, FIPS - Statistics and Information, Rome.

Ferdouse, F., 2014. Live fish trade in Asia in 2013. Aquaculture Asia-Pacific Magazine. 10, 44–45.

Harikrishnan, R., Balasundaram, C., Heo, M.-S., 2011. Fish health aspects in grouper aquaculture. Aquaculture 320, 1–21.

Heerin, S.V., 2002. Technology transfer - backyard hatcheries bring jobs, growth to Bali. Glob. Aquac. Advocate 5, 90–92.

Hick, P., Schipp, G., Bosmans, J., Humphrey, J., Whittington, R., 2011. Recurrent outbreaks of viral nervous necrosis in intensively cultured barramundi (*Lates calcarifer*) due to horizontal transmission of betanodavirus and recommendations for disease

control. Aquaculture 319, 41–52.
Hiruy, K., Murphy, R., Lewis, T., Fudge, M., 2016. ACIAR Fisheries Program since 2000: A Retrospective Evaluation. Report Prepared by RDS Partners to the Australian Centre for International Agricultural Research, August 2016.
Jones, C.M., Long, N.V., Hoc, D.T., Priyambodo, B., 2010. Exploitation of puerulus settlement for the development of tropical spiny lobster aquaculture in the Indo-West Pacific. J. Mar. Biol. Assoc. India 52, 292–303.
Jones, C.M., 2015. Spiny Lobster Aquaculture Development in Indonesia, Vietnam and Australia. In: Proceedings of the International Lobster Aquaculture Symposium held in Lombok, Indonesia, 22–25 April 2014. ACIAR Proceedings 145. Australian Centre for International Agricultural Research, Canberra.
Komarudin, U., Rimmer, M.A., Islahuttaman, Zaifuddin, Bahrawi, S., 2010. Grouper Nursing in Aceh. Aquaculture Asia-Pacific Magazine, Indonesia, pp. 21–25.
Liao, I.C., Leaño, E.M., 2010. Milkfish Aquaculture in Asia. Asian Fisheries Society, World Aquaculture Society, the Fisheries Society of Taiwan and National Taiwan Ocean University, Quezon City, Philippines; Baton Rouge, USA; Keelung, Taiwan.
Liao, I.C., Su, H.M., Chang, E.Y., 2001. Techniques in finfish larviculture in Taiwan. Aquaculture 200, 1–31.
Marte, C.L., 2010. Chapter 4 - Milkfish aquaculture in the Philippines: an overview. In: Liao, I.C., Leaño, E.M. (Eds.), Milkfish Aquaculture in Asia. Asian Fisheries Society, World Aquaculture Society, the Fisheries Society of Taiwan and National Taiwan Ocean University, Quezon City, Philippines; Baton Rouge, USA; Keelung, Taiwan, pp. 33–46.
Mous, P.J., Sadovy, Y., Halim, A., Pet, J.S., 2006. Capture for culture: artificial shelters for grouper collection in SE Asia. Fish Fish. 7, 58–72.
Nagasawa, K., Cruz-Lacierda, E.R., 2004. Diseases of Cultured Groupers. Southeast Asian Fisheries Development Centre. Aquaculture Department, Iloilo, Philippines.
Nakai, T., Mori, K.-I., Sugaya, T., Nishioka, T., Mushiake, K., Yamashita, H., 2009. Current knowledge on viral nervous necrosis (VNN) and its causative betanodaviruses. Isr. J. Aquacult. Bamidgeh 61, 198–207.
Pomeroy, R.S., Sugama, K., Slamet, B., Tridjoko, 2006. The financial feasibility of small-scale grouper *Cromileptes altivelis* aquaculture in Indonesia. Asian Fish. Sci. 19, 27–42.
Priyambodo, B., Jones, C., Sammut, J., 2015. The effect of trap type and water depth on puerulus settlement in the spiny lobster aquaculture industry in Indonesia. Aquaculture 442, 132–137.
Rabanal, H.R., 1988. History of Aquaculture. ASEAN/SF/88/Tech.7. ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project, Manila, Philippines.
Rimmer, M., 1997. Marine finfish aquaculture in Taiwan. Austasia Aquaculture 37–41.
Rimmer, M., 1998. Grouper and snapper aquaculture in Taiwan. Austasia Aquac. 3–7.
Rimmer, M.A., Glamuzina, B., 2018. A review of grouper (Family Serranidae; Sub-family Epinephelinae) aquaculture from a sustainability science perspective. Rev. Aquac (in press).
Rodger, H.D., 2016. Fish disease causing economic impact in global aquaculture. In: Adams, A. (Ed.), Fish Vaccines. Springer, Basel, pp. 1–34.
Sadovy, Y., 2000. Regional Survey of Fry/Fingerling Supply and Current Practices for Grouper Mariculture: Evaluating Current Status and Long-Term Prospects for Grouper Mariculture in Southeast Asia. University of Hong Kong, Hong Kong SAR, China, pp. 120.
Sadovy, Y., 2013. Asian Fisheries. From Development to Protection & Management. Background Paper 3 - Grouper Mariculture for the Live Reef Food-fish Trade. ADM Capital Foundation.
Sadovy, Y.J., Donaldson, T.J., Graham, T.R., McGilvray, F., Muldoon, G.J., Phillips, M.J., Rimmer, M.A., Smith, A., Yeeting, B., 2003. While Stocks Last: The Live Reef Food Fish Trade. Asian Development Bank, Manila, Philippines.
Schuster, W.H., 1952. Fish-Culture in Brackish-Water Ponds of Java. Indo-Pacific Fisheries Council Special Publications No.1, Indonesia.
Shetty, M., Maiti, B., Shivakumar Santhosh, K., Venugopal, M., Karunasagar, I., 2012. Betanodavirus of marine and freshwater fish: distribution, genomic organization, diagnosis and control measures. Indian J. Virol. 23, 114–123.
Siar, S.V., Johnston, W.L., Sim, S.Y., 2002. Study on Economics and Socio-economics of Small-scale Marine Fish Hatcheries and Nurseries, with Special Reference to Grouper Systems in Bali, Indonesia. 36 pp. Report prepared under APEC Project FWG 01/2001 - 'Collaborative APEC Grouper Research and Development Network'. Asia-Pacific Marine Finfish Aquaculture Network Publication 2/2002. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.
Sim, S.Y., Rimmer, M.A., Toledo, J.D., Sugama, K., Rumengan, I., Williams, K., Phillips, M.J., 2005. A Guide to Small-Scale Marine Finfish Hatchery Technology. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.
Su, H.M., Tseng, K.F., Su, M.S., Liao, I.C., 2001. Effect of ozone treatment on eggs and larvae of grouper *Epinephelus coioides*, 6th Asian Fisheries Forum, Kaohsiung (Taiwan), 25-30 Nov 2001. In: Book of Abstracts, pp. 232.
Su, H.M., Su, M.S., Tseng, K.F., Liao, I.C., 2008. Chapter 2 - Development of techniques for enhancing seed production of *Epinephelus coioides* in Taiwan. In: Liao, I.C., Leaño, E.M. (Eds.), The Aquaculture of Groupers. Asian Fisheries Society, World Aquaculture Society, Fisheries Society of Taiwan, National Taiwan Ocean University, pp. 29–48.
Sudradjat, A., Sugama, K., 2010a. Chapter 1 - Overview of milkfish aquaculture in Indonesia. In: Liao, I.C., Leaño, E.M. (Eds.), Milkfish Aquaculture in Asia. Asian Fisheries Society, World Aquaculture Society, the Fisheries Society of Taiwan and National Taiwan Ocean University, Quezon City, Philippines; Baton Rouge, USA; Keelung, Taiwan, pp. 3–7.
Sudradjat, A., Sugama, K., 2010b. Chapter 2 - Aquaculture of milkfish (*bandeng*) in Indonesia: fry and fingerling production. In: Liao, I.C., Leaño, E.M. (Eds.), Milkfish Aquaculture in Asia. Asian Fisheries Society, World Aquaculture Society, the Fisheries Society of Taiwan and National Taiwan Ocean University, Quezon City, Philippines; Baton Rouge, USA; Keelung, Taiwan, pp. 9–16.
Sugama, K., Koesharyani, I., 2017. Recent advances in breeding and seed production of groupers in Indonesia. World Aquac. 48, 41–45.
Sugama, K., Rimmer, M.A., Ismi, S., Koesharyani, I., Suwirya, K., Giri, N.A., Alava, V.R., 2012. Hatchery Management of Tiger Grouper (*Epinephelus fuscoguttatus*): A Best-Practice Manual. ACIAR Monograph No.149. Australian Centre for International Agricultural Research, Canberra, Australia.
Sugama, K., Muzaki, A., Permana, I.G.N., Haryanti, 2014. Fluctuating asymmetry reflect the growth of hybrid grouper *Epinephelus fuscoguttatus* and *Epinephelus polyphekadion*. Indones. Aquac. J. 9, 97–102.