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A review and SWOT analysis of aquaculture development in Indonesia

Michael A. Rimmer[1], Ketut Sugama[2], Diana Rakhmawati[3], Rokhmad Rofiq[3] and Richard H. Habgood[4]

1 Faculty of Veterinary Science, University of Sydney, ACIAR Field Support Office, Makassar, Indonesia
2 Centre for Aquaculture Research and Development, Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia
3 Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia
4 Richard Habgood Consulting, Warragul, Vic., Australia

Correspondence
Michael Rimmer, Faculty of Veterinary Science, University of Sydney, ACIAR Field Support Office, 8th Floor, Fajar Graha Pena, Jl. Urip Sumohardjo No. 20, Makassar, South Sulawesi 90234, Indonesia.
Email: mike.rimmer@sydney.edu.au

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Abstract

Indonesia has a long history of aquaculture, dating from the 15th century. Subsequently, the country has become a significant contributor to global aquaculture production, destined for both international and domestic markets. In 2009 the Government of Indonesia announced its vision to see Indonesia become the highest (volume) producer of aquaculture products in the world by 2015, with production targets equivalent to an overall increase in production of 353% between 2009 and 2014. This paper comprises a PEEST (policy, economic, environmental, social, technical) review undertaken as a background study for a SWOT (strengths, weaknesses, opportunities, threats) analysis, the outcomes of the SWOT analysis and a discussion of possible approaches to support sustainable aquaculture development in Indonesia. To meet the vision of a dramatic expansion of aquaculture production, one or more of the following strategies is required: intensification and production segmentation, areal expansion, and/or production diversification. Most likely the continued development of aquaculture in Indonesia will be a combination of these three strategies, with the relative influence of each depending on production sector and market demands. A key issue identified in the PEEST review and SWOT analysis is the dominance (in terms of number) of Indonesian aquaculture by smallholder aquaculture farmers. We argue that a range of influences, including aquaculture production expansion and changing international market requirements, have the potential to negatively impact smallholder aquaculture farmers in Indonesia, and that further policy development should specifically address these issues.

Key words: aquaculture development, brackishwater, freshwater, Indonesia, mariculture.

Introduction

The first reports of aquaculture in Indonesia date from around 1400 when Javanese law prescribed punitive measures against those who stole from freshwater or salt-water ponds (Schuster 1952; Rabanal 1988). From Indonesia, brackishwater pond farming spread to neighbouring areas including the Philippines, Malaysia, Thailand, Taiwan and southern parts of China (Taiwan) (Rabanal 1988). Freshwater aquaculture in Indonesia started with the stocking of common carp in backyard ponds in West Java and subsequently expanded to other parts of Java, Sumatra and Sulawesi in the early twentieth century (Budhiman 2007). Indonesian aquaculture continued to expand, and land resources devoted to aquaculture (brackish and freshwater ponds) grew from 0.3 million hectares to 0.7 million hectares between 1961–1965 and 2001–2005, with the rate of expansion accelerating over time (Fuglie 2010). Among Indonesia agricultural sectors, aquaculture continues to develop rapidly; Fuglie (2010) analysed Indonesian agriculture production since the 1960s and noted that while the growth rate in food crop output slowed appreciably in the 1990s and early 2000s, growth in horticulture, animal products and aquaculture remained strong.

Today, both capture fisheries and aquaculture are important contributors to the Indonesian economy, providing food security through primary production, income generation in rural areas, and generating significant export earnings. While Indonesian capture fisheries are regarded as being fully or almost fully exploited, aquaculture is growing rapidly and is viewed as having considerable potential for expansion. From 2007 to 2011, capture fisheries production grew at only 2% per annum on average, while aquaculture production grew at 30% per annum (Table 1). Consequently, the general objectives of the Indonesian Ministry of Marine Affairs and Fisheries (*Kementerian Kelautan dan Perikanan* – KKP) are: control of capture fisheries, development of aquaculture and increasing the value of fisheries products through value-addition.

In 2009 the Government of Indonesia announced that its vision is to see Indonesia become the highest (volume) producer of aquaculture products in the world by 2015, with production targets equivalent to an overall increase in production of 353% between 2009 and 2014 (KKP 2010). The extent of this vision is illustrated in Figure 1. While these production targets are optimistic, they are not out of line with recent rates of expansion of aquaculture production in Indonesia. It is this overall strategy of drastically increasing production that is currently driving Indonesia's research and development (R&D) activities in fisheries and aquaculture.

One of the key principles of the Paris Declaration on Aid Effectiveness (OECD 2008) is donor alignment with partner-country development strategies. To better understand the impacts of the current Indonesian strategy on the aquaculture R&D environment in Indonesia, the Australian Centre for International Agricultural Research (ACIAR) commissioned an analysis of aquaculture development in Indonesia, including an assessment of the strengths, weaknesses, opportunities and threats (SWOT) of aquaculture development in Indonesia. To provide a background for the SWOT analysis, we undertook a PEEST (policy, economic, environmental, social, technical) review of Indonesian aquaculture, which forms the first part of this paper. A PEEST analysis describes a framework of macro factors used in environmental scanning for strategic planning (Bryson 1988; Jeffs 2008). It is prepared in the context of the business or sector under study and used as input to a detailed SWOT analysis. The SWOT analysis is conducted for the specific business or sector under study (Bryson 1988). The second part of this paper is a summary of the output of the SWOT analysis workshop held in Jakarta on 1 December 2010, with input from government, academic and industry representatives. The PEEST and SWOT analyses form the basis of identifying critical strategic issues for the specific business or sector under study – in this case Indonesian aquaculture – and these issues are identified and briefly discussed in the final part of this paper.

Part 1: PEEST review

As far as practicable we have relied on primary (published and peer-reviewed) literature for this review of the policy, economic, environmental, social and technical aspects of aquaculture development in Indonesia. However, because many industry development issues are not recorded in the primary literature, where necessary we have used secondary publications as information sources. In addition, this review primarily relies on English language publications and makes limited use of Indonesian language publications because of their limited availability. For the Technical section of the review we have largely avoided detailed descriptions of production techniques used to produce the various species discussed (in most cases these are available from the references cited in the review), but instead have attempted to focus on the development aspects of the various sub-sectors of the industry.

Policy

Aquaculture development

Background information on Indonesia fisheries and aquaculture policy and legislation is summarized in FAO's National Aquaculture Legislation Overview (NALO) for Indonesia (FAO 2006). This review updates the NALO information, particularly regarding policies to support the proposed expansion of aquaculture production.

The development of aquaculture and marine fisheries in Indonesia makes an important contribution to the four national pillars of development: economic growth (pro-growth), the creation of job opportunities (pro-job), reduction of poverty (pro-poor), and environmental recovery and mitigation (pro-sustainability) (KKP 2010). Recognizing the importance of aquaculture as a contributor to national economic growth and food security and income generation in rural areas as noted above, the Government of Indonesia in 2009 announced its policy for increasing the country's fisheries production by 353% by 2015.

Table 1 Indonesian fisheries (capture fisheries and aquaculture) production from 2007 to 2011 (KKP 2011a), and average annual increase. Note 2011 data are provisional.

Production (tonnes)	2007	2008	2009	2010	2011	Increase (% p.a.)
Capture fisheries	5 044 737	5 003 115	5 107 971	5 384 418	5 409 100	2
Aquaculture	3 193 565	3 855 200	4 708 565	6 277 924	6 976 750	30
Combined	8 238 302	9 051 528	9 816 536	11 662 341	12 385 850	13

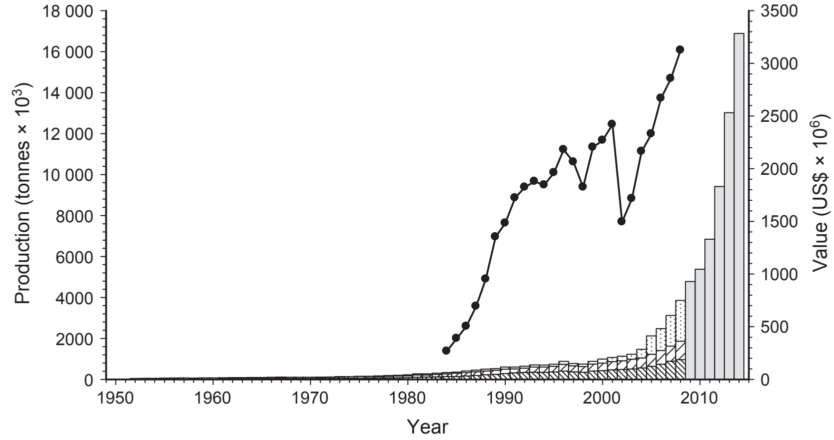

Figure 1 Annual production for brackishwater, freshwater and marine aquaculture for Indonesia from 1950 to 2008, total aquaculture value from 1984 to 2008, and projected total aquaculture production for 2009 to 2014. Data sources: 1950–2008: FAO (2011); 2009–2014: KKP (2010). (▧) Brackishwater; (▨) Freshwater; (▫) Marine; (□) Projected; (–●–) Value

Indonesian Ministry of Marine Affairs and Fisheries – KKP – regards aquaculture development in Indonesia as largely under-developed in terms of potential spatial utilization, based on estimation of the total area that can be used for various forms of aquaculture (Table 2). While potential areas for brackishwater and freshwater pond culture are currently about 50% utilized, the KKP estimates suggest that there is considerable scope for developing aquaculture in inland waters (lakes, reservoirs) and in the ocean (mariculture).

Overall, the programme to increase Indonesian aquaculture production will cover the development of hatchery, nursery and grow-out production systems, infrastructure, entrepreneurship and business, health and environmental issues, technology implementation assistance and management support. Government strategies to support this increased production include:

1 Development of 'minapolitan', a term used to designate an area that uses marine and fisheries-based economic management to boost economic growth to improve peoples' livelihoods and income. For example, a minapolitan may have aquaculture farms producing finfish, lobster and seaweed, and processing facilities that can be used by both aquaculture and capture fisheries. The approaches associated with the minapolitan concept apply integration, efficiency, quality and acceleration principles. Also integrated in the concept are trade and services issues within the minapolitan area, and thus minapolitan development relies on support from other ministries such as public works, energy and mineral resources, health, education, industry and trade, as well as local government, banking and private sectors.

2 Entrepreneurship. The government plans to stimulate the entrepreneurship spirit of farmers through the provision of motivational training in aquaculture production, processing and marketing. Following the training, it is expected that young farmers would have the ability to generate proposals for funding to banking institutions for aquaculture business development.

3 Networking. Improved networking amongst KKP and other stakeholders (intra- and inter-sector) will also be strengthened to provide mutual benefits.

4 Technology and innovation. Government agencies are supporting the development and adoption of new and innovative aquaculture technologies for dissemination and uptake by farmers to improve the sustainability of aquaculture production.

5 Empowerment. Government policy is to improve the empowerment of the community both at the individual and group levels to enable them to manage the resources for their own resilience, social security and welfare.

6 Strengthening and empowering community groups.

7 Providing superior broodstock and high quality seed in adequate quantity to support aquaculture production.

Table 2 Area currently used, and potential area for development, for aquaculture in Indonesia (KKP 2011a)

Culture system	Currently in use (ha)	Potential area (ha)	Utilization (%)
Brackishwater pond	682 857	2 963 717	23
Freshwater pond	146 577	541 100	27
Inland openwater	1390	158 125	1
Rice paddies	165 688	1 536 289	11
Mariculture	117 649	12 545 072	1
Total	1 114 161	17 744 303	6

Research, development and extension

Local implementation of these strategies is largely undertaken through the aquaculture research institutes and technical implementation units (TIUs) operated by KKP that are located throughout the archipelago to support the widespread adoption of aquaculture technologies (Table 3). The role of the research institutes and the TIUs is to develop and implement technologies for hatchery, nursery and grow-out production systems, environmental monitoring and management, and fish health management (Budhiman 2007). The TIUs in particular are an important source of seedstock to support aquaculture development, and this has been a key factor in the successful development of aquaculture in Indonesia (Hishamunda *et al.* 2009).

Since 2000, aquaculture extension has been primarily the responsibility of district-level (*Kabupaten*), and to a lesser extent provincial-level (*Provinsi*), governments (Herianto *et al.* 2010). This was one result of major government responsibility reforms that were intended to increase the autonomy of provincial-level and district-level governments. It was envisioned that these reforms would change the approach of extension services from the traditional 'top-down approach' with its one-way linear research–extension–client farmer relationship to a 'bottom-up', participatory approach responsive to farmers' needs (Herianto *et al.* 2010). In practice, however, current aquaculture extension systems are often poorly resourced and undervalued, leading to poor service provision and dissatisfaction amongst both extensionists and farmers (Herianto *et al.* 2010). The lack of capability amongst district-level extensionists and the large numbers of small-holder farmers involved in aquaculture makes large-scale roll-out of new aquaculture technologies problematic (Herianto *et al.* 2010). In some cases, private sector companies (mainly those involved in feed production or processing) play an important role in extension, but this is extremely limited in the case of smallholder farmers because, from a business development perspective, it is more efficient to deal with larger integrated operations or to integrate their business into the overall production chain (Muluk & Bailey 1996; Mudde 2009). Consequently, farmer-to-farmer transfer of knowledge is a common source of information about new technologies (Sambodo & Nuthall 2010).

Legal and regulatory framework

Policies dealing with environmental issues in aquaculture were established after the FAO Code of Conduct for Responsible Fisheries. This Code encourages states to establish, maintain and develop an appropriate legal and regulatory framework, which facilitates the development of responsible aquaculture (FAO 1995). An Environmental Impact Assessment (*Analisa Mengenai Dampak Lingkungan* – AMDAL) is required for any aquaculture development of

Table 3 List of research institutes and technical implementation units (TIUs) operated by the Ministry of Marine Affairs and Fisheries

Research centre	Location	Main role
Centre for Aquaculture Research and Development	Pasar Minggu (Jakarta)	Research management, fish health R&D
Research Institute for Mariculture	Gondol (Bali)	Mariculture R&D
Research Institute for Coastal Aquaculture	Maros (South Sulawesi)	Brackishwater aquaculture R&D
Research Institute for Freshwater Aquaculture	Bogor (West Java)	Freshwater aquaculture R&D
Research Institute for Fish Breeding and Aquaculture	Sukamandi (West Java)	Freshwater fish reproduction R&D
Research Institute for Ornamental Fish Aquaculture	Depok (Jakarta)	Ornamental fish aquaculture
Technical implementation unit	**Location**	**Main role**
Main Centre for Freshwater Aquaculture Development	Sukabumi (West Java)	Freshwater aquaculture development, broodstock and seed production
Freshwater Aquaculture Development Centres	Jambi (Sumatra) Mandiangan (Kalimantan) Tatelu (North Sulawesi)	
Main Centre for Brackishwater Aquaculture Development	Jepara (Central Java)	Brackishwater aquaculture development, broodstock and seed production
Brackishwater Aquaculture Development Centres	Ujung Batee (Aceh) Takalar (South Sulawesi) Situbondo (East Java)	
Main Centre for Mariculture Development	Lampung (South Sumatra)	Mariculture development, broodstock and seed production
Mariculture Development Centres	Batam (Riau Islands) Lombok (West Nusa Tenggara) Ambon (East Nusa Tenggara)	
Centre for Aquaculture Production and Business Services	Karawang (West Java)	Brackishwater aquaculture production
Shrimp and Shellfish Broodstock Centre	Karangasem (Bali)	Broodstock production

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shrimp or fish ponds with an area of 50 ha or more; floating net cages on lakes with an area of $\geq$ 2.5 ha or $\geq$ 500 cages. It also applies to floating net cages in sea water with an area of $\geq$ 5.0 ha or $\geq$ 1000 cages and for pearl culture farms with $\geq$50 000 animals.

Smaller developments may require a lower level assessment: Environmental Management Effort (*Upaya Pengelolaan Lingkungan*) and Environmental Monitoring Effort (*Upaya Pemantauan Lingkungan*) or UKL–UPL. To protect mangroves, brackishwater farms are not permitted within a 100 metre 'green belt' adjacent to coastal waterways (Hishamunda *et al.* 2009).

Good aquaculture practices

Good aquaculture practices (*Cara Budidaya Ikan yang Baik* – CBIB) have been promoted through legislation, education and certification schemes. Regulation under CBIB includes the control of feed, fertilizers and chemicals, and verifies sanitary requirements throughout the whole production process, including harvest, management and distribution. Producers can be evaluated under CBIB and provided with certificates of compliance.

Infrastructure development

Consecutive National Economic Development plans have aimed to develop and rehabilitate infrastructure facilities needed for the expansion of production and trade, and to increase people's well-being. The infrastructure for aquaculture such as zoning areas, roads, electricity supply lines and sea water irrigation are provided by the Government in some areas, while common water treatment ponds, roads and electricity on farms are provided by the private sector or farmers.

Property and water rights

Most of the freshwater and brackish water fish/shrimp farms in Indonesia are privately owned. This property right is defined and enforced. Shore areas, lakes, rivers and other bodies of water are part of the public domain and cannot be claimed or titled by anybody. The use of portions of a water body for aquaculture requires a permit from the local district government. Access to resources such as water is relatively limited for small scale fish-farmers (fresh water pond farmers). The Indonesian government has encouraged the creation of Water User Farmers Associations in some districts and provinces to allocate the limited water supply among farmers.

Market development

The Indonesian government is also looking at the expansion of markets and an improvement of trading promotion. These activities are linked to economic transformation and selling of diversified products. Special priorities are put toward promotion of international markets and strengthening human capacity for people working on trading and export of aquaculture products.

The government realises that it is necessary to stimulate marketing information activities, enable the identification of – and access to – markets for different product groups and to gather information with regard to product quality, hygiene and consumer preferences. In order to gain access to international markets, communication between producers and exporters from Indonesia will provide opportunities to participate in international exhibitions and to communicate with foreign buyers to introduce and improve the position of Indonesian aquaculture products.

Economic

Economic aspects of aquaculture production in Indonesia are important both from the perspective of income generation for rural communities, and for the production of export commodities to bring in foreign earnings. While it is difficult to disaggregate production data in terms of domestic or export markets, Table 4 lists recent production data for the major aquacultured commodities and indicates their main market (domestic/export).

Sumatra, Java and Sulawesi are the areas that contribute most to the total value of production of Indonesian aquaculture (collectively 78%) (Table 5). In Sumatra, Java and Kalimantan freshwater production makes up just over half of total aquaculture value, and brackishwater production also makes a substantial contribution (Fig. 2). Further east, in Bali – NTB and Sulawesi, mariculture plays a much greater role in aquaculture production, and production in Maluku – Papua area is dominated (89%) by mariculture (Fig. 2).

Dey *et al.* (2005a) note that freshwater fish farming in Asia, including in Indonesia, is generally profitable. Although their results suggest that returns from monoculture of carnivorous fish species appear to be higher than for polyculture of omnivorous and herbivorous fish species, they suggest that resource-poor fish farmers may be unable to adopt more profitable technologies because of the high capital costs associated with these production systems.

Domestic consumption of aquaculture products is significant, and accounts for much of the consumption of freshwater aquaculture production. For example, the majority of milkfish, tilapia, common carp, clariid catfish, pangasiid catfish and giant gourami produced by aquaculture are consumed domestically. Based on 2011 production data, domestic consumption could account for up to 1.9 million tonnes or about 28% of total aquaculture production (Table 4). However, if seaweed (which is not directly consumed) is excluded from this estimate, domestic consumption of aquaculture production accounts for about 72% of total production.

Table 4 Production of major aquaculture commodities in Indonesia from 2007 to 2011 (KKP 2011a), with an indication of their main market (D, domestic; E, export). Note 2011 data are provisional

Commodity (tonnes)	2007	2008	2009	2010	2011
Seaweed (E)	1 728 475	2 145 060	2 963 556	3 915 017	4 305 027
Shrimp (E)	358 925	409 590	338 060	380 972	414 014
Grouper (E)	8035	5005	5073	10 398	12 561
Barramundi (E)	4418	4371	6400	5738	3464
Milkfish (D)	263 139	277 471	328 288	421 757	585 242
Tilapia (D)	206 904	291 037	323 389	464 191	481 440
Common carp (D)	264 349	242 322	249 279	282 695	316 082
Clariid catfish (D)	91 735	114 371	144 755	242 811	340 674
Pangasiid catfish (D)	36 755	102 021	109 685	147 888	144 538
Giant gourami (D)	35 708	36 636	46 254	56 889	59 401
Other	195 122	227 317	193 826	349 568	314 306
Total	3 193 565	3 855 201	4 708 565	6 277 924	6 976 749

Table 5 Value of production (USD millions) for mariculture, brackishwater aquaculture and freshwater aquaculture by major production area in Indonesia, and percentage contribution to total aquaculture production value (KKP 2011b)

Production area	Production value (USD $\times$ 10^6)				
	Mariculture	Brackishwater	Freshwater	Total	Proportion (%)
Sumatra	225.1	913.8	1204.6	2343.5	33
Java	126.2	710.4	1043.8	1880.4	27
Bali – NTB	307.5	193.8	41.4	542.7	8
Kalimantan	8.7	407.2	427.7	843.6	12
Sulawesi	658.5	495.4	137.1	1291.1	18
Maluku – Papua	128.7	5.2	11.3	145.2	2
Total	1454.7	2725.8	2865.9	7046.4	

Indonesia is a net exporter of seafood products. In 2011, Indonesia exported over USD 3 billion worth, but imported only USD 0.5 billion worth, of seafood (Table 6). Consequently, fisheries and aquaculture exports are an important source of export earnings for Indonesia. Shrimp produced from aquaculture are a particularly important source of export earnings – Indonesia is the main exporter of shrimp products to Japan and one of the largest suppliers to the United States (Jha *et al.* 2008).

Environmental

Major environmental impacts from aquaculture can be categorized as (i) establishment impacts, and (ii) operational impacts (Páez-Osuna 2001). Establishment impacts arise primarily from the conversion of one type of land use to another (aquaculture). In the case of freshwater aquaculture this is usually the conversion of agricultural land to aquaculture use. Substantively more contentious is the modification of coastal habitats (particularly mangroves) for construction of aquaculture infrastructure, particularly ponds (Primavera 1997; Páez-Osuna 2001). The major operational impact from aquaculture is nutrient release to the environment associated with uneaten feed and fish wastes (from egestion and excretion) (Páez-Osuna 2001).

Throughout Asia, coastal aquaculture has contributed to losses of coastal mangrove areas by conversion to brackishwater ponds (Nurkin 1994; Primavera 1997; Valiela *et al.* 2001; Armitage 2002; FAO 2007; Ashton 2008; Spalding *et al.* 2010). However, as in other countries it is unclear to what extent conversion to ponds has contributed to mangrove loss in Indonesia (Ashton 2008). In addition to conversion to coastal aquaculture ponds, mangroves are subject to a wide range of threats, including: timber harvesting, gathering of wood for fuel or construction, clearing for human settlement, conversion to terrestrial agriculture (e.g. rice farming) and conversion to salt pans (Nurkin 1994; Valiela *et al.* 2001; FAO 2007; Ashton 2008; Spalding *et al.* 2010). Ashton (2008) notes that estimates of the global loss of mangroves that is attributed to aquaculture range from 5% to 38%, and that overestimations of mangrove loss occur when areas other than mangroves are included and underestimations occur when disused ponds are not included. Although Nurkin (1994) states that 'conversion of mangroves to tambak is by far the leading direct cause of mangrove destruction', other analyses have con-

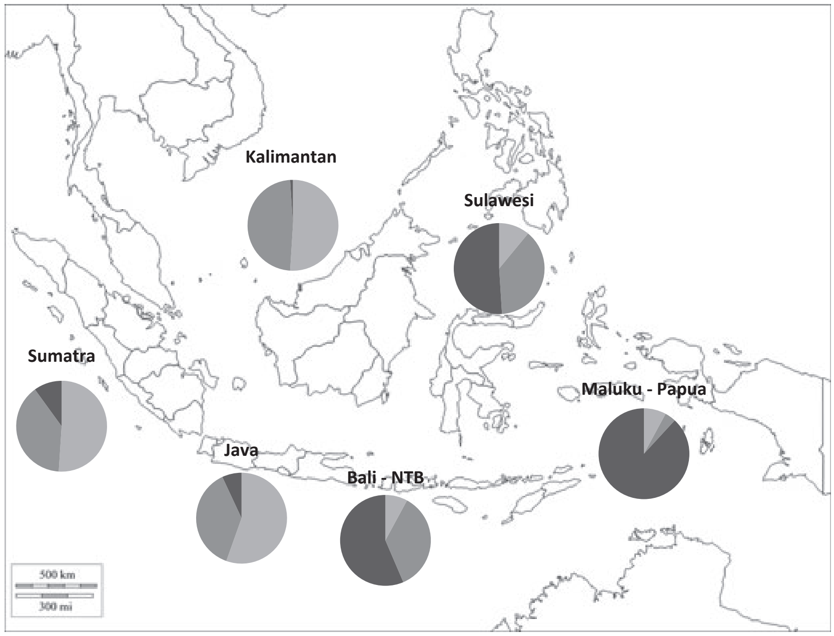

Figure 2 Map of Indonesia showing the relative proportion of value of production from freshwater aquaculture, brackishwater aquaculture and mariculture for the major production areas (2010 data). Map downloaded from d-maps.com; aquaculture data from KKP (2011b). (■) Freshwater; (■) Brackishwater; (■) Mariculture

Table 6 Annual fisheries commodity exports and imports for Indonesia, 2007–2011, in USD millions (KKP 2011a). Note 2011 data are provisional

Year	2007	2008	2009	2010	2011
Export	2259	2700	2466	2864	3205
Import	143	268	300	392	498

tradicted this assertion. In particular, a global assessment of mangrove loss by the World Resources Institute (WRI) concluded that Indonesia is estimated to have lost around 45% of its total original area of mangroves, but only about 5% of total Indonesian mangrove loss is attributable to conversion to coastal aquaculture ponds (Lewis *et al.* 2003). More recent assessments have concluded that Indonesia lost around 31% of its mangroves between 1980 and 2005 (FAO 2007; Spalding *et al.* 2010) but do not ascribe specific causes to this loss.

Aside from coastal habitat impacts associated with establishment of ponds, the operational impacts of traditional shrimp farming may be relatively minor. The majority of coastal aquaculture farms constructed on ex-mangrove land in Indonesia are extensive or 'traditional' *tambak* (Lewis *et al.* 2003), and there is little water exchange and relatively little input of nutrients in the form of fertilizer and feed in this style of farming. Indeed, Primavera (1997) regards these traditional, extensive polyculture ponds of Indonesia as an example of 'environment-friendly aquaculture within the broader framework of community-based, integrated coastal area management'. In contrast, the operational impacts of semi-intensive and intensive shrimp farming on the environment may be substantial, particularly in terms of nutrient releases to adjacent waters (Wolanski *et al.* 2000; Lewis *et al.* 2003).

A significant factor affecting ponds built in coastal low-lying areas in Indonesia is the impact of acid-sulphate soils (ASS). It is estimated that there are around 6.7 million ha of ASS in Indonesia, mainly in Sumatra, Kalimantan, Sulawesi and Papua, and that over 35% of the affected area has been developed for brackishwater aquaculture (Mustafa & Sammut 2007; Kondo *et al.* 2011). The oxidation of iron pyrite in ASS can lead to severe soil acidification (pH < 4) and elevate levels of dissolved aluminium, iron and manganese (Mustafa & Sammut 2010b). These oxidation products can cause gill damage in fish and shrimp and may result in mass mortalities in affected ponds (Mustafa & Sammut 2010b). Acidification can also lead to low phosphorus availability in ponds affected by ASS, reducing pond productivity and increasing production costs through the need for additional fertilizer (Mustafa & Sammut 2007). Although ASS can be remediated through pond substrate drying and liming, most smallholder farmers do not have access to technical support services to advise on remediation techniques, and many are unable to support the additional costs associated with soil remediation (Mustafa & Sammut 2007, 2010b). However, with proper soil remediation and pond management, shrimp ponds constructed in ASS areas can be reliably productive (Kondo *et al.* 2011).

Freshwater aquaculture in Indonesian impoundments contributes to eutrophication through the input of fish feed (De Silva & Phillips 2007; Hayami *et al.* 2008; Edwards 2010). Several freshwater reservoirs in Java where freshwater cage farming has proliferated suffer from periodic seasonal water quality degradation, leading to fish kills, particularly in the drier months (Abery *et al.* 2005). Because cage farming in reservoirs is often concentrated in sheltered bays that have relatively easy access to supporting land facilities, environmental impacts are exacerbated by the shallow water and limited water circulation in these areas, leading to accumulation of organic wastes from the cages (De Silva & Phillips 2007). Edwards (2010) reports that common carp can no longer be grown in Saguling reservoir due to water quality degradation, and that only more tolerant species such as tilapia and pangasiid catfish can be cultured there. This may be due to poor water quality leading to more frequent or severe outbreaks of koi herpes virus disease (KHVD) (Abery *et al.* 2005), as well as water quality parameters exceeding the physiological tolerances of the carp.

In Cirata reservoir, West Java, there have been several reported mass fish kills due to degraded water quality (Effendie *et al.* 2005; Phillips & De Silva 2006; Hayami *et al.* 2008; Edwards 2010). During the last turnover of the reservoir's water in 2007, there was an 80% mortality of all species (Edwards 2010). The Cirata fish kills appear to be caused by mixing of the lower anoxic layer waters, which begin at only 7–8 m depth (Effendie *et al.* 2005; Phillips & De Silva 2006; Hayami *et al.* 2008). Because of the shallow oxycline in Cirata reservoir (7–8 m depth), even moderate mixing due to wind-induced upwelling or vertical mixing can result in massive fish kills (Hayami *et al.* 2008).

However, nutrient inputs to these freshwater reservoirs are not confined to aquaculture, and it is difficult to isolate aquaculture inputs from other sources of eutrophication in these reservoirs. Saguling reservoir in West Java, in addition to supporting a substantial number of fish cages, receives a considerable quantity of domestic and industrial effluent from the city of Bandung, with an estimated population of two million (Gunawan *et al.* 2004; Abery *et al.* 2005). Saguling reservoir discharges into the Ciratum River, which in turn empties into Cirata reservoir, and hypolimnetic discharges from Saguling reservoir are likely to be major contributors to the eutrophication of Cirata reservoir (Hayami *et al.* 2008).

As noted later in this review, mariculture is a rapidly developing sub-sector of aquaculture in Indonesia. At the present time, sea cage production systems in Indonesia are relatively low intensity and hence environmental impacts from uneaten feed and fish wastes tend to be minor. Most of the wastes from sea cages are likely to be fish wastes rather than uneaten feed, most of which is consumed by wild fish living around the cages. Sudirman *et al.* (2009) found that the biomass of fish associated with, but outside, sea cages in South Sulawesi exceeded the biomass of the captive fish, and that the amount of food consumed by associated fish was likely to be equivalent to the excess feed lost from the cages.

Studies of sea cage nutrient impacts have shown that other nutrient sources (such as terrestrial run-off into near shore environments) are important contributors to coastal environments and that the relative importance of fish cage wastes must be assessed against other inputs of organic matter (Alongi *et al.* 2009). For example, studies of a sea cage farm at Ayong Bay (Sumatra) found that feeding 'trash' fish contributed 195 Kmol year^{-1} of nitrogen to the environment, but gross primary production by phytoplankton contributed 285 Kmol year^{-1} (Alongi *et al.* 2009). Another cage farm at Awerange Bay (South Sulawesi) contributed 19.3 Kmol year^{-1} of nitrogen through feeding pellets, but phytoplankton gross primary production contributed 8.3 Kmol year^{-1} (Alongi *et al.* 2009). Overall, this study showed that phytoplankton gross primary production accounted for 60–77% of the total organic input to the receiving environment, leaving fish cage wastes as a relatively minor contributor (Alongi *et al.* 2009).

Despite the relatively slight impacts of sea cage culture on local environments, it is clearly necessary to have assessment and planning systems in place to limit sea cage aquaculture to the carrying capacity of the local environment. A joint Indonesian–Australian collaboration developed one such planning tool that provides information on (i) site classification, (ii) site selection, (iii) holding capacity determination and (iv) economic appraisal of an aquaculture farm at a given site (Halide *et al.* 2009).

Capture-based aquaculture, i.e. the capture of larval, juvenile or sub-adult fish for 'fattening', short-term holding, or for grow-out (Ottolenghi *et al.* 2004), can also have negative environmental impacts. While the capture of newly settled marine species is regarded (arguably) as a relatively sustainable practice (Hair *et al.* 2002), capture of juvenile groupers (Family Serranidae, Sub-family Epinephelinae) for grow-out may involve relatively large fish (Sadovy 2000; Mous *et al.* 2006). For example, juvenile groupers captured in Sumatra typically ranged from 2.5 cm to 20 cm in length (Sadovy 2000), while green grouper (*E. coioides*) captured in western Flores averaged 13.5 cm in length (Mous *et al.* 2006). At these sizes, the fish have passed the early stages of high mortality that justify the collection of newly settled animals and their collection likely contributes to already fully exploited, or over-exploited, fisheries (Sadovy 2000; Mous *et al.* 2006). In addition, collection fisheries for groupers may have very high levels of bycatch: Mous *et al.* (2006) found that only 1.4% of fish captured in juvenile fish traps were groupers, and that the remainder included many food fish species that were too small to be utilized. Locally, the impact of collection fisheries can be substantial. In Banten Bay, 'push fishing' for juvenile groupers removed an estimated 80% of newly settled juveniles in a few weeks (Nuraini *et al.* 2007).

Several studies have noted that aquaculture development can have positive environmental impacts by providing fishers using illegal or unsustainable practices with an alternative means of income. Siar *et al.* (2002) noted that fishermen previously involved in ornamental fish capture using destructive practices in northern Bali had found employment in 'backyard' or small-scale hatcheries. Aquaculture of marine finfish species has been proposed as an alternative to the widespread use of destructive fishing practices such as explosive fishing and cyanide fishing (Halim 2001, 2003; Pomeroy *et al.* 2006a). A study by Halim (2003) found that 74% of interviewed fishermen were willing to adopt mariculture as an alternative to fishing. However, these potential benefits may be complicated by fishermen moving between fishing and aquaculture as alternative livelihoods primarily in response to the income potential of the various options; Sievanen *et al.* (2005) give examples of rural villages where fishermen shifted into and out of seaweed farming in response to the 'boom and bust' cycles in local prices for seaweed.

Social

Aquaculture is an important livelihood in rural communities in Indonesia. The KKP data indicate that there are about 3.4 million farmers, and 1.7 million households, directly involved in aquaculture (Table 7). In addition, there are an estimated 6.2 million persons involved in processing (1.3 million) and marketing (4.9 million) of seafood (from both capture fisheries and aquaculture) products (KKP 2011a).

Although freshwater products generally have lower value in international markets than those from coastal waters, freshwater aquaculture in Indonesia has contributed to improved food security and livelihoods (income generation) in rural communities (Dey *et al.* 2005a; Phillips & De Silva 2006; De Silva & Phillips 2007; Edwards 2009, 2010). This is because much freshwater aquaculture requires less space and capital to run, and is thus readily accessible to small-scale farmers (Phillips & De Silva 2006). Miyata and Manatunge (2004) evaluated the adoption of freshwater cage aquaculture amongst Indonesian farmers and found that the main reason for adopting cage aquaculture was seeing the success of friends, family or neighbours. Despite this, several authors have noted that it is difficult for resource-poor farmers to finance the initial capital cost of cages, fry, etc. (Miyata & Manatunge 2004) or to engage in the more profitable monoculture of carnivorous species (Dey *et al.* 2005a).

In the case of many smallholder farmers, aquaculture forms part of a diversified set of household livelihood options, which often include land-based agriculture. Fuglie (2010) argues that much of the growth in more intensive agricultural production systems in Indonesia, including aquaculture, has been due to farmers, having secured food security, diversifying to increase household income. However, the corollary of this is that much of Indonesia's aquaculture industry comprises smallholder farms, where landholders (owners, renters) have diversified their livelihood options. This high proportion of smallholders is an important feature of Indonesian aquaculture.

One example of the positive social and economic impacts of aquaculture on rural communities in Indonesia is the development of 'backyard' or small-scale fish hatcheries in the Gondol area of northern Bali. These were originally developed to culture milkfish (*Chanos chanos*) but subsequently have diversified into production of shrimp post-larvae and finfish fingerlings, including barramundi/Asian seabass (*Lates calcarifer*) and groupers (Ikenou & Ono 1999; Heerin 2002; Siar *et al.* 2002). Capital costs for these small-scale hatcheries are low and capital payback periods are generally less than 1 year (Siar *et al.* 2002; Pomeroy *et al.* 2006b). The small-scale hatcheries not only employ local people directly, but also provide opportunities for involvement in the market chain on the input supply side (feeds, rotifers, etc.) as well as on the market side (packaging materials, fingerling brokerage, etc.). Women are employed to grade and count fingerlings, and are often involved as brokers for fingerling sales (Heerin 2002; Siar *et al.* 2002).

Despite the strong contribution by aquaculture to rural livelihoods in Indonesia, in some areas aquaculture development has also led to social conflicts. In Java, freshwater fish culture in cages in impoundments has been promoted as a livelihood option for local people displaced by the construction of the impoundments (Miyata & Manatunge 2004;

Table 7 Number of Indonesian fish farmers by type of culture (KKP 2011a)

Number of farmers	2006	2007	2008	2009	2010
Mariculture	134 419	232 274	282 607	278 613	498 001
Brackishwater pond	482 161	469 100	642 210	470 828	553 325
Freshwater pond	1 144 557	1 166 138	1 362 649	1 332 782	1 725 283
Cage culture	53 491	72 113	79 325	87 766	104 917
Floating net cage	38 907	41 335	43 204	39 958	62 692
Paddy field	421 772	363 223	349 476	283 246	407 230
Total	2 275 307	2 344 183	2 759 471	2 493 193	3 351 448

Abery *et al.* 2005). Subsequently, however, there has been substantial expansion of cage culture by entrepreneurs from outside the area, leading to social conflict between small-scale local producers and larger 'industrialized' aquaculture operations (Abery *et al.* 2005). Furthermore, over-production of fish beyond the carrying capacity of these reservoirs has led to fish kills from eutrophication (Abery *et al.* 2005).

In East Kalimantan, new (i.e. post-1980s) migrants from South Sulawesi have developed shrimp ponds on land unused by the local people. The Buginese migrants developed 'patron-client' (*punggawa-sawi*) relationships with local people who are employed to guard and manage the ponds (Timmer 2010). Such systems have been criticized for trapping local people in arrangements of ongoing financial dependency on the patron, and the resultant economic inequity contributes to local tension and conflict (Timmer 2010). Another approach involving small-scale shrimp farmers that has attracted criticism is the plasma-nucleus or nucleus-estate (NESS) shrimp farming schemes. These schemes have been criticized for locking participating farmers into a system of credit extension that makes them wholly dependent on their credit wholesalers or providers, and in many cases farmers make no income at all (Mudde 2009). In the worst cases, when a shrimp harvest fails, the entire burden falls on the smallholders, who fall deeper into debt, leading to the farming households becoming 'trapped into a vicious cycle of poverty and debt' (Oktaviani *et al.* 2009, p.13).

Technical

Freshwater aquaculture

Aquaculture production of freshwater species has increased steadily over the period 2007–2011 (Table 4). Edwards (2010) ascribes this increase in freshwater fish production to two main factors: (i) a shift from low-intensity 'traditional' culture methods towards monoculture production systems and increasing intensification through the use of pelleted feeds, and (ii) the introduction of new species, such as tilapia (*Oreochromis* spp.). Although carp (*Cyprinus carpio*) culture has long dominated inland aquaculture production in Indonesia, more recently tilapia has overtaken carp as the dominant freshwater cultured species (Table 4). This is partly due to consumer demand – tilapia have fewer bones in the muscle than carp – and partly due to the negative impacts of koi herpes virus disease (KHVD) on carp production in Indonesia (Sunarto & Cameron 2005; Edwards 2009; Walker & Winton 2010; Sunarto *et al.* 2011). In addition, the introduced African catfish *Clarias gariepinus* and striped catfish *Pangasianodon hypophthalmus* have largely displaced the local *lele* catfish *C. batrachus* and the native *patin* catfish *Pangasius djambal*, respectively, as the dominant species for aquaculture in Indonesia (Lazard *et al.* 2009; Edwards 2010). Overall, introduced species (tilapia, clariid catfish and pangasiid catfish) now make up about 70% of freshwater fish production (Table 4).

Seed supply is largely from hatcheries, with developed hatchery technologies for about 20 species (Budhiman 2007). In addition to the four TIUs that specialize in freshwater aquaculture (Table 3), there are around 400 other provincial and district-level government hatcheries in Indonesia (Budhiman 2007), including the Fish Seed Centres (Balai Benih Ikan – BBI) that are operated by Provincial or District level government. Government agencies, universities and the private sector have all implemented selective breeding programmes with freshwater fish species. There are at least two selected strains of *C. gariepinus* and at least four selected strains of *O. niloticus* available in Indonesia.

Various farming methods are used by Indonesian farmers, including static water ponds, running water ponds, cages in reservoirs and rice-fish culture ponds (Edwards 2010), depending on space and capital available to the farmers. Cage culture in reservoirs in Indonesia is described in detail by Phillips and De Silva (2006), while other freshwater culture systems are described by Edwards (2009, 2010). While the bulk of freshwater aquaculture production in Indonesia is still from small-scale farms, there is a trend to increasing 'modernization', at least in Java (Edwards 2009, 2010). Many traditional integrated practices, such as some forms of rice-fish culture (Sambodo & Nuthall 2010), have declined considerably, while others, such as the use of terrestrial animal manure as a fish pond fertilizer to produce natural food, have been discouraged by the government on food safety grounds (Edwards 2009). Freshwater aquaculture in Indonesia may be highly segmented. Edwards (2009) describes four stages of tilapia nursing in the Cianjur area of West Java, each undertaken by different groups of farmers: (i) spawning and fry harvest, (ii) first-stage nursing to 2–3 cm TL, (iii) second-stage nursing to 3–5 cm TL, and (iv) third-stage nursing to 5–8 cm TL. After this stage, the fingerlings are transported mainly for grow-out in cages in reservoirs (Edwards 2009).

Compared with brackishwater or marine aquaculture, freshwater aquaculture is practised intensively in relatively small areas. For example, clariid catfish are produced at the equivalent of 160–300 tonnes per hectare over a relatively short grow-out period of 3–3.5 months (Edwards 2010). However, the limited profitability of traditional 'low value' freshwater fish species is forcing farmers to specialize in specific parts of the production cycle, such as nursing (Edwards 2010). Grow-out to market size requires more areal resources, more water and a longer period of time, and thus higher levels of investment, than nursing. In addition, nursing cycles are relatively short (typically around 21 days in segmented carp nursing), reducing the risk of crop losses and providing a regular income to farmers through faster cash-flow (Edwards 2010). Consequently, in Java there has been a major shift by small-scale farmers from grow-out to nursing (Edwards 2010).

The outbreak of KHVD in Indonesia in 2002 had a major impact on carp production. Although the Indonesian government attempted to confine the outbreak to the islands of Java and Bali by allowing only quarantined fish to be moved (Sunarto & Cameron 2005), within 4 years KHVD had spread throughout the archipelago from Lake Toba in North Sumatra in the west to Sentani Lake in West Papua in the east (Sunarto *et al.* 2011). Koi herpes virus disease is associated with mortality rates up to 95%, resulting in significant economic losses – estimated at US$25 million in the first 3 years of the Indonesian outbreak – and negative social impacts from production disruption and loss of income (Sunarto & Cameron 2005; Sunarto *et al.* 2011).

Sumatra and Java are the major production areas for freshwater aquaculture production with a 67% and 23% share of production, respectively (Budhiman 2007). Freshwater aquaculture in some areas of Java, particularly West Java, is being impacted by the increasing demand for freshwater for human use, associated with expansion of urban areas (Edwards 2010). As competition for land and water in Java increases, more freshwater aquaculture production is likely to move to Sumatra or to other islands with adequate freshwater resources and lower population pressures (Edwards 2010).

Brackishwater aquaculture

As noted above, brackishwater pond aquaculture was the earliest form of aquaculture practised in Indonesia, dating from the 15th century (Schuster 1952; Rabanal 1988). By area, brackishwater aquaculture is the dominant form of aquaculture in Indonesia with an estimated 680 000 hectares of brackishwater ponds (known locally as *tambak*) throughout the country (Table 8). Of this total, Kalimantan has almost one-third, Java and Sulawesi are estimated to have about 170 000 and 150 000 ha of brackishwater ponds respectively, and Sumatra has almost 130 000 ha (Table 8).

Table 8 Estimated area of brackishwater ponds (*tambak*) in Indonesia in 2010 by island/region (KKP 2011b)

Island	Area (ha)
Sumatra	128 044
Java	173 216
Bali – Nusa Tenggara	8515
Kalimantan	211 323
Sulawesi	152 843
Maluku – Papua	8916
Total	682 857

Brackishwater aquaculture development in Indonesia has been described as having a pattern of 'dualistic development' (Muluk & Bailey 1996; Hall 2004). Brackishwater farming initially developed to culture milkfish in coastal ponds, and shrimp were only incidentally produced in these ponds (Schuster 1952). However, the shrimp farming 'boom' of the 1980s, led by strong demand from a strengthening Japanese economy, saw shrimp become the target species for *tambak* production (Muluk & Bailey 1996; Armitage 2002; Hall 2004; Hatanaka 2010a). At this time, Indonesia also began adopting new shrimp farming technologies, originally developed in Taiwan, using more intensive production approaches (Chamberlain 1991; Muluk & Bailey 1996; Hall 2004). Today there are effectively two separate production systems for brackishwater aquaculture in Indonesia: 'traditional' shrimp farms based on the historical *tambak* model which originally focused primarily on milkfish culture, with shrimp only cultured incidentally; and 'modern' larger-scale farms, usually corporate, using semi-intensive or intensive production systems (Davies & Afshar 1993; Muluk & Bailey 1996; Mudde 2009).

Shrimp

From the early 1980s, shrimp farming development has been supported strongly by the Indonesian government as a way to halt the slide in export earnings resulting from a ban on shrimp trawling, and a means of diversifying the national economy away from the oil sector (Davies & Afshar 1993; Muluk & Bailey 1996; Hall 2004). During the 1980s shrimp farming expansion was assisted by various Indonesian government and donor-funded schemes to increase shrimp production (Muluk & Bailey 1996; Hall 2004). Muluk and Bailey (1996) estimate that in excess of US$ 50 million in official development assistance was provided during the 1980s to support the development of shrimp farming in Indonesia. Although much of the rapid expansion of shrimp farming in the 1980s was due to private sector investment, the development of Indonesian government policies and infrastructure were key preconditions to this expansion (Muluk & Bailey 1996; Hall 2004).

A second 'boom' in shrimp farming occurred in the period 1997–2002, when the Asian economic crisis of this period caused a drop in exchange rates, resulting in increased profitability of shrimp farming (Dale Yi *et al.*, unpubl. data, 2010). The consequence was increased expansion and intensification of production to take advantage of these strong export prices (Hatanaka 2010a; Dale Yi *et al.*, unpubl. data, 2010). However, increasing production losses due to outbreaks of white spot disease (WSD) during this period saw a shift from the traditionally farmed black tiger shrimp (*Penaeus monodon*) to the introduced Pacific white-leg shrimp (*Litopenaeus vannamei*)

(Hall 2004; Jha *et al.* 2008; Flegel 2009). Dale Yi *et al.* (unpubl. data, 2010) note that from 2004 to 2007, increased shrimp production in Indonesia was almost entirely due to increasing production of *L. vannamei*, and that over the same period the production of *P. monodon* remained static. More recently, *L. vannamei* production has been adversely impacted by outbreaks of infectious myonecrosis virus (IMNV) (Jha *et al.* 2008; Flegel 2009; Walker & Mohan 2009; Walker & Winton 2010).

Muluk and Bailey (1996) categorize Indonesian shrimp farms into two groups: 'traditional' and 'modern', which corresponds to Dale Yi *et al.*'s (unpubl. data, 2010) similar scheme of 'traditional' and 'modernizing', although most of the 'modern' farms have switched from *P. monodon* to *L. vannamei*. 'Traditional' farmers generally stock *P. monodon* at low densities (1–3 shrimp m^{-2}), do not use aeration, may use small amounts of pelleted feed (usually towards the end of the production cycle when pond biomass is relatively high), and have low labour requirements. Often, shrimp are polycultured with milkfish (Sudradjat & Sugama 2010c; Padiyar *et al.* 2012). From a production perspective, these farms can be categorized as 'extensive' (Chamberlain 1991; Davies & Afshar 1993). In contrast, 'modern' or 'modernizing' farms generally stock *L. vannamei* at high densities (in excess of 100 shrimp m^{-2}), use aeration and pelleted feeds to support high biomass in the ponds, and have a much higher labour requirement due to the technical interventions needed to farm at higher densities (Chamberlain 1991; Davies & Afshar 1993). While the bulk of Indonesian shrimp farms are 'traditional' their productivity is relatively low, and most of Indonesia's shrimp production in fact comes from the 'modernizing' farms (Dale Yi *et al.*, unpubl. data, 2010). Mudde (2009) estimates that 70–80% of Indonesian shrimp production is in the hands of three companies, around 5% of production comes from small-scale traditional farms, and about 15% of production is from medium-scale semi-intensive or intensive farms.

While 'upgrading' extensive shrimp farms to more intensive production has been a goal of Indonesian policy (Muluk & Bailey 1996; Kusumastanto *et al.* 1998; Hall 2004), success has generally been limited. For farmers to move from 'traditional' to 'modernizing' production systems requires not only infrastructure investment (deepening ponds, installing aerators, etc.) but also requires that the farmers acquire specific knowledge and skills in regard to monitoring water quality, feeding practices and other technical aspects of farming (Davies & Afshar 1993; Dale Yi *et al.*, unpubl. data, 2010). Muluk and Bailey (1996) note that some 'rural elite' investors in shrimp farming expanded their ownership of *tambak* area rather than intensifying production. This category of landowners usually undertake sharecropping arrangements with local residents to operate their farms (Muluk & Bailey 1996).

In response to this reluctance to increase the productivity of 'traditional' *tambak*, government policy shifted to requiring larger corporations to develop cooperative agreements with local farmers (Muluk & Bailey 1996; Hall 2004). This led to the development of the 'nucleus-estate smallholders scheme' (NESS), also known as the 'nucleus-plasma estate scheme', under which shrimp farming companies developed large areas of land into shrimp ponds, and established agreements with local smallholders to purchase inputs from, and sell back to, the parent company (Muluk & Bailey 1996; Jha *et al.* 2008; Mudde 2009; Oktaviani *et al.* 2009). Such schemes have been criticized for their control of input and output prices, whilst placing the burden of risk on the smallholder farmers themselves, leading to the farmers becoming 'trapped into a vicious cycle of poverty and debt' (Oktaviani *et al.* 2009, p;.13). In some cases, NESS schemes have been responsible for considerable social conflict arising from land acquisition issues, provision of credit to farmers, and monopolization policies, particularly regarding shrimp prices (Mudde 2009; Oktaviani *et al.* 2009). Even successful NESS schemes in Java have been described as being 'like a drop in the proverbial bucket' (Muluk & Bailey 1996, p. 205) in terms of their application more broadly in Indonesia.

While the impacts of white spot disease caused most 'modernized' farms to switch from *P. monodon* to *L. vannamei* (Hall 2004; Flegel 2009), 'traditional' farmers have generally continued to struggle with culture of *P. monodon*. Recurring crop failures ascribed to WSD outbreaks have severely limited production by *P. monodon* farmers throughout Asia (Walker *et al.* 2011), and Indonesia is no exception. One response has been to implement better management practices (BMP) to improve the overall productivity of 'traditional' shrimp farms and to reduce the risk of *P. monodon* crop failure (ADB *et al.* 2007; Herianto *et al.* 2010; Walker *et al.* 2011; Padiyar *et al.* 2012). Trials of BMP programmes in Aceh province demonstrated that BMP implementation reduced the prevalence of disease outbreaks from about 63% to 22% and reduced the production costs for participating farms (Padiyar *et al.* 2012). However, the ongoing sustainability of such donor-supported programmes remains problematic. One significant impediment to the expansion, or even long-term implementation, of such schemes is the limited capacity of government departments to provide extension and technical support services to the degree necessary to support their widespread implementation (Herianto *et al.* 2010).

Another factor impacting on Indonesian shrimp production has been the transition of international market requirements, initially demanding improved food safety systems, but which are increasingly focused on environmental sustainability issues (Lebel *et al.* 2008; Oktaviani *et al.* 2009; Tongeren *et al.* 2010). Several OECD countries have rejected shipments of farmed shrimp from Indonesia, imposed temporary import bans, and demanded stronger health and safety controls (Tongeren *et al.* 2010). Compliance with these market requirements is more difficult for smallholder farmers, and for processors accessing product from smaller farms. Furthermore, the transaction costs associated with increased regulation have reduced margins, particularly for farmers (Jha *et al.* 2008; Dale Yi *et al.*, unpubl. data, 2010). Because of these factors, and the lower production costs associated with economies of scale, the 'modernizing' farms that produce the bulk of farmed shrimp in Indonesia have better access to export markets than do the 'traditional' farms (Jha *et al.* 2008). In response, there have been various efforts to involve 'traditional' farms in the development of specialist or 'niche' markets, such as organic shrimp farming.

Hatanaka (2010a,b) described the failure of an organic shrimp production network established in Java to produce shrimp for a Swedish supermarket, and concluded that the approach failed in regard to development of organic production standards, communication of those standards to the farmers, and compliance of the standards by farmers. Some farmers involved in the production network felt disenfranchized by the standards development process in which they felt they had not been adequately represented, and consequently felt no need to abide by those standards (Hatanaka 2010a,b).

Milkfish

Milkfish culture methods range from 'traditional' extensive (no, or limited, external fertilizer and feed inputs) to semi-intensive, relying on the use of pelleted feeds as the main food source. There is some production of milkfish in sea cages, but the bulk of the almost 600 000 tonnes per annum produced in Indonesia (Table 4) is from brackishwater pond culture (Sudradjat & Sugama 2010c).

Milkfish fry (*nener*) are captured from the wild or are produced in hatcheries. Sudradjat and Sugama (2010b) estimate that less than 50% of Indonesia's milkfish fry are supplied from wild capture. Indonesia is a major producer of milkfish seed, with much of this coming from 'backyard' or small-scale hatcheries (Siar *et al.* 2002; Sudradjat & Sugama 2010b). 'Backyard' hatcheries were originally developed through an Indonesian–Japanese collaboration at the Research Institute for Mariculture, Gondol, Bali (Ikenou & Ono 1999; Heerin 2002; Siar *et al.* 2002), and have proliferated in northern Bali, and to a lesser extent in East Java. In 1994 there were about 10–20 units (1 unit = 2 larval rearing tanks) of backyard hatchery in the Gondol area (Siar *et al.* 2002); by 2008 there were about 2500 units (Suko Ismi, unpubl. data, 2009).

Most milkfish production is from extensive culture systems with low stocking densities and limited feed and fertilizer inputs; Sudradjat and Sugama (2010a) estimate that 45% of farms do not use any form of fertilization, but rely on natural pond productivity. Ponds used for milkfish culture are typically large (0.5 to several hectares) and shallow (usually less than 70 cm depth) to promote the growth of a benthic algal mat known as *klekap* in Indonesia and *lablab* in the Philippines (Sudradjat & Sugama 2010c). Recently, more intensive methods of production have been developed and extended to farmers, but uptake of these technologies by farmers has been slow (Sudradjat & Sugama 2010a). While research has demonstrated that yields of 2 tonnes per hectare per annum are achievable using 'traditional' or 'traditional plus' techniques, the average yield in Indonesia is 450 kg per hectare per year (Sudradjat & Sugama 2010c). In comparison, intensive production can yield 8–10 tonnes per hectare per annum (Sudradjat & Sugama 2010c).

Milkfish produced for food are reared to 200–500 g (Sudradjat & Sugama 2010c). In addition, there is demand for smaller (80–120 g) milkfish for bait for tuna fishing with some farms in East Java and in West Java focussing on this market (Sudradjat & Sugama 2010c). Because milkfish is primarily herbivorous, there has been considerable research on polyculturing milkfish with other species, including shrimp, tilapia, mud crabs (*Scylla* spp.), barramundi/Asian seabass and seaweed (*Gracilaria* spp.) (Sudradjat & Sugama 2010c).

Sudradjat and Sugama (2010c) note that demand for seafood products generally is increasing in Indonesia, and milkfish has considerable potential to contribute to meeting this demand. Post-harvest processing of milkfish has developed products such as boneless milkfish and *bandeng presto* (milkfish cooked under pressure to soften the bones), adding value to the raw product and allowing market access to consumers who dislike bony fish (Sudradjat & Sugama 2010c).

Seaweed

Indonesia is a significant producer of the agarophyte seaweed *Gracilaria*, which is the preferred seaweed for making food grade agar (Armisen 1995; McHugh 2003; Bixler & Porse 2010). Most *Gracilaria* culture is undertaken in brackishwater ponds, usually in polyculture with milkfish, shrimp or other species (Mustafa & Sammut 2010a). *Gracilaria* cultured in ponds produces agar of lower gel strength than wild collected seaweed and thus brings prices toward the bottom range for food agar (McHugh 2003). *Gracilaria* is also the preferred food for the culture of abalone (Fermin *et al.* 2009).

Mariculture

Mariculture (defined as the production of aquatic plants or animals in the sea) is the fastest growing type of aquaculture in the Asia-Pacific region (Hishamunda *et al.* 2009), and this trend is also apparent in Indonesia. In Indonesia, the dominant maricultured commodity group is carrageenan-producing seaweed (mostly *Kappaphycus* and *Eucheuma* species) which accounts for 98% of production and 84% of value of Indonesian mariculture production (Rimmer 2010). The other major mariculture commodity groups listed in Table 4 are groupers and barramundi/Asian seabass.

Mariculture is a relatively new sub-sector in Indonesia, in contrast to freshwater and brackishwater aquaculture, both of which have been practised for centuries. Indonesia is an archipelagic country comprising around 17 000 islands, so there are large areas that have considerable potential for mariculture development. Culture techniques for commodities such as tropical rock lobster are being pursued actively by government research and development agencies. Aside from the commodities discussed below, there has been research into aquaculture of corals (Ferse & Kunzmann 2009) and sponges (de 2007b; de Voogd 2007a) but there is currently little or no commercial production.

Seaweed

Seaweed mariculture in Indonesia is focused on producing *Kappaphycus* and *Eucheuma* species for the production of carrageenan, a family of gel-forming polysaccharides that are used widely in processed foods and cosmetics (McHugh 2003; Feng *et al.* 2004; Bixler & Porse 2010). Seaweed production in Indonesia has increased rapidly since 2000 and Indonesian production overtook that of the Philippines (the other major producer of carrageenan seaweeds) around 2005 (Neish 2008; Bixler & Porse 2010). Since then Indonesian seaweed production (both from mariculture and from brackishwater pond culture of *Gracilaria*) has continued to increase steadily to more than 4 million tonnes in 2011 (Table 4). Historically, most production has been from Bali and eastern Indonesia, with relatively little production from a few areas in Java (Kepulauan Seribu and Cilacap) and Sumatra (Pulau Banka) (Luxton 1993).

A recent review of seaweed markets concluded that while seaweed hydrocolloid markets continue to grow, instead of the 3–5% per annum growth achieved in the 1980s and 1990s, recent market growth has dropped to 1–3% per year (Bixler & Porse 2010). Despite this apparently consistent market growth, seaweed culture may undergo local 'boom and bust' cycles, typically associated with dramatic price fluctuations (Luxton 1993; Sievanen *et al.* 2005). For example, in 2008 the prices paid for 'cottoni' (*Kappaphycus alvarezii*) per tonne of dry product in Indonesia more than doubled, from USD 811 in 2007, to USD 2166; then in 2009 the price dropped to USD 1208 (Bixler & Porse 2010). In response to these cycles, seaweed farmers often move between seaweed farming and other livelihood activities, such as fishing (Sievanen *et al.* 2005).

Because cultured seaweeds reproduce vegetatively, seedstock is obtained from cuttings. Grow-out is undertaken using natural substrates, long-lines, rafts, nets, ponds or tanks (Tseng & Borowitzka 2003; Neish 2008). In Indonesia the favoured culture method is the floating line system. Because of low capital costs and the use of vegetative propagules, which can be obtained locally, as seedstock, seaweed aquaculture is well suited for small-scale, household-level business operations run by people living in rural coastal communities. Adoption of seaweed culture in Indonesia has been responsible for increased employment and increased household income in rural areas (Sievanen *et al.* 2005). Seaweed farming typically involves all members of the household (Sievanen *et al.* 2005); while the men undertake the at-sea culture duties, women and children are involved in harvesting and processing (i.e. drying), repairing ropes and tying on new propagules.

Seaweeds are subject to a range of physiological and pathological diseases, at least some of which appear to be associated with physiological stress resulting from low light levels or reduced salinity (Ask & Azanza 2002; Tseng & Borowitzka 2003; Neish 2008). In addition, cultured seaweeds are often consumed by herbivores, particularly sea urchins and herbivorous fish species such as rabbitfish (Family Siganidae) and even turtles (Ask & Azanza 2002; McHugh 2003; Neish 2008).

Neish (2008) notes that, while it is likely that there has been inadvertent selection by farmers, attempts to develop improved cultivars that exhibit superior growth, farmability or carrageenan characteristics using traditional genetic selection and hybridization techniques have not been successful. While transgenic techniques are likely to provide improvements in desirable traits (Ask & Azanza 2002), there is likely to be substantial market resistance to the use of carrageenan from genetically modified organisms (Neish 2008).

In 2009, Indonesia and the Philippines accounted for 94% of the global production of 'cottoni' (Bixler & Porse 2010). Bixler and Porse (2010) note that other countries seem unable to increase their production of carageenan seaweeds, and production in the Philippines is declining steadily. They ascribe the increasing production from Indonesia to increasing numbers of farmers opening up new areas for 'cottoni' culture. This combination of a steady increase in demand for hydrocolloids, limited capacity for production expansion by other countries, suitability of seaweed culture for smallholder farmers in remote rural areas, and the potential number of suitable culture sites in eastern Indonesia, suggests that there is considerable potential for expansion of seaweed mariculture in Indonesia.

Molluscs
Mollusc aquaculture in Indonesia is unusual in that it is focused on production of pearls rather than on edible bivalves. Pearl farming is carried out in Bali, Lampung, Lombok, Nusa Tenggara Barat, Nusa Tenggara Timur, Maluku, Papua and Halmahera. The FAO data suggest that the total value of production for Indonesia is around USD 130–200 million per annum (Rimmer 2010). Poernomo (2006) provides a brief history of pearl farming in Indonesia, including its various 'ups and downs', and notes that the challenge of the future lies in marrying stable production with developing markets and ensuring a balance between supply and demand.

Pearl culture is technically intensive, particularly the process of inserting a nucleus to promote formation of a pearl, and is thus suited to large-scale commercial ventures rather than small-holder operations. The period between nucleus insertion and harvest generally ranges between 9 months and 3 years. Pearl oysters are usually grown out using suspended culture systems, usually suspended below rafts or on long-lines. The quality of the pearl is related to the length of the culture period, but many insertions are unsuccessful, resulting in the death of the pearl oyster or ejection of the nucleus (Lucas 2003). Poernomo (2006) notes that one of the factors leading to the success of Indonesian pearl farming has been the transfer of technologies once considered secret (e.g. seeding) and only available through contracting foreign experts, to local people.

There has been substantial interest in selective breeding of pearl oysters, and a joint Indonesian–Australian research project is currently underway to develop appropriate tools and to evaluate the practicality of this approach (Evans *et al.* 2007).

Another mollusc that is currently being developed for mariculture in Indonesia is abalone, which brings prices up to US$33 kg^{-1} (Fermin *et al.* 2009). Several KKP centres have successfully produced seed of abalone *Haliotis asinina* and *H. squamata*. There is also interest in culturing the 'tokubushi' abalone *H. diversicolor diversicolor*, which is marketed as cocktail abalone in China, Hong Kong, Japan and Taiwan (Fermin *et al.* 2009). Abalone has potential for grow-out in islands throughout Indonesia, particularly eastern Indonesia (Fermin *et al.* 2009).

Tropical rock lobster
Tropical rock lobster culture is practised in Lombok, and has considerable potential for expansion to other regions of Indonesia (Jones *et al.* 2007; Pahlevi 2009; Priyambodo & Suastika Jaya 2010). In 2008 Indonesia produced 292 tonnes of lobsters from aquaculture, valued at USD 2.9 million (Rimmer 2010). However, much of this production may be of lobster held only for short periods ('fattening') either to build up farm production or between visits by collectors/middlemen.

There are several species of spiny lobsters and slipper lobsters (*kipas*) caught and/or cultured in Indonesia (Jones *et al.* 2007). The two main species of lobster farmed in Indonesia, *Panulirus ornatus* and *P. homarus*, are both highly marketable and bring farm gate prices of around USD 14–17 per kg (Jones *et al.* 2007; Hart 2009). The price paid for *P. ornatus* would be higher if the lobsters were grown out to around 1 kg, which is the preferred market size (Priyambodo & Suastika Jaya 2009). In general, the slipper lobsters (*Scyllarides*, *Parribacus* and *Thenus*) spp. bring lower prices than spiny lobsters (Hart 2009).

Tropical spiny rock lobsters are cultured in sea cages (Priyambodo & Suastika Jaya 2009). Currently, hatchery techniques for spiny rock lobster remain experimental and aquaculture is dependent on the capture of wild seedstock. Pueruli (the unpigmented settlement stage) or juvenile lobsters are captured after settling, often on fish traps (*bagan*) (Priyambodo & Sarifin 2009). Some farmers collect pueruli using shelter traps, with bundles of rice bags, canvas or netting as the settlement substrate (Priyambodo & Sarifin 2009). Catches of pueruli and juvenile lobsters are strongly seasonal, with peak catches in Lombok occurring in November and December (Priyambodo & Sarifin 2009). As the industry develops it is likely that it will segment, and that a specialized seed capture segment will develop to supply grow-out farms (Priyambodo & Sarifin 2009).

Marine finfish
Production technology for marine finfish is well established in Indonesia. While total production, by global standards, is relatively low, a wide variety of species is farmed, including barramundi/Asian seabass, groupers, snappers and milkfish (Kongkeo *et al.* 2010). In addition, other species, such as cobia and pompano, are beginning to emerge as options for Indonesian mariculture production (Wahjudi & Michel 2007; Juniyanto *et al.* 2008).

Groupers (Family Serranidae, Subfamily Epinephelinae) are a popular commodity for culture in Indonesia. The demand for aquacultured groupers is expanding rapidly in Asia, driven by high prices in the live fish markets of China and Hong Kong, and the decreasing availability of wild-caught product due to overfishing (Sadovy *et al.* 2003). Grouper aquaculture in Indonesia was originally reliant largely on wild-caught fingerlings or sub-adults. Sadovy (2000) notes that the major collection sites for grouper seedstock were Sumatra (particularly the northern provinces of North Sumatra and Aceh) and Java (mainly Banten Bay in West Java and Situbondo in East Java). Catches generally are dominated by *Epinephelus coioides*, with smaller numbers of *E. malabaricus* and *E. bleekeri* also caught, and occasionally small numbers of *E. fuscoguttatus* and *Plectropomus* spp. (Sadovy 2000; Mous *et al.* 2006).

The development of hatchery technology for a range of grouper species allowed grouper farming in Indonesia to expand both in terms of total production as well as in the diversity of species farmed. Small-scale or 'backyard' hatcheries, originally developed to produce milkfish (Ikenou & Ono 1999), subsequently proved adaptable to the production of other species, including groupers (Siar *et al.* 2002). Many hatcheries now produce grouper fingerlings, particularly the popular tiger grouper (*E. fuscoguttatus*), as well as smaller numbers of mouse grouper (*Cromileptes altivelis*) and leopard coralgrouper (*Plectropomus leopardus*) (Suko Ismi, unpubl. data, 2009). Small-scale hatcheries (defined as hatcheries that do not have broodstock facilities) purchase grouper eggs from government research or development institutions (Table 3), or from commercial large-scale hatcheries that sell surplus eggs or larvae (Siar *et al.* 2002).

A feature of grouper aquaculture in Indonesia is its segmentation into hatchery, nursery and grow-out segments. The nursery culture segment has developed to fill a gap between the hatcheries, which prefer to turn out fingerlings of 2–3 cm total length and the grow-out farms, which prefer to stock fish 7–10 cm total length (Komarudin *et al.* 2010). Specialized grouper nursery operations have developed in disused shrimp ponds in Aceh and in East Java. In Aceh, grouper are nursed in *hapa* nets in shallow *tambak* where they are fed mysid shrimp or 'trash' fish, and are regularly graded to reduce mortalities from cannibalism (Komarudin *et al.* 2010). Nursery culture provides a steady income for small-scale farmers, since the culture cycle is short (30–45 days), and grouper nursing now employs substantial numbers of farmers in Aceh province (Komarudin *et al.* 2010).

Between 2005 and 2009, production data for grouper culture in Indonesia showed no particular trend, varying between 4000 tonnes and 8000 tonnes per annum, but since 2009 production has risen to the 2011 figure of about 12 500 tonnes (Table 4). The reasons for these earlier fluctuations, if real, are not known. Barramundi/Asian seabass production also shows substantial variation, trending upwards from 2007 to 2009, then declining in 2010 and 2011 (Table 4). In Indonesia, most barramundi/Asian seabass is produced in sea cages, whereas in other countries, most barramundi production is from brackishwater culture in cages or ponds, or, in Australia, from freshwater ponds (Rimmer 2003). Barramundi/Asian seabass culture in Indonesia provides an example of a shift from 'traditional' farming methods to new and more intensive production systems. Much of the barramundi/Asian seabass production in Indonesia now comes from large integrated sea cage farms that have incorporated technologies from Europe or Japan.

Indonesian mariculture farms also produce a range of other marine finfish species, particularly snappers (Family Lutjanidae). Two species that have been trialled recently for culture in Indonesia are pompano (*Trachinotus blochii*) and cobia (*Rachycentron canadum*). Although both these species have potential for large-scale sea cage farming, currently, Indonesia produces only small quantities of cobia and pompano, mainly from farms in Kepulauan Seribu (Wahjudi & Michel 2007) and Lampung.

Kongkeo *et al.* (2010) note that most Indonesian sea cage operations can be classified as medium-scale, i.e. 20–100 cages, rather than small-scale (<20 cages) or large-scale (>100 cages). This can be explained partly by the results of an economic evaluation of grouper aquaculture in Indonesia (Riau Islands, Lampung, East Java and Bali) which showed that, for tiger grouper, small farms (defined in this study as 7–15 cages) provided negative economic indicators, while medium farms (20–28 cages) provided only marginal positive indicators, and only large (48 cages) farms culturing tiger grouper provided strongly positive economic indicators (Afero *et al.* 2010). All farm sizes culturing mouse grouper provided positive economic indicators, but these improved as farm size increased (Afero *et al.* 2010). The relative paucity of small-scale marine finfish farms in Indonesia may be due to the poor profitability of such operations, even when culturing medium-value species such as tiger grouper. In addition, in the likely scenario that margins for marine finfish farming are reduced by higher input costs and lower output prices, farms will need to maintain profitability by expanding to better adopt efficiencies of scale.

Although pelleted feeds have been trialled by a number of farmers, there is still strong reliance on the use of 'trash' fish for feeding marine finfish in Indonesia (Sim *et al.* 2005; Kongkeo *et al.* 2010). Kongkeo *et al.* (2010) note that sourcing of 'trash' fish for feed is an important livelihood, providing thousands of jobs. Constraints faced by Indonesian marine finfish farmers include: access to markets, price fluctuations, irregular fingerling supply by hatcheries, lack of cost-effective grow-out feeds and production losses caused by diseases (Kongkeo *et al.* 2010).

Part 2: SWOT analysis

A facilitated workshop was held in Jakarta in December 2010 to conduct a SWOT analysis for the Indonesian aquaculture industry. A SWOT analysis considers the strengths and weaknesses of the internal operating environment (in this case, defined as the production and processing activities of the aquaculture sector) and the potential opportunities and threats from the external operating environment that could impact on the sector (such as customers, markets, government policy, community pressures etc.). Representation included government agencies involved in

Table 9 Summary SWOT table for aquaculture development in Indonesia

Strengths	Weaknesses
Site availability	Limited farmer capability
High biodiversity	Limited enforcement of policies and regulation
Good environment and climate	Limited extension capability
Good R&D capability	High cost and variable quality of feeds
Good government support	Processing and marketing limitations
Available and cheap labour	Limited technology
High market demand	Poor transport infrastructure
Available ingredients for feeds	Restricted access to finance
High potential for seed production	Limited R&D capability
	Variable product quality
	Disease impacts on production
	Environmental degradation
	High production costs
Opportunities	**Threats**
Increasing market demand	Markets – prices and competition
Product/species opportunities	International trade issues
Farmer training and extension	Environment
Increasing employment and incomes	Increasing cost of production
Planning and siting	Land use conflicts
Improve product quality	Disease introductions
Increase the use of local ingredients in feeds	Use of new technologies by overseas competitors
Improve outcomes from R&D	
Increased support for aquaculture	
Product promotion	

research, development and extension, and private sector representation of the finfish mariculture, seaweed aquaculture, aquafeeds and processing sub-sectors.

A summary SWOT analysis is shown in Table 9. Based on the SWOT analysis and the workshop discussions, a number of relatively consistent industry development issues were identified.

Aquaculture industry development issues

Site availability and potential for expansion

It was generally felt that Indonesia has considerable potential for aquaculture expansion. Although it was not specified in the workshop, this presumably relates primarily to the potential for mariculture expansion since brackish-water and freshwater pond areas are already considered to be well exploited (Table 2). Indonesia has around 17 000 islands and mariculture production is currently relatively limited with only around 1% of potential area currently utilized (Table 2). On the other hand, the workshop noted that much of the available area (particularly in eastern Indonesia) has limited infrastructure, including transport infrastructure. Conflicts of land use and zoning were also alluded to as potential limitations for industry expansion.

Biodiversity

The high level of biodiversity of the Indonesian fauna and flora was regarded as a particular strength, providing opportunities for diversification of production. This provides opportunities for a wide range of species to be produced in aquaculture. This diversity of production is typical of tropical aquaculture generally, particularly in Asia, and contrasts with aquaculture in, for example, Europe where a much more limited number of species is farmed. The advantage to the limited diversity of production in Europe is that the R&D effort can be focused on fewer species, leading to greater depth of knowledge on each cultured species. In contrast, the diversity of aquaculture production in Indonesia tends to dilute the R&D focus and effort; R&D resources are spread between a wide range of species. One response to this issue proposed by the workshop was to focus the R&D effort on high-value species, to provide more information about culture techniques for these targeted species.

Capacity of farmers

As noted in the PEEST review, a major feature of Indonesian aquaculture production is that all sectors tend to be dominated by smallholder farmers, at least in terms of numbers of farms, although this is unlikely to be the case in terms of production. The limited capability of farmers to adopt new technologies and approaches was consistently identified as a significant constraint to aquaculture development generally, and more specifically to the uptake of new and improved technologies. In general, small-scale farmers have a relatively limited capacity to make significant technological changes due to educational and attitudinal constraints, as well as resource constraints such as access to finance.

Technological capability

The SWOT analysis demonstrated that participants aspire to Indonesia being perceived as a technologically advanced aquaculture producer. It was felt that Indonesia was being competitively disadvantaged by other countries (perceived as competitors) that could more easily develop or adopt new technologies to reduce costs and/or improve quality. It was not clear whether this relates to specific topics (e.g. selective breeding, genetic modification) or whether it is a general perception.

The general view of R&D capability in Indonesia was unclear – Indonesian R&D capability was recognized both as a strength as well as a weakness, requiring further development.

Feed cost and quality
The high cost and variable quality of aquaculture feeds was a recurring issue raised during the workshop. A number of workshop participants saw opportunities to make greater use of local materials potentially to lower input costs for feed production.

Product quality
Issues relating to product quality were listed under various headings: variable product quality was listed as a weakness, and the need to improve product quality was listed as an opportunity. Both these points related to the variable quality of aquaculture products, including spoilage due to poor handling, as well as improving product quality and value through value-addition. Poor/inconsistent product quality was also listed as a threat in terms of limiting international market access. The key challenge is for Indonesia to produce aquaculture products that consistently meet the needs of target markets and consumers

Discussion

The PEEST review and SWOT analysis together provide insight into the aquaculture development environment in Indonesia. Furthermore, they highlight the complex nature of the potential interventions required to increase aquaculture production in line with government objectives. Interestingly, many of the industry development issues identified in this exercise have also been identified in SWOT analyses for (terrestrial) agriculture in Indonesia, particularly the large number of smallholder farmers and the resultant limitations on adoption of new, and implicitly more complex, farming technologies, the potential for expansion of production outside the more populated islands and the lack of infrastructure outside Java and the major population centres on other islands that restricts production expansion (BMI 2010). Clearly, these factors are not limited to aquaculture, but are key developmental issues across both terrestrial as well as aquatic agriculture in Indonesia.

There are effectively three strategies to achieve the scale of increase targeted for Indonesian aquaculture production within the current 5-year time frame:

1. Intensification of existing production systems and commodities;
2. Areal increase of existing production systems and commodities;
3. Increased diversity of production through adoption of new commodities.

These three strategies are not mutually exclusive. Indeed, a combination of two or more may provide an optimal aquaculture development strategy, depending on local context. However, there are significant limitations associated with each option.

As noted in the PEEST review and as recognized in the SWOT analysis, a significant feature of Indonesian aquaculture is the large number of smallholder farmers. Despite the predominance of smallholder farmers, their contribution to national aquaculture production of many commodities (notably shrimp) is low. However, the continued participation of smallholder farmers is critical from social and economic perspectives as aquaculture is an important livelihood for many parts of Indonesia.

Shrimp farming provides an example of this apparent dichotomy between maintaining the livelihoods of smallholder farmers and increasing national production. Davies and Afshar (1993) note that 'traditional' tambak farming is more accessible where farmers have limited access to funds from savings or from government or commercial loans. If farmers have access to significant amounts of credit, semi-intensive or intensive shrimp farming is more profitable per volume of production and thus is economically a better option. They also note that from the government perspective, semi-intensive and intensive culture systems are preferred because they generate higher earnings per unit of production and generate foreign exchange from earnings (Davies & Afshar 1993). While similar studies for freshwater aquaculture and mariculture are not available from the literature, it is clear that similar issues are applicable to these sub-sectors.

Although there is some potential for some increases in production from smallholder farmers, in general this is limited and will make little overall impact on production targets of the order targeted by the Indonesian government. Consequently, aquaculture development is likely to focus on expansion of existing large-scale production systems (either through increasing the intensity of production or areal expansion) and increased national production through the promotion of new large-scale farms.

Intensification

Intensification and production segmentation are options to increase production from freshwater and brackishwater aquaculture. Some Indonesian freshwater production is already very intensive: clariid catfish are produced at the equivalent of 160–300 tonnes per hectare (Edwards 2010). Dey *et al.* (2005a) note that resource-poor smallholder freshwater aquaculture farmers may not easily switch from relatively low intensity polyculture of omnivorous and herbivorous fish species to the generally more intensive culture of carnivorous fish species because this shift requires considerable capital investment, which may be beyond these smallholder farmers. However, a combination of intensification and segmentation of production may support increased production. Edwards (2009, 2010) noted that there is a general 'modernizing' trend in freshwater aquaculture production by smallholder farmers, at least in Java, with a shift away from more traditional integrated practices and a stronger focus on specific production segments, such as nursing. Under such a scenario – increasing intensity of production coupled with increasing segmentation – smallholder farmers can potentially contribute to increased national aquaculture production.

The potential for increased intensification in brackishwater aquaculture is unclear. As noted above, much of the area developed for brackishwater aquaculture in Indonesia is occupied by 'traditional' tambaks. The potential for these to intensify their production is limited by structural and environmental limitations (shallow ponds, the lack of effective inlet and outlet drainage systems), social limitations (the need for farmers to improve their skills and knowledge to cope with the technical demands associated with higher intensities of shrimp production) and economic limitations (the need for increased capital and operating funds to support more intensive production) (Chamberlain 1991; Davies & Afshar 1993; Dale Yi *et al.*, unpubl. data, 2010). The SWOT analysis also noted the limited capability of small-scale farmers to make substantial technological changes due to their educational and attitudinal constraints, as well as resource constraints.

A negative aspect of increasing intensification is the likely adverse environmental impacts associated not only with higher production densities, but from the shifting of low-impact 'traditional' aquaculture to semi-intensive or intensive aquaculture. In the case of coastal pond aquaculture, much of Indonesia's *tambak* are used for extensive production of shrimp and milkfish, with relatively little effluent from additional feed and fertilizer inputs (Primavera 1997; Lewis *et al.* 2003). In contrast, intensive shrimp farming produces significant amounts of organic waste that are usually released into coastal waters (Wolanski *et al.* 2000). While coastal pond effluents can be reduced substantially through the use of settlement ponds and water recirculation (Anonymous 2006), such systems increase both capital and operating costs and are generally only used when there are appropriate legislative requirements in place, or potential benefits (e.g. improved market access through certification schemes).

Yet another constraint to intensification is the limited capability of government agencies, particularly at province and district (Kabupaten) level, to provide training, extension and technical support to farmers wishing to intensify their production systems. Herianto *et al.* (2010) note that much district-level funding for extension is being allocated to routine programmes rather than to agricultural development and related extension activities and that extensionists are uncertain about their roles, are poorly paid and have little support for their activities. Attempts to improve aquaculture smallholders' access to training and extension information have included project-based training and support for district extension services (Millar 2009; Herianto *et al.* 2010), and establishing extension and technical support service centres based on farmer groups (Ravikumar & Yamamoto 2009). In contrast to the 'top-down' approach of government extension services (Herianto *et al.* 2010), farmer-to-farmer learning seems to be a more effective mechanism for the adoption of aquaculture technologies. Miyata and Manatunge (2004) noted that the observation of the success of other farmers was a key element in technology adoption for floating cage aquaculture, particularly amongst 'early adopters' and 'mid-adopters', but was a less critical element amongst 'late adopters'.

Areal expansion

As discussed above, the potential for areal expansion is largely limited to mariculture, since areas deemed suitable for freshwater and brackishwater aquaculture are already largely exploited. However, the SWOT analysis recognized that there are severe infrastructure limitations in many parts of Indonesia that are likely to limit aquaculture development.

One aquaculture production system that superficially appears to have potential for expansion is 'inland openwater' which is regarded as only 1% exploited (Table 2). However, the studies on Cirata and Saguling reservoirs in West Java indicate that eutrophication of reservoirs through aquaculture and urban effluent has already caused significant environmental impacts (Gunawan *et al.* 2004; Abery *et al.* 2005; Effendie *et al.* 2005; Phillips & De Silva 2006; Hayami *et al.* 2008; Edwards 2010). In such cases, the expansion of aquaculture production will be limited by the environmental carrying capacity of the reservoir, regardless of the area used for aquaculture.

Increased diversity of production

The SWOT analysis identified Indonesia's high biodiversity as a strength for aquaculture development. Indonesia already cultures a relatively diverse selection of species, including several introduced species, and this seems likely to expand in the future as new commodities (e.g. lobster) are more widely adopted. In some cases, such as the Asian live reef food fish and lobster markets, production targets relatively low-volume but high diversity markets (Johnston & Yeeting 2006; Hart 2009), and Indonesian production matches well with the market requirement for the diversity of product supply.

However, this high biodiversity also dilutes research and development efforts. The situation is exacerbated by the tendency of the industry to shift quickly between species, particularly in response to disease problems: e.g. the shift from *P. monodon* to *L. vannamei* production due to white spot disease, and the shift from common carp to other freshwater species (including several species introduced deliberately to compensate for the decline in carp farming) in response to koi herpes virus disease (Edwards 2009).

Market potential

A drastic increase in production naturally assumes that there will be existing or developing markets to accept the products. The proportion of fish in animal protein consumption in Indonesia is higher than the global average (Dey *et al.* 2008; Hishamunda *et al.* 2009), and per caput consumption of fish products in Indonesia is steadily increasing, from 26 kg per person per year in 2007 to around 32 kg per person per year in 2011 (KKP 2011a). The Indonesian consumption of freshwater fish species is slightly higher than for marine fish products (Dey *et al.* 2008). Dey *et al.* (2008) found that high-value fish species in Asia, including in Indonesia, had more elastic demand than did low-value species, suggesting that most households are generally less responsive to changes in prices for lower-value fish. This reflects the importance of fish protein in the diet of households throughout Asia (Dey *et al.* 2005b, 2008). Together, these trends suggest that the domestic demand for Indonesian aquacultured products is likely to remain strong, although much of the expected increase in demand is expected to be for lower-value species for which there is limited substitution by other protein sources (Dey *et al.* 2008).

Indonesia's aquaculture industry is ideally placed to benefit from the increasing demand for seafood in Asia. The global consumption of fish has doubled since 1973, and a recent study by the International Food Policy Research Institute (IFPRI) and the WorldFish Centre (WFC) found that 90% of this increased demand for fish as food has come from developing countries (Delgado *et al.* 2003). China has led this trend, accounting for about 36% of the global consumption in 1997, compared with only 11% in 1973. India and Southeast Asia together accounted for another 17% in 1997, and these markets are expected to continue to expand in the immediate future. In contrast, the demand in growth for fish as food in the richer countries has tapered off over the same period (Delgado *et al.* 2003). Indonesia's geographical location provides a strategic advantage to supply these expanding markets.

Much of Indonesia's export commodities are currently destined for high-value or niche markets: shrimp, grouper, barramundi/Asian seabass and lobsters (although seaweed is an important exception to this). In contrast, the production of lower-value 'whitefish' species, such as tilapia and pangasiid catfish, is mostly absorbed by the domestic market. Asche *et al.* (2009) note that the global 'whitefish' market is the largest seafood market segment – estimated at between 6 and 15 million tonnes per annum – and is increasingly being supplied by aquacultured product, particularly pangasiid catfish and tilapia. This would appear to provide opportunities for increased production of these species to target this large, and expanding, international market segment.

However, the dominance (in terms of numbers) of small-scale farmers may restrict Indonesia's ability to access many of these developing international markets. High value and niche export markets typically require consistent, year round, high quality product which is often difficult to source from geographically dispersed and often low skilled small-scale farmers. Increasingly, the seafood trade in developed countries is being influenced by the demands of environmental non-government organizations (ENGOs) for increased 'sustainability' of production, from both wild fisheries and aquaculture (Jacquet & Pauly 2007). Among the many criticisms of these schemes, it is clear that certification schemes as currently practised disadvantage smallholder farmers and benefit larger integrated operations that can absorb the establishment and operational costs associated with certification (Belton *et al.* 2009, 2010). Currently these schemes impact primarily on markets in the United States and European Union countries and it is not clear what impact they will have in the future in light of the predicted expansion of demand in Asia (Delgado *et al.* 2003).

Conclusion

A common theme raised by the groups who participated in the SWOT analysis to identify critical development issues was the need for improved coordination and linking of industry development efforts. This drew on a number of specific issues raised in the SWOT analysis. Improved coordination of aquaculture industry development is a complex issue with a number of dimensions such as coordination across levels of government, consistent implementation of regulations and the linking of research, development, extension and training activities. The 'minapolitan' concept that links fisheries and aquaculture production with infrastructure development, social development (such as farmer group formation) and improved access to credit appear to offer opportunities for improved coordination of effort in focused areas. The KKP plans to develop 'minapolitan' in 24 districts throughout Indonesia in 2011, as 'case studies' for further development of this concept.

Regardless of the outcomes of the current vision to increase aquaculture production by 353% by 2015, it is clear that Indonesia is positioned to remain a major global aquaculture producer. The need to promote large-scale aquaculture to achieve the Indonesian government's objective of increasing national aquaculture production, and the limited capacity of small-scale farmers to support this objective, leaves small-scale farmers relatively vulnerable to a stronger focus on large-scale commercial aquaculture and its associated issues. To some extent this is mitigated by the government's focus on the creation of job opportunities (pro-job) and the reduction of poverty (pro-poor), as well as economic growth and sustainability.

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