

Chapter 12. Aquaculture

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1. Scale and distribution of aquaculture

Aquaculture is providing an increasing contribution to world food security. At an average annual growth rate of 6.2 per cent between 2000 and 2012 (9.5 per cent between 1990 and 2000), aquaculture is the world's fastest growing animal food producing sector (FAO, 2012; FAO 2014). In 2012, farmed food fish contributed a record 66.6 million tons, equivalent to 42.2 per cent of the total 158 million tons of fish produced by capture fisheries and aquaculture combined (including non-food uses, see Figure 1). Just 13.4 per cent of fish production came from aquaculture in 1990 and 25.7 per cent in 2000 (FAO, 2014).

In Asia, since 2008 farmed fish production has exceeded wild catch (freshwater and marine), reaching 54 per cent of total fish production in 2012; in Europe aquaculture production is 18 per cent of the total and in other continents is less than 15 per cent. Nearly half (49 per cent) of all fish consumed globally by people in 2012 came from aquaculture (FAO, 2014).

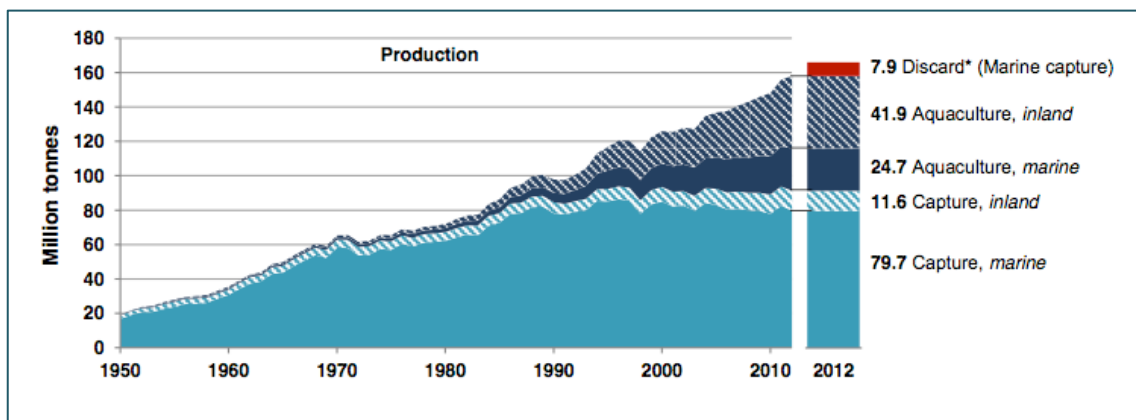


Figure 1. World capture fisheries and aquaculture production between 1950 and 2012 (HLPE, 2014).

In 2012, world aquaculture production, for all cultivated species combined, was 90.4 million tons (live weight equivalent and 144.4 billion dollars in value). This includes 44.2 million tons of finfish (87.5 billion dollars), 21.6 million tons of shellfish (crustacea and molluscs with 46.7 billion dollars in value) and 23.8 million tons of aquatic algae (mostly seaweeds, 6.4 billion dollars in value). Seaweeds and other algae are harvested for use as food, in cosmetics and fertilizers, and are processed to extract thickening agents used as additives in the food and animal feed industries. Finally 22,400 tons of non-food products are also farmed (with a value of 222.4 million dollars), such as pearls and seashells for ornamental and decorative uses (FAO, 2014).

According to the latest (but incomplete) information for 2013, FAO estimates that world food fish aquaculture production rose by 5.8 per cent to 70.5 million tons, with production of farmed aquatic plants (including mostly seaweeds) being estimated at 26.1 million tons.

2. Composition of world aquaculture production: inland aquaculture and mariculture

Although this Chapter is part of an assessment of food security and food safety from the ocean, to understand the trends in the development of world aquaculture and its impact on food security it is relevant to compare inland aquaculture, conducted in freshwater and saline estuarine waters in inland areas, versus true mariculture, conducted in the coastal areas of the world ocean.

Of the 66.6 million tons of farmed food fish¹ produced in 2012, two-thirds (44.2 million tons) were finfish species: 38.6 million tons grown from inland aquaculture and 5.6 million tons from mariculture. Inland aquaculture of finfish now accounts for 57.9 percent of all farmed food fish production globally.

Although finfish species grown from mariculture represent only 12.6 percent of the total farmed finfish production by volume, their value (23.5 billion United States dollars) represents 26.9 percent of the total value of all farmed finfish species. This is because mariculture includes a large proportion of carnivorous species, such as salmon, trouts and groupers, “cash-crops” higher in unit value and destined to more affluent markets.

FAO (2014) concludes that freshwater fish farming makes the greatest direct contribution to food security, providing affordable protein food, particularly for poor people in developing countries in Asia, Africa and Latin America. Inland aquaculture also provides an important new source of livelihoods in less developed regions and can be an important contributor to poverty alleviation.

3. Main producers of aquaculture products

In 2013, China produced 43.5 million tons of food fish and 13.5 million tons of aquatic algae (FAO, 2014, p 18), making it by far the largest producer of aquaculture products in the world. Aquaculture production is still concentrated in few countries of the world. Considering national total production, the top five countries (all in Asia: China, India, Viet Nam, Indonesia, Bangladesh) account for 79.8 per cent of world production while the top five countries in finfish mariculture (Norway, China, Chile, Indonesia, and Philippines) account for 72.9 per cent of world production (Table 1, Figure 2).

¹ The generic term “farmed food fish” used here and by FAO, includes finfishes, crustaceans, molluscs, amphibians, freshwater turtles and other aquatic animals (such as sea cucumbers, sea urchins, sea squirts and edible jellyfish) produced for intended use as food for human consumption.

4. Species cultivated

It is estimated that more than 600 aquatic species are cultured worldwide² in a variety of farming systems and facilities of varying technological sophistication, using freshwater, brackish water and marine water (FAO, 2014). In 2006, the top 25 species being farmed accounted for over 90 percent of world production (FAO, 2006a). Of the more than 200 species of fish and crustaceans currently estimated to be cultivated and fed on externally supplied feeds, just 9 species account for 62.2 percent of total global-fed species production, including grass carp (*Ctenopharyngodon idellus*), common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*), catla (*Catla catla*), whiteleg shrimp (*Litopenaeus vannamei*), crucian carp (*Carassius carassius*), Atlantic salmon (*Salmo solar*), pangasiid catfishes (striped/tra catfish [*Pangasianodon hypophthalmus*] and basa catfish [*Pangasius bocourti*]), and rohu (*Labeo rohita*; Tacon et al., 2011). The farming of freshwater tilapias, including Nile tilapia and some other cichlid species, is the most widespread type of aquaculture in the world. FAO has recorded farmed tilapia production statistics for 135 countries and territories on all continents (FAO, 2014). In this respect, aquaculture is no different from animal husbandry, in that global livestock production is concentrated in a few species (Tacon et al. 2011).³ Among molluscs only 6 species account for the 64.5 per cent of the aquaculture production (15.5 million tons in 2013) and all of them are bivalves: the cupped oyster (*Crassostrea spp*), Japanese carpet shell (*Ruditapes philippinarum*), constricted Tagelus (*Sinnovaluca constricta*), blood cocked *Anadara granosa*, Chilean mussel (*Mytilus chilensis*) and Pacific cupped oyster (*Crassostrea gigas*).

² Up to 2012, the number of species registered in FAO statistics was 567, including finfishes (354 species, with 5 hybrids), molluscs (102), crustaceans (59), amphibians and reptiles (6), aquatic invertebrates (9), and marine and freshwater algae (37).

³ On land, the top eight livestock species are pig, chicken, cattle, sheep, turkey, goat, duck and buffalo (Tacon et al. 2011)

Table 1. Farmed food fish production by 15 top producers and main groups of farmed species in 2012 (FAO, 2014).

Producer	Finfish		Crustaceans	Molluscs	Other species	National total	Share in world total
	Inland aquaculture	Mariculture					
	(Tonnes)		(Tonnes)			(Percentage)	
China	23 341 134	1 028 399	3 592 588	12 343 169	803 016	41 108 306	61.7
India	3 812 420	84 164	299 926	12 905	...	4 209 415	6.3
Viet Nam	2 091 200	51 000	513 100	400 000	30 200	3 085 500	4.6
Indonesia	2 097 407	582 077	387 698	...	477	3 067 660	4.6
Bangladesh	1 525 672	63 220	137 174	1 726 066	2.6
Norway	85	1 319 033	...	2 001	...	1 321 119	2.0
Thailand	380 986	19 994	623 660	205 192	4 045	1 233 877	1.9
Chile	59 527	758 587	...	253 307	...	1 071 421	1.6
Egypt	1 016 629	...	1 109	1 017 738	1.5
Myanmar	822 589	1 868	58 981	...	1 731	885 169	1.3
Philippines	310 042	361 722	72 822	46 308	...	790 894	1.2
Brazil	611 343	...	74 415	20 699	1 005	707 461	1.1
Japan	33 957	250 472	1 596	345 914	1 108	633 047	1.0
Republic of Korea	14 099	76 307	2 838	373 488	17 672	484 404	0.7
United States of America	185 598	21 169	44 928	168 329	...	420 024	0.6
Top 15 subtotal	36 302 688	4 618 012	5 810 835	14 171 312	859 254	61 762 101	92.7
Rest of world	2 296 562	933 893	635 983	999 426	5 288	4 871 152	7.3
World	38 599 250	5 551 905	6 446 818	15 170 738	864 542	66 633 253	100

Note: The symbol "..." means the production data are not available or the production volume is regarded as negligibly low.

5. Aquaculture systems development

The cultivation of farmed food fish is the aquatic version of animal husbandry, where full control of the life cycle enables the domestication of wild species, their growth in large-scale farming systems and the application of well-known and well-established techniques of animal artificial selection of desirable traits, such as resistance to diseases, fast growth and size.

For most farmed aquatic species, hatchery and nursery technologies have been developed and well established, enabling the artificial control of the life cycle of the species. However wild seed is still used in many farming operations. For a few species, such as eels (*Anguilla* spp.), farming still relies entirely on wild seed (FAO, 2014).

Aquaculture can be based on traditional, low technology farming systems or on highly industrialized, capital-intensive processes. In between there is a whole range of aquaculture systems with different efficiencies that can be adapted to local socioeconomic contexts.

Physically, inland aquaculture and coastal shrimp mariculture uses fixed ponds and raceways on land that put a premium on the use of land. Finfish mariculture and some farming of molluscs such as oysters and mussels tend to use floating net pens, cages and other suspended systems in the water column of shallow coastal waters, enabling these systems to be fixed by being anchored to the bottom.

Direct land use needs for fish and shrimp ponds can be substantial. Current aquaculture production occupies a significant quantity of land, both in inland and coastal areas. Aquaculture land use efficiency, however, differs widely by production system. While fish ponds use relatively high amounts of land (Costa-Pierce et al., 2012, cited in WRI, 2014), flow-through systems (raceways) use less land, while cages and pens suspended in water bodies use very little (if any) land (WRI, 2014).

The handling of monocultures with high densities of individuals in confinement replicates the risks typical to monocultures in land-based animal husbandry, such as the spread and proliferation of parasites, and the contagion of bacterial and viral infections producing mass mortalities, and the accumulation of waste products. If on land these risks can be partially contained, in mariculture, the use of semi-enclosed systems open to the natural flow of seawater and sedimentation to the bottom, propagate these risks to the surrounding environment affecting the health of the ecosystems in which aquaculture operations are implanted.

The introduction of these risks to the coastal zones puts a premium in the application of good management practices and effective regulations for zoning, site selection and maximum loads per area.

In 1999 during the early development of shrimp culture, a White Spot Syndrome Virus (WSSV) epizootic quickly spread through nine Pacific coast countries in Latin America, costing billions of dollars (McClennen, 2004). Disease outbreaks in recent years have affected Chile's Atlantic salmon production with losses of almost 50 percent to the virus of "infectious salmon anaemia" (ISA). Oyster cultures in Europe were attacked by herpes virus Os HV-1 or OsHV-1 μ var, and marine shrimp farming in several countries in Asia, South America and Africa have experienced bacterial and viral infections, resulting in partial or sometimes total loss of production. In 2010, aquaculture in China suffered production losses of 1.7 million tons caused by natural disasters, diseases and pollution. Disease outbreaks virtually wiped out marine shrimp farming production in Mozambique in 2011 (FAO, 2010, 2012).

New diseases also appear. The early mortality syndrome (EMS) is an emerging disease of cultured shrimp caused by a strain of *Vibrio parahaemolyticus*, a marine micro-organism native in estuarine waters worldwide. Three species of cultured shrimp are affected (*Penaeus monodon*, *P. vannamei* and *P. chinensis*). In Viet Nam, about 39 000 hectares were affected in 2011. Malaysia estimated production losses of 0.1 billion dollars (2011). In Thailand, reports indicated annual output declines of 30–70 percent. The disease has been reported in China, Malaysia, Mexico, Thailand and Viet Nam (FAO, 2014).

It is apparent that intensive aquaculture systems are likely to create conditions that expose them to disease outbreaks. When semi-enclosed systems are used, as in mariculture, pathogens in their resting or reproductive stages propagate directly to

the environment, where they can persist for long periods of time as a potential source of recurring outbreaks.

Optimization of industrial systems selects for few or a single preferred species. This is the case in the oyster culture with the widespread culture of *Crassostrea gigas* and in the shrimp industry by the dominance of *Penaeus vanamei*, the white shrimp as the preferred species. This can be also an additional source of risk, if evolving pathogens develop resistance to antibiotics or other treatments used to control well-known diseases.

6. Fed and non-fed aquaculture

Animal aquaculture production can be divided among those species that feed from natural sources in the environment in which they are grown, and species that are artificially fed. The output of naturally-fed aquaculture represents a net increase of world animal protein stock, while the contribution of fed aquaculture, consuming plant or animal protein and fat, depends on conversion rates controlled by the physiology of the species and the effectiveness of the farming system.

In 2012, global production of non-fed species from aquaculture was 20.5 million tons, including 7.1 million tons of filter-feeding carps and 13.4 million tons of bivalves and other species. Accordingly, 46.09 million tons or 69.2 per cent of total farmed food fish (FAO, 2014) was dependent upon the supply of external nutrient inputs provided in the form of (i) fresh feed items, (ii) farm-made feeds or (iii) commercially manufactured feeds (Tacon et al., 2011).

The share of non-fed species in total farmed food fish production continued to decrease to 30.8 percent in 2012 compared with about 50 percent in 1982, reflecting stronger growth in the farming of fed species, especially of high value carnivores (FAO, 2014).

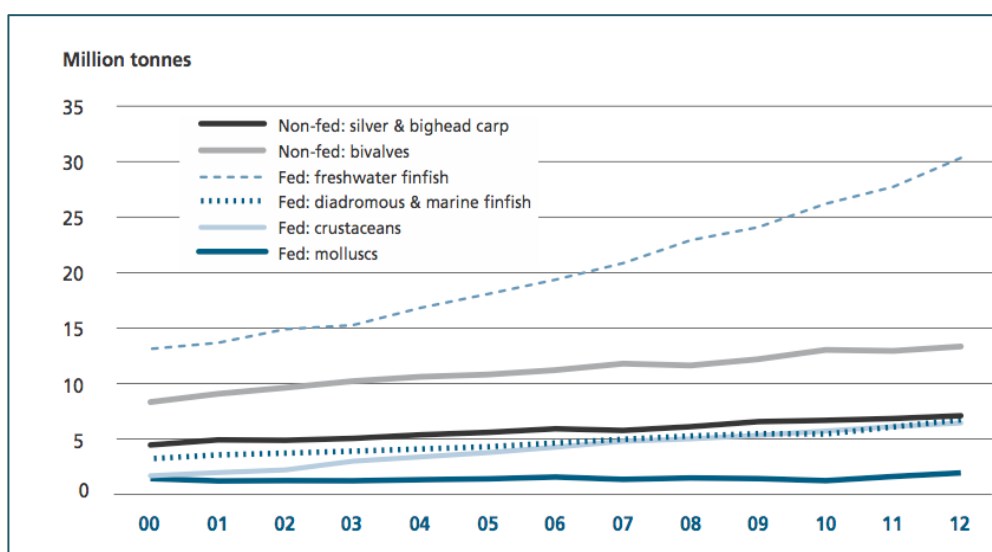


Figure 2. World aquaculture production, fed and non-fed between years 2000 and 2012 (FAO, 2014)

In Europe, after much publicly and privately sponsored research, the technology to farm cod was fully developed and supported by large amounts of venture capital, and industrial production of cod started. In the early 2000s this industrial development suffered from the financial crisis of 2008, and further growth and development almost stopped. Although the participation of risk capital in the development of aquaculture might be an option in particular places and circumstances, it is far from being the preferred option. Development of aquaculture systems, supplying domestic and international markets, has a better chance to succeed if supported by a mix of long-term public support systems (credit, technical assistance) for small and rural producers coupled with entrepreneurial initiatives well implanted in the markets.

Marine finfish aquaculture is rapidly growing in the Asia-Pacific region, where high-value carnivorous fish species (e.g. groupers, barramundi, snappers and pompano) are typically raised in small cages in inshore environments. In China this development has led to experiments in offshore mariculture using larger and stronger cages. (FAO, 2014).

These examples show that at least to the present, decision-making for the development of mariculture, particularly finfish mariculture, tends to be dominated by economic growth and not by food security considerations. To balance this trend, the intergovernmental High Level Panel of Experts on Food Security has recently advocated the need to define specific policies to support current targets on food security in view of the projected growth of human population (HLPE, 2014).

The potential for non-fed mariculture development is far from being fully explored particularly that of marine bivalves in Africa and in Latin America and in the Caribbean. Limited capacity in mollusc seed production is regarded as a constraint in some countries (FAO, 2014).

7. Aquafeed production

Total industrial compound aquafeed production increased, from 7.6 million tons in 1995 to 29.2 million tons in 2008 (last estimate available, Tacon et al., 2011). These are estimates because there is no comprehensive information on the global production of farm-made aquafeeds (estimated by FAO at between 18.7 and 30.7 million tons in 2006) and/or on the use of low-value fish/trash fish as fresh feed.

Fishmeal is used as high-protein feed and fish oil as a feed additive in aquaculture (FAO, 2014). Fishmeal and fish oil are produced mainly from harvesting stocks of small, fast-reproducing fish (e.g., anchovies, small sardines and menhaden) and for which there is some, but limited, demand for human consumption. This use, promoted in the 1950s by FAO as a means to add value to the massive harvesting of small pelagic fish, raises the question of the alternative use of this significant fish biomass for direct human consumption (HLPE 2014).

In 2012 about 35 per cent of world fishmeal production was obtained from fisheries by-products (frames, off-cuts and offal) from the industrial processing of both wild caught and farmed fish. Commercial operations harvesting myctophids⁴ for fishmeal and oil are being piloted in some regions, though the ecological consequences of exploiting these previously untapped resources have not been evaluated. In 2007 the largest producer of fishmeal was Peru (1.4 million tons) followed by China (1.0 million tons) and Chile (0.7 million tons). Other important producers were Thailand, the United States of America, Japan, Denmark, Norway and Iceland (Tacon et al., 2011).

Estimates of total usage of terrestrial animal by-product meals and oils in compound aquafeeds ranges between 0.15 and 0.30 million tons, or less than 1 percent of total global production.

Patterns in the use of fishmeal and fish oil have changed in time due to the growth and evolution of the world aquaculture industry. On a global basis, in 2008 (the most recent published estimate), the aquaculture sector consumed 60.8 percent of global fishmeal production (3.72 million tons) and 73.8 percent of global fish oil production (0.78 million tons, Tacon et al., 2011). In contrast, the poultry and pork industries each used nearly 26 per cent and 22 per cent respectively of the available fishmeal in 2002 while aquaculture consumed only 46 percent of the global fishmeal supply and 81 percent of the global fish oil supply (Pike, 2005; Tacon et al., 2006)

Fish oil has become also a product for direct human consumption for health reasons. Long-chain Omega-3 fatty acids, specifically EPA and DHA, have been shown to play a critical role in human health: EPA in the health of the cardiovascular system and DHA in the proper functioning of the nervous system, most notably brain function. In 2010 fish oil for direct human consumption was estimated at 24 per cent of the total world production, compared with 5 per cent in 1990. (Shepherd and Jackson, 2012).

The total use of fishmeal by the aquaculture sector is expected to decrease in the long term in favour of plant-based materials (Figure 3). It has gone down from 4.23 million tons in 2005 to 3.72 million tons in 2008 (or 12.8 percent of total aquafeeds by weight), and is expected to decrease to 3.49 million tons by 2020 (at an estimated 4.9 per cent of total aquafeeds by weight) (Tacon et al., 2011).

These trends reflect that fishmeal is being used by industry as a strategic ingredient fed in stages of the growth cycle where its unique nutritional properties can give the best results or in places where price is less critical (Jackson, 2012). The most commonly used alternative to fishmeal is that of soymeal. Time series of the price of both products show that use of fishmeal is being reduced in less critical areas such as grower feeds, but remains in the more critical and less price-sensitive areas of hatchery and brood-stock feeds. (Jackson and Shepherd, 2012)

⁴ Myctophids are small-size mesopelagic fish inhabiting between 200 and 1000 metres that vertically migrate on a daily basis. Biomass of myctophids is estimated to be considerable worldwide.

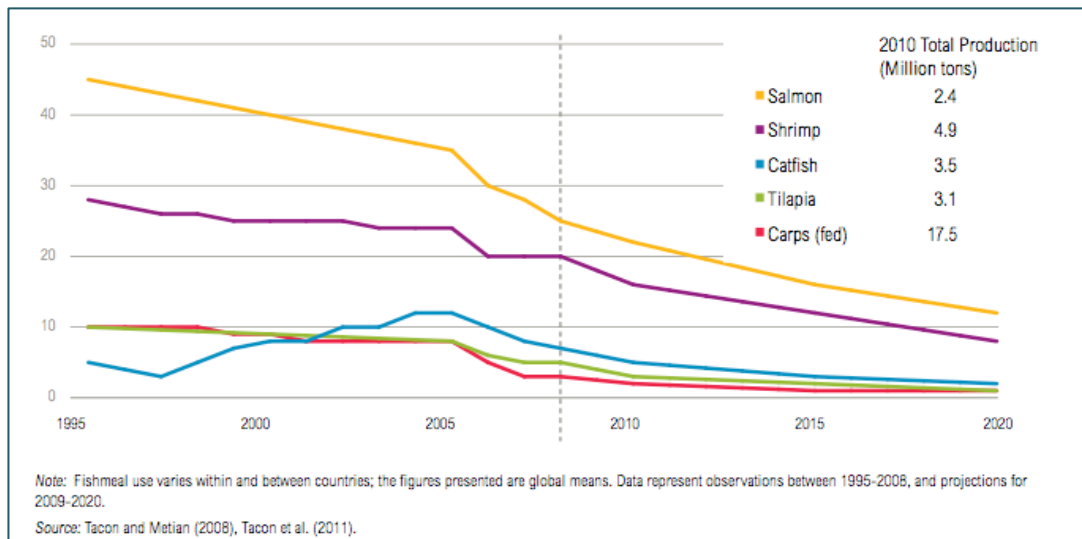


Figure 3. The aquaculture industry has reduced the share of fishmeal in farmed fish diets (percent) (FAO, 2014).

The use of fish oil by the aquaculture sector will probably increase in the long run albeit slowly. It is estimated that total usage will increase by more than 16 percent, from 782,000 tons (2.7 percent of total feeds by weight) in 2008 to the estimated 908,000 tons (1.3 percent of total feeds for that year) by 2020. It is forecast that increased usage will shift from salmonids, to marine finfishes and crustaceans because of the current absence of cost-effective alternative lipid sources that are rich in long-chain polyunsaturated fatty acids. (Tacon et al., 2011)

8. Economic and social significance

At the global level, the number of people engaged in fish farming has, since 1990, increased at higher annual rates than that of those engaged in capture fisheries. The most recent estimates (FAO 2014, Table 2) indicate that about 18.9 million people were engaged in fish farming, 96 per cent concentrated primarily in Asia, followed by Africa (1.57 percent), Latin America and the Caribbean (1.42 percent), Europe (0.54 per cent), North America (0.04 per cent) and Oceania (0.03 per cent). The 18,175 million fish farmers in 2012 represented 1.45 per cent percent of the 1.3 billion people economically active in the broad agriculture sector worldwide. (FAO, 2014).

Table 2. FAO (2014) estimates that the total number of fish farmers in the world has grown from 8 million in 1995 to close to 19 million today, representing an increasing source of livelihoods. Not all these jobs are permanent and year-around, since many are seasonal.

	1995	2000	2005	2010	2011	2012
	<i>(Thousands)</i>					
Of which, fish farmers						
Africa	65	91	140	231	257	298
Asia	7 762	12 211	14 630	17 915	18 373	18 175
Europe	56	103	91	102	103	103
Latin America and the Caribbean	155	214	239	248	265	269
North America	6	6	10	9	9	9
Oceania	4	5	5	5	6	6
World	8 049	12 632	15 115	18 512	19 015	18 861

Out of the 18.8 million of fish farmers in the world (Table 2), China alone employs 5.2 million, representing 27.6 per cent of the total, while Indonesia employs 3.3 million farmers, representing 17.7 per cent of the total. Employment at farm level includes full-time, part-time and occasional jobs in hatcheries, nurseries, grow-out production facilities, and labourers. Employment at other stages along aquaculture value-chains includes jobs in input supply, middle trade and domestic fish distribution, processing, exporting and vending (HLPE, 2014). More than 80 per cent of global aquaculture production may be contributed by small- to medium-scale fish farmers, nearly 90 per cent of whom live in Asia (HLPE, 2014). Farmed fish are expected to contribute to improved nutritional status of households directly through self-consumption, and indirectly by selling farmed fish for cash to enhance household purchasing power (HLPE, 2014)

The regional distribution of jobs in the aquaculture sector reflects widely disparate levels of productivity strongly linked to the degree of industrialization of the dominant culture systems in each region. In Asia, low technology is used in non-fed and inland-fed aquaculture, using extensive ponds, which is labour intensive compared with mariculture in floating systems. In 2011, the annual average production of fish farmers in Norway was 195 tons per person, compared with 55 tons in Chile, 25 tons in Turkey, 10 tons in Malaysia, about 7 tons in China, about 4 tons in Thailand, and only about 1 ton in India and Indonesia (FAO, 2014).

Extrapolating from a ten-country case study representing just under 20 per cent of the global aquaculture production, Phillips and Subasinghe (2014, personal communication, cited in HLPE, 2014) estimated that *“total employment in global aquaculture value chains could be close to 38 million full-time people.”*

Table 3. Per capita average outputs per fish farmer by region (in FAO, 2014).

	Production ¹ per person				
	2000	2005	2010	2011	2012
	<i>(Tonnes/year)</i>				
Aquaculture					
Africa	4.4	4.6	5.6	5.4	5.1
Asia	2.3	2.7	2.9	3.0	3.2
Europe	19.8	23.5	24.9	26.0	27.8
Latin America and the Caribbean	3.9	6.3	7.8	9.0	9.7
North America	91.5	68.2	70.0	59.5	59.3
Oceania	23.1	29.5	33.8	30.4	32.7
World	2.6	2.9	3.2	3.3	3.5

¹ Production excludes aquatic plants.

Fish is among the most traded food commodities worldwide. Fish can be produced in one country, processed in a second and consumed in a third. There were 129 billion dollars of exports of fish and fishery products in 2012 (FAO, 2014)

In the last two decades, in line with the impressive growth in aquaculture production, there has been a substantial increase in trade of many aquaculture products based on both low- and high-value species, with new markets opening up in developed and developing countries as well as economies in transition.

Aquaculture is contributing to a growing share of international trade in fishery commodities, with high-value species such as salmon, seabass, seabream, shrimp and prawns, bivalves and other molluscs, but also relatively low-value species such as tilapia, catfish (including *Pangasius*) and carps (FAO 2014). *Pangasius* is a freshwater fish native to the Mekong Delta in Viet Nam, new to international trade. However, with production of about 1.3 million tons, mainly in Viet Nam and all going to international markets, this species is an important source of low-priced traded fish. The European Union and the United States of America are the main importers of *Pangasius*. (FAO, 2014)

9. Environmental impacts of aquaculture

Environmental effects from aquaculture include land use and special natural habitats destruction, pollution of water and sediments from wastes, the introduction of non-native, competitive species to the natural environment through escapes from farms, genetic effects on wild populations (of fish and shellfish) from escapes of farmed animals or their gametes, and concerns about the use of wild forage fish for aquaculture feeds.

9.1 Land use

WRI (2014) estimate that inland aquaculture ponds occupied between 12.7 million ha and 14.0 million ha of land in 2010, and that brackish water or coastal ponds

occupied approximately 4.4 million ha—for a combined area of roughly 18 million hectares, overwhelmingly in Asia. Many of these ponds were converted from rice paddies and other existing cropland rather than newly converted natural lands—but even so, aquaculture adds to world land use demands.

In 2008, global land use efficiencies of inland and brackish water ponds averaged 2.3 tons of fish per hectare per year (t/ha/yr). Expanding aquaculture to 140 million tons by 2050 without increases in that average efficiency would imply an additional area of roughly 24 million ha directly for ponds—about the size of the United Kingdom. (WRI, 2014)

9.2 *Interaction with mangroves*

Land conversion for aquaculture can lead to severe ecosystem degradation, as in the case of the proliferation of extensive low-yield shrimp farms that destroyed large extensions of mangrove forests in Asia and Latin America (Lewis et al., 2002, cited in WRI, 2014). Since the 1990s, non-governmental organizations and policy-makers have focused on curbing the expansion of extensive, shrimp farms into mangrove forests in Asia and Latin America (FAO et al., 2006b). As a result, mangrove clearance for shrimp farms has greatly decreased, thanks to mangrove protection policies in affected countries and the siting of new, more high-yield shrimp farms away from mangrove areas. (Lewis et al., 2002).

9.3 *Pollution of water and sediments*

Wastes from mariculture generally include dissolved (inorganic) nutrients, particulate (organic) wastes (feces, uneaten food and animal carcasses), and chemicals for maintaining infrastructure (anti-biofouling agents) and animal health products (antiparasitics, disinfectants and antibiotics). These wastes impose an additional oxygen demand on the environment, usually creating anoxic conditions under pens and cages.

Research in Norway has shown that benthic effects decline rapidly with increasing depth of water under salmon nets, but situating farms as close to shore as possible may be a prerequisite for economic viability of the industry. Following periods of several years have been found necessary in Norway to allow benthic recovery. Research elsewhere indicates that benthic recovery may be quicker under some conditions (WHOI, 2007)

9.4 *Impact of escapes*

With the use of floating semi-enclosed systems, escapes are inevitable in mariculture and inland aquaculture. Catastrophic events (e.g., hurricanes or other storms), human error, seal and sea lion predation and vandalism will remain potential paths for farmed fish to escape into the wild. Advancements in technology are likely to continue to reduce the frequency and severity of escape events but it is unlikely that this ecological and economic threat will ever disappear entirely. There is considerable evidence of damage to the genetic integrity of wild fish populations when escaped farmed fish can interbreed with local stocks. Furthermore, in semi-enclosed systems, cultured organisms release viable gametes into the water.

Mariculture industry has undertaken a significant effort to produce and use variants of cultivated species that are infertile, diminishing the risk of gene-flow from cultivated/domesticated species to their wild counterparts when escapes occur.

9.5 *Non-native species.*

Aquaculture has been a significant source of intentional and unintentional introductions of non-native species into local ecosystems worldwide. The harm caused by invasive species is well documented.

Intensive fish culture, particularly of non-native species, can be and has been involved in the introduction and/or amplification of pathogens and disease in wild populations (Blazer and LaPatra, 2002, cited in WHOI, 2007).

Non-native oysters have been introduced in many regions to improve failing harvests of native varieties due to diseases or overexploitation. The eastern oyster, *Crassostrea virginica*, was introduced to the West Coast of the United States in 1875. The Pacific or Japanese oyster *Crassostrea gigas*, native to the Pacific coast of Asia, has been introduced in North and South America, Africa, Australia, Europe, and New Zealand and has also spread through accidental introductions either through larvae in ballast water or on the hulls of ships (Helm, 2006).

9.6 *Genetically modified organisms*

Although the use of transgenic, or genetically modified organisms (GMOs), is not common practice in aquaculture (WHOI, 2007), nevertheless the potential use of GMOs would pose severe risks. The production and commercialization of aquatic GMOs should be analyzed considering economic issues, environmental protection, food safety and social and health well-being (Muir, et al., 1999; Le Curieux-Belfond et al., 2009).

9.7 *Use of chemicals as pesticides and for antifouling*

A wide variety of chemicals are currently used in aquaculture production. As the industry expands, it requires the use of more drugs, disinfectants and antifouling compounds (biocides)⁵ to eliminate the microorganisms in the aquaculture facilities. Among the most common disinfectants are hydrogen peroxide and malachite green. Pyrethroid insecticides and avermectins are used as anthelmintic agents (Romero et al., 2012). Organic booster biocides were recently introduced as alternatives to the organotin compounds found in antifouling products after restrictions were imposed on the use of tributyltin (TBT). The replacement products are generally based on copper metal oxides and organic biocides. The biocides that are most commonly used in antifouling paints include chlorothalonil, dichlofluanid, DCOIT (4,5-dichloro-2-n-octyl-4-isothiazolin-3-one, Sea-nine 211®), Diuron, Irgarol 1051, TCMS pyridine

⁵ Biocides are chemical substances that can deter or kill the microorganisms responsible for biofouling.

(2,3,3,6-tetrachloro-4-methylsulfonyl pyridine), zinc pyrithione and Zineb. (Guardiola et al., 2012). The use of biocides is not as well-regulated as drug use in aquaculture because the information available on their effects on ecosystems is still limited.

9.8 Use of antibiotics

Antibiotic drugs used in aquaculture may have substantial environmental effects. The use of antibiotics in aquaculture can be categorized as therapeutic, prophylactic or metaphylactic. Therapeutic use is the treatment of established infections. Metaphylaxis are group-medication procedures, aimed at treating sick animals while also medicating others in the group to prevent disease. Prophylaxis means the precautionary use of antimicrobials in either individuals or groups to prevent the development of infections (Romero et al., 2012).

In aquaculture, antibiotics at therapeutic levels are frequently administered for short periods of time via the oral route to groups of fish that share tanks or cages. Fish do not effectively metabolize antibiotics and will pass them largely unused back into the environment in feces. 70 to 80 per cent of the antibiotics administered to fish as medicated pelleted feed are released into the aquatic environment via urinary and fecal excretion and/or as unused medicated food (Romero et al., 2012). For this among other reasons, antibiotic use in net, pen or cage mariculture is a concern because it can contribute to the development of resistant strains of bacteria in the wild. The spread of antimicrobial resistance due to exposure to antimicrobial agents is well documented in both human and veterinary medicine. It is also well documented that fish pathogens and other aquatic bacteria can develop resistance as a result of antimicrobial exposure. Examples include *Aeromonas salmonicida*, *Aeromonas hydrophila*, *Edwardsiella tarda*, *Yersinia ruckeri*, *Photobacterium damsela* and *Vibrio anguillarum*. Research has shown that antibiotics excreted tend to degrade faster in sea-water, while they persist more in sediments. (Romero et al., 2012)

The public health hazards related to antimicrobial use in aquaculture are twofold: the development and spread of antimicrobial-resistant bacteria and resistance genes and the presence of antimicrobial residues in aquaculture products and the environment (Romero et al., 2012). The high proportions of antibiotic-resistant bacteria that persist in sediments and farm environments may provide a threat to fish farms because they can act as sources of antibiotic-resistance genes for fish pathogens in the vicinity of the farms. Because resistant bacteria may transfer their resistance elements to bacterial pathogens, the implementation of efficient strategies to contain and manage resistance-gene emergence and spread is critical for the development of sustainable aquaculture practices.

Industry faced with uncertainties created by the limited knowledge of infectious diseases and their prevalence in a particular environment tends to abuse the use of antibiotics. Defoirdt et al. (2011, cited by Romero et al., 2012) estimated that approximately 500–600 metric tons of antibiotics were used in shrimp farm production in Thailand in 1994; he also emphasized the large variation between different countries, with antibiotic use ranging from 1 g per metric ton of production in Norway to 700 g per metric ton in Viet Nam. In the aftermath of the ISA infection in the salmon culture in Chile, SERNAPESCA, the Chilean National Fisheries and

Aquaculture Service, recently released data reporting unprecedentedly high amounts of antibiotics used by the salmon industry.⁶ Inefficiencies in the antibiotic treatment of fish illnesses now may lead to significant economic losses in the future (Romero et al., 2012).

Antimicrobial-resistant bacteria in aquaculture also present a risk to public health. The appearance of acquired resistance in fish pathogens and other aquatic bacteria means that such resistant bacteria can act as a reservoir of resistance genes from which genes can be further disseminated and may ultimately end up in human pathogens. Plasmid-borne resistance genes have been transferred by conjugation from the fish pathogen *A. salmonicida* to *Escherichia coli*, a bacterium of human origin, some strains of which are pathogenic for humans (Romero et al., 2012).

9.9 Diseases and parasites

Farming marine organisms in dense populations results in outbreaks of viral, bacterial, fungi and parasite diseases. Diseases and parasites constitute a strong constraint on the culture of aquatic species and disease and parasite translocation by host movements in different spatial scales is common. In molluscs the main parasites are protozoans of the genus *Bonamia*, *Perkinsus* and *Marteilia*. The pathogens *Haplosporidium*, bacteria (rickettsial and vibriosis) and herpes-type virus have a great impact on the rates of mortality. In shrimps the most relevant diseases are viral (white spot disease, WPS, yellow head disease, YHD, taura syndrome disease, TSD) (Bondad-Reantaso et al., 2005).

The “Sea lice (Copepoda, Caligidae) have been the most widespread pathogenic marine parasite” in Salmon farming, affecting also other cultured fishes and wild species (Ernst et al., 2001; Costello, 2006). The global economic cost of sea lice control was estimated at over 480 million dollars in 2006 (Costello, 2009); however, there are other impacts such as the decrease in conversion efficiency (Sinnott, 1998) and the depression of immune systems, which allow the outbreak of bacterial (vibriosis and furunculosis) and viral diseases (infectious salmon anaemia virus, ISA, infectious pancreatic necrosis, IPN and pancreas disease, PD) (Robertson, 2011).

References

Blazer, V.S., and LaPatra, S.E. (2002). Pathogens of cultured fishes: potential risks to wild fish populations. pp. 197-224. In *Aquaculture and the Environment in the United States*, Tomasso, J., ed. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

⁶ According to SERNAPESCA, the industry used an estimated 450,700 kilos of antibiotics in 2013.

- Bondad-Reantaso, M.G., Subasinghe, R. P., Arthur, J. R., Ogawa, K., Chinabut, S., Adlard, R., Tan, Z and Shariff, M., (2005). Disease and health management in Asian aquaculture. *Veterinary Parasitology* vol 132, pp. 249–272.
- Costa-Pierce, B.A., Bartley, D.M., Hasan, M., Yusoff, F., Kaushik, S.J., Rana, K., Lemos, D., Bueno, P. and Yakupitiyage, A. (2012). Responsible use of resources for sustainable aquaculture, In *Global Conference on Aquaculture 2010*, Subasinghe, R., ed. Sept. 22-25, 2010, Phuket, Thailand. Rome: FAO. Available from [http://ecologicalaquaculture.org/Costa-PierceFAO\(2011\).pdf](http://ecologicalaquaculture.org/Costa-PierceFAO(2011).pdf).
- Costello, M.J. (2006). Ecology of sea lice parasitic on farmed and wild fish. *Trends in Parasitology* vol 22, No 10, pp 475-483
- Costello, M.J. (2009). The global economic cost of sea lice to the salmonid farming industry. *Journal of Fish Diseases*, vol 32. pp 115-118.
- Defoirdt, T., Sorgeloos, P., Bossier, P. (2011). Alternatives to antibiotics for the control of bacterial disease in aquaculture. *Current opinion in microbiology*, vol. 14, No. 3, pp. 251-58.
- Ernst, W., Jackman, P., Doe, K., Page, F., Julien, G., Mackay, K., Sutherland, T. (2001). Dispersion and toxicity to non-target aquatic organisms of pesticides used to treat sea lice on salmon in net pen enclosures. *Marine Pollution Bulletin*, vol. 42, No. 6, pp. 433-44.
- FAO (2006a). State of world aquaculture 2006. *FAO Fisheries Technical Paper*, No. 500. Rome: FAO. 134 pp.
- FAO, NACA, UNEP, WB, WWF (2006b). *International Principles for Responsible Shrimp Farming*. Network of Aquaculture Centres in Asia-Pacific (NACA). Bangkok, Thailand. 20 pp. Available from <http://www.enaca.org/uploads/international-shrimp-principles-06.pdf>.
- FAO (2010). *The State of World Fisheries and Aquaculture 2010*. Rome: FAO. 197 pp.
- FAO (2012). *The State of World Fisheries and Aquaculture 2012*. Rome: FAO. 209 pp.
- FAO (2014). *The State of World Fisheries and Aquaculture 2014*. Rome: FAO. 223 pp.
- Guardiola, F.A., Cuesta, A., Meseguer, J. and Esteban, M.A. (2012). Risks of Using Antifouling Biocides in Aquaculture. *International Journal of Molecular Sciences* 13(2): 1541–1560.
- Helm, M.M. (2006). *Crassostrea gigas*. Cultured Aquatic Species Information Programme, FAO Fisheries and Aquaculture Department, Rome: FAO. Available from http://www.fao.org/fishery/culturedspecies/Crassostrea_gigas/en.
- HLPE (2014). *Sustainable fisheries and aquaculture for food security and nutrition. The High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome: FAO.
- Jackson, A.J., and Shepherd, J. (2012). The future of fish meal and oil. In *Second International Conference on Seafood Technology on Sustainable, Innovative and Healthy Seafood*. Ryder, R., Ababouch, L., and Balaban, M. (eds).

- FAO/The University of Alaska, 10–13 May 2010, Anchorage, the United States of America. pp. 189–208. FAO Fisheries and Aquaculture Proceedings, No. 22. Rome: FAO. 238 pp. Available from www.fao.org/docrep/015/i2534e/i2534e.pdf.
- Jackson, A.J. (2012). Fishmeal and Fish Oil and its role in Sustainable Aquaculture. *International Aquafeed*, September/October, pp.18 – 21.
- Le Curieux-Belfond, O., Vandelac, L., Caron, J., Séralini, G.-E., (2009). Factors to consider before production and commercialization of aquatic genetically modified organisms: the case of transgenic organisms: the case of transgenic salmon. *Environmental Science & Policy*, 12: 170-189.
- Lewis, R. R., Phillips, M. J., Clough, B., Macintosh, D.J. (2002). *Thematic Review on Coastal Wetland Habitats and Shrimp Aquaculture*. Washington, DC: World Bank, Network of Aquaculture Centres in Asia-Pacific, World Wildlife Fund, and FAO.
- McClenen, C. (2004). *The Economic, Environmental and Technical Implications of the Development of Latin American Shrimp Farming*. Master of Arts in Law and Diplomacy Thesis, The Fletcher School. Available from <http://dl.tufts.edu/bookreader/tufts:UA015.012.DO.00040#page/1/mode/2up>.
- Muir, W.M., and Howard, R.D. (1999). Possible ecological risks of transgenic organism release when transgenes affect mating success: Sexual selection and the Trojan gene hypothesis. *Proceedings of the National Academy of Sciences, USA*, vol. 96, No. 24, pp. 13853-56.
- Pike, I.H. (2005). Eco-efficiency in aquaculture: global catch of wild fish used in aquaculture. *International Aquafeed*, 8 (1): 38–40.
- Robertson, B. (2011). Can we get the upper hand on viral diseases in aquaculture of Atlantic salmon? *Aquaculture Research* 2011, vol. 42, pp 125-131.
- Romero, J., Feijoo, C.F., Navarrete, P. (2012). Antibiotics in Aquaculture – Use, Abuse and Alternatives. In *Health and Environment in Aquaculture*, Carvalho, E.D., David, G.S., Silva, R.J., (eds.) InTech. Available from <http://www.intechopen.com/books/health-and-environment-in-aquaculture/antibiotics-in-aquaculture-use-abuse-and-alternatives>.
- Shepherd, C.J., and Jackson, A.J. (2012). *Global fishmeal and fish oil supply - inputs, outputs, and markets*. International Fishmeal & Fish Oil Organisation, World Fisheries Congress, Edimburgh. Available from http://www.seafish.org/media/594329/wfc_shepherd_fishmealtrends.pdf.
- Sinnot, R. (1998). Sea lice – watch out for the hidden costs. *Fish Farmer*, vol 21 No 3, pp 45-46.
- Tacon, A.G.J.; Hasan, M.R.; Subasinghe, R.P. (2006). Use of fishery resources as feed inputs for aquaculture development: trends and policy implications. *FAO Fisheries Circular*. No.1018. Rome, FAO. 99p.

- Tacon, A. G. J., Hasan, M. R., Metian, M. (2011). Demand and supply of feed ingredients for farmed fish and crustaceans -Trends and prospects. *FAO Fisheries Technical Paper*, No. 564. Rome, FAO.
- WHOI (2007). *Sustainable Marine Aquaculture: Fulfilling the Promise; Managing the Risks*. Marine Aquaculture Task Force, Marine Finfish Aquaculture Standards Project, 128 pp.
- WRI (2014). *Creating a Sustainable Food Future: A menu of solutions to sustainably feed more than 9 billion people by 2050*. World Resources Report 2013–14: Interim Findings. World Resources Institute, Washington D.C., USA, 144 pp.