Strengthening Adaptive Capacities to the Impacts of Climate Change in Resource poor Small-scale Aquaculture and Aquatic resources-dependent Sector in the South and South-east Asian Region - AquaClimate

Resource use and greenhouse gas emissions by aquaculture systems in the case study areas

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Introduction

Aquaculture is seen as a potential production system to compensate with the declining production from marine capture to meet the global demand for food. The growth of aquaculture is continuously increased much more than other food sectors. Especially in the developing countries where it is the main hub of production, the aquaculture sector has played a significant role not only for food but also for socio-economic benefits in terms of foreign revenue, job creation and local livelihood.

However, the aquaculture sector has also been receiving a great deal of criticisms on its potential environmental impacts. The potential impacts from aquaculture systems often highlighted are: GHG emissions, Water pollution, and Resource use (i.e. wild seed, fish in-fish out ration). Recently, there is a major interest on its potential emissions of GHG (Greenhouse Gas) which is being the international agenda on climate change mitigation as well as adaptation.

In order to identify culture systems that produce the most greenhouse gas emissions (GHGs) and prioritise better practices for the culture systems with high environmental impact, the different case studies need to be benchmarked against each other and other aquaculture technologies. This analysis uses resource use analysis to estimate the resource use and nutrient impact to the environment and Life Cycle analyses to estimate GHG emission. In this way the aquaculture culture systems that are resource heavy or have high GHG emissions can be highlighted and best practice guidelines to reduce impacts. The analysis assesses the GHG emissions and resource use per tonne of food produced by the case study culture systems.

The culture systems investigated in this study vary between very high intensive Pangasius catfish culture through semi-intensive culture systems (P. monodon shrimp culture in India and milkfish pond production in the Philippines to extensive P. monodon shrimp culture systems in Vietnam.

In Vietnam, the case study was on P. monodon shrimp culture under improved extensive farming conditions. Farmers undertaking improved extensive farming also typically undertake polyculture of tiger shrimp with mud crab and highly intensive Pangasius catfish culture in ponds using pumper water and complete diets. The case study in the Philippines was on milkfish pond farming in shallow extensive ponds tend (about 30-40 cm deep) and typically use tidal changes to manage water movement into and out from the farm. The majority of extensive pond farms rely on fertilization of ponds and primary production as the feed source of fish. In India, the csase study was on semi-intensive P.monofdon shrimp culture in Andhra Pradesh which contributes more than half of India's shrimp production and the state has been at the forefront of the industry since the beginning. Here shrimp culture relies on pumped water and aeration which are heavy cost elements and technical uncertainties, risking both the technical and economic viability.

The Bangkok Declaration and Strategy for Aquaculture Development Beyond 2000 [NACA/FAO 2000] expressed the need to develop resource-efficient farming systems which make efficient use of water, land, seed and feed inputs by exploring the potential for commercial use of species feeding low in the food chain. Although significant resource competition exists, significant technological advancements in aquaculture over the past decade have occurred to make production systems less consumptive of land, water and energy, to the point where aquaculture resource use, overall, is comparable to poultry production.

However, the next 20 years will see an increase in the efficient use of land, water, food, seed and energy through intensification and widespread adoption of integrated agriculture-aquaculture

farming ecosystems approaches. However, this will not be enough to increase aquaculture production as these will improve only the efficiency of use, and increase aquaculture yields per unit of inputs. A growing population will require aquaculture to expand rapidly into land and water areas that are currently held as common pool resources (commons). This raises issues of access to and management of common pool resources, which could result in conflicts with exiting users and potentially acute social, political, and economic problems.

Assessing environmental performance of aquaculture is difficult because activities and potential impacts are extremely diverse. However there is an increasing emphasis on using holistic analyses to compare overall impacts of different agricultural production systems and to assess impacts and resource use within a production process to identify opportunities for increasing resource use efficiency. Life Cycle Assessment is the most common comprehensive analytical tool currently used to quantify environmental impacts of a production process. The LCA concept has been formalized into an analytical methodology under ISO 14000 standards and has been proposed as a measure of environmental performance and sustainability by numerous agencies and environmental groups.

The LCA approach is useful because the impacts of all activities involved in production, use, and retirement of a product are expressed in a single "common currency"—energy use, for example—thereby making it easy to compare impacts among various products, processes, or activities. Life cycle assessment must have clearly defined boundaries because impacts can, in theory, flow almost endlessly upstream and downstream of the actual production process. For example, an energy LCA for aquaculture may include energy costs to procure pelagic fish for reduction to fish meal that will be used in feeds. The energy cost of fishing is primarily embodied in the fuel used by the fishing vessel, but can also include the energy used to manufacture the fishing vessel, to produce the steel and fiberglass used to fabricate the vessel, to produce the nylon used in nets, and so on. In this analysis the boundary for analysis is set to the production phase only. Production data and resource use was collected through detailed questionnaires from owner operators. Combining the power of LCA with individual resource use indicators based on specific impacts provides a comprehensive set of tools for assessing environmental performance.

1. **Life Cycle analysis**

   To assess the GHG emissions associated with aquaculture systems, Life Cycle Assessment (LCA) is the selected analytical tool to evaluate the potential impacts from the compiling of inputs and outputs of the whole life cycle stages of product covering from raw material production, manufacturing, distribution, consumption and final disposal. The methodology is internationally standardized in ISO 14040/44: 2006 and has been applied in agri-food products including aquatic products. LCA is based on the holistic approach thus offering the most comprehensive analysis and giving the most possible impacts that can occur. More importantly, GHG emissions or called in LCA as "Global Warming Potential" is not the only aspect considered in LCA but also other categories, such as Eutrophication, Resource depletion, Stratospheric Ozone Depletion, Eco-toxicity, etc. It is also worth to highlight the unique characteristics of LCA results as the relative potential impacts in quantitative terms, which are very useful for making management or policy decisions.

   All of the issues mentioned above have led to the question "Which aquaculture practices would be friendly for climate and environment?" and "How can the environmental performance of aquaculture systems be improved?" – which are the ultimate goal of this LCA study.

1.2 LCA methodology

Goal and scope

The goal of LCA study was aimed to evaluate the potential impacts associated with inputs and outputs into different pond-based aquaculture system of Pangasius (Viet Nam), Black tiger prawn (Viet Nam), Black tiger prawn (India), and Milkfish (Philippines). The system boundary was at the farm-gate level, thus covering the hatchery, farm and feed production activities (Figure 1). However, related transports in all stages are excluded. The functional unit was set as one ton of fish/shrimp (wet weight). The impact categories of interest are: Biotic resource use (wild seed, fish-in:fish-out), Abiotic resource use (land, water, and energy), Global Warming Potential, and Eutrophication Potential. The impact methodology used was based on midpoint impact by following the CML2 Baseline 2000 method. The results of LCA study would be used to identify the hot spots where improvement can be made, including the potential options for environmental performance improvement.
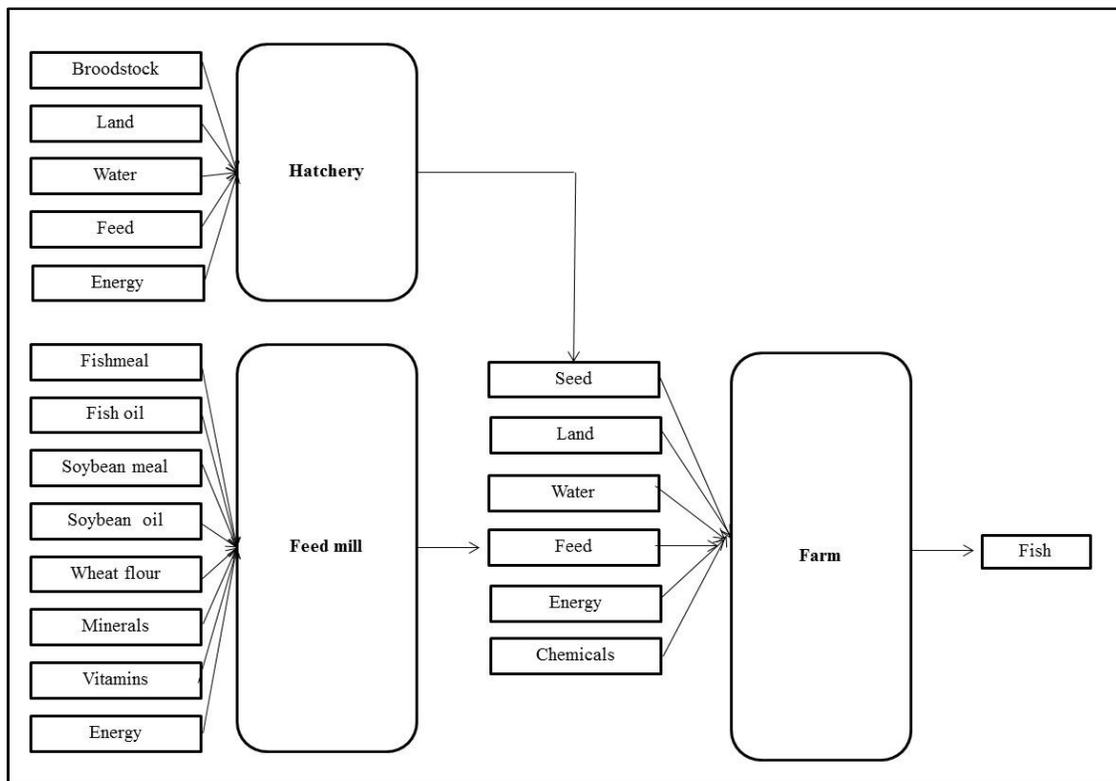

Figure 1: System boundary of LCA study

Data collection

The required inventory data were identified, i.e. the associated inputs and outputs in each stage of the system boundary. The foreground data were mainly from the primary data collected via questionnaires. The amount of inputs and outputs were based on the average data of annual production in 2010. The background data, such as the production of inputs, were gathered from the literatures most relevant to the studied site (Table 1-4).

Table 1: List of required inventory data and sources of data of the inputs and output from milkfish farming system in Philippines

Life cycle stage	Data source	
	Primary data	Secondary data
Farm	*Inputs:*	*Background data:*
	Hatchery-reared seed	Electricity production
	Land	Diesel production and combustion
	Water	Limestone production
	Feed	Vitamin production
	Electricity	Feed production
	Vitamin	
	Limestone	
	Diesel	
	Outputs:	
	Milkfish	
	Total N	
	Total P	

Table 2: List of required inventory data and sources of data of the inputs and output from shrimp farming system in India

Life cycle stage	Data source	
	Primary data	Secondary data
Hatchery	*Inputs:*	*Background data:*
	Wild broodstock	Electricity production
	Land	Fertilizer production
	Water	Probiotic production
	Artemia	Crop production (feed ingredients)
	Feed	Feed production
	Electricity	
	Fertilizer	
	Outputs:	
	Hatchery-reared seed	
	Waste water	
	Total N	
	Total P	
Farm	*Inputs:*	*Background data:*
	Hatchery-reared seed	Electricity production
	Land	Diesel production and combustion
	Water	Limestone production
	Feed	Feed production
	Electricity	
	Limestone	
	Diesel	
	Outputs:	
	Shrimp	
	Wastewater	
	Total N	
	Total P	

Table 3: List of required inventory data and sources of data of the inputs and output from shrimp farming system in Viet Nam

Life cycle stage	Data source	
	Primary data	Secondary data
Hatchery	*Inputs:*	*Background data:*
	Wild broodstock	Electricity production
	Land	Fertilizer production
	Water	Feed production
	Feed	
	Electricity	
	Fertilizer	
	Outputs:	
	Hatchery-reared seed	
	Waste water	
	Total N	
	Total P	
Farm	*Inputs:*	*Background data:*
	Hatchery-reared seed	Electricity production
	Land	Diesel production and combustion
	Water	Limestone production
	Feed	Feed production
	Electricity	
	Limestone	
	Diesel	
	Outputs:	
	Shrimp	
	Wastewater	
	Total N	
	Total P	

Table 4: List of required inventory data and sources of data of the inputs and output from Pangasius catfish farming system in Viet Nam

Life cycle stage	Data source	
	Primary data	Secondary data
Hatchery	*Inputs:*	*Background data:*
	Wild broodstock	Electricity production
	Land	Fertilizer production
	Water	Feed production
	Feed	
	Electricity	
	Fertilizer	
	Outputs:	
	Hatchery-reared seed	
	Waste water	
	Total N	
	Total P	
Farm	*Inputs:*	*Background data:*

	Hatchery-reared seed	Electricity production
	Land	Vitamin production
	Water	Feed production
	Feed	Probiotic production
	Electricity	
	Vitamin	
	Probiotic	
	Outputs:	
	Pangasius	
	Waste water	
	Total N	
	Total P	

1.3 Results

Inventory analysis results

The inputs and outputs in quantitative terms were analysed and expressed in terms of quantity per ton of fish/shrimp to reflect the material intensity level as well as the resource use efficiency (Table 5-8).

Table 5: Inventory table of the inputs and output from milkfish farming system in Philippines

Life cycle stage	Inventory item	Amount	Unit
Farm	*Inputs:*		
	Hatchery-reared seed	67,573	numbers
	Compound feed	6.07	kg
	Electricity	0	kWh
	Limestone	0	kg
	Diesel	0	L
	Water	8,010	m3
	Outputs:		
	Milk fish	1,000	kg
	Wastewater	8,010	m3
	Total N	NA	mg/L
	Total P	NA	mg/L

P. monodon shrimp (Indian)

Table 6: Inventory table of the inputs and output from shrimp farming system in India

Life cycle stage	Inventory item	Amount	Unit
Hatchery	*Inputs:*		
	Compound feed	5	kg
	Electricity	229	kWh
	Fertilizer	2	kg
	Probiotic	2	kg
	Artemia	4.5	kg
	Water used	35	m3

Life cycle stage	Inventory item	Amount	Unit
	Outputs:		
	Hatchery-reared seed	1,000,000	numbers
	Wastewater	35	m^3
	Total N	0.59	mg/L
	Total P	0.11	mg/L
Farm	*Inputs:*		
	Hatchery-reared seed	NA	numbers
	Compound feed	1,499	kg
	Electricity	2,732	kWh
	Limestone	62	kg
	Fuel	1,326	L
	Water	33,155	m3
	Outputs:		
	Shrimp	1,000	kg
	Waste water	33,155	m3
	Total N	NA	mg/L
	Total P	NA	mg/L

P. monodon shrimp (Viet Nam)

Table 7: Inventory table of the inputs and output from shrimp farming system in Viet Nam

Life cycle stage	Inventory item	Amount	Unit
Hatchery	*Inputs:*		
	Compound feed	NA	kg
	Electricity	NA	kWh
	Fertilizer	NA	kg
	Probiotic	NA	kg
	Artemia	NA	kg
	Outputs:		
	Hatchery seed	NA	numbers
	Waste water	NA	m^3
	Total N	NA	mg/L
	Total P	NA	mg/L
Farm	*Inputs:*		
	Hatchery-reared seed	NA	numbers
	Compound feed	NA	kg
	Electricity	NA	kWh
	Limestone	NA	kg
	Diesel	NA	L
	Water	NA	m3
	Outputs:		
	Shrimp	NA	kg
	Wastewater	NA	m3
	Total N	NA	mg/L
	Total P	NA	mg/L

Pangasius catfish (Viet Nam)

Table 8: Inventory table of the inputs and output from Pangasius farming system in Viet Nam

Life cycle stage	Inventory item	Unit	Amount
Hatchery	*Inputs:*		
	Compound feed	NA	kg
	Farm feed	NA	kg
	Electricity	NA	kWh
	Fertilizer	NA	kg
	Probiotic	NA	kg
	Chemical	NA	kg
	Water	NA	m3
	Outputs:		
	Hatchery-reared seed	NA	numbers
	Waste water	NA	m^3
	Total N	NA	mg/L
	Total P	NA	mg/L
Farm	*Inputs:*		
	Hatchery-reared seed	1,876	numbers
	Compound feed	1,310	kg
	Electricity	43	kWh
	Limestone	0	kg
	Diesel	31	L
	Vitamin	0.80	kg
	Probiotic	0.20	kg
	Water	1,327	m3
	Outputs:		
	Pangasius	1,000	kg
	Waste water	1,327	m3
	Total N	NA	mg/L
	Total P	NA	mg/L

Impact assessment results

Table 9 shows the GWP values of different aquaculture products. Shrimp (India) has the highest impacts, followed by pangasius (Viet Nam) and Milkfish (Philippines). When compared between shrimp and pangasius, the impact of shrimp is almost three times higher than pangasius as the consequences of GHG emissions related to the use of compound feed in feed production at the feed mill as well as the use of electricity in aerators at the shrimp farm (Figure 2). With respect to the feed production, the use of fish meal and wheat flour contributed dominantly to the GHG emissions.

Table 9: Life cycle impact assessment results

Aquaculture system	GWP (kg CO2e/t fish or shrimp)	EP (kg PO43-e/t fish or shrimp)
Milkfish (Philippines)	6.04	NA
Shrimp (India)	3,676.47	NA
Shrimp (Viet Nam)	NA	NA

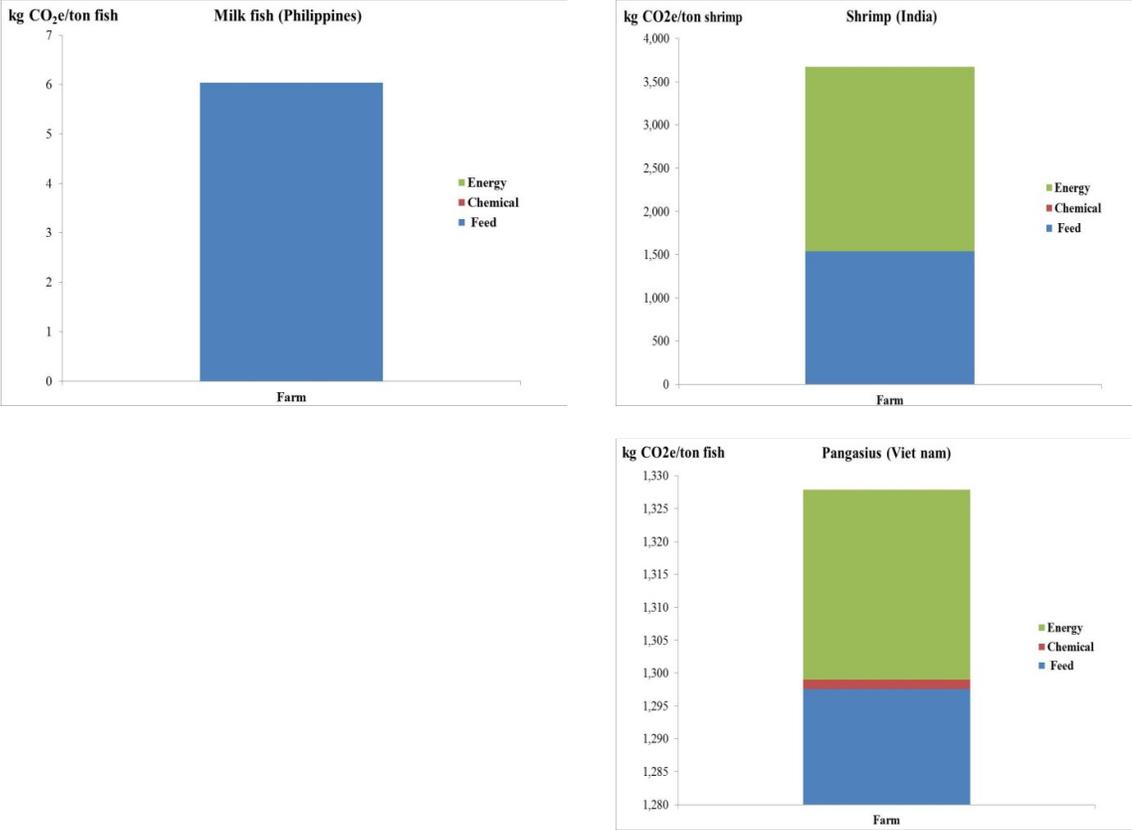| Pangasius (Viet Nam)	1,327.90	NA

Figure 2: Contribution analysis of GWP results of different aquaculture products

4. Discussion

Figure 3 shows the comparative GWP figures of different aquaculture products. The level of GHG emissions of Indian shrimp is lower than Chinese shrimp and French trout, but higher than Canadian salmon, Norwegian salmon, Indonesian tilapia, Vietnamese pangasius catfish, and Filipino milkfish. Vietnamese pangasius and Filipino milkfish are much lower than the others, as it requires rather low level of inputs and no use of electricity.
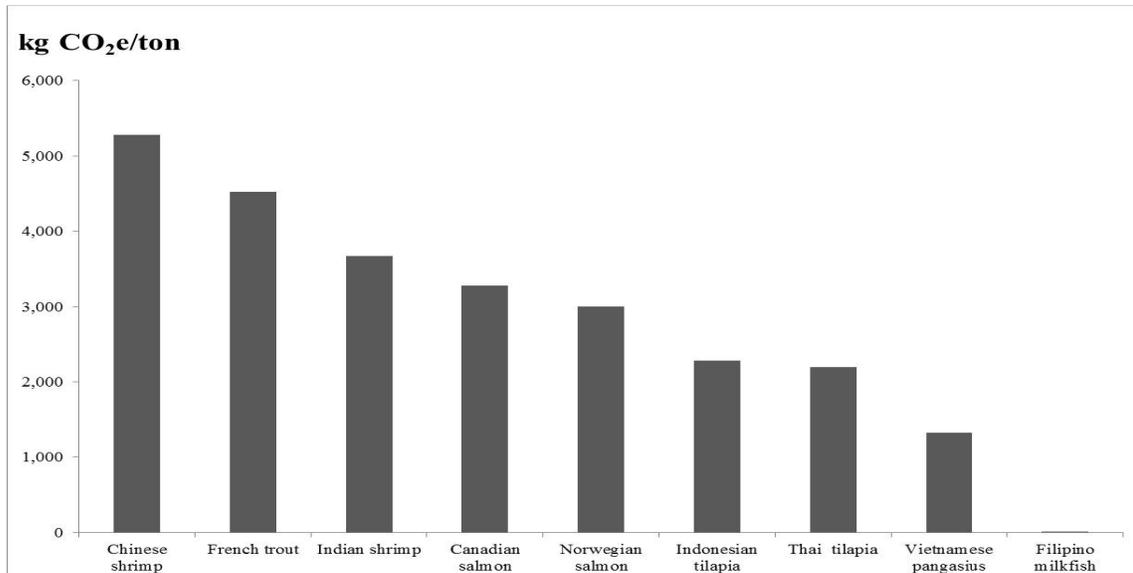
Figure 3: Comparative GWP figures of different aquaculture products

Conclusions

The GHG emissions from aquaculture products are mainly from the use of compound feed and electricity for aerators. Thus, the feeding management and the optimal operation of aerators must be given the attention in order to reduce the GHG emissions. More importantly, the potential impacts associated with feed ingredients especially fish meal and wheat flour should be taken into account at the feed mill. The energy performance of aerators used should also be considered at the farm, i.e. aerators with high-energy efficiency are preferred with the monitoring of optimal level of oxygen in ponds. Another considerable factor affecting to the potential impacts of aquaculture systems are related to the quality of seed which is linked to the farm productivity (though the impacts from seed production itself is rather low) and therefore the GWP values.

2. **Analysis of feed resource use**

Nutrient requirement for the fish and shrimp production in ponds is provided either by natural productivity of the pond or by feed. This ratio varies with the culture system. A large proportion of the nutrient requirements for semi-intensive milkfish pond and shrimp pond production are provided by pond water productivity (phytoplankton, zooplankton and other micro-organisms) which is enhanced by using organic and/or inorganic fertilisers. On the other hand, almost all the nutrient requirements for intensive Pangasius catfish pond production are provided by inert feeds. In some cases aquaculture feed often incorporates high levels of fish meal and fish oil provided from wild stocks and so aquaculture fish may not be a net producer of fish.

Feeds are usually are the most costly aquaculture input, and feed ingredient production, feed manufacture and transport constitute large proportion of energy inputs to aquaculture production.

The efficiency of feed use varies between species, feed quality and feeding strategy. This can vary between culture systems and species where the feed conversion rate for salmon is close to 1:1, Milkfish cage production at 2.5:1 using inert feeds to grouper cage production at 5:1 using trash fish.

Not all the nutrients produced through the feed are taken up by the fish with the majority of nutrients lost to the environment either as solids (uneaten feed or faeces) or as dissolved nutrients (excretion). These nutrients are assimilated by the environment but if there are excess nutrients, they can form an anoxic layer on the seabed surface or cause eutrophication or trigger algal blooms. It also is significant to note that the amount of waste generated per unit of production decreases as the FCR declines.

The most widely used indicator of production and feed use efficiency in aquaculture is the feed conversion ratio (FCR). This indicator is calculated as follows:

FCR =   feed provided, kg
            Net aquacultural production, kg

Aquaculture uses most of the world's fishmeal (68%) and fish oil (88%) with the balance used by intensive livestock agriculture and for pet foods (Tacon, 2005; Tacon et al., 2006; Tacon and Metian, 2008). Salmon, trout and shrimp aquaculture which account for less than 10% of world aquaculture production, use an estimated 26% of the world's fish meal, but 74% of the fish oil (Tacon and Metian, 2008). However, Tacon and Metian (2008) predict that fishmeal and oil use in aquaculture will decrease while aquaculture production grows significantly, and that fish meal/oil will increasingly be diverted from uses as bulk feed products to high priced, specialty, feed ingredients.

Fish Oil
Fish oil also is a component of some of aquaculture feeds. There is a finite supply of fish meal and oil. Because fish oil has traditionally been viewed as a by-product of fish meal production, more concern has been expressed in the past about the fish meal supply than the fish oil supply. The yield of fish oil from reduction fisheries is significantly lower than the yield of fish meal. This suggests that fish oil may in the future be a scarcer commodity than fish meal for use in aquafeeds. It takes 10 to 20 kg live fish to produce a kilogram of fish oil, but the quantity varies greatly by species and season (Tacon et al., 2006).

However, "fish-oil ratios" and feed-fish equivalences that include oil are more difficult to calculate and interpret than those for fish meal because of the large variation in fish oil yield and the history of fish oil as a by-product of fish meal production. Nevertheless, the wild fisheries conservation benefit of substituting vegetable oil for fish oil in aquaculture feeds is great. The main problem with complete substitution is that marine species need long-chain polyunsaturated fatty acids in their diet and fish oils are an excellent source. Also, the fatty acid profile of fish produced on feeds containing only vegetable oil is different than fish produced with feeds containing fish oil, and this may change the taste of the fish.

Fish meal
Fish used for making fish meal are provided primarily from wild pelagic fishery. In fish meal manufacturing, the ratio of live fish to fish meal is about 4.5. Fish meal can also be produced from the offal from processing of wild-caught or farmed fish. Offal contains more ash and less protein than live fish, and fish meal from offal is of lower quality than that from live fish. Nevertheless, fish meal from offal can be used in many applications to supplement marine fish meal. Shrimp heads from processing can be used to make shrimp head meal that can be used in animal feeds.

Environmentalists are concerned over inefficient use of feed fish to make fish meal and fish oil for aquaculture feeds. Feed fish are a component of world fisheries production, and it can be logically argued that unless a Fish-in to fish out ratio (FIFO) of 1.0 or less is obtained, feed-based aquaculture detracts from world fisheries production.

Currently, about 40% of aquaculture depends on formulated feeds: 100% of salmon, 83% of shrimp, 38% of carp (Tacon and Metian, 2008). An estimated 72% of all use of global aquaculture feeds is by low trophic level herbivorous and omnivorous aquatic organisms (carps, tilapias, milkfish and shrimp) each of which dominates in various countries.

Fish-in Fish-out Ratio (FIFO)

One of the current concerns in the aquaculture sector is the amount of wild fish that is required to produce farmed fish. A number of different methods have been developed to calculate the amount of wild fish that it takes to produce one tonne of farmed fish. One such methodology is based on the Fish-in : Fish-out ratio (FIFO ratio). Using dry pellets, FIFO ratios for salmon range between 3:1 to 10:1 with Tacon and Metian (2008) calculating a FIFO ratio of 4.9:1 for salmon production, indicating that 4.9 tonnes of wild fish are required to produce 1 tonne of farmed salmon.

A number of authors have developed methodologies for calculating FIFO ratios. These include:
- Tilapia Aquaculture Dialogue draft v2.0 (WWF, 2009),
- Tacon and Metian (2008),
- International Fishmeal and Fish Oil Organisation (IFFO) methodology (Jackson, 2009),
- EWOS methodology for fatty fish such as salmon (EWOS, 2009)

Table 1. Trends in Fish-In Fish-Out Ratios from 1995 to 2008 (Tacon and Metian, 2008).

Subsidised aquaculture	FIFO (1995)	FIFO (2008)
Salmon	7.5	4.9
Trout	6.0	3.4
Eels	5.2	3.5
Misc. Marine Fish	3.0	2.2
Shrimp	1.9	1.4
Net production aquaculture		
Chinese and Indian major carps		0.2
Milkfish		0.2
Tilapia		0.4
American catfish		0.5
Freshwater prawns		0.6

The following provides a brief review of the assumptions that are used in the various models.

1. Tilapia Aquaculture Dialogue draft v2.0 Methodology

These models are based on the weight of fish caught and produced, and provide Fish Feed Efficiency Ratios for fishmeal and fish oil.

$$FFERmeal = \frac{(\% \text{ fish meal in feed}) \times (eFCR)}{22.2}$$

$$FFERoil = \frac{(\% \text{ fish oil in feed}) \times (eFCR)}{5.0}$$

The model assumes that the fishmeal produced from the fish caught for fish oil is wasted.

2. Tacon and Metian (2009)

The method used by Tacon and Metian (2009) effectively assumes that the excess fishmeal produced from the fish caught for fish oil is wasted. In fact it is used as ingredients and materials for other feed production. The IFFO (2009) method addresses this issue, but fails to recognise that cultured salmon have a higher lipid level than the average wild fish. The models assume a yield of fishmeal and fish oil of 22.5 and 5 percent on a wet weight to dry weight basis respectively.

3. IFFO methodology (Jackson, 2009)

The IFFO method applies the following equation:

$$\text{IFFO FIFO Ratio} = \frac{\text{Level of fishmeal in the diet} + \text{level of fish oil in the diet}}{\text{Yield of fishmeal from wild fish} + \text{level of fish oil from wild fish}} \times \text{FCR}$$

This model corrects the Tacon and Metian (2009) model that implies that the extra fishmeal is wasted and takes into account of both the fishmeal and fish oil use. However, the model is biased against fish with high lipid levels such as salmon, trout and eels due to the differential between some species of cultured fish with high lipid level compared to wild fish used for the production of fish meal and fish oil.

4. EWOS methodology

The EWOS model compensates for fish that have relatively high fish oil concentrations (e.g. salmon) on the basis of nutrients used and produced, and compares the ratios using the same assumptions (fish meal and fish oil yields). The nutrient based ratio corrects this bias, and is the preferred ratios to use for fatty fish such as salmon, trout and eels. The calculations are as follows:

For Marine Protein.

$$\text{Marine Protein Dependency Ratio} = \frac{\text{kg marine protein used}}{\text{kg marine protein produced}}$$

$$\text{MPDR} = \frac{\text{FMfeed} \times \text{PrFM} \times \text{eFCR}}{\text{PrtSalm}}$$

where
MPDR Marine Protein Dependency Ratio
FMfeed Concentration of fishmeal in the feed (%)
PrFM Concentration of protein in fishmeal (as a proportion)
eFCR economic Feed Conversion Ratio
PrtSalm Concentration of protein in the salmon on whole fish basis (%)

For Marine Oil

$$\text{Marine Oil Dependency Ratio} = \frac{\text{Kg marine oil used}}{\text{Kg marine oil produced}}$$

$$\text{MPDR} = \frac{(\text{Fofeed} \times \text{FMfeed} \times \text{FoFM})) \times \text{eFCR}}{\text{OilSalm}}$$

where
MODR Marine Oil Dependency Ratio
FoFeed Concentration of fish oil in the feed (%)
FMfeed Concentration of fishmeal in the feed (%)
FoFM Concentration of fish oil in fishmeal (as a proportion)
eFCR economic Feed Conversion Ratio
OilSalm Concentration of oil in the salmon on whole fish basis (%)

For the purpose of this report, the IFFO formula was adopted and used to analyse the results of this study as the trial species do not have high lipid levels when compared to salmon, and accounts for other uses of the unused fishmeal and fish oil which is not the case with the method used by Tacon and Metian (2009).

The estimated FIFO ratios for the case study culture systems used the following formula;

$$\frac{\text{Level of fishmeal in the diet} + \text{level of fish oil in the diet}}{\text{Yield of fish meal from wild fish} + \text{yield of fish oil from wild fish}} \quad \times \quad \text{FCR}$$

The results indicate that the FIFO ratio for the case study culture systems was as follows

Table 2. Results of AquaClimate case study analysis for FIFO Ratio

Case study culture system	FIFO
Shrimp pond culture, India	1.23
Pangasius pond culture, Vietnam	0.28
Shrimp pond culture, Vietnam	0.07
Milkfish pond culture, Philippines	0.00

The difference between the Indian and Vietnamese shrimp FIFOs is in large part because the Vietnamese system depends on natural productivity rather than feed input; catfish and milkfish FIFO is low because they are omnivorous/herbivorous and can be grown on lower protein diets / algal mats

The case study results were benchmarked against other estimated FIFO ratios as follows:

Table 3.Fish In Fish Out Ratios (Adapted from Tacon and Metian, 2008)

Subsidized aquaculture	FIFO (2008)
Salmon	4.9
Trout	3.4
Eels	3.5

Misc. Marine Fish	2.2
Shrimp	1.4
Shrimp in India (AC)	1.23
Net production aquaculture	
Freshwater prawns	0.6
American catfish	0.5
Tilapia	0.4
Pangasius catfish (AC)	
Chinese and Indian major carps	0.2
Milkfish	0.2
Shrimp in Vietnam (AC)	0.07
Milkfish in Philippines(AC)	0.0

*AC = AquaClimate results

Figure 1. Comparison of wild fishery resource use efficiency (Fish-in Fish-out ratio)
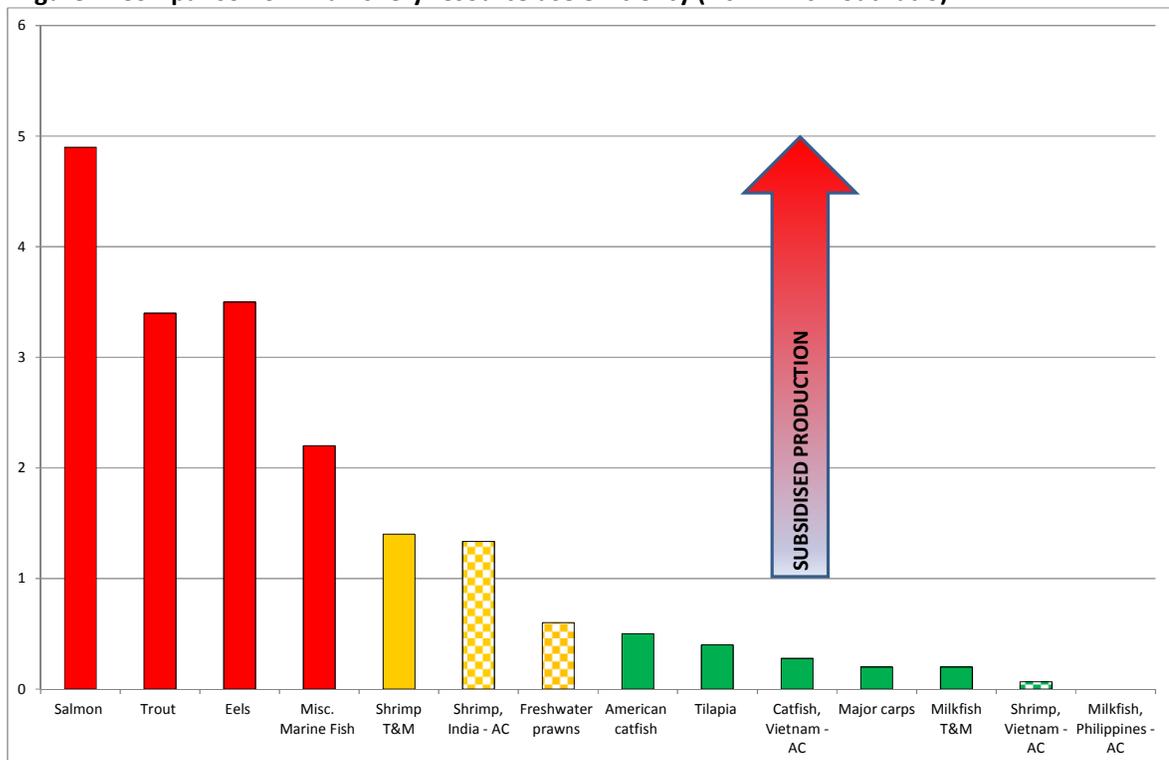
Note. There is a difference in the intensities of the production systems. Vietnamese shrimp systems are 'low' intensity shrimp culture systems Indian shrimp and Philippine milkfish are 'medium' intensity culture systems and Pangasius catfish culture systems are very intensive culture systems.

3. **Analysis of water Resource use**

Water use in aquaculture can be extreme—as high as 45 m3/kg of fish production (FAO). The potential for increased water use efficiencies in aquaculture is higher than terrestrial systems. Globally about 1.2 m3 (or 1200 liters) of water is needed to produce 1 kg of grain used in animal feed (Verdegem et al., 2006). A kg of tilapia can be produced with no consumptive freshwater use (cages, seawater farming systems), or using as little as 50 L of freshwater (Rothbard and Peretz, 2002). Seawater aquaculture systems (mariculture) can use brackishwaters unsuitable for agriculture; plus, integrated, land-based saltwater faming is possible (Fedoroff et al., 2010).

Water use in aquaculture may be classified as either total use or consumptive use (Boyd, 2005). Total water use is the sum of all inflows (precipitation, runoff, seepage, and management additions) to production facilities. Much of the water entering production facilities passes downstream in effluent discharge. Consumptive water use includes reduction in stream flow as a result of increased evaporation and seepage from the aquaculture facility, freshwater from wells, and water removed in biomass of aquatic animals at harvest (Boyd, 2005). Water in harvest biomass averages about 0.75 m3/t, a minor quantity that usually can be ignored.

Boyd (2005) proposed indices for water use and water value that can be calculated for either total or consumptive use as follows:

Water use index,m3/t = $\dfrac{\text{Water use,m3}}{\text{Production, t}}$

Total water use varies greatly in aquaculture depending mainly upon the culture method used. Cage and net pen culture use water passively as it passes through the nets by the currents and raceway culture uses the most water where water actively passes through the tanks by gravity or pump. Water use in ponds varies with the intensity of production, frequency of draining, and amount of water exchange employed.

Consumptive use of freshwater in aquaculture is an important conservation issue. Total and consumptive water use is the same for cage and net pen culture, for the only water consumed is that incorporated into biomass. In raceway culture, water in biomass plus evaporation from raceways is consumptive use.

Table 3. Results of AquaClimate case study analysis for water use

Case study culture system	m^3/t
Shrimp pond culture, Vietnam	47,500
Shrimp pond culture, India	33,155
Milkfish pond culture, Philippines	8,010
Pangasius pond culture, Vietnam	1,327

These results were benchmarked against other estimates of water resource use as follows;

Table 4. Low water use - Average use less than 3000 cubic meters/tonne product. Adapted from Costa-Pierce

Systems	Estimated water use (m^3/t product)	Comments
Seawater farming (halophytes, marine fish, shellfish, seaweeds, euryhaline fish such as tilapia)	0 - 100	Freshwater use is for makeup waters to replace evaporation in land-based farming systems. Hodges et al. (1993); www.seawaterfoundation.org; Federoff et al. (2010)
Recirculating aquaculture systems	500 - 1,400	Intensive Africa catfish, eel and turbot fed complete feeds Verdegem et al. (2006)
Pangasius culture in Vietnam	1,327	Intensive striped catfish culture in ponds using complete feeds. AquaClimate

Freshwater fish production	2,700	Intensively mixed pond with production of 100 MT/ha/yr. Verdegem et al. (2006)
Tilapia	2,800	Brummett (1997)

Table 5. Medium water use   Average use 3000 - 10,000 cubic meters/tonne product

Systems	Estimated Freshwater Use (m^3/t product)	Comments
Catfish	3,350 (with reuse for irrigation)	Brummett (1997)
Catfish	4,000 - 16,000 (low - undrained embankment ponds, high - drained watershed ponds)	Eliminating well water as consumptive use would decrease water use in embankments ponds to 2,600 - 3,200. Boyd (2005)
Fish in freshwater ponds	5,200	If infiltration, drainage and recharge are considered green water
Pangasius catfish Vietnam	6,400 average industry wide	Phan et al. (2009)
Fish in freshwater ponds	4,700 - 7,800	Production of 10-20 MT/ha/yrwith night time aeration
Milkfish culture in the Philippines	8,010	Semi-intensive milkfish culture in ponds using supplementary feeds. AquaClimate

Table 6. High water use (average use >10,000 cubic meters/tonne product)

Systems	Estimated water Use (m^3/t product)	Comments
Shrimp farming in ponds	11,000 – 43,000	Beveridge et al. (1991) *
Fish culture	11,500	Fed freshwater species Verdegem et al. (2006)
Trout (90% recycling)	25,000 (252,000 withdrawal)	Brummett (1997)
Fish in freshwater ponds	30,100	Production of 30 MT/ha/yr with20% water exchange Verdegem et al. (2006)
Shrimp culture in India	35,155	Semi –intensive striped monodon shrimp culture in ponds. AquaClimate
Extensive fish culture	45,000	No feed Verdegem et al. (2006)
Shrimp culture in Vietnam	50,179	Semi –intensive striped monodon shrimp culture in ponds. AquaClimate
Pangasius catfish Vietnam	up to 59,700	Wide range from 700 to 59,700 Phan et al. (2009)
Trout (75% recycling)	63,000 (252,000 withdrawal)	Brummett (1997)

* This figure may not still be accurate as in the 90's shrimp farms used to undertake regular water changes. However, that practice stopped when whitespot virus became prevalent and farmers minimised water exchange to reduce risk of disease entry.

Figure 2. Comparison of direct water use efficiency (m³/t)
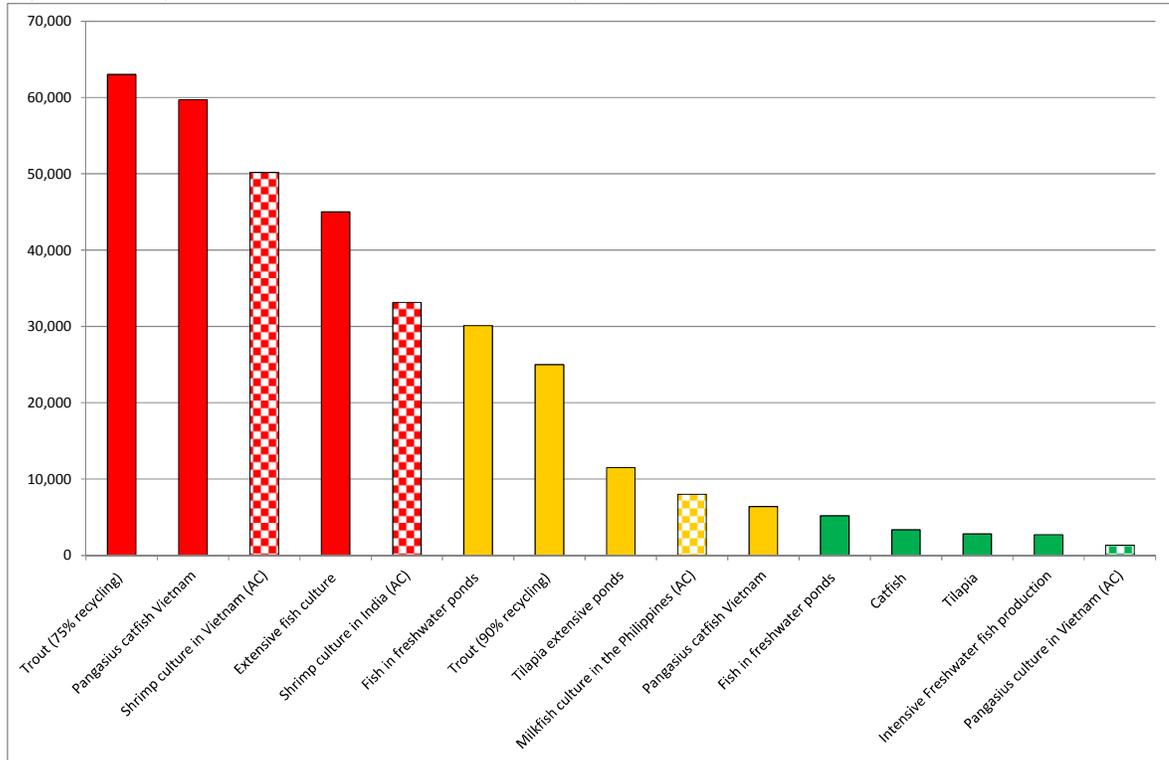
Note. There is a difference in the intensities of the production systems. Vietnamese shrimp systems are 'low' intensity shrimp culture systems Indian shrimp and Philippine milkfish are 'medium' intensity culture systems and Pangasius catfish culture systems are very intensive culture systems.

Total water use is important where water is pumped into aquaculture facilities, for there is an energy cost for doing so. In marine shrimp culture, large amounts of water may be pumped into ponds to effect water exchanges. Total water use also is important where water right issues are involved.

Competition may occur between aquaculture and other water uses (Yoo and Boyd, 1994; Boyd et al., 2005). Withdrawal of groundwater for use in ponds may lower water table levels and lessen the discharge of other wells in the vicinity. Installation of several ponds on a watershed may lessen downstream flow. Some large, flow-through aquaculture facilities may take water from streams, irrigation systems, or other sources and discharge into different water courses. Although these aquaculture facilities do not consume large amounts of water, they may alter downstream flow patterns and lessen the amount of water available to other users. Cage and net pen culture consumes little water and coastal ponds for brackish water aquaculture consume none. Nevertheless, these facilities may interfere with the use of water bodies or adjacent land areas by other resource users.

Table X Comparison of Aquaculture production against other livestock production

Case study culture system	m³/t	
Shrimp pond culture, Vietnam	47,500	AquaClimate
Beef	15,000 -43,000	Smil (2008); Pimentel and Pimentel (2003)
Shrimp pond culture, India	33,155	AquaClimate
Pork	10,000	Smil (2008)

Milkfish pond culture, Philippines	8,010	AquaClimate
Pork	6,000	Pimentel and Pimentel (2003)
Chicken	4,000	Smil (2008)
Broiler Chickens	3,500	Pimentel and Pimentel (2003)
Egg production	2,700	Verdegem et al. (2006)
Milk production	2,700	Verdegem et al. (2006)
Pangasius pond culture, Vietnam	1,327	AquaClimate

4. **Analysis of land resource use**

Aquaculture uses land in two ways. First, aquaculture facilities occupy a defined area or space on land or in water; however, facility area accounts for only a portion of the total land or water area needed to produce an aquaculture crop. Additional ecosystem area is needed to provide support or service functions. The two most important of those functions are food production and waste treatment (Boyd, 2006; Boyd and Polioudakis, 2006).

Land-based aquaculture converts land surface area to water surface area. Pond production data reflect this land use when reported as biomass harvested per unit water surface area. However, land use for production facilities in not always conveniently reported in area terms. Production in raceways, tanks, and indoor water reuse systems is reported on a volume (kg/m3, for example) or water-flow (kg/m3 per sec, for example) basis because the culture unit surface area usually is small. Cages, net pens, and shellfish plots do not use land in the traditional sense, but they occupy space in water bodies.

When expressed on an area basis, the land or water area needed per unit production of aquaculture crop varies over more than two orders of magnitude. At one extreme are highly intensive water recirculating systems, which are capable of annually producing 1,000 to 2,000 tonnes of fish per hectare of culture unit (Timmons et al., 2001) or 350 tonnes of Pangasius catfish per hectare. Fish and shrimp production in ponds requires several hundred times the land area compared with intensive recirculating systems.

In addition to surface area devoted to culture of aquatic organisms, land surface area must be dedicated to support of production facilities. Pond aquaculture requires embankments, intake and discharge canals, settling basins, and pump stations. Aquaculture facilities have access roads, parking lots, storage areas, staging areas, space for administrative and service buildings, etc. Boyd (2010) estimated that with watershed catfish ponds in Alabama that the land used for support purposes typically is about 25% of pond water surface area. Watersheds normally have other uses, and although necessary for aquaculture, they are not dedicated specifically to aquaculture.

In marine shrimp culture, canals are used to supply and discharge water at farms. Farms of 25 ha or more in size usually have support areas of about 25% of water surface areas, but the support area may increase to as much as 50% at smaller farms. Catfish pond facilities in Mississippi typically have only 10–15% of the total land area devoted to support, and the support area as a proportion of total land area decreases slightly as farm size increases (Keenum and Waldrop, 1988). For a farm with a total land area of 65 ha, 2% of the area is used for buildings, parking, feed storage, etc., 13% of the area is in embankments, and the water surface comprises 85% of the area. For a farm with a total area of 260 ha, the estimates are 1%, 11%, and 88%, respectively.

Table 7. Results of AquaClimate case study analysis for land use

Case study culture system	m^2/t
Shrimp pond culture, Vietnam	80,594

|	
Shrimp pond culture, India	14,095
Milkfish pond culture, Philippines	2,339
Pangasius pond culture, Vietnam	24.16

The large land use by shrimp farming in Vietnam again reflects the very low intensity of the system.

These results were benchmarked against other estimates of water resource use as follows;

Table 8. Efficiencies of land use for aquaculture system. Adapted from Verdegem et al. (2006).

System types	Descriptions	Production (kg/ha/year)	Efficiency of land use (m2/MT)
Extensive	On-farm resources	100 - 500	20,000 - 100,000
Semi-intensive shrimp (Vietnam)	Very low intensity system with some supplemental feed use	120	80,594
Extensive	On-farm resources, fertilizers	100 - 1000	10,000 - 100,000
Semi-intensive shrimp (India)	Low intensity system with supplemental feeds,	710	14,095
Semi-intensive	Supplemental feeds, static	2,000 - 8,000	1,250 - 5,000
Extensive Milkfish (Philippines)	Supplemental feeds,	4,270	2,339
Semi-intensive	Supplemental feeds, water exchanges	4,000 - 20,000	500 - 2,500
Semi-intensive	Supplemental feeds, water exchanges, night aeration	15,000 - 35,000	300 - 700
Intensive	Complete feeds, water exchanges, night aeration	20,000 - 50,000	200 - 500
Intensive	Complete feeds, water exchanges, constant aeration	20,000 - 100,000	100 - 500
Intensive Pangasius (Vietnam)	Complete feeds	4,130,000	24.16

Figure 3. Comparison of land use efficiency (m^2/t log scale)
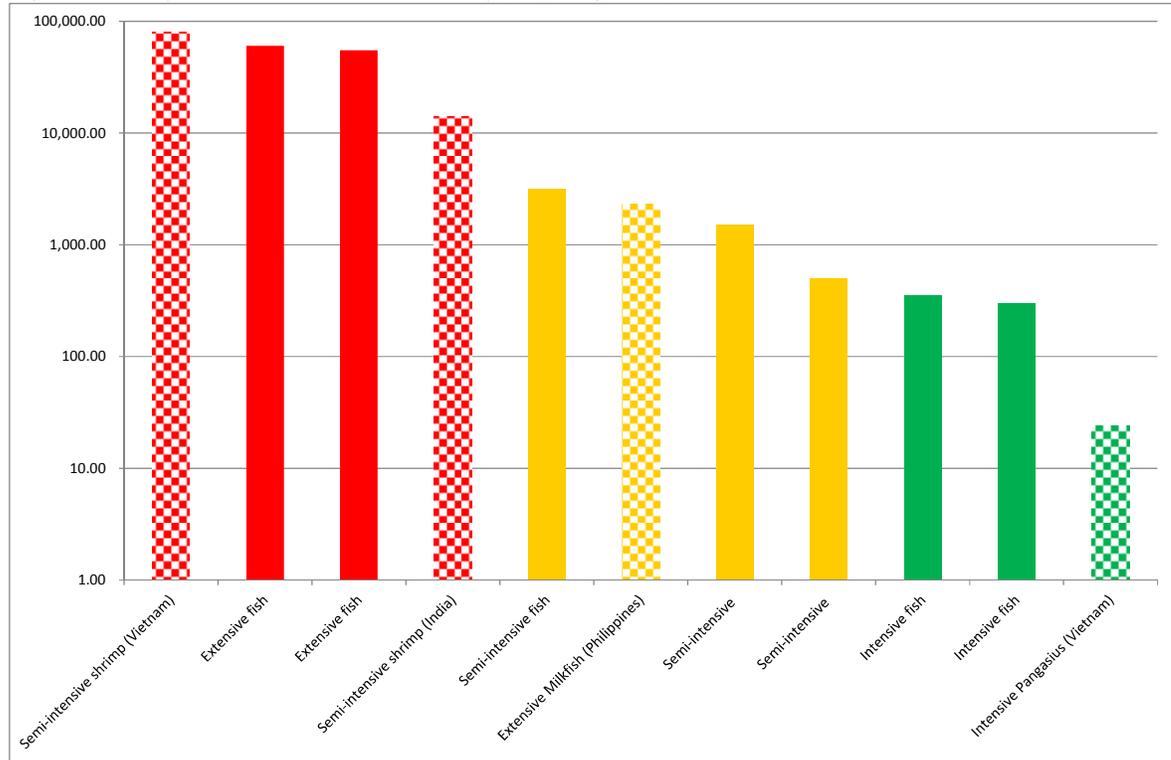
In addition to the physical space occupied by the facility, land is required to produce plant meals and oils for aquafeeds. Corn meal, soybean meal, peanut meal, cottonseed meal, wheat middlings, rice flour, and vegetable oils are common plant products used in aquafeeds. Cotton seed meal and wheat middlings are by-products of cotton fiber and wheat flour production. Vegetable oils are extracted from soybeans, peanuts, corn, and other seeds in the process of making meals. Their use in aquafeeds usually does not require land dedicated specifically for production. Land must be dedicated specifically for the production of corn, soybean, peanut, and certain other plant meals used in aquafeeds.

In addition to land area for facilities and to produce food, ecosystem area is needed to assimilate wastes produced during aquaculture. In ponds and recirculating systems, significant quantities of waste produced during culture are treated within the facility, and there is relatively little external area needed for waste treatment. On the other hand, much of the waste produced in raceway and net pen culture is discharged directly to the outside environment. The ability of the external ecosystem to assimilate those wastes may limit aquaculture production either by polluting the surrounding water to the point where animal welfare inside the facility is endangered ("self-pollution") or by imposing limits to the amount of waste that can be discharged due to regulatory constraints. In addition to effects on aquaculture production, waste discharge into public waters creates societal externalities such as degraded water quality, water treatment costs, and other downstream impacts.

However in this study we do not estimate land requirement for feed ingredient production or effluent water treatment.

5. **Analysis of energy resource use**

There are many uses of energy in aquaculture including energy used for construction of facilities, production of liming materials, fertilizers, production and transport of feed and feed ingredients,

operation of machines and vehicles during culture and harvesting, processing, transportation, etc. However, only two of these energy inputs can be readily estimated at the farm level. These are energy uses for pumping water and for mechanical aeration, and, at the farm level, they are the major, direct energy inputs. This discussion will be limited to pumping and aeration, but studies of total energy use per tonne of aquaculture production should be conducted for a number of species and culture methods.

Mechanical aerators powered by internal combustion engines or electric motors are used to supplement the natural supply of dissolved oxygen in grow-out systems. Aeration allows greater stocking and feeding rates to increase production.

Aeration rates in pond aquaculture often are expressed in horsepower per hectare or horsepower applied per volume (Boyd and Tucker, 1998). In channel catfish farming, aeration usually is applied at 4 to 8 hp/ha, while in intensive marine shrimp culture, rates of 10 to 30 hp/ha may be applied. Use of electricity typically is measured in kilowatt·hours (kW·h), and 1 hp = 0.745 kW. However, there are inefficiencies in the use of electricity by machines, and for aerators, the typical efficiency is about 90% (Boyd, 1998). Thus, electricity use for aeration can be estimated as follows:

$$\text{Aeration energy, kW} = \frac{\text{Aerator power, hp} \times \text{Aeration time, hr} \times 0.745 \text{ kW/hp}}{\text{Production, t} \times 0.9}$$

Aerators in channel catfish ponds in the southeastern United States normally are operated between May and September for about 10 h/night. Aeration at 6 hp/ha in a catfish pond will use 7,599 kW·h of electricity during a crop year or about 950 kW·h/t for production of 8,000 kg/ha.

Production of marine shrimp in a pond with 15 hp aeration/ha might be 8,000 kg/ha for a 120-day crop. Aeration usually is supplied 24 h per day for at least 100 days, but only half of the aerators may be operated during the day. The total electrical use will be about 27,000 kW·h or 3,375 kW·h/t—over three times the amount of aeration used for channel catfish.

In Asia, paddlewheel aerators often are driven by small, internal combustion engines powered by diesel fuel or gasoline. Energy use can be estimated from fuel consumption; 1 L diesel fuel is equal to 3.27 kW-h while 1 L of gasoline equates to 2.21 kW-h (Yoo and Boyd, 1994).
The energy use for pumping water to supply ponds can be estimated as follows:

$$P = \frac{\gamma QH}{E}$$

where P = power required by pump (kW), γ = specific weight of water (9.81 kN/m3), Q = discharge (m3/sec), H = pumping head (m), and E = pump efficiency (decimal fraction).

Boyd and Tucker (1995) used this equation and water management data to estimate that about 1,275 kW·h of electricity typically would be used to fill a 1-ha channel catfish ponds. Annual energy use for pumping water to maintain water levels would be less than 500 kW·h in humid climates and up to 2,000 kW·h in arid climates. Assuming total energy use of 1,775 kW·h//ha per year for catfish ponds in a humid climate, the energy use for pumping would be about 296 kW·h/t as compared to 950 kW·h/t for aeration.

Table 9. Results of AquaClimate case study analysis for energy use

Case study culture system	MJ/t
Shrimp pond culture, India	57,718

|	
Pangasius pond culture, Vietnam	1,287
Shrimp pond culture, Vietnam	517
Milkfish pond culture, Philippines	2

The Indian shrimp culture system has a much larger energy use compared to the other culture systems due to the use of pumps and aerators. Al though Pangasius catfish culture also uses pumps for water exchange, Pangasius catfish energy use is surprisingly efficient because of the economies of scale offered by its extreme intensity. The Vietnamese shrimp and milkfish power use is low because they don't use aeration and/or are system is tidally fed.

These results were benchmarked against other estimates of water resource use as follows;

Table 10. Efficiencies of energy use for aquaculture system. Adapted from Costa-Pierce

Food Systems	Production (MT/ha)	MJ/MT	References
Canada Salmon Net Pen Water-Based	1,000	26,900	Ayer and Tyedmers (2008)
Canada Salmon Bag System Water-Based	1,733	37,300	Ayer and Tyedmers (2008)
Canada Salmon Flow-through Land Based	2,138	132,000	Ayer and Tyedmers (2008)
Canada Salmon Recirculating Land-Based	2,406	233,000	Ayer and Tyedmers (2008)

Table 4. Comparison of direct energy use efficiency (MJ/t)
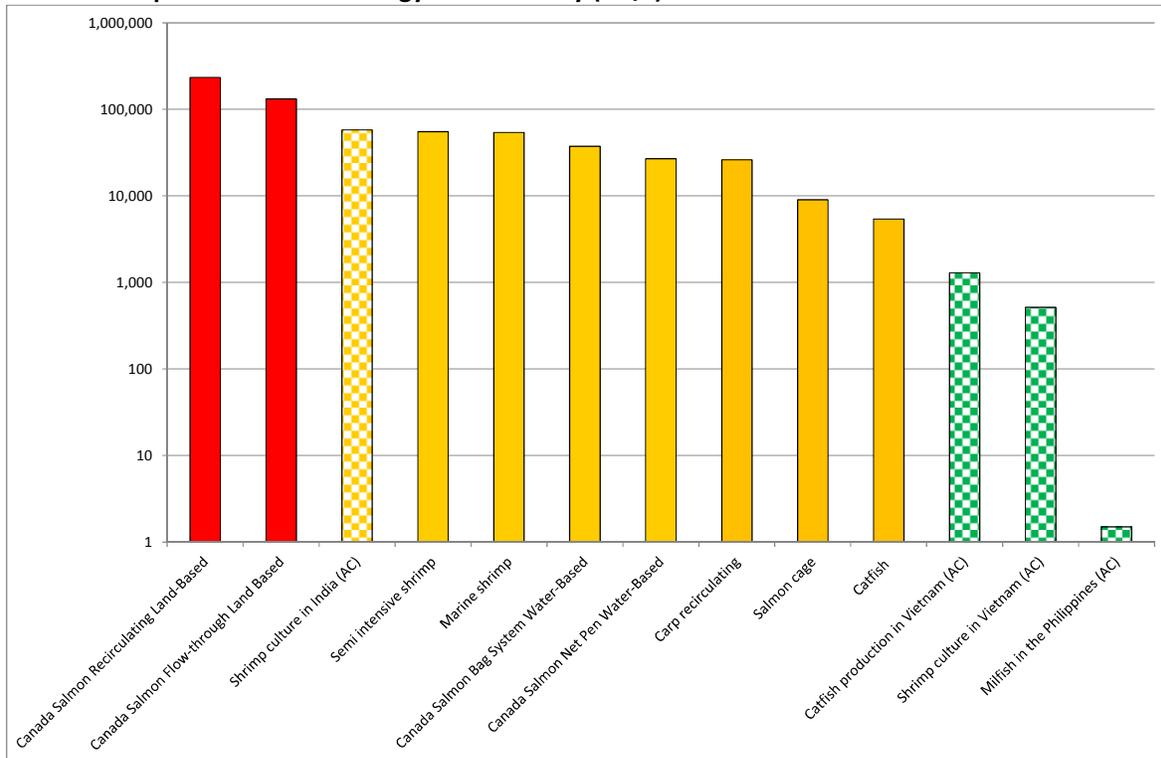
Note. There is a difference in the intensities of the production systems. Vietnamese shrimp systems are 'low' intensity shrimp culture systems Indian shrimp and Philippine milkfish are

'medium' intensity culture systems and Pangasius catfish culture systems are very intensive culture systems.

Studies using modified LCA methodology consistently show that the energy used to produce aquafeeds dominates the energetics of aquaculture production. For example, more than 75% of the total energy cost of producing Atlantic salmon in net pens is used in procuring or growing feed ingredients and manufacturing the feed (Folke, 1988; Troell et al., 2004; Tyedmers, 2004; Ellingsen and Aanondsen, 2006). The remaining energy inputs, in order of importance, were fuel and electricity used to operate the facility, embodied energy costs (manufacture, maintenance, etc.) associated with physical infrastructure, and energy used to produce smolts). Feed production dominates the energy budgets of all aquaculture systems relying on aquafeeds, regardless of species (Troell et al., 2004).

Life-cycle assessment of energy use can include post-harvest functions such as processing, freezing, refrigeration, storage, transportation, marketing, waste treatment, and even household activities such as refrigeration, freezing, and cooking. Energy use in these activities apparently has not been assessed for aquaculture but may be an important part of the overall energy costs of delivering aquaculture products to a consumer's plate. For example, energy used in on-farm production of the United States food supply accounts for only about 20% of the energy used to deliver food to the consumer's plate (Heller and Keoleian, 2000). Post-harvest processing and transportation each consume about 15% and household preparation accounts for more than 30% of the total energy consumed. Ultimately, it will be economically and socially imperative to improve the energy efficiency of all aspects of the food-supply chain. However, it is possible that greater overall gains in energy savings can be made by improving the efficiencies of processing, transport, retailing, and even household storage and preparation than can be made by improving energy efficiency in the production sector. This may have particular relevancy in aquaculture, where important products are produced only in certain regions (marine shrimp in the tropics; salmon in the north-temperate) and are stored and shipped long distances for ultimate consumption.

Energy comparisons between systems have become part of more detailed analyses of life cycles (Papatryphon et al., 2004; Ayer and Tyedmers, 2008). Comparisons of these with terrestrial farming show clearly the huge production benefits of intensive aquaculture albeit at a much higher energy cost, contained mostly in feed (Ayer and Tyedmers, 2008). Over the coming decades, increasing global energy, processing, shipping/transportation costs of both products and feeds are predicted (FAO, 2008; Tacon and Metian, 2008).

In this study, we only consider the use of energy on the farm.

Table X Comparison of Aquaculture production against other livestock production

Case study culture system	MJ/t	Reference
Shrimp pond culture, India	57,718	AquaClimate
Norwegian Chicken	55,000	Munkung and Gheewala, 2007
Swedish Beef	33,000	Munkung and Gheewala, 2007
Pangasius pond culture, Vietnam	1,287	AquaClimate
Shrimp pond culture, Vietnam	517	AquaClimate
Milkfish pond culture, Philippines	2	AquaClimate

6. **Analysis of wild seed and broodstock resource use**
   Capture-based aquaculture (CBA) does not have full control of the life cycle and relies on the collection of seed, fry, fingerlings or broodstock from the wild. In other cases a proportion of the

seed is still collected from the wild as there is insufficient production of seed from hatcheries or broodstock collected from the wild as it is difficult to condition mature broodstock artificially.

It is also used on low-value fish species that are sometimes extensively farmed with minimum inputs. The main concern related to the collection of wild seed or broiodstock is whether the wild fishery has a negative impact on wild stocks of the targeted species as well as non-targeted species.

Much is still unknown about early life history stage dynamics, however it is assumed that there is some degree of linkage between seed collection and adult fisheries particularly when billions of seeds taken each year such as was the case for milkfish.

Milk fish

Milkfish fry can either be obtained through collection from coastal areas or littoral waters or can be produced in captivity. The supply of wild fry is often unpredictable; catches in recent years have diminished and cannot satisfy the demand from ongrowing farms. Milkfish fry are phemonenally abundant. Total catch potentials are not known but some 1.35 billion fry were collected in the Philippines in 1974 and 700-800 million fry are collected in Indonesia each year. These fry go into a grow-out culture industry that produces 285 000t of milkfish a year in southeast Asia.

Wild-caught fry are collected with fine-mesh seines and bag nets of various indigenous designs and the most commonly used gear are push net 'sweepers' and dragged seines.

Shrimp

Due to their larger size and better survival, captured wild seeds were used commonly in south Asia for extensive ponds, which require a minimal amount of seed for stocking. However, the use of wild seeds has been reduced, due to overfishing and the outbreak of white spot disease in shrimp nursery grounds. Therefore most Penaeus monodon grow-out farms now rely solely on hatchery-produced seeds.

Indian monodon shrimp hatcheries were totally dependent upon the capture of gravid females from the wild as a by catch from near shore shrimp trawling but there were shortages and it was found that wild shrimp have a prevalence of MBV and WSSV. When MBV is less WSSV is more significant and vice versa. This has triggered the research to condition broodstock in ponds.

Pangasius

Traditionally, aquaculture enterprises in the Mekong Basin were capture-based. Large numbers of tra catfish larvae (Pangasianodon hypophthalmus) were, until recently, caught in the upper Mekong delta near the border between Viet Nam and Cambodia. The fishery was concentrated in Chao Doc and Tan Chau districts of An Giang Provinces in Viet Nam. Estimates from 1977 suggest that 200 to 800 million fry, 0.9 – 1.7 cm in length, were caught annually (based on data from An Giang Department of Agriculture, cited in Trong, Hao and Griffiths, 2002). Pangasianodon hypophthalmus were first artificially propagated in Thailand in 1959, and the technology has since spread throughout south-east Asia (Trong, Hao and Griffiths, 2002).

However the aquaculture of Pangasiid catfishes is now largely based on hatchery produced seed. In 2006 there were 130 hatcheries (An Giang 15; Can Tho 5; Tien Giang 4; Vinh Long 3; and Dong Thap 103) in the Mekong Delta region of Viet Nam producing 10 billion catfish larvae and the production of Pangasianodon hypophthalmus fingerlings reached 1 billion

7. **Resource use and Global Warming Potential mitigation strategies**
Fishmeal and fish oil use
Research on the use of agricultural meals and oils to replace use of fish meals and fish oil is a major subject of aquaculture research and development (Watanabe, 2002; Opstvedt et al., 2003). Turchini et al. (2009) reported that for all of the major aquaculture fish species 60–75% of dietary fish oil can be substituted with alternative lipid sources without significantly affecting growth performance, feed efficiency, and feed intake.

Terrestrial proteins and oils from soybeans, sunflowers and lupins are more readily available than the fishmeal supplies. Soybeans have high protein content of around 28%, peas have around 22%, and these have good amino acid profiles. However, soybean meal processing can create protein concentrates with protein levels of greater than 50% (Bell and Waagbo, 2008). Vegetable oils have very low EPA and DHA levels. However, substitution of plant oils upwards of 50% of added dietary oil has not resulted in growth reductions or increased mortalities in fish such as salmon and trout.

Further research is required to identify feed ingredients that have the potential to eliminate the needs for fishmeal and oils in aquaculture. For example beta-glucans that stimulate the immune system of fish and protect against the effects of bacterial furunculosis also allow reductions in fishmeal contents in diets to 25% (Skretting). Phospholipids and antioxidants from other feed ingredients (such as algal, bacterial, yeasts meals and oils) have the potential to provide the required nutrient for good production performance with the inclusion of no marine fishmeal and oil.

Water use (to be expanded)
Intensification
Biosecurity

Land use (to be expanded)
Intensification

Recapture (to be expanded)
Mangroves
Rice
Orchards

8. **Better management practices to reduce greenhouse gas emissions and resource use (to be expanded)**

Existing BMPs for shrimp, catfish should serve as a starting point, as they are basically about improving resource use efficiency and animal health, and will reduce greenhouse gas emissions simply by reducing wastage. E.g.:

- Emission - reducing management strategies that also improve farmer income include:
    - Improving animal health (everything from good pond preparation to screening seed for disease), to reduce mortalities and crop losses. This ultimately reduces wastage of feed and other inputs, and keeps the real world FCR and FIFO good.
    - Other better management practices (for example there are quite a few things that can be done to optimise feed use (although seldom practiced), such as feeding to

support the economically optimum growth rate rather than the biological maximum, mixed feeding schedules, monitoring and storage etc.)
- o Selective breeding to improve biological performance of the animals per unit input.
- Resource reduction strategies
  - o The case study data suggest that a moderate degree of intensification can dramatically improve efficiency with regards to water and land use, probably power too. It is worth noting that the most intensive system - catfish - is also the most efficient user of power, land, water (this is partly also a species difference - tough, air breathing, tolerant of crowding, deep ponds and environmental difference - Mekong water supply).
  - o Grow low food chain species - herbivorous milkfish and omnivorous catfish are more efficient from a FIFO perspective than carnivorous shrimp.
  - o Etc.

9. Conclusion

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