Feeds and fertilizers for sustainable aquaculture development: a regional review for Latin America

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Flores-Nava, A. 2007. Feeds and fertilizers for sustainable aquaculture development: a regional review for Latin America. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 49–75.

SUMMARY

In 2004 total aquaculture production in Latin America (South and Central America and the Caribbean) was 1.32 million tonnes. This review focuses on six countries (Brazil, Chile, Cuba, Ecuador, Mexico and the Bolivarian Republic of Venezuela), which collectively accounted for 86.8 percent of the total production. The balance is contributed by 29 other countries. Chile is the largest producer country contributing 51 percent to total production.

Given the semi-intensive and intensive nature of most production systems, there is an almost exclusive dependence on manufactured feeds throughout the region. Although fertilizers, chiefly inorganic, are still widely used there is a gradual decline in organic and inorganic fertilizer use as farmers are shifting to more intensive systems.

High quality aquafeeds are produced for at least 9 species, in more than 200 feed mills throughout the region. Sinking as well as extruded floating pellets are available in a wide range of sizes. Protein levels, depending on the species, range from 25 to 42 percent. In 2003 Chile produced 750 000 tonnes of high protein feeds for Atlantic salmon and is the largest producer in the region. Feeds for marine shrimp and tilapia follow in terms of volume, and these are produced and traded in a number of countries in the region.

Despite the regions high biodiversity and availability of agricultural and industrial by-products little has been done to gradually replace fishmeal, fish oil and soybean meal. The price of these feed commodities is increasing due to rising demand and climate induced erratic supplies, hence feed prices will continue to escalate.

The Latin American aquafeed industry maintains close links with farmers and provides them with technical assistance and credit. This relationship influences the feeding regimes and practices, which are practically the same throughout the region. Farmers are increasingly forming clusters, which allow them to use economies of scale, implement quality assurance strategies and strengthen their capacity to comply with international food safety requirements. As a consequence traceability and food safety programmes are rapidly being adopted by the industry and governments are gradually following suite.

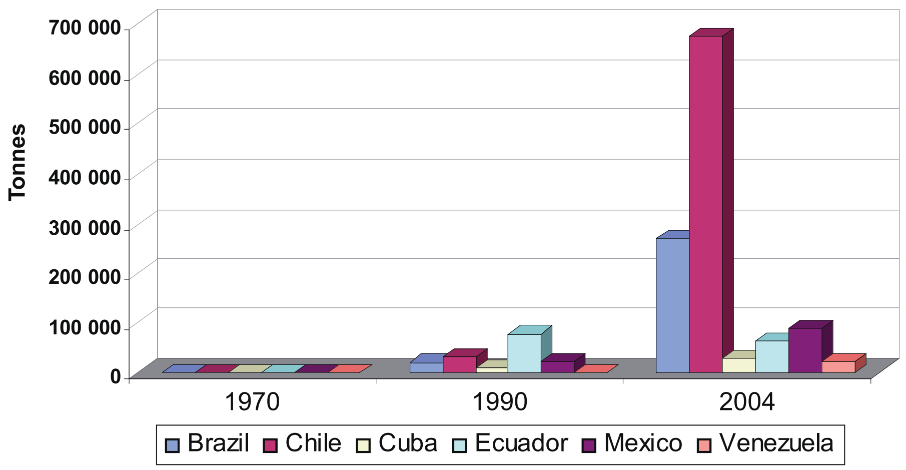
In response to disease outbreaks and national environmental regulations, heterotrophic systems are gradually becoming common in the region, especially in shrimp and tilapia farms. This presents opportunities for reducing aquaculture discharges into the environment and improved feed utilization.

Small-scale aquaculture and agriculture farmers that wish to integrate aquaculture into their traditional agricultural systems are constrained by the high cost of formulated feeds and the lack of basic knowledge on the use of locally available ingredients for the production of low cost, farm-made feeds. This could make a significant contribution to the economic sustainability of rural aquaculture, thus benefiting large sectors of the population.

1. GENERAL OVERVIEW OF AQUACULTURE IN LATIN AMERICA

In 2004, the estimated total aquaculture production (excluding seaweeds and aquatic plants) for the Latin American region (South and Central America and the Caribbean) was 1.32 million tonnes, representing 2.3 percent of the global aquaculture production (FAO, 2006a), showing an overall average growth of 21.3 percent per year during the period 1950–2004 (FAO, 2006b). Throughout the region the aquaculture sector has been growing rapidly in the last decade. Since 1994 total production for the region has increased by 73 percent. This review focuses on the six countries (Figure 1), which on a combined basis account for 86.8 percent of the regions total production.

FIGURE 1
Aquaculture production statistics for the six most important producer countries in Latin America for 1970, 1990 and 2004



Source: FAO (2006a)

The six countries included in this review are Brazil, Chile, Cuba, Ecuador, Mexico and Bolivarian Republic of Venezuela. In 2004, Chile contributed 51.1 percent of the regional total, based chiefly on the production of Atlantic salmon (*Salmo salar*), followed by Brazil (20.4 percent) with a more diversified industry in which Pacific white shrimp (*Litopenaeus vannamei*) is the most important and with increasing production levels of tilapia, carp and native finfish such as the tambaqui (*Colossoma macropomum*) and pacú (*Piaractus mesopotamicus*). Mexico, in which marine shrimp and tilapia are the most important species, is the third largest producer (6.7 percent), followed by Ecuador (4.8 percent), which is the regions top exporter of shrimp (Table 1).

While the review only considers six countries to illustrate among other aspects the geographical diversity of aquaculture in the region, the sector is also well developed in several other countries (Table 2). The expansion of the aquaculture industry within the region has been stimulated by a steady increase in foreign investment, as well as local agricultural diversification and expansion of international markets for fishery products. Overall this has resulted in a rapidly growing, export-orientated sector.

Apart from Chile, where the industry is based on temperate species, all other countries of the region practice aquaculture of tropical and sub-tropical species. Since the early 1970's there has been a general and distinct trend towards greater intensification, from extensive to intensive systems. This has stimulated the development of support industries and services such as producers and suppliers of feeds, fertilizers, consulting services, equipment, drugs, etc.

TABLE 1
Aquaculture production (tonnes) and value (thousand US$) of the top ten aquaculture producing countries of Latin America in 2004

Country	Volume (tonnes)	% of regional production	Value (thousand US$)	% of regional value
Chile	674 979	51.1	2 814 837	53.6
Brazil	269 699	20.4	965 628	18.4
Mexico	89 037	6.7	291 329	5.5
Ecuador	63 579	4.8	292 077	5.6
Colombia	60 072	4.5	277 036	5.3
Cuba	27 562	2.1	29 434	0.6
Costa Rica	24 708	1.9	80 218	1.5
Honduras	22 520	1.7	114 942	2.2
Bolivarian Republic of Venezuela	22 210	1.7	65 785	1.3
Peru	22 199	1.7	130 555	2.5

Source: FAO (2006a)

TABLE 2
The range of aquaculture production volumes (2004) in Latin American countries not included in this review

Production (tonnes)	Country
>60 000	Colombia
20 000–-30 000	Costa Rica
	Honduras
	Peru
10 000–12 000	Belize
4 000–8 000	Guatemala
	Jamaica
	Nicaragua
	Panama
1 000–3 000	Dominican Republic
	El Salvador
	Paraguay
400–1 000	Bolivia
	Guyana
	Puerto Rica

Source: FAO (2006a)

Contrary to many Asian and African countries (see De Silva and Hasan, 2007 and also Hecht, 2007), the bulk of the aquaculture industry in Latin America is export-orientated. However, price-related market constraints have recently prompted shrimp producers to focus on local markets. This has been greatly facilitated in countries such as Brazil and Mexico where economic stability has improved the purchasing power of a growing middle class.

The Chilean salmon industry is expected to keep pace with the rising global demand for the next decade. However, the number of salmon farming companies is likely to remain unchanged as the relatively few larger firms have strongly consolidated their international market share.

Overall, the regional expectations of increased production levels of shrimp have been high. However, both climatic (El Niño events in Ecuador) and pathogenic outbreaks (severe viral epizootics in Central and South America) have caused regional production to grow slower than expected over the last five years. The lower than expected growth rate has to a certain extent been counterbalanced by an expansion in the overall regional open pond surface area.

The regional aquaculture industry will face several challenges in the decade ahead. In particular these are: decreasing international prices for some species like shrimp and tilapia due to steady increases in supply; increasing cost of fishmeal; non-competitive energy and wage levels in some Latin American countries in relation to Asian producers and tougher environmental protection measures imposed by local governments as well as regional and international agreements, which result in higher investment costs to meet quality and sanitary standards.

Despite the challenges, the industry's horizon seems promising, stimulated by continued foreign investment, steady regional economic growth and stability and local economic diversification towards aquaculture. These factors, together with the increasing adoption of responsible, certifiable aquaculture practices by new and established farmers, ensure higher productivity, better quality and continued presence in both North American and European markets.

2. OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

2.1 Chile

The evolution of Chilean aquaculture can be divided into "before and after" the salmon industry. The first attempts to culture aquatic organisms in the country date back to 1850, with the introduction of rainbow trout and common carp. However, the sector only really took off in the early 1990s after the introduction of Atlantic salmon (*Salmo salar*).

Between 1993 and 2004 salmonid (trout and all salmon species) production increased seven-fold from 77 500 tonnes to 568 900 tonnes (FAO, 2006a). In 2002, salmon exports reached 350 000 tonnes (Figure 2), and in 2004 cultured salmon was second to copper in the ranking of Chilean export products, reaching US$1 439.4 million and representing five percent of the total national value of exports (Aqua.cl, 2005: www.aqua.cl). Other aquaculture species of economic importance in the country include rainbow trout (*Onchorhynchus mykiss)*, oysters (*Ostrea chilensis, Crassostrea gigas*), scallops (*Argopecten purpuratus*); macroalgae (*Gracilaria spp*); turbot (*Scophthalmus maximus*) and abalone (*Haliotis spp*) (Table 3).

Culture systems

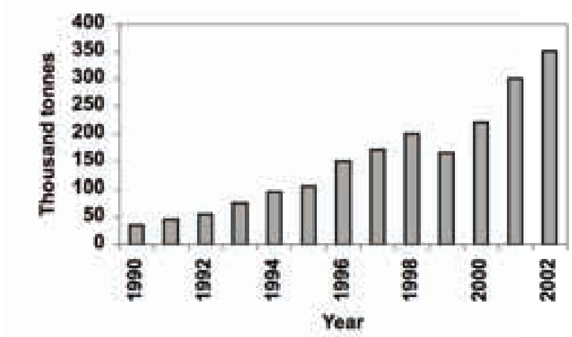
In general Chilean aquaculture is intensive and chiefly devoted to marine species, with the exception of rainbow trout. Coastal aquaculture is practically feasible in all regions of the country, although the density of aquafarms (salmon and trout), is significantly higher in southern areas (regions X and XI), due to the presence of fjords and other naturally protected areas (Figure 3). The culture of molluscs, flatfish and marine macrophytes is practiced mostly in the north, in regions III and IV. Table 4 summarizes the culture systems and production parameters of several commercially important aquaculture species of Chile.

TABLE 3
Production (tonnes) and value (thousand US$) of the most important aquaculture species in Chile for the period 1999–2003

Year	Atlantic salmon	Rainbow trout	Gracilaria	Oysters	Turbot	Abalone	Total export value
1999	179 774	50 414	31 278	26 400	333	48	-
2000	296 311	79 566	33 471	24 859	259	66	999 229
2001	460 065	109 895	65 638	25 852	303	73	1 002 026
2002	345 582	105 410	14 597	18 482	217	60	1 000 092
2003	377 350	109 658	16 259	18 723	340	80	1 177 954

Source: Aqua.cl magazine (March, 2005) available at www.aqua.cl

FIGURE 2
Evolution of Chilean salmon exports for the period 1990–2002



Source: Villarroel (2003)

FIGURE 3
Aerial view of a salmon cage farm in a Chilean Fjord

COURTESY OF M. ARANEDA

TABLE 4
Summary of culture parameters employed for important aquaculture species in Chile

Species	System	Culture facilities	Stocking density	Feeding	Source of larvae or juveniles
Atlantic salmon, *Salmo salar*	Intensive	Hatchery-reared alevines cultured in round tanks in freshwater until smolts are transferred to cages in estuaries and fjords	10 000/m^2 (alevines) 60–120 kg/m^3 (fattening)	45% protein	Artificial insemination in hatchery
Rainbow trout, *Onchorhynchus mykiss*	Intensive	2–6 m x 12–30m concrete or earthen raceways, water exchange: 100–400%/day in 90–230 m^3 cages	10–20 kg/m^3 (earthen ponds) 30–90 kg/m^3 (cages)	35–42% protein trout feed	Artificial insemination in hatchery
Red abalone, *Haliotis rufescens*	Intensive	Trocophore and veliger tank rearing. Settling tanks with algal grazing sheets. Juvenile rearing tanks (2x10m)	200–300/m^2 (larval stages) 60–100/m^2 (juveniles)	Diatoms *Macrocystis Gracilaria* and artificial feeds	Thermal or UV-induction to spawn

Source: M. Araneda, Universidad Católica del Norte, Chile (2006, pers. comm.)

2.2 Mexico

Although dating back to the late 18th century, aquaculture in Mexico only became an important economic activity in the early 1970s. Over the past three decades, the industry has grown rapidly in terms of production volumes, economic contribution and number of species cultured. In 2004, aquaculture production in Mexico amounted to 89 037 tonnes, which accounted for approximately 5.7 percent of the total national fisheries production (capture fisheries plus aquaculture) of 1.57 million tonnes (FAO, 2006a). The most important aquaculture species of the country, both by volume and value, are marine shrimp and tilapia. In 2002, shrimp and tilapia accounted for 73 and 14 percent in terms of total aquaculture produce value, respectively (SAGARPA, 2002), while in 2004 these proportions had shifted to 82.4 and 5.3 percent, respectively (FAO, 2006a). Pacific white shrimp (*Litopenaeus vannamei*) accounts for over 90 percent of shrimp production in Mexico.

Other finfish species include carp (*Cyprinus carpio*) along with Chinese carps, rainbow trout (*Oncorhynchus mykiss*), channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides)* and the native white fish (*Chirostoma spp.).* The two most important mollusc species are *Crassostrea virginica*, which accounts for 97 percent of oyster production and the introduced *C. gigas*, through intensive, closed-cycle production, contributed with the balance (SAGARPA 2002), although the former is chiefly produced through enhanced fisheries. The industry is mainly concentrated in the north western states of the country.

TABLE 5
Percent contribution by species groups to total Mexican aquaculture production and value in 2004

Species groups	Percent contribution to total production	Percent contribution to total value
Shrimps	70.0	82.4
Tilapia	7.9	5.2
Carps	13.5	4.0
Trout	3.9	3.8
Tuna	0.6	2.5
Catfish	1.1	0.7
Shellfish	2.0	0.8
Others	1.0	0.6

Note: Total production = 89 037 tonnes; total value = US$291.33 million
Source: FAO (2006a)

Culture systems

Some 61 aquatic species are farmed in Mexico, for which a wide spectrum of aquaculture systems are employed, ranging from fisheries enhancement, culture in enclosures, extensive, semi-intensive and intensive pond culture as well as tanks and raceways. In the case of shrimp farming, larviculture is strongly encouraged by government, although small-scale farmers still depend on wild post larvae. Captive breeding is becoming a regular practice, although the majority of hatcheries still rely on wild breeders.

TABLE 6

Summary of aquaculture practices of commercially important aquaculture species in Mexico

Species	Farming/culture system	Culture facilities	Stocking density	Fertilization/ feeding	Source of larvae
Pacific white shrimp, *Litopenaeus vannamei*	Extensive	5–80 ha ponds with tidal or minimum water exchange (<5%/day stocked with wild PLs. No nursery stage[1] and generally with low input monitoring and management.	1–5 /m^2	Inorganic fertilization sometimes supplemented with low quality shrimp feed.	Mostly seasonally caught larvae from the wild.
	Semi-intensive	2–25 ha ponds with pumped water exchange (5–30%/day), stocked mostly with hatchery-produced PLs. Nursery stage. Weekly monitoring for management decision making.	6–25 /m^2	Initial inorganic fertilization. Supplementary shrimp feed throughout the culture period.	Hatchery-produced.
	Intensive	0.1–2 h ponds with pumped water exchange (30–100%/day). Acclimation period of PLs in pvc-lined[2] or fibreglass aerated raceways, nursery stage (2–3 weeks) in 0.01–0.1 earthen aerated ponds. High aeration practiced in on-growing ponds.	25–150 /m^2	100% high quality shrimp feed. Use of probiotics is common.	Most intensive farms have hatcheries and produce their own postlarvae.
Tilapia, *Oreochromis spp.*	Cage culture	Two types: 56 m^3 (7x4x2m) used in northern states, and 18 m^3 (3x3x2m) used in southern states. Nylon, 0.75–1.5"-meshed bag with pvc frame and floats and mooring devices. Two stages: initial (10–50g) and terminal (50–450+g) on- growing stage.	Initial stage: 80–100/m^3. Final stage: 50–75/m^3	100% tilapia feed.	Hatchery-produced, sex-reversed fingerlings. Most farms buy from independent hatcheries.
	Semi-intensive pond culture	Breeding 0.1–-0.2 ha earthen ponds. In-pond incubation. Sex-reversal "happas" or tanks nursery ponds (0.1–0.5 ha) (from 0.1–10g). Transferred to initial on-growing ponds (0.1–0.75 ha) (from 10–40g). Transferred to final on-growing ponds (40–300g) Pumped water exchange (10–25 lps/ha[3]).	Broodstock: 1–2/m^2 Sex reversal: 2 000 /m^3. Nursery: 120–150/m^2. Initial stage on-growing: 20–25/m^2. Final stage: 5–10/m^2	Initial inorganic fertilization in nursery stage. Tilapia feed from nursery through to harvest.	Hatchery-produced, sex-reversed fingerlings. Most farms buy from independent hatcheries.
	Intensive pond/tank culture	Breeding in 0.1–0.2 ha earthen ponds. Egg collection and indoor incubation. Sex-reversal tanks (0.025 ha), nursery ponds (0.1–0.5 ha) (from 0.1–10g). Transferred to initial on-growing ponds (0.1–0.75 ha) (from 10–40 g). Transferred to intermediate ponds or raceways (0.1–0.15 ha) (40–150 g). Transferred to final stage ponds or raceways (0.1 ha), 100–400%/day water exchange.	Broodstock: 1–2/m^2 Sex reversal: 2 000–2 500/m^3. Nursery: 120–300/m^2. Initial stage on-growing: 80–60/m^2. Intermediate stage: 40/m^2, final stage: 25/m^2.	High quality tilapia feed.	Hatchery-produced, sex-reversed fingerlings. All intensive farms produce their own seed.
Japanese oyster, *Crassostrea gigas*	Intensive raft/ long line	Mass production of spat in hatcheries: Broodstock thermally-induced to spawn. High (>150,000 cells/ml) algal counts are maintained in 5 m^3-fiberglass round tanks. Larvae attach onto crushed or whole shells. Spat (3–4mm) transferred to shallow, productive coastal lagoons in either *Nestier* boxes or hanging ropes with shells in floating rafts.	Larval culture: 1–3 larvae/ml. *Nestier* boxes: Initial: 3 000 juveniles/box. Culled down to 80/box at harvest. Bags: 600/bag, culled down to 60/bag at harvest.	Larval culture: Axenic culture of phytoplankton. Grow-out: natural productivity.	Exclusively from hatchery

[1]No nursery stage implies that PL/fry are stocked directly into on-growing ponds, as opposed to stocking them in nursery ponds and then transferring for on-growing; [2]Polyvinyl chloride; [3]lps= litre per second

Source: author's database

A range of slight variants of the "Galveston method" are employed in the approximately 40 shrimp hatcheries in the country. However, standard techniques include mass-production of larvae in 10–20 m^3 indoor, highly aerated tanks, at densities ranging between 45 and 100/l. Apart from live food, supplementary feeding is a growing practice, including commercially produced dry, moist, semi-moist and liquid formulae.

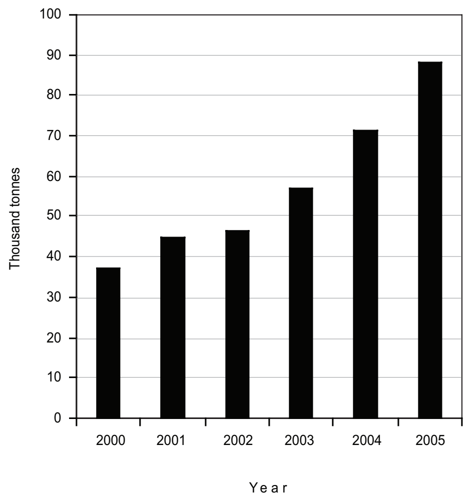
The bulk of tilapia farms (80 percent) have a closed-cycle operation, which allows for year round production of juveniles. Table 6 presents several culture systems and management practices used in Mexico.

2.3 Ecuador

Ecuadorian aquaculture began in the early 1970´s, when shrimp farming gradually replaced banana plantations along the coastal plains of Guayas Province. Ideal climatic conditions, low production costs and abundant naturally occurring shrimp larvae stimulated the impressive growth of the Ecuadorian shrimp farming industry over the last 30 years, thus becoming the largest marine shrimp producer of the Americas, and the number one exporter to the United States.

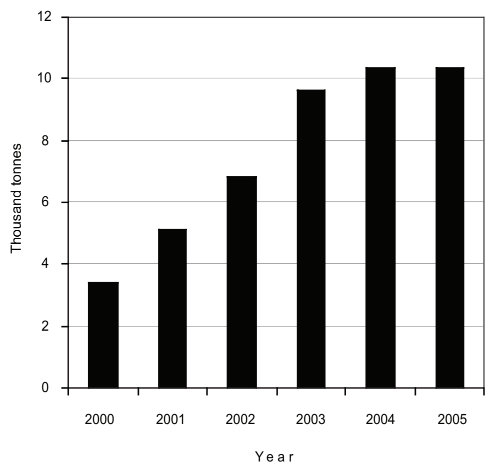
Despite favourable climatic conditions, the spectrum of aquaculture species of Ecuador is poor. Marine shrimp (Pacific white shrimp *L. vannamei* and blue shrimp *L stylirostris*), are by far the most important culture species, constituting 93.7 percent of the total national aquaculture production. The shrimp industry in Ecuador uses some 140 000 ha of extensive and semi-intensive ponds (National Agriculture Information Service, Ministry of Agriculture of Ecuador, 2004). However, viral epizootics badly impacted the shrimp industry during the 1980´s and 1990´s, resulting in significant reductions in shrimp production volumes. The industry began to recover in 2004/05 (Figure 4). As a result of the disease problems in the shrimp industry, farmers began to look for alternatives, among which tilapia has been the most popular choice. Figure 5 shows the trend in tilapia production, which has grown almost three-fold over the past 4 years.

FIGURE 4
National production of farmed shrimp in Ecuador for the period of 2000–2005 (production for 2005 is estimated)



Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

FIGURE 5
Aquaculture production of tilapia in Ecuador 2000–2005 (production for the year 2005 is estimated)



Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

TABLE 7
Summary of aquaculture practices for commercially important aquaculture species in Ecuador

Species	Farming system	Culture facilities	Stocking density	Fertilization/feeding
Shrimp, *Litopenaeus vannamei* *L. stylirostris* *L. occidentalis*	Extensive	5–30 ha ponds with tidal or minimum water exchange (<5%/day), stocked with wild or hatchery-reared PLs. Few with nursery stage and low input monitoring and management.	1–5/m^2	Inorganic or organic fertilization sometimes supplemented with low quality shrimp feed.
	Semi-intensive	1–10 ha ponds. 10–15%/day water exchange. Nursery and grow-out stages.	10–12/m^2	Inorganic fertilization and 20–35% protein shrimp feed. Use of probiotics.
Tilapia, *Oreochromis spp*	Semi-intensive	0.1–0.3 ha ponds. 10–100%/day water exchange. Nursery, juvenile and grow-out stages.	1–2.5/m^2	20–35% protein tilapia feeds.
Rainbow trout, *Oncorhynchus mykiss*	Intensive	2–6 m x 12–30m concrete or earthen raceways, water exchange: 100–400%/day	10–20 kg/m^3	35–42% protein trout feed

Source: M. Dewind, National Chamber of Aquaculturists of Ecuador (2006, pers. comm.)

Other species include the native fish Pacific fat sleeper *Dormitator latifrons*, rainbow trout *Oncorhynchus mykiss* and these are produced for the local market (M. Dewind, National Chamber of Aquaculturists of Ecuador, pers. comm.). The Australian crayfish/red claw *Cherax quadricarinatus*, introduced in 1988, became a popular species during the late 1980´s and early 1990´s, when over 50 farms were established. However, because of technical and market problems all have closed down. In addition, there are some 20 North American bullfrog (*Rana catesbeiana*) farms and all products are exported live.

Culture systems

Originally extensive shrimp farms have gradually been converted into semi-intensive and to a lesser extent intensive culture operations. This trend has been largely driven in an attempt to increase production and to prevent, through more rigorous control measures, further pathogenic catastrophes, such as the Taura and the white spot epizootics that severely hit the Ecuadorian shrimp industry during the 1990´s.

There is a growing tendency to introduce tilapia into shrimp farms, either in polyculture with shrimp or for parallel or rotational culture, thus reducing risks through diversification. The availability of idle processing facilities also provides an opportunity for expansion into fish processing. Table 7 summarizes the characteristics of the main culture systems employed in Ecuador.

2.4 Bolivarian Republic of Venezuela

As for the whole of Latin America, aquaculture in Venezuela is a relatively new economic activity. Its origins date back to the late 1930´s starting with the introduction of rainbow trout (*Oncorhynchus mykiss)* and common carp (*Cyprinus carpio).*

According to the National Fisheries Institute of Venezuela some 25 species are presently cultured in the country, at different levels of intensification. These include three exotic fish species (tilapia, rainbow trout and common carp) and 12 native species of finfish, including pirapitinga/black pacú, (*Piaractus brachypomus*), which with a production volume of 5 000 tonnes is the second most important aquaculture species in the country after shrimp; tambaqui (*Colossoma macropomum*), striped mullet (*Mugil cephalus*) and white bass (*Morone chrysops*), among others. Three species of marine shrimp, *Litopenaeus vannamei, L. stylirostris,* and *L. schmitti* are produced extensively and semi-intensively. In 2004, approximately 16 500 tonnes of shrimp were produced, which accounted for 74.3 percent of total production, while indigenous characins contributed about 22.5 percent (FAO, 2006a).

TABLE 8
Summary of aquaculture practices of commercially important aquaculture species in the Bolivarian Republic of Venezuela

Species	Culture facilities	Stocking density	Fertilization/feeding
Shrimp *L. vannamei* *L. stylirostris* *L. schmitti*	0.05–0.1 ha nursery raceways or ponds and 2–12 ha grow-out ponds	120–200/m^2 nursery 7–40/m^2 grow-out	Fertilizer and 25–35% protein feed
Tambaqui, *Colossoma macropomum*	0.05–0.1 ha ponds	1/m^2	Fresh fruits and 20% protein feed
Tilapia, *Oreochromis spp*	0.1–0.2 ha ponds	20/m^2 nursery and 3–5/m^2 grow-out	Pelleted feed
Rainbow trout, *Oncorhynchus mykiss*	12–30 x 2.5–8m raceways	10–24 kg/m^3	20–33% protein tilapia feed

Source: J. Velazco, National Fisheries and Aquaculture Institute, Bolivarian Republic of Venezuela (2006, pers. comm.)

Culture systems

Table 8 summarizes the main characteristics of the most representative culture systems employed by farmers in Venezuela.

2.5 Brazil

Aquaculture has been practiced in Brazil since the early 1900´s. Given its continental dimensions and climatic diversity, both temperate and tropical species are widely cultured. Currently, there are at least 64 species cultured in the country, including a number of native fish. Predominately based on small-scale farms, Brazilian aquaculture production in 2004 amounted to some 269 699 tonnes, valued at some US$965.6 million (FAO, 2006a). In 2003 there were approximately 100 000 farms occupying an area of 80 000 hectares. In 2004, finfish production comprised 62.7 percent by volume (66.3 percent by value) and shrimp production accounted for 28.1 percent by volume and 31.4 percent by value. Fish production was dominated by cichlids (25.6 percent), characins (mainly chachama) 17.9 percent and cyprinids (16.7 percent) (FAO, 2006a)

Shrimp farming began in the early 1980´s and after the introduction of *L. vannamei* in 1995 the industry expanded rapidly.

Culture systems

A wide range of aquaculture systems are employed in Brazil that include all levels of intensification, depending on the species, the region and the environment. Table 9 presents a summary of the main characteristics of the culture strategies for the most important aquaculture species of the country.

TABLE 9
Summary of culture systems for important aquaculture species in Brazil

Species Scientific name	Culture facilities	Stocking density	Fertilization/feeding
Shrimp, *L. vannamei* *L. stylirostris and L. schmitti*	0.05–0.1 ha nursery flow-through channels or ponds, and 2–40 ha grow-out ponds.	120–200/m^2 for nursery and 7–40/m^2 for grow-out	Fertilizer and 25–35% protein feed
Pacú, *Piaractus mesopotamicus*	0.05–0.1 ha ponds	1/m^2	Fresh fruits and 20% protein feed
Tilapia, *Oreochromis spp*	0.1–0.2 ha ponds 2–38 m^3 cages in reservoirs	20/m^2 nursery, 3–5/m^2 grow-out 80–100/m^3 juveniles and 20–50/m^3 final stage	Pelleted feed Extruded pelleted feed
Silver carp, *Hypophthalmichthys molitrix*; grass carp, *Ctenopharyngodon idella;* common carp, *Cyprinus carpio*	0.1–1.5 ha ponds	0.1–0.5/m^2 in polyculture	Organic and inorganic fertilizer; chopped grass.
Tambaquí, *Colossoma macropomum*	0.05–0.1 ha ponds 2–16 m^3 cages	0.25–1.0/m^2 30/m^3 initial stocking and 10–15/m^3 final stage	Chopped meat and fruits in juveniles and 20% pelleted feed in final stage
Rainbow trout, *Oncorhynchus mykiss*	12–30 x 2.5–8m raceways	10–24 kg/m^3	20–33% protein tilapia feed

Source: FAO Fisheries Global Information System (2006); M. Hipólito, Biology Institute of Sao Paulo, Brazil (2005, pers. comm.)

2.6 Cuba

Aquaculture is a strategic activity in Cuba both for producing animal protein and for earning foreign currency through export. The absence of suitable native species for cost-effective aquaculture was the reason for introducing a wide range of species. These are cultured both extensively and semi-intensively in more than 148 000 ha of small to medium sized reservoirs nationwide. In addition, there are 26 state-owned and operated fish breeding stations where fry of different species are mass produced and distributed to 30 stations for on-growing with approximately 1 000 ha of fish ponds. In 2004, total Cuban aquaculture production amounted to some 27 562 tonnes valued at US$29.4 million (FAO, 2006a).

Fish is the most important product and collectively contributed 94.3 percent to total production by volume and 91.3 percent by value (FAO, 2006a). The main species are Oreochromis spp, common carp Cyprinus carpio, channel catfish *Ictalurus punctatus*, and Chinese grass carp *Ctenopharyngodon idella* and silver carp *Hypophthalmichthys molitrix*. The white shrimp L. vannamei and the native white shrimp L. schmitti are cultured in 4 semi-intensive farms, using larvae produced in 3 hatcheries. Total production of farmed shrimp was 1 370 tonnes in 2003, which then accounted for 5.1 percent by volume and 17.2 percent by value (the reported production for 2004 was 390 tonnes, but it is not known whether this is an error) (FAO, 2006a). Other species cultured in the country are the African catfish Clarias gariepinus and the Australian crayfish Cherax quadricarinatus, which were recently introduced.

Culture systems are mostly extensive. Stock enhancement is largely practiced through stocking of hatchery-reared fingerlings in large to medium sized reservoirs, which sometimes are organically or inorganically fertilized, as well as in earthen ponds that range from 0.01–0.3 ha. Most finfish species are stocked at between 0.1 and 2/m^2 and fed a wide variety of locally available protein sources, since aquaculture feeds are almost only available for shrimp farming.

Shrimp farming is semi-intensive. Hatchery-reared post-larvae are stocked in previously fertilized ponds at densities that vary between 80 and 150/m^2 during the nursery stage and between 12 and 20/m^2 in the growout stage. Shrimp are fed 20–35 percent protein feeds. Water exchange in shrimp ponds fluctuates between 3 and 15 percent/day and aeration is not employed (Toledo, 2004).

3. REVIEW OF FERTILIZERS AND FERTILIZATION

Fertilization of aquaculture ponds for tropical species is a wide-spread practice throughout Latin America. The exceptions are Chile, where temperate species such as Atlantic salmon and abalone are reared intensively and other intensive farms in the region where the species depend entirely on commercial feeds.

Given that shrimp and tilapia farming are the most important aquaculture activities in Latin America, except Chile, management strategies including fertilization are similar in most countries. Furthermore, international trade in fertilizers is dynamic within the region, such that a variety of brands with different chemical compositions are readily available.

3.1 Inorganic fertilization

Brackish-water aquaculture

The majority (more than 80 percent) of shrimp farms in the region are considered to be semi-intensive. Although higher levels of control and inputs are increasingly being introduced to counteract possible pathogenic outbreaks, shrimp are still partially dependent on natural pond productivity that is enhanced through the application of inorganic fertilizers. Application rates and strategies have been standardized through research by fertilizer companies and the academic sector.

A rapid survey carried out as part of the present analysis in Mexico, Guatemala and Belize showed that respectively 22 out of 27 (81 percent); 8 out of 8 (100 percent) and 4 out of 5 (80 percent) of the surveyed farmers use indirect or subjective methods (Secchi disk or apparent colour of pond water) to determine whether a pond should be fertilized or not, and only 4 out of 40 (10 percent) employ direct phytoplankton counts as an indicator of the need to fertilize.

Two common application methods employed by shrimp farmers in the region were observed during the present analysis, viz. direct application of water-dissolved fertilizers and a point-source gradual release method. Direct application involves calculating the amount of different fertilizers required according to standard equations, dissolving the mixed fertilizers in water and applying the solution to ponds in which the water level has been reduced to around 0.1 m during peak light hours, where after the pond is gradually filled. The point-source application method is more commonly used by small-scale farmers. It also involves calculating the required quantity of fertilizer per pond and then dividing it into several bags through which nutrient leaching can take place. The bags are submersed and tied to poles in the pond that have been arranged in a pattern to ensure homogenous distribution of nutrients.

Inorganic nitrogen and phosphorus fertilizers are available in all countries of the region. Table 10 presents a summary of chemical composition and application rates of inorganic fertilizers employed by shrimp farmers in a selected number of countries in Latin America.

A typical inorganic fertilization strategy employed by Brazilian farmers is presented in Table 11. In some regions where soils are low in silicon, Sodium metasilicate is applied at a rate of 750 cm^3/ha (Nunes, 2000).

TABLE 10
Summary of inorganic fertilizer application methods employed by shrimp farmers in Latin American countries

Fertilizer	Composition (% N, P and K)	Chemical composition	Application rate/cycle	Degree of use	Country
Urea	46-0-0	NH_2-CO-NH_2	20–24 kg/ha	***	Brazil, Colombia, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Peru, Bolivarian Republic of Venezuela
Single superphosphate	0-20-0	$Ca(H_2PO_4)_2$	1.3–3.9 kg/ha	**	Brazil, Ecuador, Mexico
Triple superphosphate (TSP)	0-42-0	$Ca(H_2PO_4)_2$	0.9–2.4 kg/ha	***	Brazil, Colombia Cuba, Ecuador, El Salvador, Honduras, Mexico, Panama, Peru, Bolivarian Republic of Venezuela
Diammonium phosphate (DAP)	16-24-0	$(NH_4)_2HPO_4$	0.9–3.0 kg/ha	*	Ecuador, Mexico, Honduras, Panama
Monoammonium phosphate	8-24-0	NH_4HPO_4	3.7–5.2 kg/ha	**	Ecuador

***Widely used, **Common, *Low use

Sources: MIDA (1998); Nunes (2000, 2004); J. Zendejas, Cargill-Purina, Mexico (2006, pers. comm.); author's own data

TABLE 11
Standard inorganic fertilization procedure employed by Brazilian shrimp farmers

	Procedure (steps)	Application rate
1	Pond water level is raised to 0.3 m	9 kg urea + 0.9 kg TSP/ha
2	Pond left for two days to bloom	
3	Pond water level raised at 50% the operational level	14 kg urea + 1.4 kg TSP/ha
4	Pond water static for 3 days to bloom	
5	Pond water level raised to full level (0.9–1.1 m)	23 kg urea + 2.3 kg TSP/ha
6	Pond water static for another five days	
7	Stocking of juveniles. Water exchange starts and is gradually increased.	Maintenance rates according to pond productivity

Source: Cook and Clifford (1998)

TABLE 12
Combined (organic/inorganic) fertilization strategy employed by Ecuadorian shrimp farmers

Fertilizer	Initial application rate (kg/ha)	Maintenance application rate (kg/ha)*
Dried chicken manure	1 000	0
Ground rice bran	50–200	6.8
Urea	28	2.4
Monoammonium phosphate	2.4	0.4
Sodium metasilicate	10	1.5

*If Secchi disk reading >45 cm
Source: Nicovita (1999)

In a relatively small proportion of farms (approximately 13 percent in the case of Mexico and 25 percent in the case of Ecuador) a combination of inorganic and organic fertilizers is employed. A typical combined fertilization strategy employed by Ecuadorian shrimp farmers is presented in Table 12.

In Cuba, inorganic fertilizer is applied routinely during the production cycle of *Cherax quadricarinatus*. Dry chicken manure (500 kg/ha) and hay (1 000–1 250 kg/ha) are applied prior to stocking juveniles in grow-out ponds (Toledo, Centro de Preparación Acuicola Mampostón, 2005, pers. comm).

A new generation of more specifically "aqua-balanced" fertilizers is being used in some countries of the region. Such is the case of a product called *Fertilizarina* (Protinal-Proagro, Venezuela) manufactured in Venezuela and sold locally. This product is an organic aquaculture fertilizer with a C:N ratio of 25:1 that has been specifically designed to enhance microbiotic colonization of the pond, thus stimulating the development of the heterotrophic food web.

Freshwater aquaculture

Because of the increasing shift towards intensification, inorganic fertilization of freshwater aquaculture ponds is declining in the Americas. Only a few species of commercial relevance are cultured in extensive and semi-intensive farming systems using chemical fertilizers, e.g. monoculture of tilapia and common carp and to a lesser extent polyculture of Chinese carps in certain areas in Brazil and Mexico. A typical fertilizer schedule for juvenile tilapia in Ecuador is Urea at 20–30 kg/ha and TSP at 2–5 kg/ha. In southern Mexico, tilapia farmers administer single superphosphate at 8 kg/ha (dissolved in water) prior to stocking fingerling ponds. Depending on water turbidity, they subsequently apply 200–250 kg/ha of dried chicken manure.

3.2 Organic fertilization

Some of the larger semi-intensive shrimp and/or tilapia farms, medium-sized fish (carp or tilapia) and red claw farmers and many small-scale farmers use manure as fertilizer. However, given the availability and relatively low price of chemical fertilizers, the overall use of animal manure and or other forms of organic fertilizers in aquaculture is limited.

Animal manure is the most widely used form, although many other agriculture by-products are used to enhance nutrient levels in ponds. Table 13 presents a summary of such products with recommended application rates.

TABLE 13
Organic nutrients used as aquaculture fertilizers in Latin American countries

Source of nutrient	Standard application rate*	Species cultured	Countries	Level of aquaculture
Chicken manure	250–500 kg/ha	Shrimp, tilapia, carp, red claw	Mexico, Ecuador, Cuba, Panama, Honduras, Brazil, Guatemala, Peru, Bolivarian Republic of Venezuela	Commercial
Cattle manure	500 kg/ha	Carps	Brazil, Cuba	Commercial
Pig manure	550–750 kg/ha	Carps, tilapia	Cuba	Commercial
Rice bran	300–400 kg/ha	Shrimp	Brazil, Ecuador, Mexico	Commercial
Sugar cane fibre	800 kg/ha	Shrimp	Belize, Brazil, Cuba, Honduras	Commercial
Molasses	19–120 kg/ha/week	Shrimp	Belize, Ecuador, Panama, Peru,	Commercial
Molasses	30–120 kg/ha	Shrimp	Colombia	Commercial
Chopped fresh vegetable	1 000–1 250 kg/ha	Tilapia, pacú	Brazil, Cuba, Mexico, Bolivarian Republic of Venezuela	Subsistence
Chopped weed	2 000–2 500 kg/ha	Tilapia	Guatemala, El Salvador, Mexico, Panama	Subsistence
Soybean meal	300–500 kg/ha	Shrimp	Brazil, Ecuador, Mexico, Honduras, Panama	Commercial
Alfalfa meal	280 kg/ha	Tilapia	Mexico, Panama	Experimental
Hay	1000–1 250 kg/ha	Red claw	Cuba	
Chaya (green leaves)	20–30 kg/100 m²/day	Tilapia	Mexico	Subsistence
Coffee pulp	300–600 kg/ha	Tilapia, carp	Cuba, Brazil, Mexico	Subsistence

Sources: Palomo and Arriaga (1993); MIDA (1998); Olvera (1994); S. Toledo, Mampostón, Cuba (2005, pers. comm.); M. Guillian, Ecuador (2006, pers. comm.); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.)

3.3 Availability

Chemical fertilizers are inexpensive and readily available throughout Latin America, due to an ever increasing demand by large and small-scale agriculture. The demand for fertilizers by agriculture is several orders of magnitude higher than the demand from aquaculture, hence aquafarmers are largely reliant on the types and composition of chemical fertilizers used by their local agriculture counterparts. Any shifts in the agriculture demand for certain fertilizers may hold distinct disadvantages for aquafarmers. For example, because of decreasing demand the largest producer of fertilizer in Mexico stopped the production of urea in 1998 (Espinosa-Carmona, 2002) (Table 14), one of the most common nitrogen sources for aquaculture ponds in Mexico. Since then urea is imported and this has put pressure on the price.

Throughout the region there is very little structured research on fertilization in aquaculture, hence the adoption of general standard rates and methods of application. For example, farmers take little cognisance of soil or incoming water chemistry.

Organic fertilizers are widely available throughout Latin America. The agriculture-based economy of many of the countries in the region, provide a huge potential resource base. The overall tendency to intensify culture practices on large-scale farms, together with a more efficient cost/benefit ratio of using readily available inorganic fertilizers, has encouraged the use of chemical as opposed to organic inputs. The rapidly emerging demand for organically-grown products may however stimulate the demand for organic nutrient sources by aquaculture.

TABLE 14
Production of inorganic fertilizers in Mexico between 1980 and 2000 (thousand tonnes)

Fertilizer	Year				
	1980	1985	1990	1995	2000
Urea	401	1367	1415	1508	0
Ammonium sulphate	1069	1614	1596	1108	1446
Diammonium phosphate	111	91	684	540	290
Single superphosphate	275	314	176	117	75
Triple superphosphate	115	253	235	281	85

Source: Espinosa-Carmona (2002)

Generally speaking, prices of inorganic fertilizers are relatively low. The cost of inorganic fertilization usually accounts for 5 percent of the costs of feeds in shrimp farms (Flores-Nava, 1994). Prices of organic fertilizers have been gradually increasing as a result of a growing demand for manure as a source of protein in animal husbandry (e.g. reaching US$130/tonne for chicken manure in Mexico).

3.4 Sustainability

Table 15 presents a summary of factors affecting the sustainable use of fertilizers in Latin American aquaculture.

TABLE 15
Summary of positive and negative externalities likely to affect the sustainability of the use of fertilizers in aquaculture in Latin America

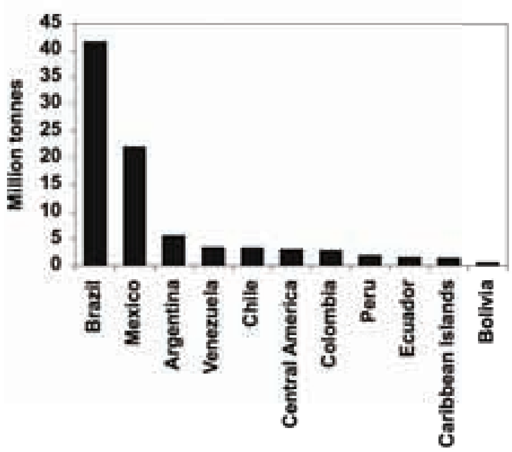
Factor	Inorganic fertilizers		Organic fertilizers	
	Positive	Negative	Positive	Negative
Form of production	Increased number of industries (i.e., Brazil and Mexico) that produce nitrogen fertilizers in sustainable forms (atmospheric sources)	Risk of decline of phosphoric rocks if used in excess	Sustainable if sources are chemical-free	Intensive form of agriculture or animal husbandry involves the use of antibiotics or pesticides that can be transferred in by-products used in aquaculture
Potential environmental impact of use	Possibility of using the adequate chemical balance for the type of water and/or soil where it is to be applied	Increasing risk of eutrophication of receiving water bodies. Most countries in the region still with soft control measures	Could be a stimulating factor for re-using agricultural wastes, thus reducing organic discharges.	Potential dissemination of pathogens if manures are not certified by sanitary personnel.
Market related issues	Inexpensive due to large supply for the agriculture sector	Specific availability dependent on the needs of the local agriculture sector. Ecological awareness of consumers will decrease demand for chemical inputs	Wide spectrum of inexpensive nutrient sources locally available in every region. Growing demand for "organic" labelled products will trigger demand for organic inputs.	Opportunity cost of avian manures is high due to growing demand as a source of protein for cattle or pigs. An increase in the demand by the "organic aquaculture" sector is likely to put further pressure on prices.
Legal aspects	Growing concern puts pressure on governments for tougher regulations	Adequate regulations still a long way from becoming strict laws.	Pressure upon agriculture and live-stock farmers to adequately dispose wastes. Their use in aquaculture could be a solution	No regulations regarding possible toxicity or pathogenicity of animal or agricultural by-products
Availability	Widely available	Limited diversity	Widely available. Possibility of widening the spectrum of nutrient sources	Increasing demand for a wider spectrum of users will affect availability in the short term

4. THE AQUAFEED INDUSTRY IN LATIN AMERICA

The animal feed milling industry of Latin America has grown steadily over the past 30 years, as a result of the intensification and expansion of the poultry, cattle, pig and aquaculture sectors throughout the region. Brazil and Mexico rate among the worlds top 10 animal feed producing nations (J. Cordeiro, Assoc. Nacional de Fabricantes de Alimentos do Brasil (ANFAL), Brazil, 2005, pers. comm.). Animal feed production in Latin American countries is summarized in Figure 6 and Table 16 summarizes aquafeed production in the six target countries as well as in Guatemala.

Salmon, shrimp and tilapia farming are the largest and most dynamic aquaculture activities in the region and the overall volume of aquafeed production is largely a reflection of the performance of these sectors in each country. Large-scale events such as over-production of feeds or the outbreak of epizootics can have a direct and serious impact on the aquaculture sector, inclusive of the aquafeed industry.

FIGURE 6
Production of animal feeds in Latin American countries in 2003



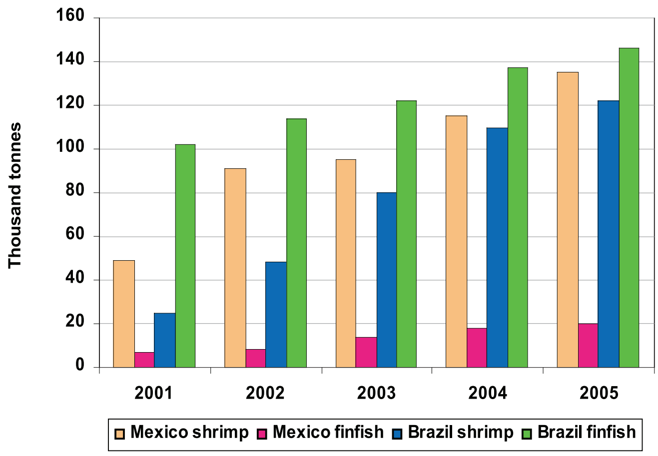
Source: J. Cordeiro, ANFAL, Brazil (2005, pers. comm.)

Figure 7 shows the production of shrimp and tilapia feeds in Brazil and Mexico. After an unprecedented increase in shrimp feed production of 46 percent in 2002, severe viral epizootics hit the Mexican shrimp farming sector, thus drastically reducing to only 4 percent the expected feed demand, despite an expansion of more than 10 percent in the shrimp culture surface area. Ecuador, the largest shrimp producer on the continent has also been severely hit by a range of viral epizootics. The first occurred in the early 1990´s when Taura syndrome caused a reduction of over 20 percent in the overall shrimp production and then in 1999, a year on year collapse of nearly 50 percent caused by "white spot" disease. Similar events have been experienced throughout Central America and all have had a negative impact on aquafeed production in the region.

TABLE 16
Production of aquaculture feeds, percent contribution to total national animal feed production and the number of aquafeed mills in several Latin American countries in 2003

Country	Number of feed mills producing aquafeeds	Production of aquafeeds in 2003 (tonnes)	% of national total animal feed production	Source
Chile	10	750 000	15	Villarroel (2003), Infante (2003)
Brazil	30	200 000	0.5	Waldige and Caseiro (2003); Scorvo (2003)
Mexico	11	109 000	0.7	Panorama Acuicola (2004a)
Ecuador	12	97 000	6.9	M. Dewind, National Chamber of Aquaculturists of Ecuador, pers. comm. Sistema de Información Agropecuaria de Ecuador (2003, pers. comm.)
Bolivarian Republic of Venezuela	4	30 000	1.7	J. Velazco, National Institute of Fisheries, pers. comm.
Cuba	2 (one experimental)	4 000 (commercial shrimp feed) and 187 000 silage (experimental)	–	S. Toledo, Centro de Preparación Acuícola Mampostón, Cuba, pers. comm. and Toledo (2004)
Guatemala	1	8 000	2	J. Zendejas, Cargill-Purina, pers. comm.

FIGURE 7
Shrimp and finfish feed production in Brazil and Mexico during the period 2001–2005 (figures for the year 2005 are estimated)



Source: Waldige and Caseiro (2003); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.)

5. A REVIEW OF FEEDS AND FEEDING IN AQUACULTURE

5.1 Feed composition

Although only a few large feed companies compete for the growing aquafeed market in the region, there is a wide spectrum of brands, species-specific feeds and formulations available in the Americas. Typical proximate analyses and compositions of commercial shrimp and freshwater fish feeds in Latin America are presented in Tables 17 and 18.

In Brazil and Mexico manufacturers recognise the growing environmental concerns and state that their feeds are highly water stable to minimize leaching of nutrients such as phosphorus into the environment. Paradoxically, feeds in Brazil have the highest phosphorus levels in the region.

Water stability of shrimp feeds varies between 30 minutes and 3 hours, depending on the binding agent used (author's observations).

Water stability of pellets depends on the processing technique. Sinking pellets for catfish and carp have a low stability (3–15 minutes, according to Nicovita, Ecuador), while extruded floating pellets are significantly more water stable.

TABLE 17

Proximate composition of commercial marine shrimp diets in selected Latin American countries

Country	Crude protein	Crude lipid	Crude fibre	Phosphorus	Sources (Brand)
Brazil	25–40	5.0–8.0	4.5–6.0	0.7–1.45	www.agribrands.com.br www.guabi.com.br www.classipet.com.br
Ecuador	20–45	5.0–8.0	3.0–5.0	1.0–1.5	www.nicovita.com.ec
Guatemala	20–35	6.5–8.5	4.0–5.0	0.9–1.25	www.agribrands.com.gu
Mexico	20–40	6.0–9.5	4.0–5.0	0.9–1.25	www.agribrands.com.mx www.nutrinas.com.mx www.piasa.com.mx www.ziegler.com.mx
Panama	20–35	4.0–9.0	3.5–6.0	1.20	J. Zendejas (2005, pers. comm.); Agribrands Purina, Mexico (2005, pers. comm.)
Bolivarian Republic of Venezuela	25–35	4.0–8.0	3.0–5.0	0.9–1.4	www.agribrands.com.ve

TABLE 18

Proximate composition of commercially available finfish feeds in Latin America

	%	Tilapia	Carp	Trout	Sources (Brand)
BRAZIL	Crude protein	20–42	20–35	30–55	www.agribrands.com.br www.classipet.com.br www.cocari.com.br www.guabi.com.br www.socil.com.br
	Crude lipid	4–6	3–6	6–12	
	Crude fibre	6–10	6–10	4–5	
	Phosphorus	0.6–1.2	0.6–1.2	0.6–1.0	
ECUADOR	Crude protein	25–45	-	35–50	www.nicovita.com.ec M. Dewind, National Chamber of Aquaculturists of Ecuador, (2005, pers. comm.)
	Crude lipid	3–6	-	6–9	
	Crude fibre	5–9	-	4–6	
	Phosphorus	0.9–1.3	-	0.9–1.0	
MEXICO	Crude protein	25–42	22–30	35–55	www.agribrands.com.mx www.nutrinas.com.mx www.ziegler.com.mx
	Crude lipid	3–4	3–4	8–12	
	Crude fibre	5–10	5–10	4–6	
	Phosphorus	0.7–1.0	0.7–1.0	0.9–1.2	
BOLIVARIAN REPUBLIC OF VENEZUELA	Crude protein	20–28	-	40–45	www.agribrands.com.ve
	Crude lipid	5.0–6.5	-	10–12	
	Crude fibre	3–6	-	3–6	
	Phosphorus	1.0–1.2	-	0.9–1.2	

5.2 Ingredients

Fishmeal continues to be the core protein source employed by aquafeed manufacturers in Latin America. Other major protein sources include commodities such as soybean meal and wheat meal, prices of which are a function of global availability and exchange rates. These key standard ingredients are common to practically all commercially available aquafeeds throughout the region and are traded within the region.

Other ingredients commonly used in aquafeed formulations include maize, sorghum, wheat bran, maize gluten, cottonseed meal, groundnut meal, sesame meal, meat meal, feather meal and alfalfa meal. For example, a Venezuelan aquafeed manufacturer (Protinal, Zulia, Venezuela) reports the following ingredients in some of their formulations: fish, soybean and meat meals; wheat bran, stabilized fat, fish oil, calcium carbonate and calcium phosphate, trace minerals (Co, Zn, Mn, Cu, Se, I); vitamins A, B1, B2, B6, B12, C, D, E, K, folic acid, biotin, pantothenic acid, choline, niacin and inositol.

Table 19 summarizes the most common protein sources employed by aquaculture feed manufacturers in Latin America, their country of origin, as well as some market related factors likely to affect their availability and prices.

Generally speaking, the core protein sources employed by the Latin American aquafeed industry are global commodities for which there is a high international demand. World prices for fishmeal, corn, wheat and soybeans show an increasing trend because of increasing demand and declining supplies caused by climatic events.

TABLE 19
Most important protein sources used by aquafeed manufacturers in Latin America and factors likely to affect their sustainable use

Source of protein	Degree of availability	Countries that produce it in the region	Market/price-related constraints to the aquaculture industry
Fishmeal	High	Chile, Peru, Ecuador, Brazil and Mexico. (only relatively small volumes produced in Brazil and Mexico)	Prices have steadily increased as a direct function of global demand. Climatic changes have had an impact on catches
Soybean meal	High	Brazil, Argentina, Uruguay, Mexico	Regardless of local availability, prices are determined by global supply/demand. Price of this commodity has increased from US$92/tonne in 2000, to US$221/tonne in 2003.
Corn	High	Argentina, Brazil, Mexico, Colombia	High demand for direct human consumption (Staple diet in many countries of the region) puts pressure on prices, which combined with local crop failures have increased prices by 100% in Brazil, or between 25 and 35% in Mexico
Blood meal, bone and meat meals	Medium	Argentina, Uruguay, Paraguay, Colombia, Mexico, Bolivarian Republic of Venezuela	By-products of the cattle farming industry. Mostly consumed locally, due to sanitary regulations. Production in some countries like Mexico and Paraguay, impacted indirectly by imports of low-cost meat, which results in local herd reduction.
Wheat bran	High	Argentina, Brazil, Colombia, Mexico	Argentina is one of the top world producers and has experienced a reduction in production due to adverse climatic conditions. Prices are also a function of world supply and demand, and increased 100% between 2000 and 2002.
Lupin seed	High	Chile, Argentina	Most of the production devoted to salmonid aquaculture. Culture areas expected to expand to meet aquaculture needs.

Source: Waldige and Casseiro (2003); Panorama Acuícola (2004a); Ministerio de Agricultura de Ecuador (2004); J. Cordeiro, ANFAL, Brazil (2005, pers. comm.); J. Zendejas, Cargill-Purina, Mexico (2005, pers. comm.); Infante (2003)

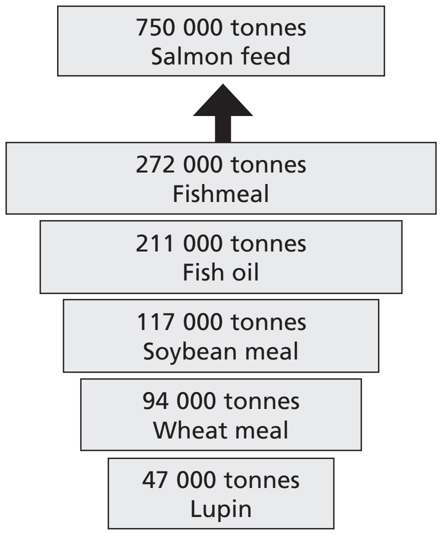
5.3 The case of Chilean salmon feeds

If aquaculture is to be sustainable in Latin America then a good example of the challenges facing the industry is the case of the salmon feed industry in Chile. In 2003, the salmon industry demanded 750 000 tonnes of feed, which included some 272 000 tonnes of fishmeal (this accounted for 78 percent of Chilean fishmeal usage in that year).

The industry also consumed 211 000 tonnes of fish oil, and a high proportion of grains produced both in and out of the country (Figure 8).

Chilean production of salmon is expected to grow at an average rate of 10 percent per annum for the foreseeable future (Infante, 2003). At this pace, within the next ten years, an additional 110 000 ha of wheat and lupin as well as 780 000 tonnes of fishmeal will be needed exclusively to meet the core demands for salmon feeds.

FIGURE 8
Schematic representation of the ingredient demand by the Chilean salmon industry in 2003



Source: Modified from Infante (2003)

5.4 Alternative protein sources

Following a global tendency, several research groups particularly in Chile, Ecuador, Mexico and Brazil have been working to identify and test a range of protein sources to replace fishmeal.

However, despite the high biodiversity in countries like Brazil, Ecuador and Mexico, research and financial resources devoted to aquaculture nutrition and more specifically to finding fishmeal replacements in the region are still very modest. Hence the Latin American aquafeeds industry is still almost exclusively dependent on the core protein sources mentioned above. Table 20 lists a number of alternative protein sources that have been tested experimentally or commercially in some countries in the region.

Lipid sources include mostly fish oil, sunflower oil, corn oil, soybean oil and cottonseed oil. The main regional producer and exporter of fish oil, which is by far the most common lipid source used in aquafeeds, is Chile followed by Peru. Lower quality fish oil is produced in smaller quantities in Mexico, Brazil and Ecuador, although mostly for domestic consumption. Vegetable oils are mainly produced in Mexico,

TABLE 20
Summary of non-conventional protein sources that have been tested and or used in some Latin American countries

Common name	Scientific name	Species cultured	Purpose	Source
Coffee pulp	*Coffea arabica*	Tilapia	Experimental	Bayne, Dunseth and Ramiros (1976)
Rum distillation wastes		Tilapia	Experimental	Kohler and Pagan-Font (1978)
Yeast	*Hanola anomala*	Rainbow trout	Experimental	De la Higuera *et al.* (1981)
Azolla	*Azolla mexicana*	Tilapia, carp	Experimental	Arrivillaga and Arredondo (1987)
Lupin seed	*Lupinus spp*	Rainbow trout	Experimental	De la Higuera *et al.* (1988)
Jack bean seed	*Canavalia ensiformis*	Tilapia	Experimental	Martínez *et al.* (1988)
Huaxim seed	*Sesbania grandiflora*	Tilapia	Experimental	Olvera *et al.* (1988)
Alfalfa leaves	*Medicago sativa*	Tilapia	Experimental	Hernández, Hernández and Martinez (1991)
Dendrocéfalo	*Dendrocephalus geayi*	Tambaquí	Experimental	Torres *et al.* (2003)
Daphnia/fly larvae	*Daphnia spp* *Culex quinquefasciatus*	*Cichlasoma istlanum*	Experimental	Luna and Figueroa (2003)
Langostilla	*Pleuroncodes planipes*	Shrimp	Experimental	Galicia (2003)
Fish silage	-	Tilapia, carp, Catfish (*Clarias* spp.)	Experimental and commercial	Toledo (2004)
Kelp	*Macrocystis pirifera*		Commercial	Panorama Acuícola (2004b)

Brazil, Argentina, Chile and Colombia and to a lesser extent in Uruguay and Venezuela. Nonetheless, feed manufacturers import large quantities of high quality vegetable oils from the United States of America and Canada. Prices of fish and vegetable oils have increased substantially with increasing demand and reduced availability because of periodic crop failures.

5.5 Feeding strategies

Shrimp farming

Feeding regimes and strategies are similar throughout Latin American aquaculture. In general, farmers follow the recommendations and advice provided by technical staff of large feed manufacturing companies.

The great majority of shrimp farms (more than 90 percent) produce Pacific white shrimp, *Litopenaeus vannamei*, therefore practically 100 percent of the commercially available feeds are designed to meet the nutritional requirements of this species. The most common practice is to follow feeding tables recommended by feed manufacturers. These normally take into account standard stocking densities and climatic conditions of the region. Table 21 presents standard feeding regimes followed by farmers in Brazil, Ecuador, Mexico, Panama and Peru.

TABLE 21
Feeding regime employed by Pacific white shrimp (*Litopenaeus vannamei*) farmers in Latin America

Shrimp weight (g)	% body weight/day				
	Brazil[1]	Ecuador[2]	Mexico[3]	Panama[4]	Peru[5]
1	13	-	16	12	14
2	11	5.5	11.7	10	8.2
3	10.5	4.7	8.6	9.0	6.2
4	10	4.2	7.2	9.0	5.2
5	9.3	3.9	6.2	8.0	4.5
6	9.0	3.6	4.8	8.0	3.9
7	8.4	3.3	4.4	7.0	3.6
8	8.0	3.0	4.0	7.0	3.3
9	7.2	2.9	3.9	6.5	3.0
10	6.3	2.8	3.6	6.0	2.8
11	5.7	2.6	3.5	5.5	2.6
12	5.0	2.6	3.3	5.3	2.5
13	4.2	2.5	3.1	5.1	2.3
14	3.4	2.4	3.0	4.8	2.2
15	3.0	2.3	2.9	4.8	2.1
16	2.5	2.3	2.7	4.5	2.0
17	2.4	2.2	2.5	4.0	2.0
18	2.4	2.1	2.4	3.5	1.9
19	2.4	2.0	2.4	3.0	1.8
20	2.4	2.0	2.4	2.5	1.8
21	2.4	1.9	2.4	2.5	1.8
22	2.4	1.8	2.4	2.5	1.8

Sources: [2]Villalón (1991); [1,5]Nunes (2000); [4]CODECA (2004); [3]Zendejas (2005)

5.6 Feeding schedules and practices

Farmers normally feed their fish or shrimp between noon and sunset to avoid low DO periods. Throughout Latin America shrimp farmers feed a minimum of 2 and a maximum of 4 times a day, depending on the number and size of ponds and the available workforce. A recommended feeding schedule for white shrimp, *Litopenaeus setiferus* in Yucatan, southeast Mexico is presented in Table 22.

Over the past 10 years, Latin American shrimp farmers have increasingly adopted the use of feeding trays, as opposed to feeding manually with the aid of a boat. Feeding trays are circular in shape, between 0.60 and 1.20m in diameter and usually made of galvanized wire and plastic mosquito mesh. Such trays are evenly distributed throughout the pond, at between 20 and 30 trays/ha. Farmers place the corresponding sub-ration of feed into each tray at pre-specified periods. The use of feeding trays is becoming very popular due to their usefulness in monitoring the feeding activity of shrimp as well as reducing the accumulation of wastes on the pond bottom.

TABLE 22
Recommended feeding schedule for white shrimp, *Litopenaeus setiferus* in semi-intensive ponds in Yucatan, southeast Mexico

Shrimp size (g)	Feeding schedule	% of daily ration
1.0–3.0	11:00	50
	17:00	50
3.1–6.5	11:00	40
	17:00	30
	22:00	30
>6.5	11:00	40
	14:00	10
	17:00	10
	21:00	40

Source: Flores-Nava (1994)

Finfish

Given the level of intensification of salmon and trout culture, automatic feeding is employed in most farms, on a continuous intermittent basis. Feeding efficiency is high with average feed conversion ratios of 1.3:1 (Villarroel, 2003).

TABLE 23
Feeding schedules for catfish, common carp and tilapia, employed by pond farmers in Mexico

Mean fish weight (g)	Catfish		Common carp		Tilapia	
	% body weight/day	Times/day	% body weight/day	Times/day	% body weight/day	Times/day
25	4.0	2	4.5	3	4.5	3
50	3.5	2	4.0	3	3.7	3
75	3.2	2	3.6	3	3.4	3
100	3.0	2	3.3	3	3.2	3
150	2.8	1	3.1	2	3.0	2
200	2.5	1	3.0	2	2.8	2
250	2.2	1	2.6	2	2.5	2
300	2.0	1	2.4	2	2.3	2
400	1.6	1	2.1	2	2.0	2
500	1.4	1	1.7	2	1.7	2
600	1.2	1	1.4	2	1.4	2

Source: Zendejas (2005)

Most of the tilapia, catfish and trout farms in Latin American are semi-intensive and intensive, while carp and indigenous species are generally farmed extensively and semi-intensively. Tilapia are normally fed during the warmest hours of the day between noon and 16:00 hours, irrespective of the culture system (floating cages or ponds). Farmers usually feed once or a maximum of twice a day, using a variety of methods that include delivery by hand, feed blowers, automatic and demand feeders.

Channel catfish *Ictalurus punctatus* farms are intensive and 100 percent dependent on commercial feeds, which are usually provided twice a day during the juvenile stages and once a day during the grow-out stages between 11:00 and 15:00 hours. Sinking pellets are fed using either feed blowers or are manually distributed. Rainbow trout *Oncorhynchus mykiss* are fed floating extruded pellets, either manually (2–4 four times a day) or using automatic feeders (4–6 times a day). Table 23 presents recommended feeding schedules for catfish, common carp and tilapia, as employed by farmers in Mexico.

5.7 Supplementary and other feeds

Farm-made feeds

Farm-made feeds are practically non-existent in the region. A limited number of small-scale farmers in Cuba and Brazil use agricultural by-products including coffee pulp, rice and wheat bran as well as fishmeal, when available, to replace or complement formulated complete diets when these are in short supply or when farm cash flow is problematic.

Farm-made feeds are more common in the ornamental fish industry, regardless of the production scale. A range of nutrient sources are used, ranging from ground, dried shrimp heads to cereals and boiled eggs.

Given the wide range of agricultural and industrial by-products and other potential nutrient sources that are readily available, capacity should be developed and built to formulate and manufacture inexpensive, farm-made feeds using agricultural by-products. This would stimulate rural aquaculture throughout the region and rural development is desperately needed throughout the region.

Use of trash fish

Trash fish is only used as feed in the emerging tuna cage culture industry in Mexico. More than 100 tonnes of tuna is currently produced and the industry is growing fast. Given the exclusive dependence on trash fish and considering an FCR of at least 3:1, then at least 300 tonnes of trash fish is used at current capacity.

6. THE POSSIBLE IMPACT OF FEEDS ON THE SUSTAINABLE DEVELOPMENT OF AQUACULTURE IN LATIN AMERICA

The pattern of growth of the aquaculture industry in Latin America is similar to many parts of the world and is characterized by intensification, increasing number and size of farms and a growing number of cultured species. Consequently, the aquafeed industry in the region has experienced dramatic growth over the past 20 years. On the other hand, the collapse of shrimp production because of diseases in several countries (Ecuador, Mexico and other Central American countries) during the 1980s and 1990s had a hugely negative impact on the aquafeeds industry in the region.

The inter-dependence of feed manufacturers and farmers is the Achilles heel of sustainable aquaculture development in Latin America. Given that the contribution of feed to total production costs has reached levels of 65 percent (Panorama Acuícola, 2007) highlights a number of factors that will impact on the future development of a sustainable aquaculture industry in Latin America. The most important of these are:

6.1 Food safety

Increasing trade of aquaculture inputs and farmed products is prompting governments, farmers and feed manufacturers to adopt quality control measures and traceability programmes to comply with international food safety requirements. This will certainly induce a feedback system of practices that will improve product quality and competitiveness within the sector.

6.2 Price-related factors

Large international corporations have been buying smaller feed manufacturers throughout the region. This has resulted in a regionalisation of markets, reducing local competition, fewer types of feeds and in some instances has resulted in reduced feed quality and higher prices.

6.3 Availability of raw materials

The main protein and lipid ingredients are world trade commodities, the availability of which is dependent upon a series of stochastic factors such as crop success or failure and climatic conditions. These, together with local exchange rates determine the pricing of such ingredients. Prices of raw materials have increased several times in some cases over the past 10 years and are likely to continue increasing, due to recent adverse climatic conditions in major producing countries (e.g. El Niño events in Peru and Ecuador have impacted on fishmeal production). Moreover, global warming and climate change will in future also affect the availability of agricultural commodities. The pressure on fishery resources to produce fishmeal and land surface area to grow increasing volumes of grains to meet a highly demanding industry will certainly compromise the sustainability of the aquaculture sector within the next decade.

6.4 Research on alternative sources of protein

Despite the great biodiversity of the Latin American region research results on potential sources of alternative protein and lipids to replace fishmeal and fish oil are still very modest. This highlights the short sightedness of those large aquaculture corporations that do not invest in research and development. The academic sector lacks the necessary resources to accelerate investigations on the wide spectrum of possible (plant and animal) feed resources to partially or completely replace fishmeal, as well as for example research on improving the nutrient utilization of agricultural and industrial by-products.

6.5 Responsible feeding practices

Although there is a growing tendency for farmers and technical advisors to implement internationally accepted and responsible aquaculture practices, many large farms throughout the region still practise feeding strategies that contribute little to sustainability. Examples of this are the absence of a monitoring scheme of water quality in relation to feeding and the absence of indicators of feed utilization and efficiency. This is a reflection of the lack of structured national responsible aquaculture programmes. Consequently and in many instances, farmer training and adoption of sustainable practices depends exclusively on the technical assistance provided by feed manufacturers and, to a lesser extent, the academic sector of each country. The use of feeding trays in the shrimp industry has become a popular way of reducing feed waste and reducing organic matter and nutrients discharges into the environment. However, it is highly questionable whether the reliance of farmers on feed manufacturers is a healthy situation with respect to the sustainable development of the sector.

6.6 Environmental regulations

The legislative frameworks in relation to sustainable aquaculture development in Latin America are still very weak. Although important advances have been made in relation to habitat modification, organic discharges and movement of exotic aquaculture species, regulations regarding feeds and fertilizers are almost non-existent. Physical properties of feed particles or levels of potentially leaching nutrients are not regulated. However, the pace at which regulations are changing with respect to aquaculture inputs is accelerating in some countries (e.g. Mexico, Brazil and Chile) and this is mainly because of increasing international trade relations, requirements and agreements.

The use of trash fish, although still limited in volume, might escalate as tuna aquaculture expands, especially in Mexico. This could raise several questions regarding quality and competition with human consumption.

6.7 Use of fertilizers

Fertilizers used in aquaculture are in most instances identical to those used in agriculture. This creates a dependency on the local agriculture sectors. Moreover, chemical fertilization is a standard practice in semi-intensive shrimp or fish farms of the region and large quantities of unused nutrients are discharged into the environment. The use of organic fertilizers is gradually decreasing, as the demand for manure in other agricultural sectors increases and consequently prices have reached non-competitive levels.

6.8 Sustainable aquaculture technologies

Use of environmentally sound technologies for aquaculture in Latin America is still incipient, although it is growing. Their use is stimulated by international acceptance and import tax reduction for "organic aquaculture products". Although limited in number, a few commercial farms in Belize, Brazil, Peru and Mexico have adopted zero-water exchange practices, high aeration culture systems. Polyculture and integrated aquaculture have slowly been adopted by farmers in Brazil, Mexico, Peru, Panama and Honduras. Aquaponics is also becoming a popular alternative in small-scale aquaculture in southeast Mexico. Such systems ensure maximum resource utilization and more farmers should be encouraged to adopt a more organic approach to aquaculture in the future.

The use of probiotics, enzymes and immuno-stimulants, as feed additives, or prebiotics applied directly into the water is also still incipient but growing. Some leading farmers have reported encouraging results, particularly in Ecuador (Garriques and Arevalo, 1995).

6.9 Feed manufacturing technologies

Extruded, coated, highly stable feed particles are becoming more common in the aquaculture industry. This directly contributes to lower levels of pollution and higher production rates through improved feed utilization. The use of such feeds must be promoted throughout the region.

7. RECOMMENDATIONS

- Governments should introduce national quality standards for raw materials and feeds as well as for farmed products to strengthen the international competitiveness of national aquaculture sectors, and to provide better quality food for human consumption. This should be done taking into account the present range of culture systems and intensification.
- Research on alternative sources of protein and energy to replace fishmeal and fish oil at least partially, should be encouraged, particularly taking into account the availability of regional resources, including agricultural and industrial by-products. Tax incentives should be granted to feed manufacturers and aquaculture farmers that invest in research and development.
- Levels of phosphorus and other potentially leaching nutrients, as well as digestibility levels of feeds should be regulated to reduce organic pollution in aquaculture discharges or cage sites.
- Aquaculture and agriculture farmers that wish to integrate aquaculture to their traditional agricultural systems are constrained by the high cost of formulated feeds and the lack of basic knowledge on the use of locally available ingredients for the production of low cost, farm-made feeds, which could substantially increase the economic sustainability of rural aquaculture, thus benefiting large sectors of the population. Governments should take cognisance of the opportunities offered by aquaculture for rural development.
- Capacity building of small-scale farmers, particularly with respect to farm-made feeds should be prioritized in aquaculture development plans. A review of locally available potential ingredients is essential, followed by training of extension officers and farmers on basic aquaculture nutrition and farm-made feed preparation. In many cases this will be the only alternative for rural aquaculture to be sustainable.
- Governments should facilitate dialogue between researchers, farmers and feed manufacturers to collectively tackle existing and emerging problems, focus research and to strengthen the competitiveness of the aquaculture sector.
- Improved management of ponds including "ecological management" (i.e. heterotrophic systems) should be promoted to increase system productivity, reduce water use and lower the dependence on high protein, fishmeal-based feeds.

ACKNOWLEDGEMENTS

The author wishes to thank the following persons for providing important information included in this contribution: Dr Marcio Hipólito, Instituto Biológico de Sao Paulo, Brazil, provided information on feedmills and aquaculture feeds in Brazil. Mr. Jesus Zendejas, Cargill-Mexico, also provided information on aquafeeds, feedmills and feeding in Latin America. Dr Miguel Olvera, CINVESTAV-Mexico, for providing useful information on alternative sources of protein in the region. Mr. M. Dewind, National Chamber of Aquaculturists of Ecuador, provided production data from Ecuador; Dr. Sergio Toledo, Centro de Preparación Acuícola Mampostón, Cuba, provided information on aquafeeds and feed research in Cuba, Biol. Jorge Velazco, INAPESCA, Venezuela, for providing aquafeeds and aquaculture production data for Venezuela, and Mr Marcelo Araneda, Universidad Marista, Mexico, for providing information on aquaculture production, systems and aquafeeds in Chile.

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