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# A Global Perspective of Aquaculture in the New Millennium

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**ABSTRACT:** In modern times, not many primary industries have consistently recorded high yearly growth over a period of two decades. Aquaculture has sustained a global growth, continues to grow, and is expected to increasingly fill the shortfall in aquatic food products resulting from static or declining capture fisheries and population increase well into the year 2025. Its further growth and development will have to occur under a different socio-economic milieu in the new millennium. The basic paradigm changes will be from an increased production at almost any cost, to a sustainable increase in production with minimal environmental perturbations. Despite such paradigm changes, aquaculture will increasingly contribute to food security, poverty alleviation and social equity.

The contribution of aquaculture to world food supply of aquatic products has been increasing over the past 10 years, in comparison to capture fisheries, growing from 15 to 28 percent of total production between 1988 and 1997. As the bulk of aquaculture is rural and subsistence, it plays a major role as a provider of direct and indirect employment to the rural poor and, thereby, to poverty alleviation. In many developing countries, aquaculture provides opportunities for diversification on agriculture farms and productive use to otherwise idle land during certain seasons. The main cause for the upsurge in the sector has been the transformation of aquaculture from an "art" form to a "science". This brought many advantages, ranging from less dependence on wild stock to the development of techniques that optimized yields, such as polyculture, or enabled the achievement of high yields with low inputs. Two major developments also enabled the sector to maintain growth momentum, appropriate institutional frameworks and concerted research and development. Regions or continents have many commonalities. These include the predominance of finfish among the cultivated species, and the predominance of species that feed lower in the food chain, although shrimp, which does not naturally feed high in the trophic level but is mostly reared on artificial feed, has become a significant culture commodity. Notable differences, however, include the fact that all regions, except Africa and the countries of the former USSR, have recorded a significant increase in per capita production between 1984 and 1997. While Asia continues to dominate world aquaculture in overall tonnage, as well as in every major commodity, South America has registered a very high (72.8 percent) average annual growth between 1984 and 1997.

The global and regional trends over the last 20 years in the sector from a number of perspectives, such as production trends, contribution of aquaculture to aquatic food consumption etc., are evaluated. Based on these different trends and in the light of changing

socio-economic conditions globally, and in particular, in developing nations, the potential changes in the sector in the new millennium are highlighted. Finally, projections are made for the next 20 years, where opportunities, constraints and strategies for achieving the targets are presented and discussed.

**KEY WORDS:** Aquaculture, Production, Aquatic Food Consumption, Global, Continents, Commodities

## Introduction

In modern times, there have not been many primary industries in the world that have recorded consistent annual growth over a period of two decades or so. Aquaculture is one of these; a sector that has not only achieved regular annual growth on a global basis, but is also continuing its expansion. Aquaculture is anticipated to account increasingly for the shortfall in aquatic food supply that would result from the population increase projected until 2025 (Hempel, 1993; Williams, 1996; Sverdrup-Jensen, 1997) and the levelling off, if not the dwindling, of the returns from wild fisheries (Botsford et al., 1997; Ye, 1999). Aquaculture is often seen as an important primary production sector from the food security, poverty alleviation, socio-economic and industrial view points, but the further growth and development of this sector in the new millennium will be forced to occur within a different socio-economic milieu. The "core paradigms" of the sector will have to be different from those of the previous 20 years and, therefore, the strategies have to be equally different and innovative.

In the new millennium, it is expected that the basic paradigm change will be from that of increasing production at almost any cost, as seen in the past, to that of

## The past 20 years

### Aquatic products as a food source

Civilisations have almost always developed in association with rivers or other suitable water resources. It is to be expected, therefore, that the hunting instincts of *Homo sapiens* were used effectively to harness the fish resources of such waters from time immemorial, as often demonstrated in ancient inscriptions. Nonetheless, the most effective exploitation of fish resources globally has occurred in the period following the Second World War (Botsford et al., 1997), when fish became an increasingly important component of our daily animal protein intake and calorie supply.

Although aquaculture originated at least two millennia ago, it was only since the latter part of the 20th Century that it began to make a significant contribution to overall human food supplies, and it is now seen as an important sector for the supply of animal protein. With the increasing awareness of the positive effects of fish consumption on health and well being, the importance of aquaculture in the food sector is destined to grow further. Equally, the sector will also continue to contribute to income generation and livelihoods of significant portions of the global population, mostly the rural poor.

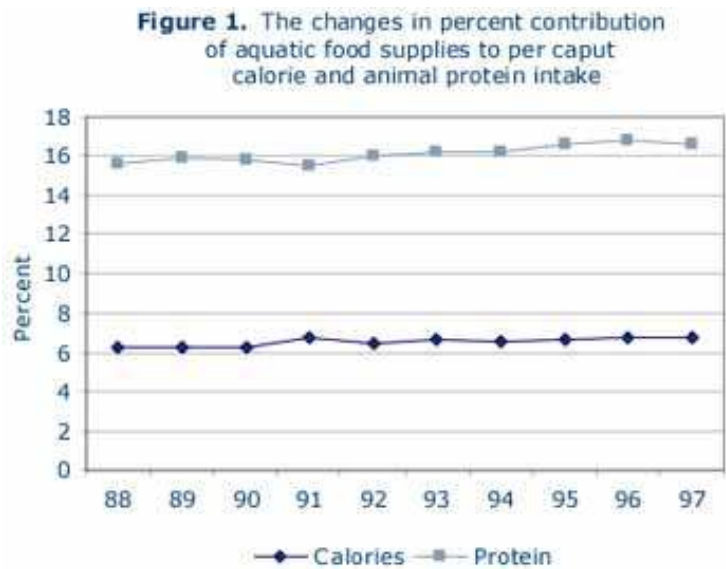
The contribution of aquatic food products to

attaining a sustainable increase in production with minimal environmental perturbation. In spite of such paradigm changes, there is little doubt that aquaculture will increase its contribution to food security, poverty alleviation and social equity. The key challenge, however, is to ensure that aquaculture development in the new millennium will continue to contribute to food supply whilst making a more effective contribution to improvement in rural livelihoods, carrying an increased emphasis on equitable development.

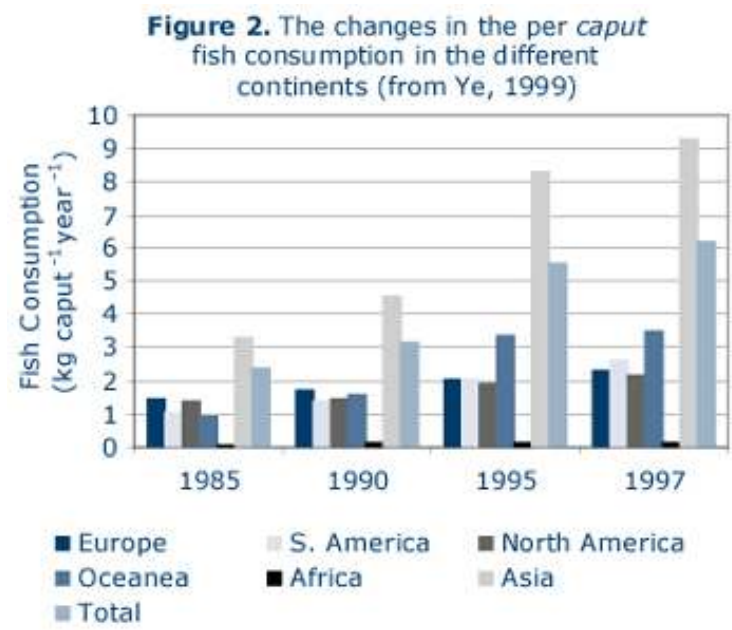
This paper attempts to provide a global synthesis of the aquaculture sector's development and performance over the last 20 years, addressing the important issues encountered during this period, particularly over last five to seven years as the vision for sustained growth has been applied to the sector. In addition, plausible changes that may be imposed on the sector are highlighted, these being the foreseen results of modifications in the socio-economic milieu, particularly in densely populated developing countries, some of which also happen to be epicentres of aquaculture activities.

Finally, and most importantly, projections are made for the next 20 years, where opportunities, constraints and strategies for achieving the targets are presented and discussed.

the per caput calorie and animal protein supplies is shown in Figure 1.



While it is clear that the figure for calorie supply has remained almost unchanged over the last 20 years or so, the contribution to animal protein supply has shown a gradual increase, currently being 16.6 percent. This gradual increase in importance of aquatic food is a reflection of the increase in world fishery production. The per caput fish consumption in 1996 was 15.8 kg/yr, and consumption has grown at an annual rate of 4.7 percent between 1990 and 1995 (Ye, 1999), noting that consumption rates differ significantly amongst continents (Fig. 2). Furthermore, there are also large differences of per caput consumption of fish in different regions/countries within a continent. This is best exemplified in the case of Europe, which has an average per caput consumption of around 16.5 kg/yr, but where the European Community (EC) countries consume around 22 kg/yr as opposed to the 6-9 kg/yr reported for the Central and Eastern European countries (Varadi et al., present volume).



The most significant change in fish consumption patterns, over the years, has also been seen in Europe, when it dropped from the top position to fourth in the ranking order, which currently is led by North America with 21.6 kg/yr. One must also note that fish consumption in low-income food-deficit countries (LIFDCs) was only 12.7 kg/yr compared to 19.5 kg/yr in the rest of the world. Overall, Ye (1999) concluded that fish has become more and more important in peoples' diets, and that, from a food security point of view, fish was important mostly to LIFDCs<sup>2</sup>.

Food security is considered to exist when all people, at all times, have physical and economic access to sufficient, safe and nutritious food, allowing them to meet their dietary needs and food preferences for an active and healthy life. Apart from the fact that, in most instances, aquatic food costs less than other animal protein supplies, aquaculture also enables employment and income generation, which in turn helps to alleviate poverty, establish food security and assist rural livelihoods in general.

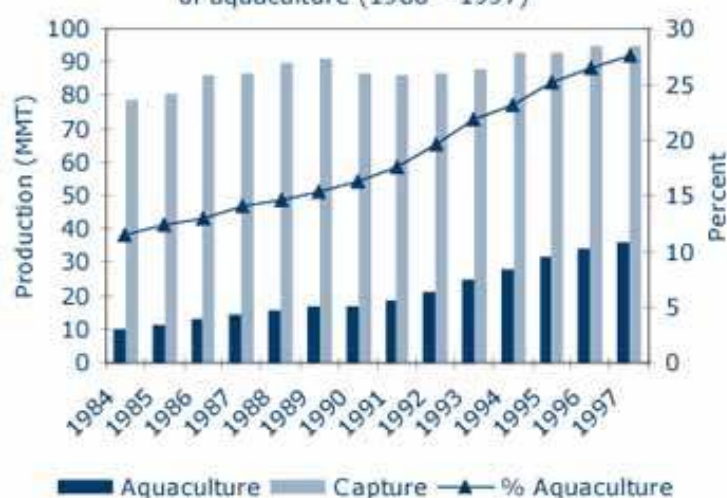
### Contribution of aquaculture to the aquatic food supply

Prior to 1980, the aquaculture sector was small and mechanisms did not exist for providing distinct data, either for production or contribution. As the sector grew and developed, combined with the simultaneous reduction in the growth of global capture fisheries, the provision of separate statistics for the sector became imperative. World aquaculture in 1997 provided 36 million mt, or 28.8 million mt if one excludes aquatic plants (FAO, 2000)<sup>3</sup>, as opposed to 87.1 million mt from the capture fisheries in 1996 (FAO, 1999).

On the other hand, and perhaps more importantly, the contribution of



**Figure 3.** The contributions of capture fisheries and aquaculture to the total aquatic food supply and the percentage contribution of aquaculture (1988 – 1997)



aquaculture to the global aquatic food supplies has increased steadily during the last 15 years by comparison to the capture fisheries (Fig. 3). Between 1984 and 1997, its share in the total supply has grown from 12 to 28 percent, tantamount to the position that nearly every third kg being consumed is cultured. These shifts within the two sectors reflect the changes in availability of aquatic food products from the capture fishery as opposed to those from aquaculture.

Accordingly, the per caput availability from aquaculture increased from 2.3 to 6.4 kg/yr over the period 1984 to 1997, a development that enabled the aquatic food supply to be maintained around 16 kg/yr, in spite of the stagnation of the returns from the capture fishery and the increasing population size.

This clearly indicates the increasing global importance of aquaculture as a valuable food resource for the growing population, particularly in developing countries with very high population densities, a position that will become apparent later.

## Review of production

It is relevant to consider the main reasons for the impressive rise of the sector over the last 20 years. One of the underlying causes can be summarized by the transformation of aquaculture from an "art" to a "science", not only in the approach, but also in the application. A

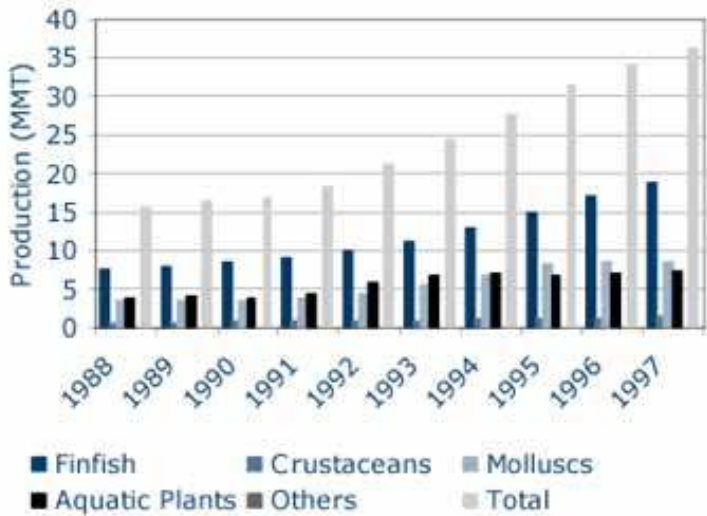
Both these aspects must continue to be nurtured, extended in scope and strengthened, if the growth of the sector is to be maintained and stabilized in the new millennium. The current (1997) aquaculture production of 36 031 129 mt (FAO, 2000) is made up of finfish, aquatic plants, molluscs, crustaceans and miscellaneous commodities (including other invertebrate and a few vertebrate species). The main trends seen for global aquaculture production since 1988 are shown in Figure 4. From 1988 to 1997, which is the period under review in this and accompanying papers, the total increase has been 132 percent, with an APR [Annual Percent Rate of growth] of 9.8 percent.

major advance has been the reduction of the sector's dependence on seed caught from the wild, and this for the great majority of species cultured.

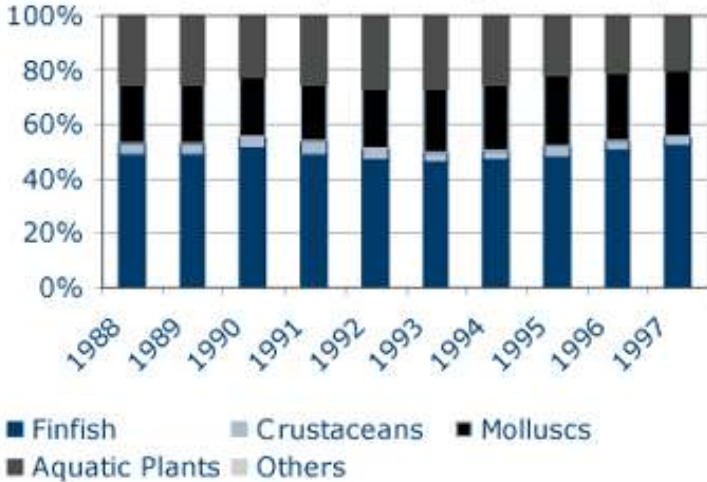
Currently, the life cycles of almost all major cultured species, except perhaps in the case of anguillid fish, have been closed, on a technical basis. On the other hand, for some species, such as the penaeid shrimps, while the life cycle has been closed technically, it is not necessarily practised commercially; i.e. this sector, in some countries, depends on wild-caught broodstock, as well as wild-caught postlarvae (Primavera, 1998). Similarly, techniques have been developed and extended to optimize yields from different culture practices. In this regard, a major stride forward encompasses the technical developments and the effective popularization of polyculture practices, when high yields were made possible with relatively low-cost inputs.

The list of technical advances that have been made in the last two decades is indeed exhaustive, and it is futile to try to summarize them all in this paper. However, it is the author's view that two other significant developments have enabled the sector to retain its momentum - the establishment of appropriate institutional frameworks, national and regional, and the initiation of a concerted R & D strategy.

**Figure 4.** The main trends in aquaculture production (quantity and value) from 1988 – 1997



**Figure 5.** The changes in percent contribution of the major commodities to total aquaculture production (1988 – 1997)



It is evident that finfish represents the bulk of the aquaculture production (by volume), contributing about 50 percent of the total, a position that has remained almost unchanged throughout this time (Fig. 5). In 1997, finfish (52 percent) was followed by molluscs (24 percent), seaweeds (20 percent) and crustaceans (4 percent). The main change to be seen, however, has been with regard to the culture of aquatic plants, whose contribution has decreased from about 25 percent to 21 percent. Mollusc production has slightly increased its contribution and, after a period of rapid growth in the second half of the 1980s, the crustacean contribution stabilized at around 4 percent.

Important changes have been seen with regard to the species cultured (Table 1). In 1988, the ten species that were produced in highest quantity included five finfish, three aquatic plants and two molluscs<sup>4</sup>, where the top four species each exceeded 1 million mt. By 1997, five finfish, three mollusc and two aquatic plant species made up the top ten. Of these, the production exceeded 1 million mt in eight taxa (Table 1). One of the important facts that emerges from the species listing is that in spite of the major strides made in terms of technology, adding value, marketing etc., all of the species (or species groups) listed are ones that feed lower in the food chain. Indeed, the list does not include a single species whose culture is dependent on the provision of an artificial feed. This statement does not, however, preclude the fact that commercial feeds are used, to varying degrees, for some of the species cited.

A key question is whether this "league table" will change markedly in the new millennium. Although some changes will occur, it is unlikely that carnivorous species, or species which are high on the trophic ladder, will enter into the table.

Exceptions could be Atlantic salmon and tiger shrimp, both of whose production is almost exclusively based on artificial feeds.

In spite of these generalized observations made for the sector, there is a marked disparity in aquaculture production between the different continents (Fig. 6), regions and countries. The reasons for these differences are manifold, and a detailed analysis at this level is beyond the scope of this paper, but is treated in the individual regional reviews.

Nonetheless, it has to be conceded that the initial upsurge in certain regions was, in all probability, linked to the cultural background, which in turn reflects a consumer preference for aquatic food products and a tradition of some form of fish culture.

One of the most important facts of the sector is that in all continents, except Africa, there has been a significant increase in the production per caput over the period 1984 to 1997. The increase in production per caput in Europe was, however, comparatively smaller. It is within this context that the leading role of Asia in the global aquaculture sector has to be considered.

On the other hand, the sector has also witnessed the development of large-scale, industrial aquaculture during the last two decades, which is not so interlinked with the traditions mentioned previously, but may be due to the consumer preferences in the developed countries. The development of aquaculture for salmonids and shrimps in South America, salmonids in northern Europe, marine finfish in the Mediterranean Region and channel catfish in the United States are examples of this from throughout the world.

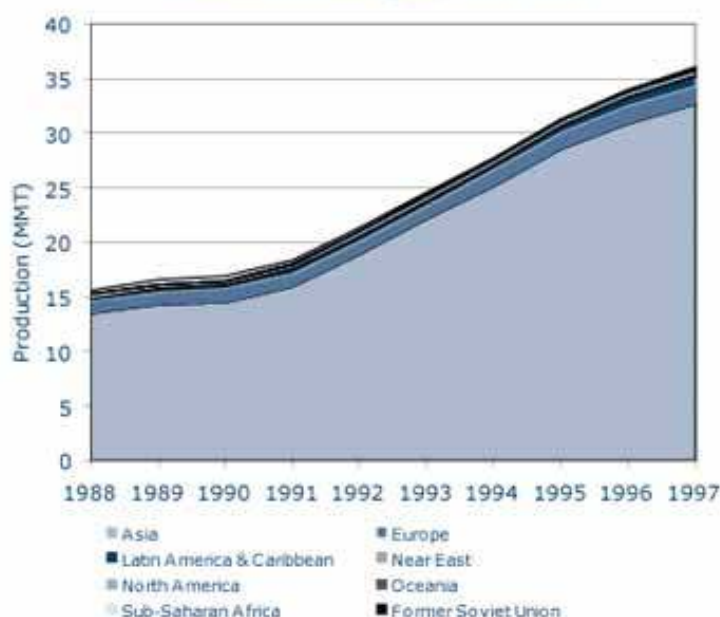


**Table 1.** The ten species that were produced in the highest quantity in 1988 and 1997, the amount produced is given in metric tones.

Species	1988		1997
Japanese kelp	2 072 383	Japanese kelp	4 401 931
Silver carp	1 587 691	Silver carp	3 227 617
Pacific cupped oyster	1 217 663	Pacific cupped oyster	2 974 460
Common carp	1 093 754	Grass carp(=White amur)	2 711 131
Bighead carp	725 603	Common carp	2 229 826
Laver (Nori)	670 816	Bighead carp	1 552 461
Grass carp(=White amur)	609 858	Japanese carpet shell	1 275 104
Wakame	492 196	Yesso scallop	1 256 799
Blue mussel	415 846	Crucian carp	862 554
Milkfish	345 829	Laver (Nori)	861 231

435

**Figure 6.** Aquaculture production in the different continents/regions, 1988 - 1997



Another major change seen has been the dramatically reduced production in the countries of the former USSR are, the only region where diminished activity has been seen, dropping from 320 000 mt to 109 000 mt, represented by a negative APR of -11.3 percent. The trends in production within each region are dealt with in detail in further reviews within this volume.

It is, however, important to underline the significance of Asia in global aquaculture production. In 1988, Asia contributed 86 percent to global aquaculture production but had increased its position to 91 percent by 1997. Furthermore, within Asia and indeed globally, China<sup>5</sup> remains the leading aquaculture producer; China's contribution<sup>6</sup> to Asian and global production in 1997 was 74 and 67 percent, respectively, demonstrating that it has retained and improved its lead position since 1988, when these figures were 55 and 47 percent,

Perhaps, in the new millennium, developments of this nature will continue to strengthen the sector, and this aspect will be considered in detail later.

Asia continues to dominate global aquaculture production, not only from the point of view of the total contribution (91 percent of reported yields), but also within the major commodity groups. A significant global change has been the increased

production in Latin America, moving from 179 000 mt in 1988 to 783 500 mt in 1997, representing an APR of 17.8 percent for the period. Aquaculture production in Oceania and sub-Saharan Africa also increased, with APRs of 11.2 and 10.2 percent, respectively but, if measured in absolute terms, these increases represented only 68 000 mt or 23 500 mt, respectively.

respectively.

In 1988, eight Asian countries/territories were among the top ten aquaculture producers, with China leading with a production of 7 million mt (Table 2). By 1997, the top ten was entirely composed of Asian nations, with China leading and providing 24 million mt. This means that its production had increased by 340 percent over the ten-year period. The Democratic People's Republic of Korea, Japan and Taiwan Province of China recorded reductions, while all the other Asian nations increased their production in this period, 13 of them recording at least a doubling in production. Also, by 1997, Thailand and Vietnam had emerged as major aquaculture nations.

**Table 2.** The top ten aquaculture producing countries in 1988 and 1997. The amount produced is given in metric tones.

Country	1988		1997
China	6 995 409	China	24 030 313
Japan	1 425 991	India	1 862 250
Korea Dem. People's Rep	1 090 000	Japan	1 339 861
Korea Republic of	898 649	Korea Republic of	1 040 230
India	893 330	Philippines	957 546
Philippines	599 464	Indonesia	777 547
Indonesia	499 597	Thailand	552 356
United States of America	357 614	Bangladesh	512 738
Taiwan Province of China	300 981	Viet Nam	509 000
Spain	271 356	Korea Dem. People's Rep	489 321

Value of production

The value of the products of world aquaculture in 1997 was US\$50.7 billion, an increase of US\$26 billion, representing an APR of 8.5 percent over the period 1988-1997. These figures suggest that, at a global level, the total value of aquaculture produce has increased at a slower rate than that of production (APR 9.8 percent). The contribution of each of the major commodities to the total value of aquaculture produce is shown in Figure 7.

It is evident that finfish contribute the highest value (55.9 percent in 1997), ranging from 52-58 percent (Fig. 8), followed by molluscs (17.2 percent in 1997) and crustaceans (16.7 percent in 1997). The high market value of crustaceans, particularly shrimp, is reflected in the lower percent contribution to production (3.8 percent) compared to that of molluscs (23.8 percent) and aquatic plants (20 percent of production but only 9.6 percent of value) [also see Fig. 5].

The distribution of the value of produce amongst the regions (Fig. 9) reflects the nature of production in these areas (also see Fig. 6). It is however, important to note that the values obtained for a majority of finfish, crustacean and mollusc species, notably those whose production exceeded 40 000 mt in 1997, have declined over the years (Tables 3 to 6). Twenty-three of the 40 species (or groups, i.e. freshwater fishes nei) show a negative APR for value/kg during the ten-year period 1988-1997.

For example, the unit value<sup>7</sup> of Atlantic salmon has decreased by US\$2.87, while even more spectacular drops have been seen for Japanese eel (-US\$6.23), gilthead seabream (-US\$6.30) and coho salmon (-US\$3.02). This general trend has interpretations that vary on the basis of

Figure 7. The contribution of each of the major commodities to the total value (billion US\$) of a quaculture produce, 1988 - 1997

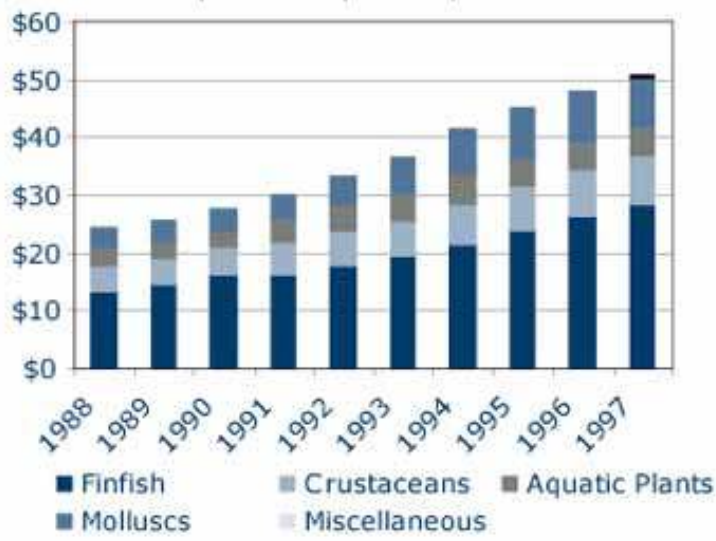
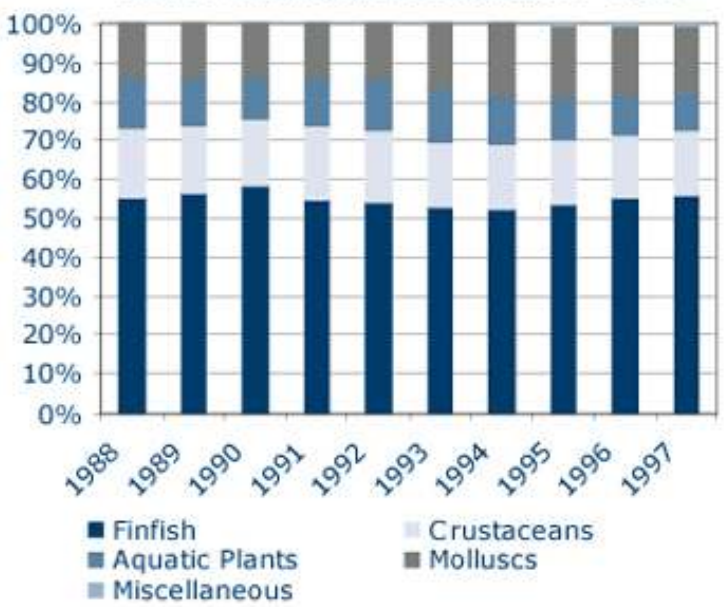


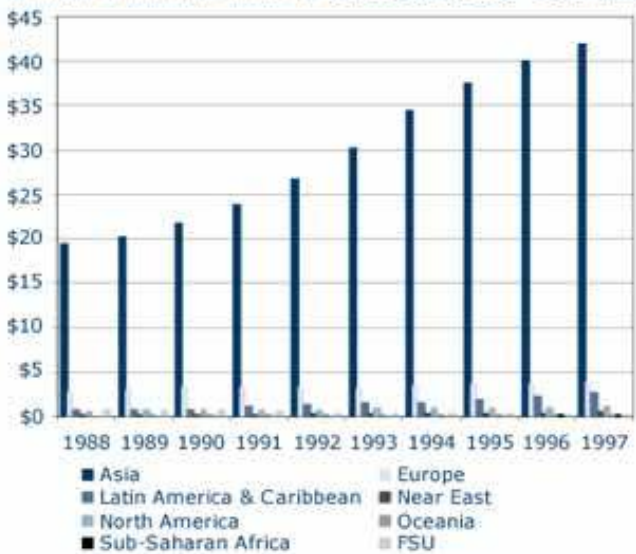
Figure 8. The changes in percent contribution in the value of the major commodities to the total value of aquaculture produce 1988 - 1997





the commodity and the market within which it is sold. The likely principal reasons for price reductions are competition between producers in the marketplace and decreased production costs due to improved efficiencies in farming systems. The improved efficiencies of different farming systems were achieved through technological advances, improved farm management and realisation of economies of scales that provide for adequate returns on investment in spite of lower sales prices.

**Figure 9.** The changes in the value of aquaculture produce of different continents and regions 1988 - 1997 (billion US\$)



**Table 3.** Finfish and crustacean species whose production exceeded 40 000 mt in 1997, showing changes in production and value (1997 vs 1988), factors of change and the change in value/kg.

Species	Production 1988	Production 1997	Factor of Change Production	Factor of Change Value	Value (US\$)/Kg 1988	Value (US\$)/Kg 1997
Gilthead seabream	1 785	41 691	23.4	12.4	13.39	7.10
Japanese eel	91 737	222 623	2.4	1.0	10.81	4.59
Coho salmon	25 780	84 794	3.3	1.8	6.83	3.81
Freshwater crustaceans nei <sup>1</sup>	28 427	44 845	1.6	1.0	7.64	4.63
Atlantic salmon	112 377	646 513	5.8	3.1	6.18	3.31
Silver seabream	45 241	81 426	1.8	1.3	10.37	7.60
Whiteleg shrimp	76 450	168 967	2.2	1.6	7.70	5.42
Chinese river crab	0	100 692			7.50	6.01
Climbing perch	37 291	61 313	1.6	0.7	2.20	1.00
Torpedo-shaped catfishes nei	42 563	126 196	3.0	1.9	2.14	1.37
Common carp	1 093 754	2 229 826	2.0	1.4	1.73	1.21
Rainbow trout	248 010	427 338	1.7	1.5	3.57	3.16
Grass carp	609 858	2 711 131	4.4	3.1	1.34	0.92
Crucian carp	121 803	862 554	7.1	5.0	1.30	0.91
Fleshy prawn	199 520	104 456	0.5	0.5	7.50	7.12
Catfish, hybrid	12 551	52 680	4.2	3.1	1.11	0.83
Marine fishes nei	37 597	280 659	7.5	6.0	1.28	1.03
Channel catfish	164 183	238 234	1.5	1.3	1.77	1.56
Silver carp	1 587 691	3 227 617	2.0	1.8	1.08	0.93
Bighead carp	725 603	1 552 461	2.1	1.9	1.05	0.92
White amur bream	194 900	434 896	2.2	2.1	1.27	1.20
Nile tilapia	129 214	741 015	5.7	5.5	1.24	1.18
Black carp	117 100	138 638	1.2	1.2	1.75	1.70
Mrigal carp	142 099	515 556	3.6	3.7	0.90	0.92
Freshwater fishes nei	551 496	1 431 621	2.6	2.6	1.14	1.16
Thai silver barb	16 673	48 047	2.9	3.0	0.95	0.97
Mud carp	78 165	150 084	1.9	2.0	1.02	1.05
Catla	207 875	577 756	2.8	3.0	0.90	0.96
Mozambique tilapia	37 058	51 507	1.4	1.5	1.96	2.16
Milkfish	345 829	367 429	1.1	1.4	1.40	1.80
Banana prawn	35 470	54 849	1.5	1.7	3.60	4.02
Giant tiger shrimp	100 808	531 108	5.3	5.9	6.63	7.17

Group	1988	1997	Factor of Change Production	Factor of Change Value	Value (US\$)/Kg 1988	Value (US\$)/Kg 1997
Catla	207 875	577 756	2.8	3.0	0.90	0.96
Mozambique tilapia	37 058	51 507	1.4	1.5	1.96	2.16
Milkfish	345 829	367 429	1.1	1.4	1.40	1.80
Banana prawn	35 470	54 849	1.5	1.7	3.60	4.02
Giant tiger shrimp	199 898	531 198	2.7	2.9	6.63	7.17
Giant river prawn	19 981	109 051	5.5	6.4	5.88	6.87
Tilapia nil	128 518	130 341	1.0	2.0	1.09	2.11
Metapenaeus shrimps nil	19 938	41 455	2.1	2.9	2.61	3.63
Rohu labeo	217 193	692 966	3.2	7.3	0.94	2.14
Penaeus shrimps nil	26 927	74 353	2.8	3.6	4.67	6.07
Japanese amberjack	167 186	138 536	0.8	1.1	6.22	8.62
Marine crabs nil	8	58 769	7 346.1	21 040.1	1.75	5.01

<sup>1</sup>nil = not elsewhere included.

**Table 4.** Major ISCAAP<sup>1</sup> groups whose production exceeded 30 000 mt in 1997, showing changes in production and value (1997 vs 1988) and factors of change.

Group	Production 1988	Production 1997	Factor of Change Production	Factor of Change Value	Value (US\$)/Kg 1988	Value (US\$)/Kg 1997
River eels	98 109	232 908	2.4	1.1	10.64	4.76
Redfishes, basses, congers	54 915	178 901	3.3	2.4	10.67	8.01
Salmon, trouts & smelts	436 390	1 225 112	2.8	2.1	4.61	3.42
Flounders, halibuts & soles	3 278	38 203	11.7	10.8	15.25	14.16
Miscellaneous marine fish	37 606	280 954	7.5	6.0	1.28	1.03
Shrimps & prawns	576 453	1 000 565	1.7	1.7	6.68	6.44
Carp, barbels & other cyprinids	5 194 827	13 230 197	2.5	2.1	1.27	1.07
Tilapia & other cichlids	309 109	938 497	3.0	3.3	1.24	1.36
Miscellaneous freshwater fish	867 690	2 085 001			1.35	1.55
Miscellaneous diadromous fish	350 166	388 313	1.1	1.5	1.42	1.93
Sea-spiders & crabs	3 574	70 948	19.9	24.0	3.94	4.76
Freshwater crustaceans	81 617	279 796	3.4	4.1	4.82	5.76
Jacks, mullets, sauries	193 711	183 983	0.9	1.2	5.77	7.24

<sup>1</sup> International Standard Statistical Classification of Aquatic Animals and Plants



**Table 5.** Molluscs, aquatic plants and miscellaneous groups whose production exceeded 40 000 mt in 1997, showing changes in production and value (1997 vs 1988), factors of change in value/kg.

Species	Production		Factor of Change		Value (US\$/Kg)	
	1988	1997	Production	Value	1988	1997
Northern quahog (=Hard clam)	23 113	43 753	1.9	1.3	1.91	1.29
Laver (Nori)	670 816	861 231	1.3	1.0	2.05	1.55
Yesso scallop	303 984	1 256 799	4.1	3.3	1.72	1.36
Japanese carpet shell	189 653	1 275 104	6.7	6.1	1.44	1.31
Gracilaria seaweeds	32 380	136 531	4.2	3.2	0.53	0.40
Mediterranean mussel	95 531	130 768	1.4	1.2	0.78	0.68
Razor clams nei <sup>1</sup>	140 673	354 152	2.5	2.3	1.00	0.90
New Zealand mussel	24 598	65 500	2.7	2.0	0.39	0.30
Eucheuma cottonii	220 509	609 287	2.8	1.3	0.16	0.08
Pacific cupped oyster	1 217 663	2 974 460	2.4	2.3	1.13	1.07
Japanese kelp	2 072 383	4 401 931	2.1	2.0	0.70	0.65
Blue mussel	415 846	401 133	1.0	0.9	0.67	0.63
Marine molluscs nei	225 210	1 135 158	5.0	4.7	0.52	0.48
Wakame	492 196	535 357	1.1	1.0	0.35	0.32
Green mussel	62 299	59 360	1.0	0.8	0.17	0.14
Red seaweeds	85 000	115 000	1.4	2.7	0.05	0.10
Aquatic plants nei	196 304	472 015	2.4	2.9	0.60	0.73
Sea mussels nei	429 784	399 095	0.9	2.7	0.07	0.20
Blood cockle	107 025	199 019	1.9	2.3	0.83	1.03
Korean mussel	15 693	63 573	4.1	6.6	0.34	0.55
American cupped oyster	81 073	65 147	0.8	1.3	0.47	0.77
Brown seaweeds	28 871	41 060	1.4	2.1	0.74	1.09
Softshell turtle	71	47 066	662.9	902.0	3.56	4.84

<sup>1</sup> nei = not elsewhere included.

**Table 6.** Molluscs, aquatic plants, invertebrates and miscellaneous groups whose production exceeded 30 000 mt in 1997, showing changes in production and value (1997 vs 1988), and factors of change.

Group	Production		Factor of Change		Value/Kg	
	1988	1997	Production	Value	1988	1997
Turtles	795	47 773	60.1	17.1	17.71	5.05
Red seaweeds	1 030 129	1 744 657	1.7	1.0	1.39	0.83
Scallops & pectens	305 444	1 269 063	4.2	3.3	1.74	1.39
Clams, cockles, arkshells	531 423	1 941 872	3.7	3.4	1.39	1.31
Oysters	1 331 402	3 082 260	2.3	2.2	1.12	1.07
Miscellaneous marine molluscs	225 210	1 135 158	5.0	4.7	0.52	0.48
Brown seaweeds	2 593 460	4 978 402	1.9	1.9	0.64	0.62
Mussels	1 047 589	1 136 050	1.1	1.2	0.39	0.44
Miscellaneous aquatic plants	196 304	472 015	2.4	2.9	0.60	0.73
Sea squirts	23 660	30 166	1.3	2.2	0.62	1.08

The combination of increased sales volumes with reduced prices has created the situation where previously high-valued species are now within the reach of a greater proportion of consumers.

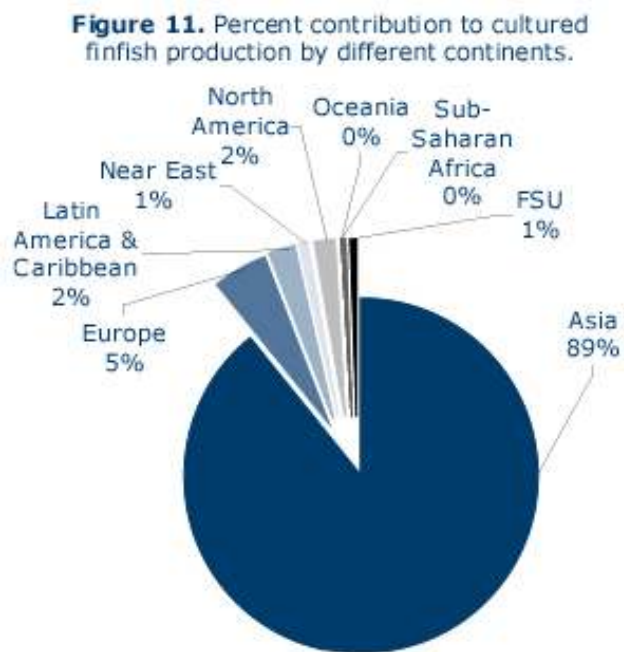
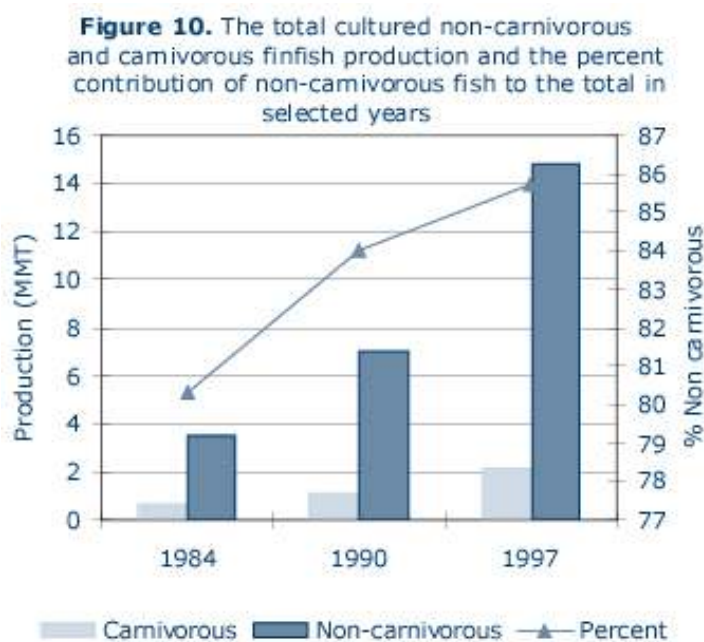
With notable price crashes seen for some of the higher valued species, one might have expected a decline in their production, since economic viability is paramount for the growth of any sector. This has rarely been the case, since buy-outs or corporate restructuring, imposing improved operations and management, have been seen in many

Higher yields per unit area, lower feed costs and better health management are the key technical elements for successful production, while improved marketing and financial management are also integral components that are required for continued growth.

## Major commodities

Aquaculture is a very diverse activity, involving the culture of invertebrates to reptiles, being done in all types of aquatic environments.

different parts of the sector.



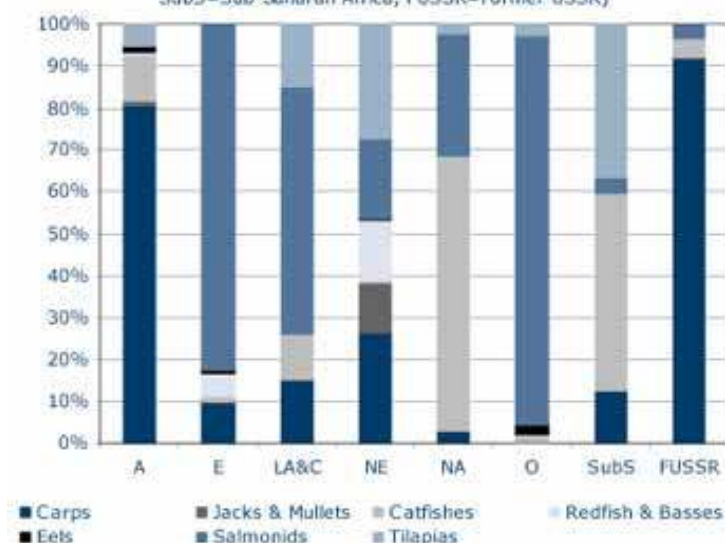
Obviously, this diversity has its pros and cons. On the positive side is the fact that the sector’s diversity allows it not only to adjust to varying consumer demands, but also to respond to the changing aspirations of society. On the negative side, one can identify the efforts that are required in research, development and marketing, which have to be dedicated to each potential commodity to render their potential technically and economically viable.

**Finfish**

As indicated earlier, finfish is the major commodity that is cultured globally, where over 125 species are contributors, in all environments (fresh, brackish and marine waters) and temperatures (warm, temperate and cold). The number of species whose production exceeds 100 000 mt /yr is less than 20, of which 11 are cyprinids. The great bulk of finfish culture is constituted by freshwater species, followed by diadromous and marine species. Cyprinids and diadromous fish dominate freshwater culture, followed by carps and salmonids, in warm and cold climates, respectively. The global value of the produce of each category reflects the amounts produced.

The changes seen for the production of carnivorous and noncarnivorous finfish production in selected years are shown in Figure 10, from which it is evident that the contribution of the latter to cultured finfish production increased continuously, always remaining in excess of 80 percent.

**Figure 12.** The distribution of major finfish groups cultured in different regions (based on 1997 data). (A=Asia, E=Europe, LA&C=Latin America, NE=Near East, NA=North America, O=Oceania, SubS=Sub-Saharan Africa, FUSSR=Former USSR)



In essence, although some minor changes have occurred in respect of individual species, the gross picture has remained almost intact over the years. The conclusion of this analysis is that the great bulk of finfish culture does not have to depend on the provision of formulated feeds.

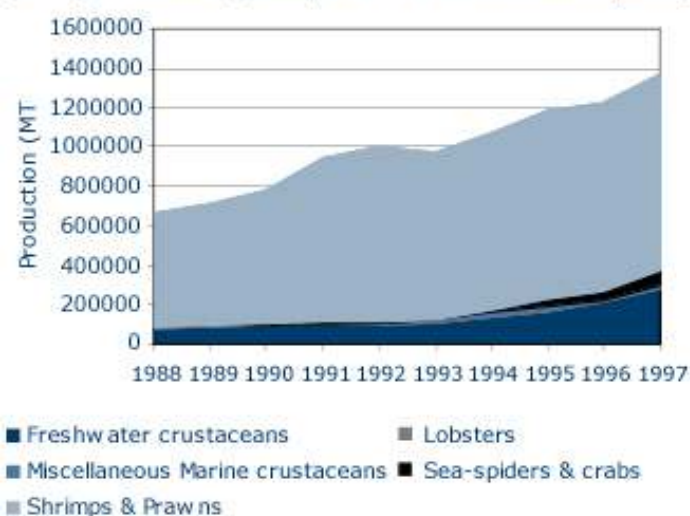
Asia leads the world in finfish culture, producing nearly 90 percent of that produced globally in 1997 (Fig. 11). The dominance of Asia in finfish culture is further exemplified when one considers the proportion of each of the seven major groups of teleost fish cultured in each continent (Fig. 12). From this analysis, it is evident that, with the exception of salmonid species, Asia leads in the culture of all the other groups.

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Upon deeper analysis of the information provided in Figures 11 and 12, notably on a regional basis, it becomes apparent that the culture of carnivorous finfish is a developed-country activity, while noncarnivorous finfish culture is essentially an activity made in developing countries.

In all continents and regions, with the exceptions of Africa and the countries of the former USSR area<sup>8</sup>, the per caput availability of cultured finfish has increased steadily, the largest increases occurring in Asia and North America, during the last decade in particular for the latter. This general trend is encouraging, in that finfish culture is appearing to keep ahead of population growth and, as such, will be able to maintain its importance from the point of view of food security.

**Figure 13.** The growth of the cultured crustacean production and the contribution of the major groups, (shrimp, freshwater prawns, crabs and miscellaneous species).





Crustaceans

Compared to that reported for finfish production, the annual yield of cultured crustaceans is relatively small, currently measuring about 1.4 million mt. This is a sector that continued to grow, consistently and substantially, although few fluctuations observed during the process (Fig. 13). A concurrent growth of crab culture, mainly a fattening process, has occurred, particularly in Asia, which has assisted the overall growth of crustacean aquaculture. All cultured crustaceans are relatively high valued, and the value of the different products is almost identical (Fig. 14) to the production.

As evident from Figures 12 and 13, marine shrimp culture almost completely dominates crustacean culture, representing 96 percent that is done in brackish water and 73 percent of all crustacean aquaculture (1997). The relative contribution of the various shrimp species to global cultured shrimp production is shown in Figure 15, which shows that the tiger prawn, *Penaeus monodon*, contributes in excess of 50 percent to the total followed by the whiteleg shrimp, *P. vannamei* (18 percent), and the oriental or fleshy prawn, *P. chinensis* (10 percent).

Shrimp culture is essentially confined to Asia and South America (Fig. 16) and, interestingly, the production share of the latter has continued to increase steadily throughout the decade, rising from around 15 percent to nearly 20 percent of global production in 1997. It is envisaged that Africa may become an important player in this sector in the future.

Figure 14. The total value of cultured crustacean produce and the contribution of the major groups cultured.

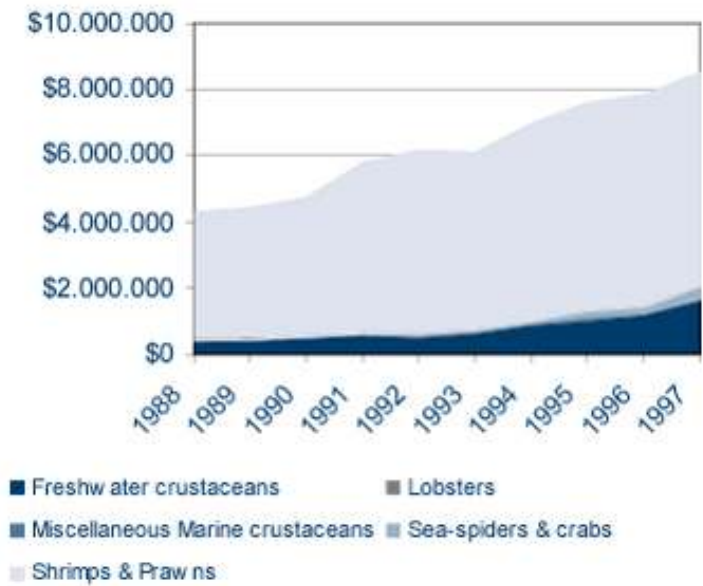
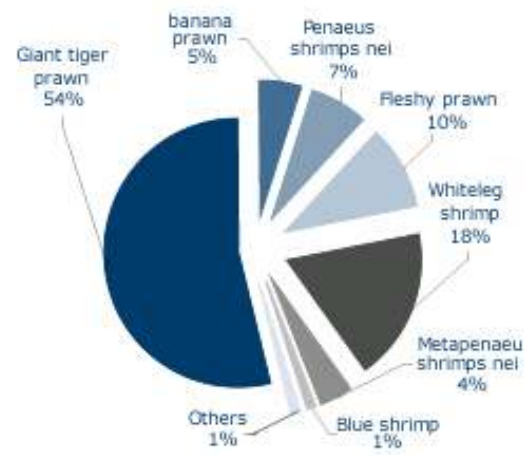
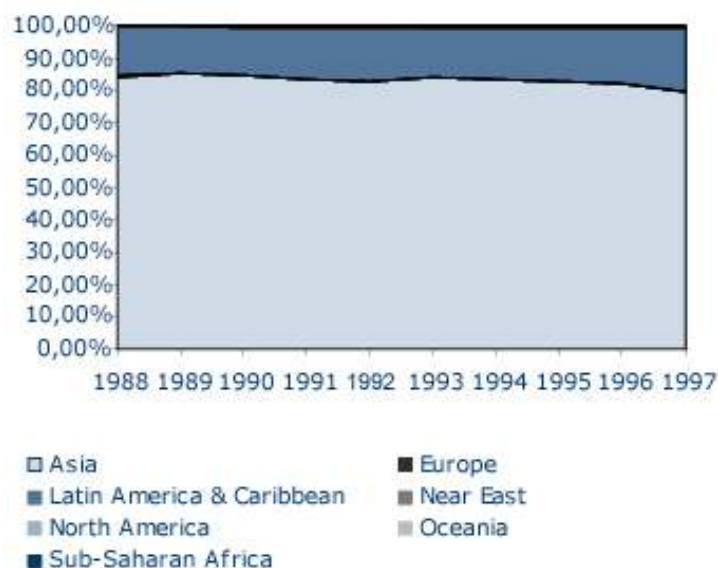


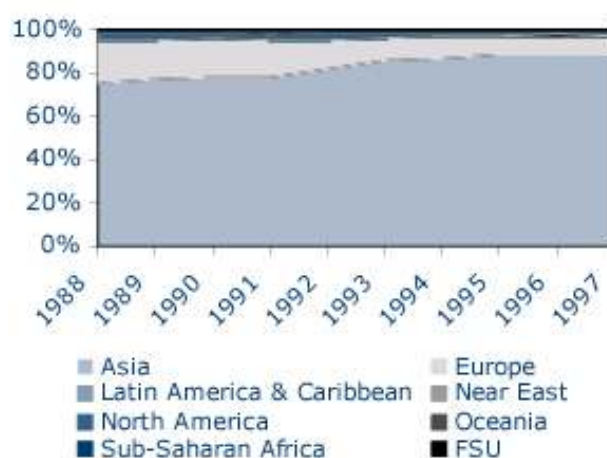
Figure 15. The relative contribution of different shrimp species to the global cultured shrimp production in 1997.



**Figure 16.** The contribution of the different continents to cultured shrimp production, 1988 to 1997.



**Figure 18.** The contribution of the different continents to cultured mollusc production, 1984 to 1997.



## Molluscs

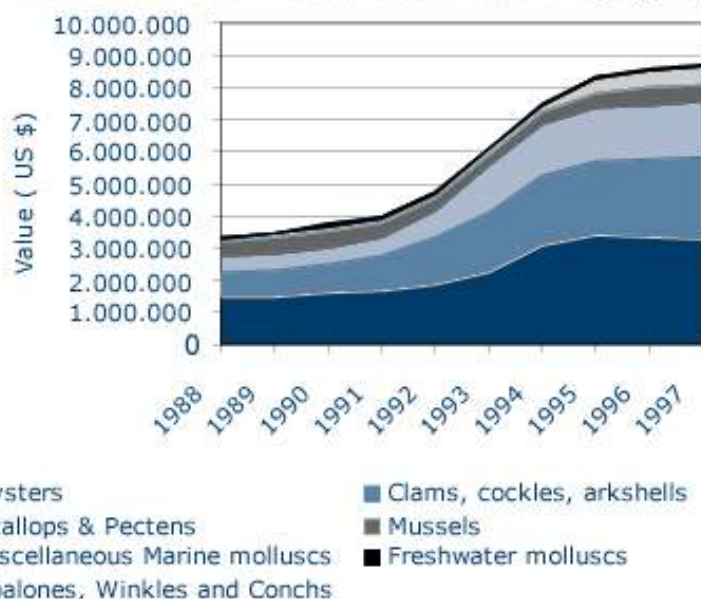
Fifty-eight species of molluscs are cultured globally, and the total production is about 8.6 million mt. However, the production exceeded 50,000 mt (in 1997) for ten species only (two oysters, five mussels, two clams and cockles and one scallop species). The relative contribution of each of the groups to total production is shown in Figure 17. As with the previous two commodities, Asia also leads global mollusc culture (Figure 18), its contribution growing steadily from about 76 percent in 1988 to nearly 90 percent in 1997, giving an APR of 12.6 percent. This has been achieved through a superior growth rate to the other important regional producer, Europe, whose expansion has been much slower, measured by an APR of 1.1 percent for the period.

## Aquatic plants

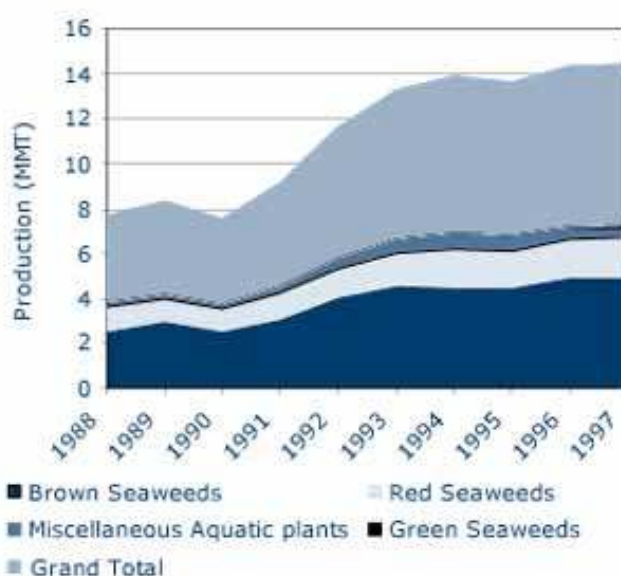
Annual aquatic plant production currently exceeds 7 million mt and is confined to three marine seaweed taxa, the brown (Phaeophyceae - four species), red (Rhodophyceae - nine species) and green (Chlorophyceae - three species) seaweeds. The relative contribution of each of these groups to total production and the value of the produce, from 1984 to 1997, is given in Figures 19 and 20, respectively, where it can be seen that the value of green seaweeds is slightly higher than that of the other two groups. Aquatic plant culture is almost totally confined to Asia, with recent culture activity expanding for Gracilaria in Chile, but elsewhere it is only of a very small scale (sub-Saharan Africa, Europe and Oceania).



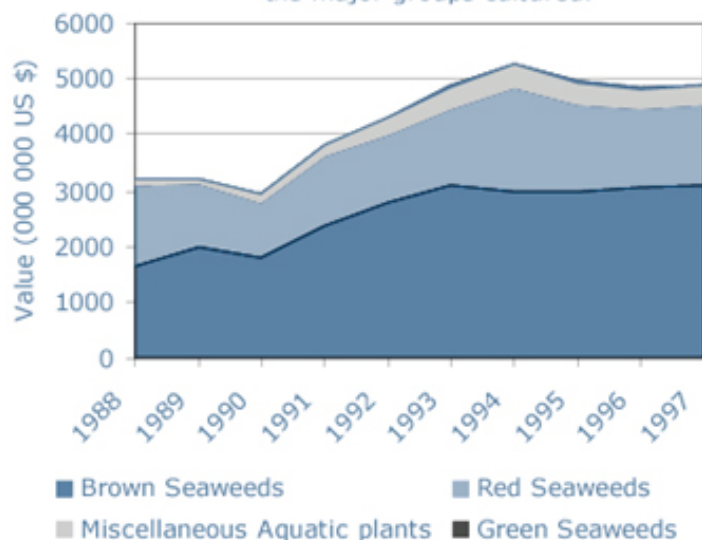
**Figure 17.** The growth of the cultured mollusc production and the contribution made to the total by the major groups



**Figure 19.** The growth of the cultured aquatic plant production and the contribution made to the total by the major groups.



**Figure 20.** The total value of cultured aquatic plants and the contribution made to the total by the major groups cultured.



The results of this analysis (in metric tonnes per annum) for global aquaculture production, together with that of the major commodity groups, in respect of value of produce and in terms of percent change, for the same time periods in all cases, are shown in Figures 21 and 22. The results show that the annual rates of change in the totals for both production and the value of produce increased steadily until about 1990, after which the increases, although positive, have tended to be smaller than in the previous years.

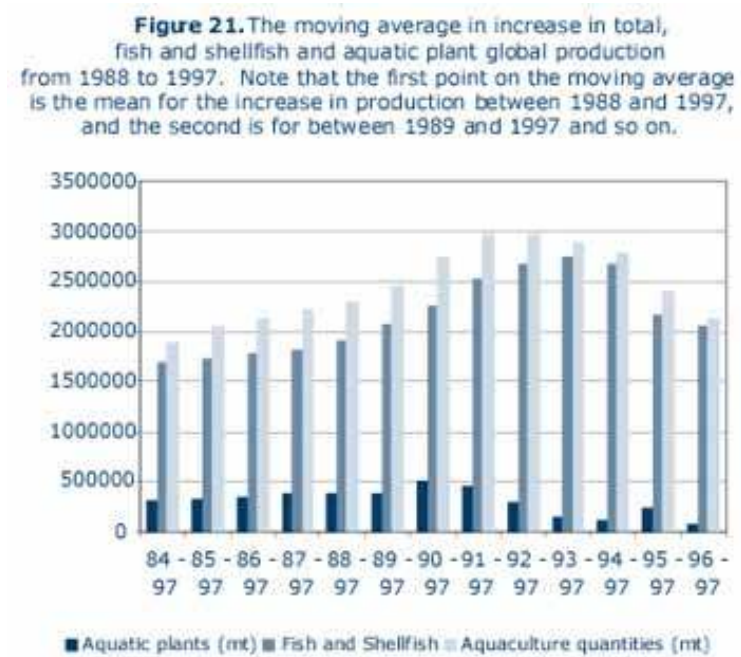
It is not realistic to expect continued and increasing growth, or as seen in some instances, bordering on exponential growth, within global aquaculture and, least of all, in a primary production sector. However, aquaculture has experienced this scenario of increasing growth for less than a decade. Furthermore, a concern for aquaculture in the new millennium comes from the observation that the continent that contributed most of

## Growth trends

As stated before, global aquaculture production has shown a steady increase from 1988 to 1997, measured as a 132 percent increase with an APR of 9.8 percent. Some

continents and regions have witnessed an even greater rate of growth. Nonetheless, the measured annual growth rates in a sector or its subsectors tend to mask important variations and intermediate trends and thus can often be misleading. De Silva (1999), in projecting fishmeal demands for the future, was the first to deviate from using the measure of mean annual growth, and quantified aquaculture growth within different stanzas. This procedure is extended further here, when the moving average growth (MAG)9 per annum was considered over the period 1984 to 1997.

the development is currently experiencing a decline in rates of growth. This recent trend indicates, therefore, that the sector cannot be complacent if it is to pursue and attain continued, long-term growth in the new millennium. On the other hand, sectoral growth has kept pace with increasing populations in all regions except Africa and the countries of the former USSR are. Even though this is a remarkable achievement for the sector, it is not a matter for complacency, particularly since aquaculture accounts for only about 30 percent of the aquatic food supply. In the new millennium, therefore, it is important that growth keeps pace with demand. All growth, however, needs to be achieved with minimal environmental perturbations.



## Other benefits

The great bulk of aquaculture is both rural and subsistence-based, where the activity plays a major role as a significant provider of employment, in particular to the rural poor, and thereby in poverty alleviation. More often than not, this important contribution of aquaculture to the socio-economic well being of rural communities is seldom taken into account, being rarely quantified or appreciated by the many lobby groups who do not believe that aquaculture should be promoted.

In China, for example, the total number of labourers in full-time employment in rural aquaculture increased from 1 530 083 in 1989 to 3 292 557 in 1997. It was estimated that 1 688 million and 93 000 persons were employed in India, in rural inland and brackishwater aquaculture, respectively (Sinha, 1999). Aquaculture also provides seasonal employment, such as in the collection of shrimp fry, for example. In leaving aside the environmental debate on this activity, it is estimated nonetheless to provide part-time employment to 1-1.2 million and 50 000 fry collectors in Bangladesh and India (West Bengal), respectively (Primavera, 1998). Similarly, in Thailand, only 1 312 persons were employed full-time in coastal aquaculture in 1987, while it currently employs around 70 000. The estimate for total employment in the aquaculture sector in Thailand is about 313 000, of which some 77 percent are engaged in inland aquaculture. The shrimp farming industry is estimated to provide direct employment to 584 000 globally (excluding China and Bangladesh), and to about 2 020 000, including indirect employment in the industry (Singh, 1999).

Such benefits are not restricted to developing countries. The growth of the salmon industry in rural areas of Scotland has not only created significant employment opportunities (estimated at around 10 000 direct and indirect jobs], but it has also

Generally speaking, in most countries, the income levels of aquaculture employees are also thought to be higher than those in the fishery sector and other primary-sector industries. For example, in China, the mean income per labourer in fishing and aquaculture has increased steadily over the years, but the average income of a fish farmer was almost always twice that of a fisherman. Comparisons on income generation from integrated rural activities are available for a number of cases. In Vietnam, within the integrated VAC systems (vegetable-fish-livestock plots or gardens), the income from aquaculture activities was higher than that from either animal husbandry or gardening. Also, in such systems, the income generated was related to the location of the activities, the lowest being in suburban regions.

Sinha (1999) conducted a comparable analysis on fish-crop-livestock-forestry integrated systems in India. He found that percentage return on fish exceeded 350 percent in all cases and that, in most instances, the net income, percentage return and cost-return ratio were best for fish, with plantation/forestry performing better only occasionally. A direct comparison of the per caput income of agriculture and aquaculture households in four provinces in China (Song, 1999) showed that the latter was higher, the difference also being dependent on the province, where the average income of aquaculture households (in 1997) was 5 324 Yuan, a figure 2.1 times that of agriculture households.

From the foregoing, it is evident that rural aquaculture plays a very important role in providing employment and in poverty alleviation of rural communities. Obviously, its contribution in this regard will also indirectly influence social equity.

The above synthesis on employment in the sector referred to direct employment only, but the sector also creates a considerable

contributed much to rural areas that have little other opportunities for development (McCunn, 1992). The potential for continuous, rather than seasonal employment, has meant that the decline of the rural population in Scotland has, for the first time in this century, stopped, leading to a slight increase in the population of some communities. The role of aquaculture can be therefore be important in contributing to and maintaining rural communities.

proportion of indirect employment, particularly in industrial aquaculture. It has been estimated that in Australia, for example, three indirect jobs are created for each direct employment in the sector (Anon., 1999). In the European Community (EC), it was recently estimated that there were 40 000 full-time equivalent employees (FTE) in production, with 4 500 FTE upstream (supply sectors) and 12 000 FTE downstream (mainly processing), representing jobs that would not exist without aquaculture. These calculations did not include the jobs maintained or created by commercial or individual spending in the areas of the farms (Macallister Elliott and Partners, 1999).

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The aquaculture sector, particularly in some developing countries, has also provided opportunities for additional food production through seasonal land use on plots that would have otherwise remained idle. A case in point in this regard is the traditional rotation in rice-shrimp farming in the Mekong Delta (Vietnam). During the dry season, because of high salinity, shrimp is farmed, whereas in the wet season, rice is grown, thereby enabling effective utilization of cultivable land throughout the year (Binh and Lin, 1995).

### **Diversity and goals of aquaculture**

The aquaculture sector is probably the most diverse of all animal food production sectors. This diversity is the result of a number of factors, the foremost of which are:

- the number of species and/or species groups cultured, which is nearly 200,

### **The new millennium**

It is to be expected that the new millennium will pose new challenges to most global primary industries, and the aquaculture sector will not be an exception. Some of the new challenges that the sector will confront will be consequent to perceptions that have been generated, many rather erroneously, in recent years. These perceptions are linked indirectly to the increasing global call to minimize environmental perturbations and the need to strive towards sustainable development, taken in the broadest context, of all primary production sectors. Some have suggested that the sector's future will not depend on its economic viability per se, but that its longterm sustainability will only be ensured by environmental viability (Kutty, 1997). The equation however, is neither that simple nor that straight forward. Other influential factors, primarily social, political and even global marketing issues, also need to be brought into the



although only about 25 of these account collectively for over 90 percent of the production;

- the range of aquatic environments (freshwater, brackish and marine) and temperatures (cold, temperate and warm) in which culture practices are conducted;
- the wide range of "containment" systems used (ponds, raceways, cages, pens etc.); and
- the differing degree of the "intensity" applied, where "intensity" is defined within the context of extensive, semi-intensive and intensive practices (Tacon, 1987; Tacon et al., 1995). These definitions are, in turn, based primarily on the degree of external nutrition supplied to the cultured stock.

Increasingly, the division between rural, subsistence aquaculture and industrial aquaculture is coming to the forefront. In the former, the species cultured are generally those that feed low in the food chain, using a low-level of primary inputs and where the culture activity may not necessarily be the main source of income of the household, but one of a diverse range of economic activities on a small-scale agriculture farm.

At the other end of the spectrum is industrial aquaculture, which tends to culture species of higher value, and generally involves more intensive practices that use a high level of primary resources, such as water, feed, energy etc. It is needless to say that issues regarding the "ecological cost" of industrial aquaculture have been raised and the sustainability of such practices questioned (Folke & Kautsky, 1992; Naylor et al., 1998).

equation.

In the past, the primary goal of the sector was to increase production and profitability, either through the application of technology, the use of more resources or an increase in the area under culture. Environmental issues were only of limited concern; likewise the social aspects have also been given limited attention. While most of the environmental and social issues were recognized, there has been limited emphasis on the development of suitable strategies to deal with these. Indeed, during the early years of sectoral growth, it was often argued that aquaculture was environmentally friendly by virtue of the fact that only marginal lands were used for aquaculture development.

We are now aware that this is a gross misnomer. Aquaculture uses primary resources, has to compete with other prospective users and is not always environmentally friendly; indeed, the degree of "environmental friendliness" depends on various factors, such as the farming system, the location, and how a particular aquaculture practice conducts its activities, among others. The aquaculture sector in the new millennium will develop, thrive and be sustained only if it can ensure environmental integrity. The sector will need to take a different emphasis, that of longterm environmental, social and economic sustainability, and adapt its goals to these requirements.



## **Public perceptions**

The public's perception of a sector influence both policy formulation and development, both directly and indirectly, of that sector. A proper, pragmatic policy structure is essential to all development, and particularly for primary production sectors. In recent years, the public's perception of aquaculture has all but tarnished the sector and, in some nations, public outcry has resulted finally in major policy changes (Murthy, 1997). In the new millennium, the sector will have to attempt to clean this tainted image and endeavour to correct the public view on aquaculture. The message in this regard should be that aquaculture is essential to meet human demand for aquatic products and will continue developing as a sector that minimally perturbs the environment; that it can be a gross environmental cleaner, a prudent user of primary resources, and a producer of healthy and nutritious food of high consumer acceptability.

It is also important to highlight the contributions of the sector to humanity, in general. First and foremost, it is a sector that is predominantly rural, which, in most instances, tends to benefit the poorer sectors of the community. Aquaculture is a gross contributor to providing food security, gainful employment and poverty alleviation. These are issues that are rarely focussed on during public debate on aquaculture and, in the new millennium, when competition for primary resources is likely to intensify, it is important that these are brought to light.

Interest groups generate and influence the public's views and perception of a sector, more often than not. In the aquaculture sector, it is unfortunate that, in recent years, exaggerating the harmful environmental impacts of certain forms of aquaculture, in particular shrimp and

Environmental problems existed, but these were not insurmountable. However, as in this case, by laying emphasis on the environmental issues, sympathy can be gained across the board, from all sectors, and the case is strengthened.

More importantly, it is appropriate to hypothesise what could have been the outcome if the same wasteland were to be used for shrimp culture (in India), but through the application of small-scale farming activity, being executed as a strategy to alleviate poverty and provide employment to the rural poor.

Aquaculture may have been more successful and, in all probability, may have resulted in less environmental problems in some countries if social objectives – such as poverty alleviation and rural development – were given a more central focus in aquaculture development strategies. For the new millennium, there is a lesson to be learnt from the above-mentioned experience, and governments need to be alert in choosing the appropriate strategies for development, minimizing the tinkering of the social fabric.

## **Environmental aspects**

The main environmental issues in aquaculture development relate to the replacement of natural and man-made habitat by aquaculture farms, the use of natural resources in farm inputs (particularly feed) and the release of materials (such as nutrients, organic matter and even pathogens) as effluent.

### ***Effluent quality***

The most direct local influence of intensive aquaculture on the environment is often through the effects of effluent discharge. The culture of most aquatic organisms that

salmon culture, has generated negative perceptions of the sector as a whole. It is also not uncommon, often in developing nations, that lobby groups with vested interests use environmental issues to mask underlying social and political issues. Of course, quantification of the latter is difficult.

For example, it is often suggested that the core of the "shrimp" issue in India was not an environmental concern but a social one. This was an issue which was created, in all probability, by promotion of the "wrong" strategy, the promotion of shrimp culture in "wasteland" through the mobilization of big businesses. This strategy was not acceptable to the community at large, which felt that rural communities were being alienated from their land and traditional farming practices.

depend on an external feed input results in the deterioration of the quality of effluent water, primarily resulting from uneaten food, faecal discharge and nitrogenous metabolism. It is estimated that in salmonid cage culture, for example, only 25 percent of the food nitrogen results in production (Hakanson, 1986). There have been marked improvements in feed utilization in salmonid culture, brought about by the use of high-energy feeds in recent years, where a protein retention of 42 percent has been achieved (Hillestad & Johnsen, 1994). In the case of organisms such as shrimp, which are not recognized to be efficient feeders, the wastage is even greater. There has been good recent progress in improving such efficiency, but the sector will increasingly need to address this issue in the new millennium.

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Some major calamities have been seen within the aquaculture sector in different nations, mostly in respect of shrimp culture ventures. Viral disease outbreaks augmented by transboundary pathogen transfers and poor management practices caused significant losses. The spread and intensification of shrimp farming is also thought, in some regions, to have brought about land subsidence (such as in Taiwan Province of China through excessive use of ground water) and the salination of freshwater resources in others.

As a result of such negative incidents, the complete withdrawal of culture activities from large pond acreage has occurred in some coastal areas, and questions as to whether shrimp culture is environmentally sustainable have been raised. Comparable

Apart from such erroneous notions, rarely substantiated by quantitative information, lobby groups have rarely appreciated the progress made through the development of "high energy" diets, which have been directly responsible for significant reductions in the amounts of nitrogen and phosphorous in salmonid culture effluent.

It is needless to say that this trend will have to be increasingly pursued with regard to the intensive culture of finfish and crustaceans in the ensuing decades and, indeed, may be considered to be a priority area for sectoral research and development in the new millennium. Pursuance of this goal also has the direct benefit of a decrease in the usage of fishmeal as a protein source in feeds, a resource that is predicted not only to become increasingly

issues have surfaced elsewhere in aquaculture. For example, stocks of southern bluefin tuna (*Thunnus maccoyii*), worth millions of dollars, were lost in cages located off the coast of south Australia, an event thought to have been caused by the upwelling of bottom sediments and anoxic water due to unusual weather conditions. However, these conditions were all attributed to farm effluents and wastes and, hence poor management practices and poor site selection. This incident resulted in the introduction of even more stringent environmental requirements and, of course, restrictions were imposed on the number of potential aquaculture permits to be granted.

Achieving sustainable development of the sector requires that water quality be protected. In many cases, multiple other users also affect water quality, and aquaculture is often a minor contributor to such deterioration as is observed. The sector needs to seek a fairer application of water quality laws, whilst continuously working towards an improved quality of water that is discharged by itself. Similarly, efficient and effective water use will also be an issue that needs to be duly addressed.

More often than not, environmental deterioration has been erroneously attributed to the sector, particularly in respect of excessive discharge of nitrogen and phosphorous in aquaculture effluent. However, when compared to traditional agriculture and municipal waste, the discharge of nitrogen and phosphorous from the sector is minuscule.

costly but whose supply may also become increasingly unreliable (Wijkstrom & New, 1989; Tacon, 1996; De Silva, 1999).

### ***Mangrove destruction***

The aquaculture sector, more particularly the shrimp industry, has often been blamed as the main cause for mangrove destruction. In the eyes of experienced aquaculturists and planners, however, the “mangrove” issue is, to all intents and purposes, closed. Nonetheless, as new regions take to shrimp and coastal aquaculture, this subject is likely to resurface again and again. In this context, it is relevant that the purported association between aquaculture and mangrove destruction be assessed by applying the available scientific information, using quantitative information, where possible.

The sector, particularly in the early stages of the expansion of the shrimp industry, was responsible for some degree of destruction. However, it is certainly not the main cause for the dwindling of the world’s mangrove acreage. As accurate, quantitative data are being made available, the general belief that shrimp farming was almost solely responsible for mangrove destruction is being increasingly and successfully challenged.

In the case of Thailand, for example, it has been shown that shrimp farming was responsible for the destruction of 17.5 percent or some 65 000 ha of mangroves between 1979 and 1986, as opposed to 35.9 percent (134 000 ha) for other uses (Menasveta, 1997).

Since 1986, the destruction of mangroves in Thailand, the current leader in world shrimp production (227 560 mt in 1997), has decreased significantly and, of the destruction that has occurred, almost none is attributable to shrimp farming. However, the figures available from a few other nations are less encouraging (Primavera, 1998).

It is important that the application of new and effective Codes of Practice is embraced by the sector, throughout the world, enabling the demonstration of responsibility and sustainability demanded by the public. It should go without saying that the sector itself is obliged to communicate such actions to the public.

As pointed out by Phillips and Barg (1999), the positive contributions made to employment and income diversification outweigh the negative aspects associated with shrimp farming, an additional and urgent message for the public. It is unlikely that the shrimp farming industry will continue to make the costly mistakes, economical and environmental, seen in the early stages of the industry. The survival and sustainability of the industry will be determined primarily by the modus operandi of the operating practices, which will, by necessity, have to be environmentally acceptable (Beveridge et al., 1997).

In a nutshell, the new millennium will, in all probability, encounter a shrimp culture industry that possesses different ethics and motives, where the primary goal will not be confined to profitability.

Other environmental issues, such as the responsible use of chemicals, relations between aquaculture development and biodiversity and conflicts with other sectors, for example, tourist development in some coastal areas, will also have to be addressed with a more concerted effort in the new millennium.

A most relevant and revealing topic, which provides evidence in this regard, is rice-fish culture, an old traditional practice that is being revived and will, in all probability, spread to regions other than Asia in the new millennium.

In China, in addition to the approximate 250 kg/ha of fish produced, rice yields from this system were 7.8 percent higher, while the combined harvest gave a total product value that was 41 percent higher than for rice alone (Xuegui et al., 1995). Additional indirect benefits include the reduced use of fertilizer and pesticides (Lightfoot et al., 1990).

Other direct environmental benefits of aquaculture include sewage fish culture, which provides a mechanism for the "stripping" of water with a high nutrient content and the production of fish, which may or may not be used for human consumption, this being determined by cultural inhibitions (Edwards, 1999).

There is a growing trend in developing countries of exploring the possibilities of using aquaculture as a means to strip nutrients from food processing waste (e.g. dairy and processing industries). In this instance the fish, if not directly available for human consumption, might be used to produce other products, or as ingredients in animal feed. For example, in Australia, there is interest in the use of such fish by the pet food industry, another sector that is under pressure to reduce the amount of wild-caught fish used.

There are many other examples of sustainable aquaculture. As pointed out earlier, aquaculture enables the use of certain land resources throughout the year, which would not be possible otherwise, through a form of crop rotation. Polyculture, a relatively common form of rural aquaculture, can also be considered to be a sound and effective sustainable system for the use of environmental resources.

### ***Environmental benefits of aquaculture***

As demonstrated in the previous sections, the aquaculture sector has been the target of much criticism from environmental groups, whose content has been exaggerated or ill founded, more often than not. However, the sector needs not only to respond to and refute such criticisms with relevant data, but also needs to enhance its public image. This can be achieved through the use of concerted communication campaigns that focus on the positive, contributory aspects of aquaculture.

Aquaculture, apart from the traditional integration with rice and/or animal farming, is increasingly finding a place for integration with other agricultural systems. Such integration generates a beneficial synergy and contributes towards the sustainable use of primary resources. Good examples of this approach are the shrimp-mangrove-forestry farming systems (Johnston et al., 1999).

Nonetheless, even in the scientific literature, the negative aspects of aquaculture tend to be highlighted, focusing on the environmental effects of the intensive aquaculture of salmonid and shrimp species (e.g., Folke & Kautsky, 1992).

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One commonly finds the extrapolation of energy needs and primary resource inputs from intensive farming being applied to the whole sector, a misleading approach, especially since the vast majority of aquaculture is rural, small scale and using semi-intensive to extensive practices.

The examples cited above are not only elements that could be used to enhance the image of aquaculture, they are also demonstrations of how aquaculture is used as a means to add value to other resources.

### ***Socio-economic milieu***

Major socio-economic changes have occurred during the last 20 years and, at a global level, these are possibly comparable to what was witnessed at the start of the industrial revolution. The development and the expansion of free-market economies have changed the socio-economic climate of nations, almost without exception.

Very little of these products are for export, the bulk satisfying the increasing demand for a new and different commodity by a growing middle class. Comparable changes are likely to occur with increasing frequency, and the aquaculture sector will have to make suitable adjustments to such demands. Evidently, if the sector's growth is to be sustained, the research and development arm of the sector has to be ahead and capable of providing the production side with the tools it needs.

In the same vein, the sector will also need to take into account that such changes in direction or in activity will have to be accommodated, to a great extent, within the context of the primary resources that are already available. These are principally the resources of land, water and feed materials and, as such, the prudent use of primary resources becomes an imperative.

Such developments can be catered to and



Indeed, some of the major impacts are still being felt a decade or so later, and certainly in the most populous nations that also happen to be “epicentres” of the aquaculture industry, such as China and India. One of the major socio-economic changes that has occurred, and will continue to do so, is the development of a substantial middle class, whose aspirations and demands are also developing. In the nations cited previously, the increasing development of an identifiable middle class will give a significantly high number, although it may be small in terms of population percentage.

As this sector of the population develops, it will demand new and/or improved food products, imposing on the aquaculture industry the need to cater to these requirements, for simple economic reasons. Already such changes are apparent in the sector in China, where the production of high-valued species, such as mandarin fish (*Siniperca chuatsi*) and the freshwater hairy crab (*Erichoeir sinensis*), reached production levels of 68 000 and 101 000 mt in 1997, respectively. These production levels were attained within a period of less than ten years. Equally, the production of the softshell turtle (*Trionyx sinensis*) is in a rapid growth phase, since its production has risen from some 70 mt in 1988 to about 45 000 mt in 1997.

the opportunities grasped, but only if research and development can establish and maintain the leads necessary to move forward. To elaborate the potential of new, and currently, “high-value” species, the question of appropriate funding is raised, as is the morality of using public funds for such activities. It is the generally accepted norm that public funds should be utilized for activities that give the highest return to the community at large. This is essentially tantamount to saying that public funds should be preferentially directed towards funding research that will accrue benefits to the largest sector of the population and, even more so, to the poorer sectors of the population. Implicit in such a stance is that the private sector be encouraged to invest research in the “higher valued” species. However, here it is assumed that poor sectors of the community do not engage in the culture of high-valued species. This is far from the truth. For example, hairy crab and mandarin fish culturists in China are mostly rural farmers. Similarly, developments of the private sector also result in a lot of “spill overs” to the poor, such as by providing direct and indirect employment opportunities, ancilliary small businesses/self-employment opportunities and the like. We are rapidly moving into an era in which it is becoming increasingly difficult to define and/or demarcate beneficiaries of research and development. The diversity of the aquaculture sector, especially with regard to the varying number of species cultured, the extent of the holdings etc. make it even harder to determine the beneficiaries of research, and hence, which should publicly funded.

What is generally known, however, is that private-sector investments in R & D in aquaculture, particularly in developing countries, are relatively low to nonexistent. This is a trend that needs to be changed if the sector is to be sustained in the long term, to the benefit of everybody.

## Targets

It is a formidable task to make reasonable and acceptable production forecasts for global aquaculture and for many reasons, including:

- the diversity of the sector, notably the number of major species that are cultured in different systems and at different intensities;
- the changing demands for produce, factors that depend on changes in disposable income and, hence, influence the target markets; and
- the fast-changing nature of the rural sector, as the great bulk of aquaculture is a rural, small-scale activity.

In spite these limitations, an attempt is made here to project qualitative changes which might occur in the sector, and to set quantitative targets to be developed in the new millennium.

All aquaculture development will strive to be sustainable, to all intents and purposes. Sustainable development was defined initially, in the Bruntland Report, as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). A more explicit definition is that proposed by the International Union for the Conservation of Nature (IUCN) - "sustainable development improves peoples quality of life within the context of earth's carrying capacity" (Girardet, 1992). Sustainability, especially in respect of rural, integrated aquaculture, has been expressed

It is arguable whether such a change is needed and, indeed, if such a change would occur in the medium term. As indicated earlier, rural and industrial aquaculture developments will develop hand in hand, much as rural rice production co-exists with industrial rice production, or as small-holdings of cash crops (such as tea, rubber and coffee) co-exist with large industrial "estates" of these crops. In all probability, both rural and industrial aquaculture will continue to contribute to the growth of the sector as a whole. Needless to say, R&D aspects that are common to all forms of aquaculture need to be shared, with information exchange being facilitated. Good examples of shared R & D within rural and industrial aquaculture would be the adoption of a selectively bred strain of a cultured species and effective disease management strategies. The growth of both rural and industrial aquaculture is needed for the well being of the sector as a whole, and they are by no means mutually exclusive.

## Qualitative changes

Aquaculture is characterized not only by its very diverse array of cultured products, but also by a wide range of management practices. At one extreme, these are the rural, subsistence-level, low-input practices that often tend to be household oriented. The system used would be depicted typically by the culture of one or two species in a relatively small, shallow pond. At the other end of the scale are those of large-scale industry, which are typically capital intensive, with high primary resource inputs, and market driven. Such industrial practices are represented, for example, by salmon culture in temperate regions and some forms of shrimp culture in the tropics.

Between the two extremes, there are many intermediate examples where it is increasingly difficult to use "industrial" as an appropriate adjective. This could perhaps be defined better by recognizing the point at

schematically (AIT, 1994 cf Edwards, 1998), where it was considered in terms of three interrelated aspects.

Recently, it has been suggested that aquaculture is at a cross-roads, and that it will come of age in this millennium. But for this is to happen, the sector will require more responsible research and more integrated research and development approaches than seen at present (Sorgeloos, 1999). In this analysis, it is implicit that aquaculture will only come of age if the bulk of aquaculture changes from food security aquaculture to business/industrial aquaculture.

which, once a production entity exceeds the requirements of the operator, the majority of the produce is sold to third parties. This circumstance is "market-driven" aquaculture. The majority of salmon farming is now deemed to be industrial, while this is not considered to be the case for shrimp culture. The climatic conditions required for the different species mean that salmonid culture has been dominated by the wealthier, industrialized nations, while shrimp culture is spread across both rich and poor nations.

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There is considerable inter-relationship between rural and industrial aquaculture and qualitative changes in the systems are expected in the first part of the next century. Indeed, the inter-relationship can be considered as a modified image of that depicting extensive, semi-intensive and intensive aquaculture practices (Tacon, 1987). It is anticipated that there will be a shift within the rural aquaculture sector towards a higher degree of intensification, a strategy driven by the need to make more effective and efficient use of natural resources.

In addition, the scope of industrial aquaculture will increase significantly. However, the intermediate practices, which are oriented towards the production of carps and other species low in the trophic chain, will probably continue to dominate and lead global production. This situation will ensure that the sector will retain its contribution and importance in respect of the existing and burgeoning global problems

While various forecasts have been made of the needs for fish and fishery product of the future, as well for aquaculture production, the most comprehensive of these is that of Ye (1999). This forecast is based on models for each global region (Africa and the Near East, Asia, Europe, Latin America, North America and Oceania), each of which was based on the historical data of individual nations for consumption patterns and gross domestic production (GDP). From this analysis, the world demand for fish and fishery products was forecast to be 183 million mt in 2030, which corresponds to an increase of 95 million mt over the 1995 fish consumption. More importantly, the increase in demand is only 110 percent when compared to the figure obtained over the last 35 years, which was 210 percent. In other words, the global demand of 183 million mt in 2030 will also represent an increase in per caput consumption from 15.6 kg to 22.5 kg (+44 percent), which is lower than that between the previous 35 years (1961-1995; 8.3 kg to 15.6 kg [+88

of poverty alleviation, food security and employment in rural areas.

In other words, the sector will continue to retain and honour its primary objectives and will also contribute substantially to the economy of major aquaculture nations.

### **Production targets**

Predicting or setting production targets for the sector cannot be done without considering three factors:

- the predicted changes in the capture fishery sector,
- the per caput consumption trends of fish and fishery products, and
- the trends in population growth.

The most variable of these factors is the per caput consumption of fish and fishery products and the trends observed (Ye, 1999). However, unlike most commodities, it is believed that consumption of fishery products is predetermined (Bird, 1986) and that, for a perishable commodity such as fish, production is very nearly equal to domestic consumption (Fox, 1992). This implies that the volume of fish production is a variable which is determined independently of the price of fish, particularly in respect of capture fisheries. As the world becomes increasingly dependent on aquaculture for the supply of its fish and fishery products, the scenario described is bound to change, and market demand theories will increasingly come into play.

percent]]).

In contrast to the prediction cited above are those forecasts for aquaculture production which have been based on the core premise that aquaculture will be required to meet the demands resulting from population growth but static capture fisheries. These forecasts are based generally on current per caput consumption rather than trends of consumption.

## **Challenges and opportunities**

### **At a global level**

Each and every forecast made for aquaculture in the new millennium provides a major challenge, while offering, at the same time, a host of opportunities, although these will differ, to a greater or lesser extent, between nations, regions and continents. There is a clear call for the development of suitable strategies, be they national, regional or inter-regional, where the sharing of information is commonly highlighted. To be concise, the global strategies may be two-fold:

- to increase aquaculture production significantly, so that it continues to have an impact on food security, employment generation and social equity; and
- for all development to be sustainable and environmentally sound.



In order to achieve these primary objectives without compromising any of the basic goals of aquaculture, there are common challenges cum strategies that the sector will have to face. The major ones<sup>10</sup> are seen to be the following:

### Technical challenges

The individual technical challenges, and the research and development needs of the sector, are treated under separate themes within this publication. Those that are likely to confront the sector are not insurmountable, provided that a coordinated effort is made and the required human resources are available. It is relevant, at this point, to highlight the main technical needs and advances that are needed by the sector so that it can meet the production targets, within a milieu of sustainability. Foremost amongst these are:

- genetic improvement of major aquatic species used in aquaculture;
- feed developments, encompassing both a decreasing dependence on fish meal as a major protein source in feeds and a lowering of nitrogen and phosphorous in effluent; and
- improvements in the health management of cultured organisms.

The above technical challenges were also previously identified as being crucial to the envisaged development of the sector (Sorgeloos, 1999).

The genetic improvement of cultured aquatic organisms has lagged behind considerably other food production sectors (i.e. plant crops and animal husbandry). Amongst the species reared, some improvement in performance has been achieved through genetic selection in only two fish groups, namely salmonids (Gjedrem, 1997), and tilapias [Nile tilapia] (Bensten et al., 1997). This appears as a poor record for a sector that is based on the culture of over 200 aquatic species, and of

Dietary developments, on the other hand, represent an area that has made significant progress, particularly in respect of improved effluent quality and reductions in fishmeal content. However, the sector will be able to realise the envisaged growth only if the reliance on fishmeal is reduced or, at least, if the increase in fishmeal requirements is not directly proportionate to the increases in aquaculture production. Since 1990, the amount of fish available for reduction to fishmeal has levelled off, between 22 and 25 million mt of wet fish (Grainger & Garcia, 1996), and most believe this situation is unlikely to change. The projections for the feed requirements of the aquaculture sector differ between authors (see De Silva, 1999), but an estimated median figure for the fishmeal requirement is about 1.5 million mt. Although much research and development is being done in respect of fishmeal substitution in diets, an additional problem is likely to be the supply of fish oil. While this aspect has received scant attention as yet, it will also provide a major challenge for researchers in the ensuing years.

Disease is recognized clearly to be one of the most significant constraints to aquaculture production and trade, affecting both economic and socio-economic development in many countries of the world. Within the shrimp culture sector, disease is currently considered to be the single most important limiting factor on production. Although environmental factors, such as poor water quality due to effluent and waste mismanagement, have been implicated in major disease outbreaks, the underlying cause(s) of epizootics are usually more complex and difficult to pinpoint. Experience in trying to control aquatic disease outbreaks demonstrates the importance of taking all components of the production system into account. This includes the need for broader "ecosystem management" approaches, actively preventing environmental deterioration, as well as the introduction of pathogens

which most of the important species have a relatively short life cycle. Furthermore, when one considers that more than 75 percent of aquaculture production occurs in the tropics, the achievements for the genetic improvement of appropriate species and the concomitant sectoral impact are almost negligible. One could envisage, therefore, considerable scope for improved production performance through genetic improvement. In addition, issues concerning the use of transgenic organisms will be in the forefront, and researchers and developers will have to confront associated public perceptions before such technical advances can be fully transferred to the production sector.

through live introductions and transfers. This is otherwise known as the "systems management approach" (SMA) to aquatic animal health.

Controlling all aquatic diseases would require a level of understanding that we lack at present, not only in respect of the pathogens themselves but also for the host. For example, many important aquaculture species require accelerated investigation, at the molecular level, of both the host and its pathogens, in order to improve the efficacy of proposed therapies and other disease prevention measures. Such work must go hand-in-hand with a concerted effort to develop certified domesticated stocks.

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Protocols for the safe transboundary movement of aquatic animals and animal products form a first line of defence against the inadvertent introduction or transfer of infectious pathogens or diseases. Countries which are particularly vulnerable in this respect are those that depend on imported broodstock and fry to sustain their aquaculture industries. Protocols must therefore be developed for the needs for sustainable culture within national, regional or international contexts. Detailed Codes of Practice have been developed by international organizations to address minimizing the risks associated with introduction and transfer of live aquatic organisms. These provide a good starting point for conceiving appropriate national fish health legislation and related international agreements.

However, to be maximally effective, such efforts must be accompanied by:

Similarly, an imperative for the new millennium is that such networking is extended further, and this theme could, in all probability, be the dominant issue in the short term. The core of this should be inter-regional cooperation and networking that focuses on facilitating the transfer and exchange of technology and information, education and training and the dissemination of relevant knowledge to all. Involvement in longterm research and development programmes is also seen as a key priority in cooperative programmes. It is heartening to see that some headway has been made recently in this regard when the Network of Aquaculture Centres in Asia-Pacific (NACA), an inter-governmental regional body in Asia, entered into a memorandum of understanding with the Peruvian government.

### **Governmental role**

The role of government will undoubtedly be

- agreed lists of certifiable pathogens,
- the standardization of acceptable diagnostics techniques, and
- the presentation of health certificates of unambiguous meaning.

The establishment of intra- and inter-regional fish health information systems, linked to those of relevant regional and international agencies, would also be a significant support for regional aquatic animal health control efforts. The success of such programmes depends entirely on strong commitment by national governments, as well as that of the producer and the import/export sectors. Mutually acceptable approaches to health control benefit all of those concerned, where sectoral participation in the formulation of appropriate health control programmes reduces further the risk of noncompliance and the spread of disease.

### **Inter-regional cooperation**

It is often conceded that the Asian dominance in global aquaculture is partly a result of effective cooperation amongst the nations of this region, especially in facilitating the transfer, adoption and extension of technology. A significant part of this is due to the institutional frameworks that were established over 20 years ago and have become increasingly effective, leading the nations through the path of sustainable development. Unfortunately, however, the equivalent structures in Africa and Latin America did not reach a position of self-reliance, and the time is now perhaps ripe for these institutions to be reconstituted and nurtured.

the most variable element in the aquaculture development equation. The suggested roles for government range from zero involvement to complete control of aquaculture development. In the early years of this millennium, national governments will have to make crucial decisions concerning the sector, particularly in regard to its role in extension services and active participation in regional and inter-regional institutions. Governments will also need to establish suitable policies to facilitate and augment aquaculture development and, most of all, remain alert to the establishment of fair legislation and not be subject to the dictates of various lobbyists. Governments need to accept that regulatory frameworks have to be fair whilst being responsible and responsive to identifiable problems and constraints.

The governmental role has to go beyond mere "policing" of the sector's activities and be developed, so that it encompasses working hand-in-hand with practitioners. To be more effective than in the past, government should make investments in partnerships, where appropriate and needed, in order to solve common problems. One of the best examples that can be given is the partnership made for the development, including investment, of seawater irrigation systems for shrimp culture in Thailand (Tookwinas & Yingcharoen, 1999). This specific example will enable, in all probability, this nation to maintain its dominance in the shrimp culture industry. Indeed, this example essentially encompasses the establishment of cultivated/culture areas, supplying the required infrastructure. It reflects a policy that requires serious consideration by other nations, at least by those which are seeking to expand their industrial aquaculture activities, which otherwise tend to happen in clusters.

Lee (1997) suggests that such demarcation of culture areas, accompanied by the provision of appropriate infrastructure, will avoid the over-exploitation of ground water, improve water quality management and provide a range of other benefits.

It is important, and indeed crucial, that governments give sufficient recognition to the sector. It is a fact that the sector has almost always played second fiddle to agriculture and fisheries, for instance. While recognizing that, in most countries, agriculture contributes more than aquaculture to the GDP, it is timely that governments recognize both the contribution and the development potential of the sector, providing the recognition it deserves in national planning and policy development.

Nonetheless, it has also to be conceded that the practitioners in the sector, particularly in the "epicentres" of activity, are not sufficiently organized into professional groups or other suitable organizations. The lack of suitable organizational elements corresponds directly to the lack of proper representation with government. In the new millennium, it is expected that, accompanied by appropriate governmental recognition of the sector, representative associations of the sector will take root, and work responsibly in conjunction with governments.

## **Other challenges and opportunities**

### ***Culture-based fisheries***

As pointed out previously, the availability of resources (land and good quality water) for expansion of the area allocated to aquaculture is likely to be small. Consequently, the majority of the

The annual yield of culture-based fisheries in China is known to be around 740 kg/ha, totalling over 1 million mt, having experienced an estimated annual increase in production of 53 percent since 1979 (Song, 1999). More importantly, this development has been achieved through a long planning process, starting with the planning stages of reservoir impoundment (when fishery needs were taken into consideration) and augmented by a concerted management strategy in which stocking size, species ratio, harvesting time and methods have been well researched, developed and extended. Large areas of small-sized reservoirs are available throughout the tropics (Sugunan, 1997; De Silva, 1996), and numerous attempts have been made in the past to utilize such resources (De Silva, 1988). In South America, of the estimated 1 million ha of reservoir surface, only about 12 percent is used for fish production, and this not as effectively as it could be (Hernández-Rodríguez et al., this volume).

Culture-based fisheries are attractive to most environmental groups, as the activity entails little to no manipulation of the environment, except in cove culture (Lu, 1986). A good example of the effectiveness of culture-based fisheries in increasing fish production is China. In China, a well planned and executed stock and recapture strategy yields an average of 743 kg/ha/yr, which has resulted in the production of 11 605 075 mt in 1997 from culture-based fisheries (Song, 1999). Also, the improvements to culture-based fishery practices in China have resulted in 52.5 percent per annum growth of the fishery between 1979 to 1997 (Song, 1999).

Culture-based fisheries, however, will continue to use exotic species where



production increases foreseen will have to be obtained through increased productivity. Many nations are now examining the possibilities of using inland lakes and reservoirs to improve and/or start culture-based fisheries<sup>11</sup>. Indeed, this subject is seen as a major means of enhancing fish production, and Welcomme (1996) estimated that this form of aquaculture is one of the fastest expanding sectors of fisheries. The aims will differ between nations and regions since, in the developed world, sport fishing will be the main result while, in developing countries, culture-based fisheries provide an easy access to a source of animal protein.

appropriate (e.g. where the exotic species already exists or where environmental impacts have been minimal). Exotic species have often proven to be the ones that give the most effective and profitable yields (De Silva, 1988; Quiros, 1994). In general, most successful stocking and enhancement programmes involve both introduced and native species (Born, 1999). This stance should not be misunderstood as being an advocacy for introducing exotic species; the introduction of new species is a practice that seems to be decreasing globally.

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The responsible use of exotic species is advocated here and best achieved by following internationally accepted codes of practice and guidelines such as those of the International Council for the Exploration of the Sea (ICES) and the European Inland Fisheries Advisory Commission (EIFAC) (e.g. ICES, 1995).

Reservoirs can also provide a suitable means for the expansion of inland cage culture, which is also often seen as a means of alternative employment to displaced persons (Costa-Pierce and Soemarwoto, 1990), as well as for rural communities that live in the vicinity. In some instances, such developments have assumed industrial proportions, on a collective basis, and many nations view inland cage culture as a major option for development in the immediate future. Needless to say, cage culture development in such water bodies has to be managed very carefully, both from the environmental and social points of view.

It is relevant, at this time, to pose the question whether or not researchers need to be oriented towards a systems approach. In hindsight, one could argue that if a systems approach had been applied to the research sector, the losses due to the many epidemics during the last decade might have been minimized. In the new millennium, researchers with different expertise will have to work together and not in watertight compartments, and this target should be considered a priority.

In most nations, and indeed in some regions (e.g. Africa), one of the biggest impediments to successful aquaculture development is seen as being the lack or improper extension of technology. A classic example of this is the observation of Gregory (1999), on the understanding on stock maintenance of a rural fish farmer in Uganda. Extension is an essential ingredient for the sustenance of rural aquaculture and, in this regard, Asian know-how on rural aquaculture should be used to the best

One of the key limitations experienced in this activity is the availability of suitably sized fingerlings for the development and maintenance of rural aquaculture activities, primarily those based on pond culture. Such limitations cause the stocking of under-sized fingerlings, or even fry, which results in suboptimal yields. This important factor is not a result of inadequate hatchery technology, but is due mostly to having inadequate facilities for fry to fingerling rearing, and distribution of the live fish to the area of culture. It will be appropriate to explore the possibility of using reservoir resources for enhancing such nursery aquaculture activities.

### **Education, training and extension**

The education and training needs of global aquaculture, as well as the extension requirements, will be different within the regions, following the degrees of sectoral development. For example, in Asia, training and education is fairly satisfactory at the farmer level, this being an ongoing activity facilitated by regional bodies such as NACA. In most regions, extension workers have a very strong commodity and/or discipline-oriented background. In view of the envisaged aim, that aquaculture should move rapidly towards sustainable development, a more holistic approach would need to be superimposed over the classic methodology. Regional institutions are likely to play an increasingly important role in providing guidance at the national level in this regard.

benefit of Africa, for example, through the vehicle of regional cooperation.

Certain regions are perhaps ready for the next step forward, which can only be achieved through technological advances and development. In Asia, on the other hand, a contrasting situation is to be seen. While there is already a large amount of knowledge available on small-scale/rural aquaculture, the dissemination of this knowledge to practitioners is, unfortunately, less effective than desired. On the other hand, Asia will also need to prepare for the next technological leap, which calls for a rationalization of its education programmes and the acquisition of critical mass of researchers, a subject which is discussed in detail in elsewhere in this volume.

The issues concerning education, training and extension are closely linked to capacity building and the development of human resources. This aspect requires to be accelerated within the aquaculture sector if it is to maintain its growth momentum in an environmentally sustainable milieu. In view of the rapid developments concerning communication using information technology, the sector will have to be increasingly innovative in the methods of the dissemination of knowledge.

### **Markets and marketing**

Marketing issues are common to both rural and industrial aquaculture, but the manner of their handling may be different. These are issues that are common to the sector in both developed and developing countries.

Poor understanding and weak marketing are often seen as hindrances to aquaculture development in Europe (Varadi et al., present volume). Similarly, in Latin America, rural aquaculture has difficulty in making significant impetus due to lack of suitable markets for the produce (Hernández-Rodríguez et al., present volume).

It is not uncommon for sectoral analysts to refer to aquaculture products as being high- and low-valued commodities. In the past five to ten years, some notable changes have occurred within the national and international markets for aquaculture products, where the specific examples of Atlantic salmon, European seabass and tilapia can be cited. These changes are not only in respect of prices, but also the market destinations. The prices of Atlantic salmon and European seabass have diminished considerably (-53 percent in both cases), their target markets being those that displayed keen competition (with other fish or food products) but which were also restructuring (shifting towards the multiple retail store, away from the fishmonger, as the point of sale). While this has been attributed to being a result of "industrial" methods of production (New, 1999), this is perhaps a simplistic conclusion. As in many sectors, the aquaculture sector of the developed countries is no exception, the producer does not control the price; the sector has to adapt to market changes and demands, which are predominantly influenced by consumer preferences.

On the other hand, tilapia, once mooted as the "aquatic chicken" of the 1980s and the "poor man's fish" (Smith & Pullin, 1984), has established a position within the supermarkets in developed countries. The success of tilapia is, without doubt, linked to the provision of fillets at a reasonable price, giving consumer satisfaction. A parallel "success" story is that of the Nile perch fillet (*Lates niloticus*), a product that has

The case in point is the aquaculture development in the Mediterranean Region in the past decade, during which dramatic price reductions have been seen for both European seabass and gilthead seabream, 34 percent in the last three years alone (see the European review by Varadi et al., this volume). Different interpretations exist for this phenomenon, including the considerations of oversupply and inadequate marketing efforts. An interesting analysis, from within the sector itself (Federation of European Aquaculture Producers (FEAP), pers. comm.), is that there were too many suppliers, who are geographically dispersed, for relatively few buyers, who were concentrated in one major market, namely Italy. It was estimated recently, that six to seven points of purchase are responsible for over 75 percent of fish sales in France.

It has been suggested that aquafarmers are weak individual players within modern economic activities (Lee, 1997), where the author believes that governments need to provide a helping hand to organize producers within structures (e.g. cooperatives or associations), which in turn should assume the marketing and sale of the produce. Indeed, this is the position adopted within the European Community (EC), where producer organizations<sup>12</sup> are being increasingly used as the entities for marketing and sales. It has been argued that dearth of cooperative marketing has resulted in unfavourable prices, making aquaculture less economical.

## Conclusions

We are in a new millennium that promises to deliver breathtaking changes in our lives. Plausible developments that have been put forward range from humans stepping onto Mars to the near eradication of most diseases caused by genetic disorders. The human genome has been unravelled and our lives are likely to be dominated and

established its place in the European market, without much advertising, on the basis of being an inexpensive, boneless fillet.

A common pattern has been the early focus on established markets followed by market diversification (i.e. targeting different markets or providing different products) when prices are too competitive or market saturation (for the product concerned) is identified. These circumstances impose on the supply sector the requirement to market their product, a situation in which few producers have real experience.

Where aquaculture production has increased, but is not associated with concurrent market development, market crashes can occur.

revolutionized by biotechnology developments as they were with the transistor, plastics and the microchip during the last 50 years of the previous millennium. In spite of these miracles of technology, a major issue that faces the globe remains poverty and the feeding of the hungry.

This does not appear to be an easy task when the trends of food production are taken into consideration. The world has experienced a decline in the rate of growth of agricultural production, dropping from an annual increase of about 3 percent in the 1960s, the period of the "green revolution", to 1.6 percent in the period 1986-1995.

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The outlook until 2010 is an annual growth of 1.8 percent, a position that is only marginally better (FAO, 1999). When this prediction is combined with the growing concerns for improvements in health and human well being, and with no further increases to the aquatic food supply from capture fisheries, aquaculture may well have an increasing role to play in the next decade and beyond.

Aquaculture should become the mainstay in the supply of aquatic food supplies in the new millennium. This is not an unrealistic goal. However, this will be achieved only if further developments in aquaculture are environmentally sustainable at all levels. The primary aim of increasing aquaculture production should be pursued in conjunction with

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alleviating poverty and contributing to food security of the masses. Indeed, none of these aims are mutually exclusive, and all can be pursued in such a manner as to generate synergies that will help the cause further and allow aquaculture to respond to the hopes anticipated.

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<sup>2</sup> LIFDC's having an average per capita income less than US\$1 505/annum in 1996.

<sup>3</sup> For the purpose of this review, all aquaculture production data were obtained from FAO FISHSTAT PLUS Version 2.3. <http://www.fao.org/fi/statist/fisoft/fishplus.asp>.

<sup>4</sup> Individual species do not include freshwater fishes nei (not elsewhere included) and sea mussels nei from the statistical data.



<sup>5</sup> In this volume China refers to Peoples Republic of China.

<sup>6</sup> Including China, Hong Kong SAR and Taiwan Province of China.

<sup>7</sup> Calculated from the total value divided by total production (FAO Statistics).

<sup>8</sup> See review for this region by Varadi et al. in this volume.

<sup>9</sup> MGA was calculated by determining the percentage rate of increase in production per annum, over a decreasing time scale; for example if the production was  $y_1$ ,  $y_2$  and  $y_3$  in years  $x_1$ ,  $x_2$  &  $x_3$ , respectively, and the period  $x_1$  to  $x_3$  was ten years, then the ten-year average is  $y_3 - y_1$ ,  $x_3 - x_1$  ( $=10$ ) and the moving average between years  $x_2$  and  $x_3$  will be  $y_3 - y_2$ ,  $x_3 - x_2$  and so on.

<sup>10</sup> More specific issues, including those concerning food safety and trade, regulatory frameworks etc., are treated separately within this publication.

<sup>11</sup> see Regional Reviews, this volume.

<sup>12</sup> Producer organizations have to be officially recognized by national governments and the European Commission

