AQUACULTURE: THE LAST FRONTIER FOR SUSTAINABLE FOOD SECURITY?

Meryl J. Williams and Mary Ann P. Bimbao

Dean D.K. Villaluz Memorial Lecture

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SEAFDEC

ICLARM
International Center for Living Aquatic Resources Management

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ABSTRACT

Fish has become a political commodity, thanks to its increasing scarcity and its high value. Aquaculture offers opportunities as the last frontier for sustaining the contribution of fish to food security. Asia is at the forefront of world aquaculture development and has many lessons to share, even within the region. Though aquaculture has made remarkable contributions to availability of food, it promises far more than has already been achieved. Aquaculture can produce more affordable fish, income-generating activities and rural development. If well managed, aquaculture can even contribute to conservation of the environment. These benefits will not be realized, however, without the removal of several constraints that it currently faces. Feed costs must be reduced, better quality seed made available, more ecologically friendly, safer and healthier farming practices used, the rights of poor farmers and local communities protected, and sound regulations implemented to underpin equity, sustainability and trade. For this, greater investment in research, technologial development, information dissemination and training will be needed. These investments, will help tame the last frontier for sustainable food security - aquaculture - and ensure that its benefits are available to all, not just the wealthy but also the poor for whom food security is still a primary challenge.

Speaker's Introduction

I want to start my presentation today by congratulating SEAFDEC AQD (Southeast Asian Fisheries Development Center, Aquaculture Department) on the achievements in its first 25 years. I am deeply honored to be invited to take part in the celebrations. Anniversaries, particularly the one being celebrated this week—a silver anniversary—are milestones. They are also opportunities to take stock of what the institution has achieved so far and to gaze into the future and imagine what lies ahead.

SEAFDEC is a proud achievement of its member countries and those who have worked in it and supported it. It is a regional organization in the most important fisheries development region of the world. Born in 1967 as one of the solutions to the troubled times of the 1960s, it is a regional organization with a truly global reach and significance. As the member countries wanted a better command over the production of fish in the region, the Aquaculture Department was established as SEAFDEC's third technical department in 1973 and charged to carry out aquaculture research and development. The silver anniversary of AQD comes just as we are about to enter the next millenium.

To celebrate this anniversary, I am honored to present the Dean Domiciano K. Villaluz Memorial Lecture. Dean Villaluz was a leader and a pioneer throughout his long and distinguished career. He is recognized here by us today as the first Chief of AQD from 1973 to 1979. Before this he was also the first Dean of the College of Fisheries of the Mindanao State University (MSU) and the first Director of the Institute of Fisheries Research at MSU. He pioneered research into the culture of oysters (*Crassostrea* spp.) and the giant tiger prawn (*Penaeus monodon*).

Dean Villaluz was also a man of vision. He recognized environmental and ecological concerns before it was fashionable to do so and when natural resources were still abundant. And he carried a lifelong concern for developing technologies that would enable small scale producers to improve their nutrition and income through the use of aquatic life.

Last but not least, Dean Villaluz was a Filipino. I take this opportunity to congratulate and join the Filipino people in celebrating their Centennial of Independence this year, 1998.

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[1]Dean D.K. Villaluz Memorial Lecture, 25th Anniversary of SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines, 8 July 1998.

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Introduction

Today, we want to emphasize that fish is a political commodity in SEAFDEC member countries and this is spurring greater efforts to look at the prospects for meeting the growing demand for fish at prices which are affordable for the majority of the people. Aquaculture seems to be the best bet. It may be our last frontier. We want to look at the prospects and constraints for aquaculture through the eyes of its stakeholders and show that appropriate research, such as carried out by SEAFDEC AQD, has an essential part to play in realising the potential of aquaculture in a sustainable way.

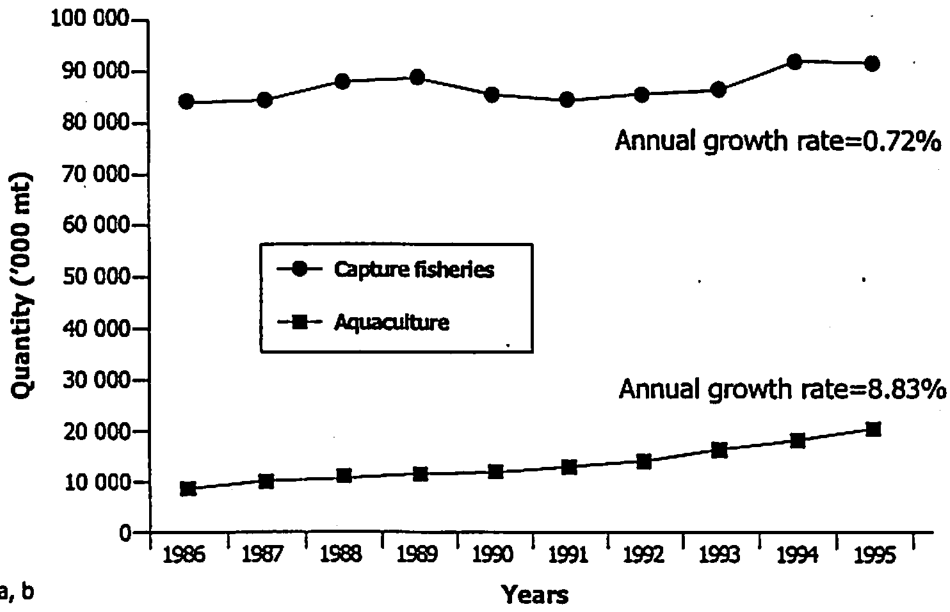
World and Asian Aquaculture and Fisheries Outlook

The demand for fish continues to grow worldwide, driven by growing populations, increasing affluence and greater awareness of the health benefits of seafood (Westlund 1995). Capture fisheries production, that is fish caught from natural stocks, has not been able to keep pace with this growth in demand. Indeed, during the early 1990s, capture fisheries production even declined for some years, raising fears of looming shortfalls (Table 1). However, this shortfall has been compensated by a better than expected increase in aquaculture production. Aquaculture now contributes 19% of the total world fish production. It has been growing at the extraordinary rate of 8.8% per year since 1986, compared to only 0.7% for capture fisheries production (Fig. 1). The growth rate of aquaculture has outstripped that of livestock production, which has been a healthy 3% per year on average (FAO 1997c).

Table 1. Total world catch: capture fisheries and aquaculture, 1986-1995.

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Annual growth rate (%)
Quantity ('000 mt)											
Capture fisheries[a]	84224	84553	88168	88919	85563	84801	85725	86730	92099	91972	0.72
Aquaculture[b]	8827	10134	11168	11741	12409	12996	14452	16442	18439	20938	8.83
Total[c]	93051	94687	99336	100660	97972	97797	100177	103172	110538	112910	2.00
Quantity (%)											
Capture fisheries	91	89	89	88	87	87	86	84	83	81	
Aquaculture	9	11	11	12	13	13	14	16	17	19	

[a]Derived statistics subtracting aquaculture production from total world catch.
[b]Under 'Fish and Shellfish' group: includes all fishes, crustaceans, molluscs, frogs and other amphibians, turtles, sea-squirts and other tunicates, horseshoe crabs and other arachnoids, sea urchins and other echinoderms, and miscellaneous aquatic invertebrates. Excludes products not used directly for human food. (FAO 1997a)
[c]Excludes whales, seals, other aquatic mammals and plants. (FAO 1997b)



Sources: FAO 1997a, b

Figure 1. Total world catch: capture fisheries and aquaculture (1986-1995).

Table 2. World aquaculture food production: by environment, 1986-1995. (FAO 1997a)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Annual growth rate (%)
Quantity ('000 mt)											
Freshwater culture	5447	6216	6766	7214	7682	7916	8962	10163	11684	13208	9.15
Brackishwater culture	709	905	1016	1066	1162	1302	1293	1283	1374	1478	6.91
Mariculture	2671	3013	3386	3461	3565	3778	4197	4996	5381	6252	8.66
Total*	8827	10134	11168	11741	12409	12996	14452	16442	18439	20938	8.83
Value (million US$)											
Freshwater culture	7693	9277	10467	11182	12421	12172	13488	14599	16226	17484	8.19
Brackishwater culture	1981	3249	4105	4387	4919	5747	6034	5934	6748	7010	11.78
Mariculture	3908	5026	5937	6059	6545	7337	8301	9731	10790	11751	11.39
Total*	13582	17552	20509	21628	23885	25256	27823	30264	33764	36245	9.80

*Under 'Fish and Shellfish' group: includes all fishes, crustaceans, molluscs, frogs and other amphibians, turtles, sea-squirts and other tunicates, horseshoe crabs and other arachnoids, sea urchins and other echinoderms, and miscellaneous aquatic invertebrates. Excludes products not used directly for human food.

Are capture fisheries really in trouble? We believe the answer is yes. Recent studies by ICLARM have helped highlight the scientific basis of the concerns hinted at in the FAO global fisheries production statistics that existing fishing pressure is seriously damaging the long term sustainability of natural stocks. Humans have, indeed, been "fishing down the food web". In most of the world's fisheries, the average trophic level (approximate position on the pyramid of who eats who) has declined as the top level predators have been depleted and often smaller, less valuable, species are now more common in the harvests (Pauly et al. 1998). Therefore, major steps are needed to rehabilitate the productive capacity of capture fisheries while all the time the demand for fish grows. Serious research is needed on how this can be achieved.

Side by side there has been a great deal of research on developing new aquaculture technologies and analyzing the potential benefits to producers, consumers and the environment. Is aquaculture going to provide our last frontier?

Though freshwater aquaculture production dominates total aquaculture production (Table 2), aquaculture in all environments - freshwater, brackishwater and marine - has been growing rapidly (Fig. 2).

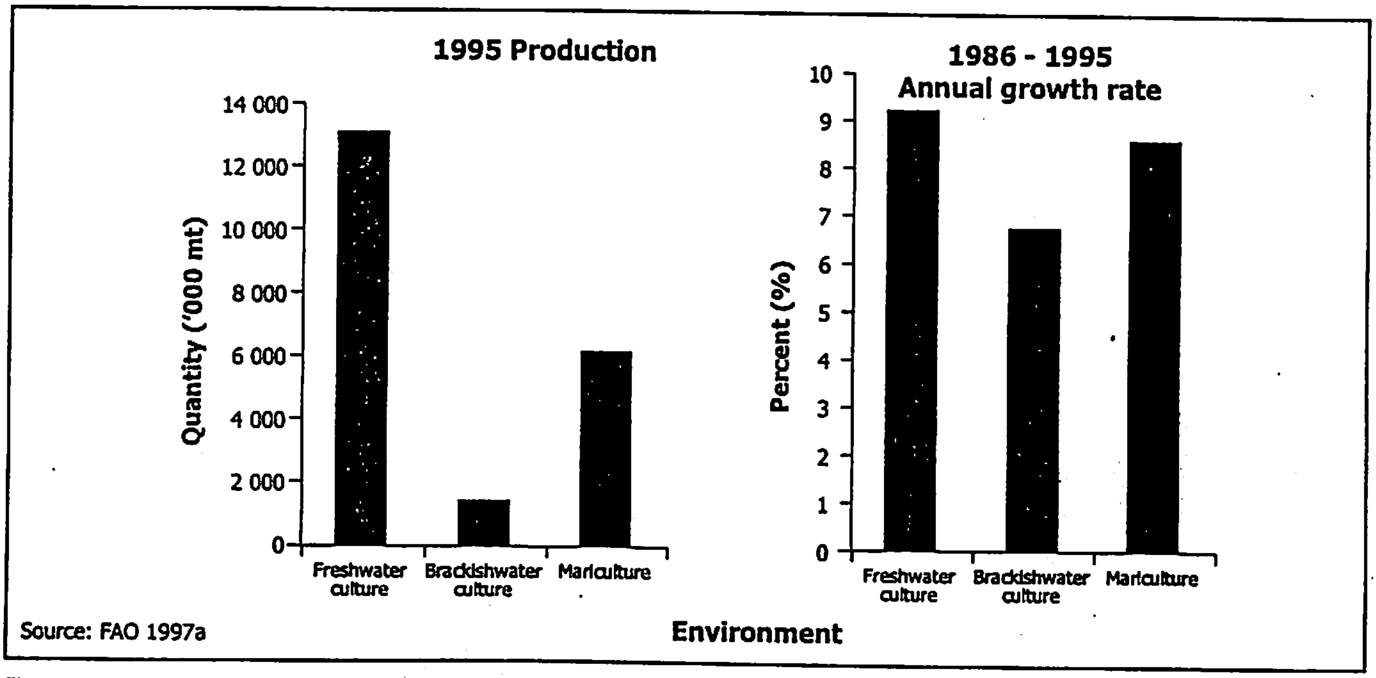


Figure 2. World aquaculture food production: by environment (1986-1995).

Table 3. World aquaculture food production: by continent, 1986-1995. (FAO 1997a)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Annual growth rate (%)
Quantity ('000 mt)											
Africa	41	43	51	71	56	68	71	71	74	82	7.20
America, North	462	491	480	504	463	504	557	566	574	600	2.82
America, South	64	95	113	119	149	195	237	241	276	329	17.17
Asia	6860	8043	9017	9483	10072	10698	12109	14073	15916	18271	10.07
Europe	1054	1088	1151	1172	1228	1220	1177	1206	1357	1407	2.66
Oceania	26	29	41	41	42	64	69	71	73	95	13.85
Former USSR area	320	345	315	351	399	247	232	214	169	154	-9.20
Total*	8827	10134	11168	11741	12409	12996	14452	16442	18439	20938	8.83
Value (million US$)											
Africa	38	58	83	124	127	151	173	168	176	187	16.25
America, North	578	663	757	813	898	1001	1170	1344	1460	1351	10.25
America, South	389	629	772	687	661	904	1120	1169	1298	1493	12.74
Asia	10160	13367	15508	16328	18000	19358	21454	23725	26654	28832	10.45
Europe	1955	2282	2618	2840	3248	3178	3258	3227	3582	3781	6.38
Oceania	37	50	80	101	107	118	133	142	183	219	17.36
Former USSR area	425	503	691	735	845	546	514	489	412	382	-3.39
Total*	13582	17552	20509	21628	23886	25256	27822	30264	33765	36245	9.80

*Under "Fish and Shellfish" group: Includes all fishes, crustaceans, molluscs, frogs and other amphibians, turtles, sea-squirts and other tunicates, horseshoe crabs and other arachnoids, sea urchins and other echinoderms, and miscellaneous aquatic invertebrates. Excludes products not used directly for human food.

Not all regions are equally productive in aquaculture (Table 3). Asia dominates the world total with 87% of production of fish and shellfish (Fig. 3), and 90% if aquatic plants are included. The top aquaculture countries are in Asia (Table 4), with four SEAFDEC member countries included among the top producers (Fig. 4).

However, fish production statistics only tell part of the story as large quantities of fish and shellfish are traded on the international markets and fish produced in one country will often be consumed in another. Trade balances - that is the differences between exports and imports of fish and shellfish - have changed over the years. For Asian countries overall, the value of imports is much greater than the value of exports largely due to high value imports

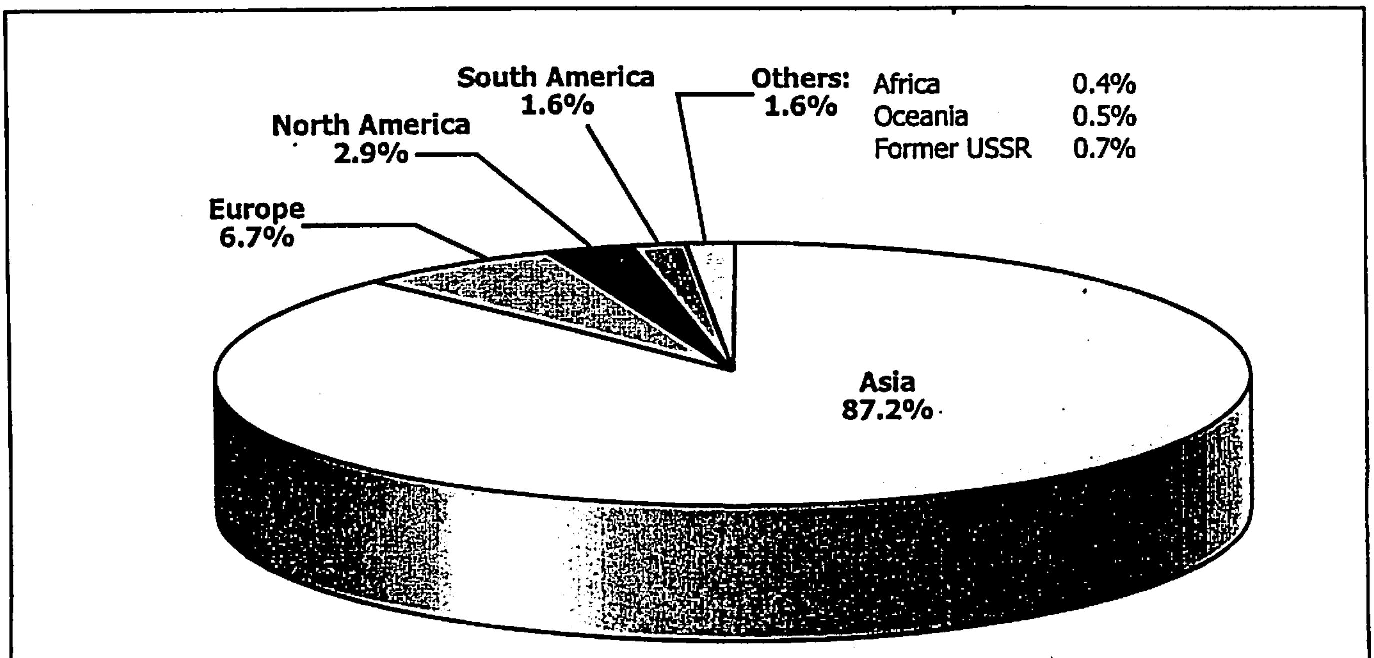
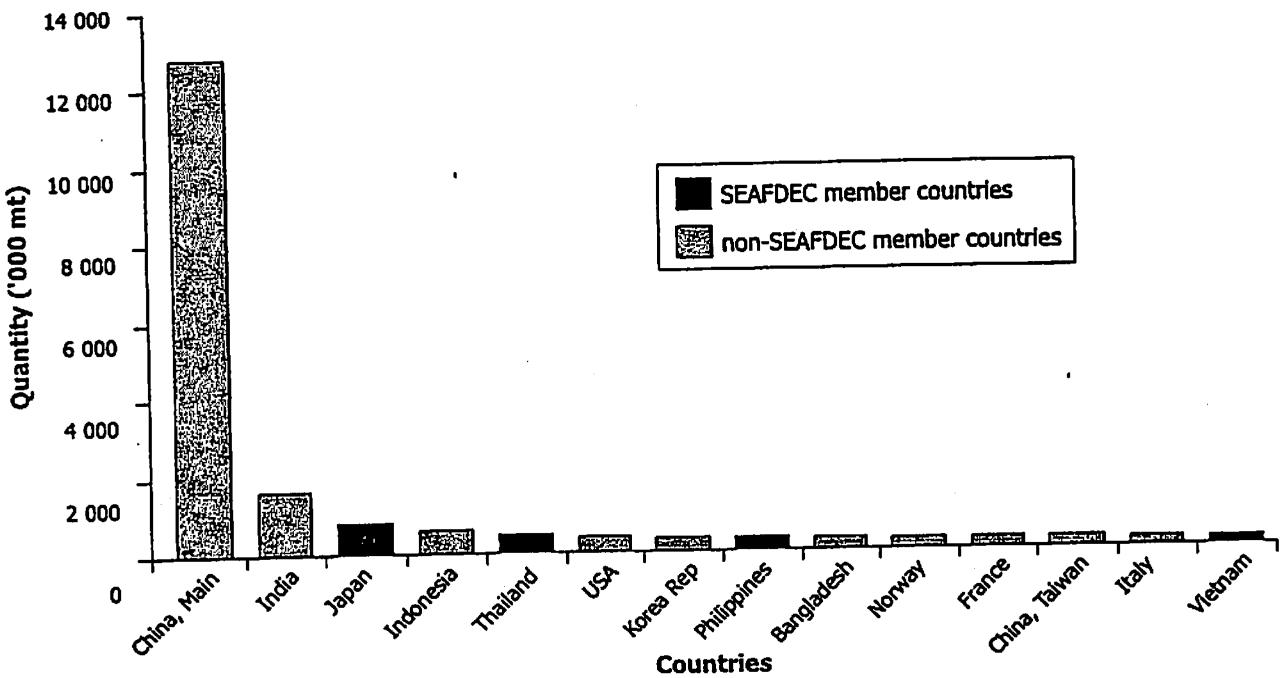


Figure 3. World aquaculture food production (1995).

Table 4. World aquaculture food production by principal producers and other selected countries, 1986-1995. (FAO 1997a)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Annual growth rate (%)
Top countries											
China, Main	3579	4381	5077	5449	5804	6134	7210	8870	10612	12792	12.93
India	686	788	893	1005	1012	1221	1389	1427	1528	1609	9.58
Japan[a]	693	739	807	785	804	803	818	833	781	820	1.32
Indonesia	333	377	413	441	500	518	550	600	598	611	6.82
Thailand[a]	134	152	219	260	292	353	371	457	514	464	14.93
USA	372	383	358	369	315	364	414	417	391	413	1.42
Korea, Rep.	428	477	457	404	377	342	376	392	343	368	-2.88
Philippines[a]	302	340	343	360	380	409	390	392	380	346	1.81
Bangladesh	134	150	155	163	170	178	230	253	270	322	9.43
Norway	50	56	90	114	150	161	131	173	218	282	17.48
France	244	232	228	225	257	245	250	277	281	281	2.34
China, Taiwan	257	300	294	235	334	283	250	277	282	278	0
Italy	107	119	132	134	144	146	162	169	180	220	6.79
Vietnam[a]	131	140	142	149	153	175	185	190	198	211	5.45
Total	7450	8634	9608	10093	10692	11332	12726	14727	16576	19017	9.63
Other SEAFDEC member countries											
Malaysia	52	46	47	53	52	65	80	105	114	133	12.29
Singapore	1	2	2	2	2	2	2	2	2	4	7.56
Brunei (mt)	0	2	2	2	2	1	17	36	72	103	49.50
Other countries	1324	1452	1511	1593	1663	1597	1644	1608	1747	1784	2.05
Total[b]	8827	10134	11168	11741	12409	12996	14452	16442	18439	20938	8.83

[a]SEAFDEC member countries.
[b]Under "Fish and Shellfish" group: includes all fishes, crustaceans, molluscs, frogs and other amphibians, turtles, sea-squirts and other tunicates, horseshoe crabs and other arachnoids, sea urchins and other echinoderms, and miscellaneous aquatic invertebrates. Excludes products not used directly for human food.



Source: FAO 1997a

Figure 4. World aquaculture food production by principal producers (1986-1995).

Table 5. International trade in fishery commodities: by continent, 1986-1995. (FAO 1997b) (Value in million US$)

	Exports				Imports				Trade balance			
	1992	1993	1994	1995	1992	1993	1994	1995	1992	1993	1994	1995
Africa	1584	1576	1973	2435	838	744	893	951	746	832	1080	1484
America, North	6795	6472	6799	7449	7027	7486	8380	8550	-232	-1014	-1581	-1101
America, South	3519	3662	4417	5034	279	371	496	696	3240	3291	3922	4338
Asia	13226	14648	16996	18285	18220	19461	22298	24658	-4994	-4814	-5302	-6373
Europe	12854	11985	13669	15064	18356	15947	18116	20133	-5502	-3963	-4447	-5069
Oceania	1380	1397	1543	1773	496	508	562	579	884	889	982	1193
Former USSR area	859	1669	2021	1994	39	65	336	458	821	1604	1685	1536
World[a]	40217	41409	47418	52034	45255	44582	51081	56025	-5038	-3173	-3663	-3991
Low-income food-deficit countries[b]	6345	6850	8518	9816	1607	1505	1922	2060	4738	5345	6596	7756

[a]Records total imports and total exports including re-exports.
[b]Include developing countries whose annual per caput net income are below US$1,395 (1990 GDP) and are net importers of food with imports of basic food stuff outweighing exports.

of Japan (Table 5). In 1995, there was a trade imbalance in the region of US$6.4 billion. For Africa, the value of exports is much greater than the value of imports and the excess of exports over imports has grown in the 1990s. This occurs because of the poverty and lower per caput consumption of fish in much of Africa, so people must sell on the open market the more expensive tradable part of their catch, while they can only afford to buy some cheaper fish products, if any, in return. Worldwide, the poorest countries, the low-income food-deficit countries, have an excess of US$7.8 billion of exports over imports of fish and shellfish in 1995.

Among SEAFDEC member countries of Asia, the more affluent countries such as Japan, Singapore and Brunei cannot produce sufficient fish to meet their own consumption needs and so they import much of their needs (Table 6). The other countries have taken advantage of this and export many high value products and thus have a positive balance of trade. In 1995, Thailand exports were valued at US$4.4 billion. This made Thailand the biggest seafood

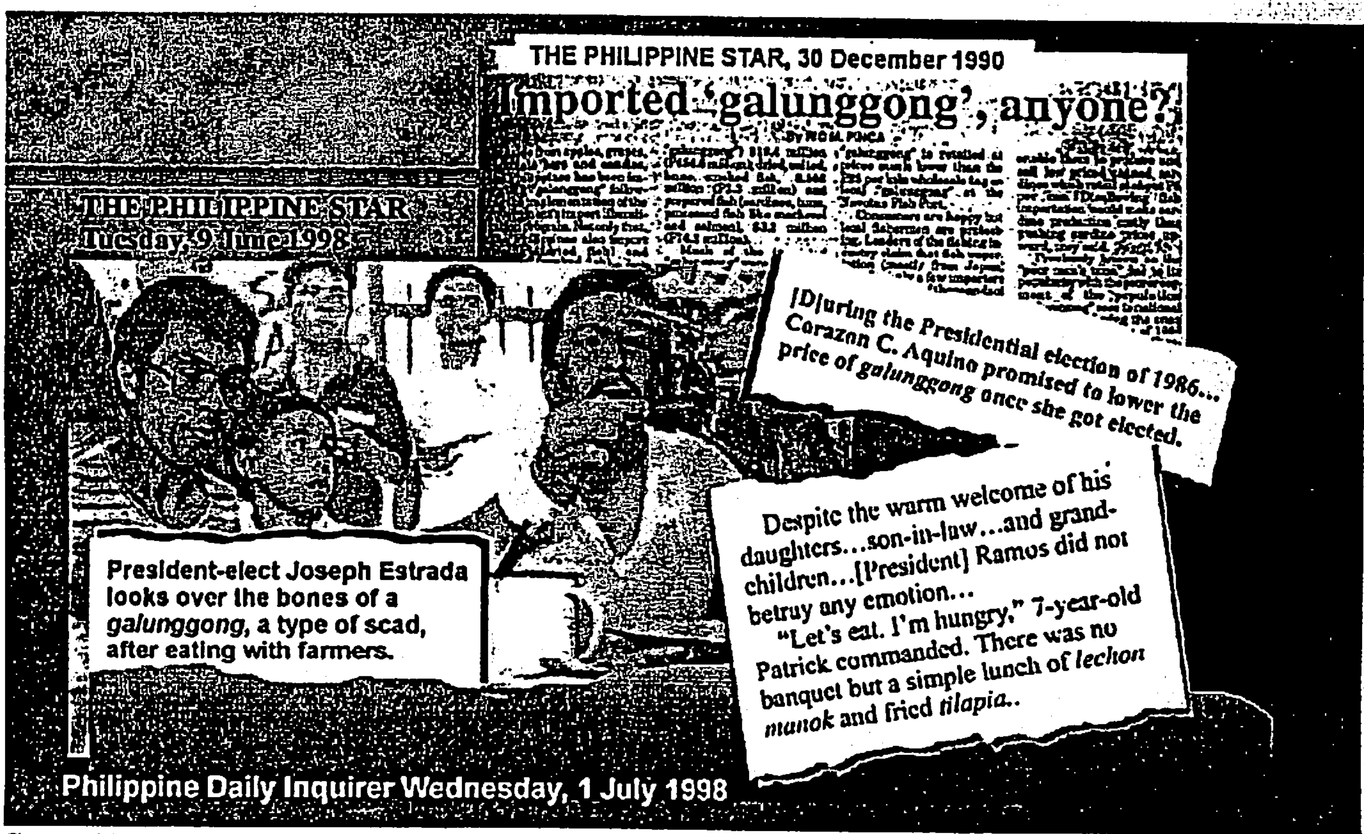


Figure 5. Fish as a political commodity: the Philippine context.

Table 6. International trade in fishery commodities for SEAFDEC member countries, 1986-1995. (FAO 1997b) (Value in '000 US$)

	Exports				Imports				Trade balance			
	1992	1993	1994	1995	1992	1993	1994	1995	1992	1993	1994	1995
Japan	792369	766952	742972	713219	12831760	14187149	16140465	17853481	-12039391	-13420197	15397493	-17140262
Singapore	494128	482312	563502	584594	543769	566502	619595	659681	-49641	-84190	-56093	-75087
Brunei	450	510	520	629	6760	6380	6590	6551	-6310	-5870	-6070	-5922
Malaysia	294636	306845	324857	334873	244789	265032	304258	323619	49847	41813	20599	11254
Philippines	393993	478086	533087	502201	110986	94601	108193	134789	283007	383485	424894	367412
Vietnam	305163	368235	483677	512937	0	0	0	2506	305163	368235	483677	510431
Thailand	3071780	3404268	4190036	4449457	942090	830480	815616	825606	2129690	2573788	3374420	3623851

exporter in the world. Since Thailand imported less than US$1 billion of seafood, it ended up with a positive balance of US$3.6 billion from its seafood trade.

The economic, technical and natural resource factors which govern imports, exports and domestic supply of fish have not been studied in-depth though their interplay is of great importance. In Asia, low income countries get most of their fish supply from domestic sources, export what high value products they can and import little in return. The middle income countries import more of their needs and the high income countries import the majority of their needs (Table 7).

The interplay of domestic needs and international trade creates opportunities and challenges for fish production and has made fish a political commodity especially in countries where it is a staple of the diet of the majority of the people. Here in the Philippines, our politicians highlight its importance in their public statements (Fig. 5). In the 1986 Presidential election, candidate Corazon C. Aquino promised to lower the price of *galunggong* (round scad, *Decapterus* spp.). This year, in early June, then President elect Joseph Estrada was shown eating *galunggong* with farmers picketing the Department of Agrarian Reform, and the day after President Fidel V. Ramos became an ordinary citizen again, he was reported in the newspaper as enjoying a simple lunch of *lechon manok* (roasted chicken) and fried tilapia. The price of small fish can send large political signals. Traditionally, fishers in the Philippines see the price of *galunggong* as an important indicator of fish prices and fish supply.

What do different stakeholders want from aquaculture? Let us now examine this question from the viewpoint of the stakeholders and let us keep in mind that sustainable food security means a long term productive and healthy environment, equal opportunity of access to fish by all sectors of society and adequate nutrition for each person so that all can lead productive and fulfilled lives. Is aquaculture going to provide our last frontier now that capture fisheries production limits appear to be reached?

Table 7. Domestic food fish production and per caput supply[a] in selected Asian countries, 1991-1993. (FAO 1997b; WB 1995)

Countries	Per caput supply	Food fish production from domestic sources (mt)	
	(mt)	Total	Per caput
Low income			
Afghanistan	0.1	1167	0.1
Bangladesh	8.2	963653	8.5
Cambodia	10.3	112617	12.2
China, Main	12.4	14740096	12.7
India	4.0	3808889	4.3
Lao PDR	6.7	29833	6.7
Mongolia	0.7	117	0.1
Myanmar	15.9	699106	16.3
Nepal	0.8	16321	0.8
Pakistan	2.2	379601	3.0
Sri Lanka	16.5	208377	12.0
Vietnam[b]	13.5	1037493	14.9
Middle Income			
Fiji	36.5	24248	32.5
Indonesia	15.6	3415672	18.1
Korea, Dem. Rep.	46.5	1023413	48.7
Korea, Rep.	47.7	2190250	50.1
Macao	36.8	2280	5.8
Malaysia[b]	29.5	463623	24.7
Maldives	125.9	82960	360.7
New Caledonia	20.9	3189	18.4
Philippines[b]	36.0	2282497	35.9
Samoa	41.8	1157	7.1
Solomon Islands	32.2	52203	152.2
Thailand[b]	25.5	1993187	35.1
Tonga	23.9	2241	23.1
Vanuatu	29.3	3053	19.4
High Income			
Australia	19.5	219300	12.7
Brunei[b]	21.6	1704	6.3
China, Taiwan	37.0	1331888	64.5
French Polynesia	34.3	2981	14.5
Hongkong	57.9	197019	33.6
Japan[b]	67.0	5171981	41.6
New Zealand	17.8	462849	134.7
Singapore[b]	32.4	12086	3.8

[a]A lower value of per caput food fish production from domestic sources for caput supply of a country implies it imports more of its food fish requirements than it produces itself.
[b]SEAFDEC member countries.

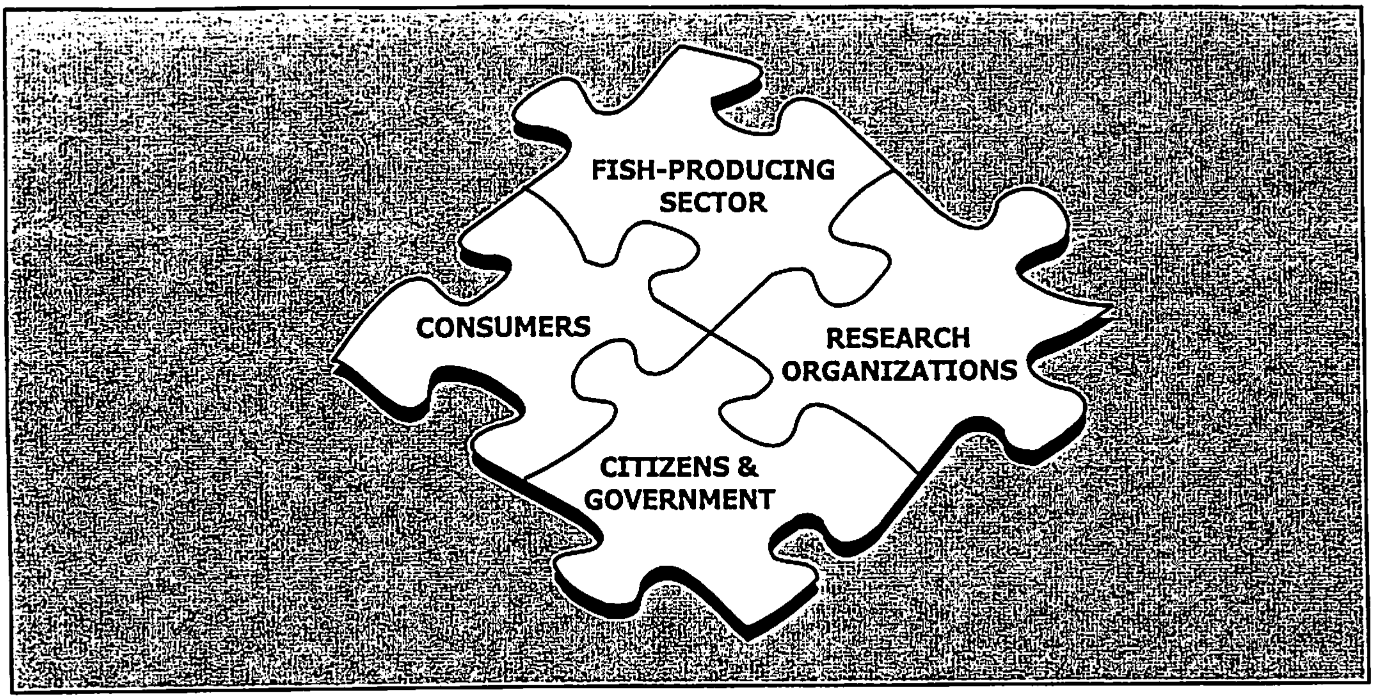


Figure 6. Stakeholders in aquaculture.

Aquaculture for a Sustainable Food Security: from the Viewpoint of the Stakeholders

We are all stakeholders in the future of aquaculture (Fig. 6) because we all fit into one or more of the following groups: consumers, fish producers, citizens, government and researchers.

Consumers

We are all consumers and, in SEAFDEC member countries, most people like to eat fish (Fig. 7). Indeed, per caput fish consumption is among the highest in the world. Consumers want adequate supplies of fish at affordable prices in their local markets. Wealthier consumers may be more interested in supply, quality and variety of products than price while middle class and poor consumers will seek good supplies at affordable prices. Although fish may be preferred over other animal and cereal protein, its affordability will often determine whether a consumer will choose it. Fish was once known as the "poor man's protein" but today its price is a politically sensitive issue.

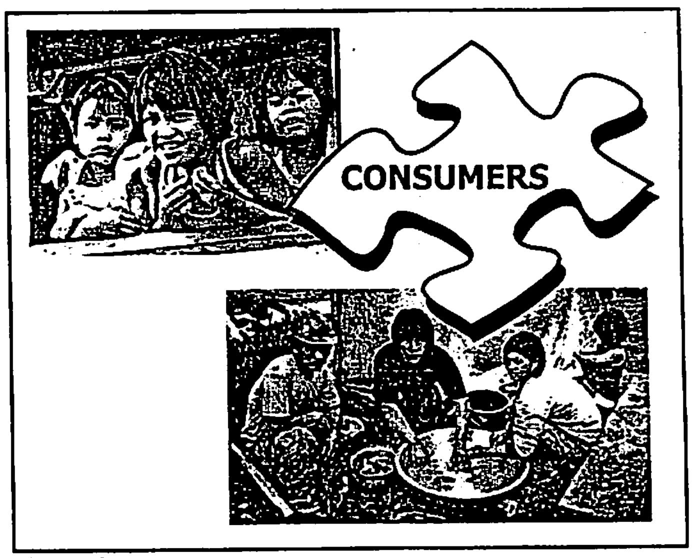


Figure 7. Consumers.

There are several success stories around the world showing how aquaculture has made fish more available and affordable. The most striking example is China, where the increased supply of carp and other fish species from aquaculture has meant an increase in annual consumption of aquatic products from only 2.67 kg per caput in 1952 to 7.29 kg per caput in 1992 (Wang 1996), even as the population grew from 575 million to 1,172 million. On world markets, increased production of farmed salmon and trout brought down the average price of these fish by 21% between 1989 and 1994, from US$3,500 per ton to US$2,750 per ton. During this time, the prices of most other seafood caught from the wild went up (Delgado and Courbois 1997). In the future, aquaculture will make more species of fish and shellfish affordable for the average consumer.

The price of fish can be lowered by increasing its supply, but this will require new and more efficient production methods. Research, followed by technology verification, field testing and adoption by industry, can have an enormous impact on the efficiency of production and thus on making fish more affordable. If fish is to be brought within the reach of all consumers, however, large and sustained increases in supply and production efficiency will be required. ICLARM and its partners in five countries (Philippines, Thailand, Vietnam, Bangladesh and China) recently studied the likely impact on production costs of Nile tilapia through the introduction of the faster growing GIFT (Genetically Improved Farmed Tilapia) strain (ICLARM 1998). The studies found that production costs could be lowered by 20-30% and that relatively poor consumers and producers benefit most from this. In the surveys, these consumers indicated they would buy more tilapia if it became more affordable. Unfortunately, the very poor consumers would still not be able to afford tilapia. Therefore, special measures need to be developed to reach the poorest consumers.

Most segments of the aquaculture industry are decades behind the chicken, pork and other animal industries in addressing consumer needs. In the future, consumers will demand more variety, more convenience foods and better quality products requiring improved handling and presentation. Aquaculture can deliver these but to do so will require continuous increases in productivity and substantial investments in research and development to domesticate new species and to document and improve the production processes of existing species.

Fish-producing Sector

The fish-producing sector includes fishers, fish farm owners, workers on fish farms and all those involved in auxiliary industries (Fig. 8). These include hatcheries, feed suppliers, equipment and chemical suppliers, canning and processing plants, marketing and sales. We will look at aquaculture producers of different sizes and what they need to stay in business, what will attract new entrants and what the employment outlook is in the sector.

Figure 8. Fish-producing sector.

Large scale, intensive aquaculture enterprises will need good returns on their investments of capital, labor and other inputs. The large scale segment of the aquaculture industry is still finding its way. Returns and risks of investment in this sector are hard to calculate due to the pioneering nature of the enterprises. Some of the best documented examples are found in the Norway salmon industry which has grown rapidly over the last 30 years into a well organized industry which has learned and continues to learn from its mistakes, opportunities and innovations. World salmon producers have recently looked ahead at their industry's prospects (ISFA 1998). Shrimp producers are also becoming more organized as they seek to make their industry sustainable as well as profitable.

In the future, other segments of the industry will become more organized. More large companies will enter aquaculture. The new entrants will come from various business backgrounds, traditional and non-traditional. Among the non-traditional entrants we already have brewers such as Kirin in Japan and power conglomerates such as Norsk Hydro in Norway. Among the more traditional are the agribusiness companies such as feed, seed, veterinary drugs, farm machinery and equipment suppliers. They will be seeking to form vertically integrated production chains as they have in agriculture and cross link aquaculture with their businesses in agriculture, e.g., through feeds, genetics technologies, drugs and markets. A critical decision will be whether to involve themselves in the actual production or to outsource this to small and medium scale producers as is common in the chicken industry. Experience from agribusiness suggests that market share and profitability are eventually controlled through attention to the two ends of the production chain - choice of species and genetics of the basic stock on the one end and the market or consumer outlets on the other.

Our advice to aquaculturists would be to look closely at what has happened and is happening in agribusiness in their own countries and internationally. Aquaculture could evolve along the same lines as other agricultural sectors, with more involvement from large scale agribusiness and less from the small to medium scale producers. As in agriculture, however, all scales of enterprise will co-exist far into the future as each has its own strengths.

Small and medium scale owner-producers, who still produce the vast majority of aquaculture products, differ in their operations from the more vertically integrated larger companies. They also need financial profitability but their enterprises need to be closely allied with the support sectors such as the auxiliary industries, research, extension and marketing services. Often, these producers are also linked to the large scale producers and there may even be tension between the two with respect to pricing of farm inputs and price of fish sold. Very small producers will often be producing other products on their farms, such as rice and vegetables, or may be part-time fishers or farm laborers. This is the most vulnerable sector.

For aquaculture production to expand further, potential producers must perceive it as a more profitable way to use existing resources such as land, water, feed, capital and labor, or as a non-competitive form of rural and coastal diversification. At present, the relatively high price and growing demand for fish is making aquaculture more profitable than other types of farming. Another attraction is that aquaculture is an exciting and attractive industry, filled with frontier-like challenges, rewards and disappointments. Thus, it appeals to many entrepreneurs.

Regardless of scale, farm profitability will depend on fish prices, farm production costs and a healthy environment. To lower production costs, the aquaculture industry needs continual improvement in feed prices and feed efficiency, farm management, germplasm lines and disease prevention and treatment. Also, if farms suffer environmental problems of their own making or due to external causes, they will lose profitability or may collapse altogether.

In lake culture and along the coasts, aquaculture competes with nature for space and environmental goods. Since nature has no voice, no clearly defined owner and no easily calculated value, the true costs and benefits of aquaculture are hard to determine. SEAFDEC and others, including ICLARM and the University of the Philippines in the Visayas, are working to provide the scientific basis for: 1)environmental management of lakes for fisheries and aquaculture; 2) rehabilitation of mangrove areas damaged by shrimp farming; and 3) valuation of coastal resources used for fisheries and aquaculture. The lessons of the shrimp industry have shown that unsustainable practices affect the farmers, damage the environment and may displace many low-income coastal fishers and farmers (Primavera 1997).

There is also a great deal of discussion about the sustainability of culturing carnivorous fish and shellfish, such as prawns and groupers (*Epinephelus* spp.), as these fish need high protein feeds, usually based on fishmeal and fish oil. They use up the limited supplies of natural fish to make higher value fish protein. At present, the relative pricing is such as to make the culture of carnivorous fish profitable. However, in the next few decades, the industry will have to rethink its choice of species. Species which feed lower on the food chain, such as tilapia, are likely to become more profitable and better long term prospects for culture.

What then of employment opportunities in aquaculture? At present, the small to medium scale sector accounts for the majority of employment in aquaculture. Aquaculture does not create a large number of new jobs and poorer people need special assistance if they are to take part at all in production. Community-based schemes, such as SEAFDEC AQD has pioneered along with NGOs at Malalison Island and is now taking further in Honda Bay, Palawan and which ICLARM and NGO partners have developed in Bangladesh, have the potential to reach many small scale producers, including women. Adoption of aquaculture by women can help their personal empowerment because it offers them the opportunity for direct control of some cash income (Nandeesha and Hanglomong 1997). Research on integrated aquaculture-agriculture systems in Asia and Africa is assisting the poor and small farmers to increase farm productivity and their income earning opportunities. When aquaculture is added to existing farming systems, new jobs or tasks are created but usually for a good return. In Vietnam, researchers showed that some farm labor was freed up for aquaculture when new labor-saving rice growing technology was introduced (Vo Thi Ngoc Ba and Tran Thi Thanh Hien 1997).

Citizens and Government

The public has a major stake in the future progress of aquaculture. Few will be actively involved in the sector but many will be concerned with: 1) whether it supplies the affordable fish they want as consumers; 2) whether it does so in an environmentally friendly and sustainable way; and 3) whether it indirectly contributes to economic development through being a profitable and competitive industry sector.

Governance within the aquaculture sector is a largely unexplored territory and will most likely evolve as a hybrid between capture fisheries and agricultural models. The agricultural model will usually dominate since property rights and responsibilities are easier to define in aquaculture than

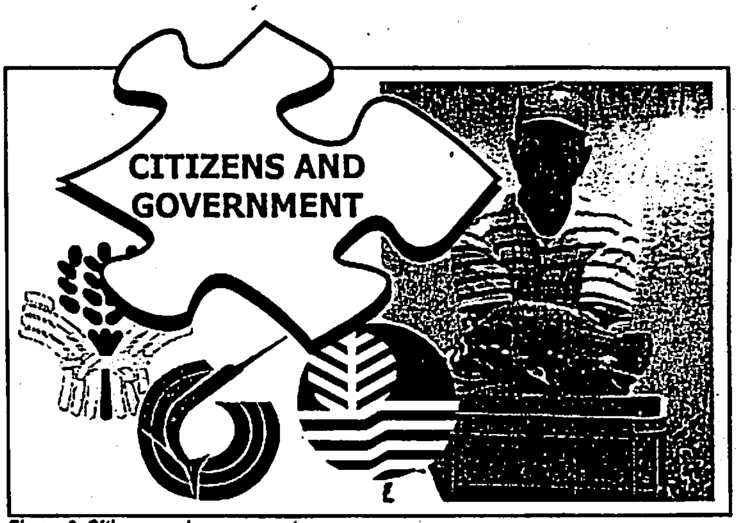


Figure 9. Citizens and government.

in fisheries due to its privatized nature. However, waterbodies are more physically connected than tracts of lands due to the flows of water. They also tend to be downstream from all terrestrial activities, and hence the recipients of many pollutants. Thus, aquatic resource systems experience and cause many externalities. For example, aquaculture is badly affected by water pollution and itself may deplete biodiversity and damage the environment if badly managed.

Governments have adopted the role of promoting aquaculture through information, training and research support (Fig. 9). Governments also license fish ponds, cages and coastal culture sites and promote trade in aquaculture products. Some governments are still involved in hatcheries and state farms but the worldwide trend to privatization will eliminate government involvement in production over the next decade, to the great benefit of the industry.

Governments also regulate the credit and investment sectors. The present currency crisis will surely slow down domestic borrowing from overseas sources for aquaculture investments, thus making domestic credit and investment facilities more important. The devaluation introduces uncertainty and will raise the cost of imported inputs. On the other hand, exports to some countries are now more valuable.

Regulation is another major role for governments in aquaculture. Governments all over the world have been reactive rather than proactive in regulating the impact of aquaculture on the environment. Two major obstacles stand in the way of such regulation. The first is that most developed and developing countries do not have the scientific knowledge to establish effective environmental legislation for aquaculture. The second is that regulation is difficult to implement because it requires: 1) cooperation between government regulators and the industry; 2) economic and social incentives for the industry to comply; and 3) commitment by the government to enforce where necessary. Here again, research should study and assess the effectiveness of different management systems and incentives.

Local communities, concerned citizens, scientists, NGOs and the media will remain vocal advocates of environmental and social justice issues in aquaculture. Governments must facilitate the processes of governance so that the many voices may be heard, including those of the poor and socially disadvantaged. Trading partners and the marketplace will become more discerning of product quality and quarantine, placing their own demands on governments and the industry.

Research Organizations

So far we have addressed the role of the consumers, the fish-producing sector, and the citizens and government in aquaculture. The last group of stakeholders is the research industry and researchers. As the founding of SEAFDEC AQD so well illustrates, research was quite rightly one of the first solutions which member governments turned to when they wanted to promote fish production through aquaculture. Research plays many roles in natural resource industries (Williams 1996). It provides basic knowledge, identifies issues, resolves conflicts and suggests options and solutions to problems. Many of the above stakeholder needs cannot be met without the assistance of relevant research.

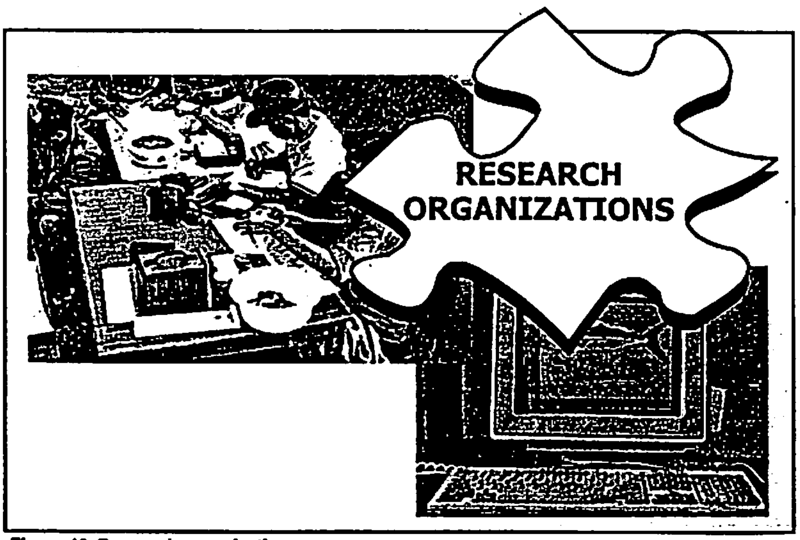


Figure 10. Research organizations.

Research on aquaculture in the region started off from a minimal knowledge base but is making great strides, though the resources available are small relative to the value of the industries served (Fig. 10). As aquaculture becomes more efficient and competitive, it will move from its initial phase which relies totally on resource factors of production to a more advanced phase where knowledge plays the major role. Knowledge can be bound into the genetic selection and breeding of better species and strains, the development of cheaper, better assimilated and less polluting feeds and better production management.

If we look at the species that have been the focus of SEAFDEC AQD and ICLARM's aquaculture research to date, we see that Asian production accounts for an average of 98% of their world production (except for seaweed (*Gracilaria* spp.) with only 23%) (Table 8). Around 70% of the aquaculture publications from the two institutions are species-specific. Species such as prawns (*Penaeus monodon*), milkfish (*Chanos chanos*), tilapia (*Oreochromis niloticus*) and several marine species have been well researched (Table 9, Fig. 11). There has been an increasing amount of research over time on most of these species, except milkfish which has dropped slightly. In keeping with

Table 8. World production of selected species of importance in SEAFDEC AQD and ICLARM's research, 1986-1995. (FAO 1997a) (Quantity in mt)

Species	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Annual growth rate (%)
Freshwater											
Nile tilapia											
(Oreochromis niloticus)											
Asia	83063	94538	97299	167384	193357	226156	283571	342228	390452	429165	20
World	110974	122862	126894	197837	224984	256217	321800	378889	432152	473641	18
Common carp											
(Cyprinus carpio)											
Asia	474550	668669	744634	623268	689784	784429	866223	1093795	1329992	1596645	11
World	823015	1031703	1069168	988786	1111980	999523	1121766	1311736	1528315	1783420	7
Catla											
(Catla catla)											
Asia	155000	181000	207000	233000	234003	289928	301306	341604	353351	381143	10
World	155000	181000	207000	233000	234003	289928	301306	341604	353351	381143	10
Thai silver barb											
(Puntius gonionotus)											
Asia	10611	12842	16673	17247	18395	20908	29624	26250	28528	19100	9
World	10611	12842	16673	17247	18395	20908	29624	26250	28528	19100	9
Roho labeo											
(Labeo rohita)											
Asia	163552	189327	216318	242869	243428	314984	356153	411495	432198	458795	12
World	163552	189327	216318	242869	243428	314984	356153	411495	432198	458795	12
Silver carp											
(Hypophthalmichthys molitrix)											
Asia	1190959	1335183	1507284	1367774	1431670	1393493	1576205	1843698	2177992	2507187	7
World	1285579	1438542	1587776	1456654	1504192	1471851	1637273	1904575	2221357	2555407	6
Bighead carp											
(Aristichthys nobilis)											
Asia	604637	640013	715812	640890	670507	693679	784645	914221	1068749	1250140	7
World	613262	647147	724728	652604	676767	705016	794146	923537	1076404	1256930	6
Brackishwater											
Milkfish											
(Chanos chanos)											
Asia	310701	332326	345737	333394	434030	416445	343294	358937	376882	358050	1
World	310765	332398	345829	333497	434123	416520	343359	359007	376952	358125	1
Giant tiger prawn											
(Penaeus monodon)											
Asia	96856	155323	168549	222579	250510	322655	391676	434602	475458	499318	18
World	96884	155356	168758	223056	251127	333529	392712	436637	482556	502701	18
Marine											
Snappers											
(Lutjanes spp.)											
Asia	41	35	49	69	61	207	767	702	900	900	44
World	41	35	49	69	61	290	860	794	953	942	45
Grouper											
(Epinephelus spp.)											
Asia	1261	1696	1555	982	2774	1737	2323	4844	3052	2806	12
World	1261	1696	1555	982	2774	1737	2323	4845	3053	2806	12
Seaweed											
(Gracilaria spp.)											
Asia	11181	7386	8517	11182	12814	12518	16284	13176	12365	16508	6
World	16523	16574	31630	47336	56776	73025	70370	67105	83343	71533	18

the need to first learn the basic aquaculture biology of culture species, studies into genetics and reproduction, nutrition and culture systems predominate (Table 10). Studies on economics, socioeconomics, policy and research became more important in the 1990s, which registered a 135% increase in the number of publications from the 1980s level (Fig. 12). In general, the range of publications shows that researchers are in touch with the needs of the industry. What will the future research landscape look like?

Aquaculture is the prime method for increasing the supply of many fish commodities when supplies from the wild are already fully utilized. For example, SEAFDEC AQD's research on giant tiger prawns was instrumental in

Table 9. Number of SEAFDEC AQD and ICLARM publications by selected species, 1976-1996. (SEAFDEC AQD and ICLARM Annual Reports; ASFA 1978-3/98)[a]

Species	1976-1980	1981-1985	1986-1990	1991-1996	Total
Prawn	39	15	43	66	163
Milkfish	17	45	53	38	153
Tilapia	2	34	37	79	152
Bivalves[b]	2	8	15	34	59
Seabass	0	1	13	25	39
Carps	2	3	19	11	35
Seaweeds	2	1	2	30	35
Rabbitfish	0	3	13	12	28
Groupers, snappers	0	0	1	22	23
Catfish	0	1	0	10	11
Others					
Minor species[c]	4	5	15	32	56
Non-species specific	8	9	24	32	73
General aquaculture	13	20	53	169	255
TOTAL	89	145	288	560	1082

[a]Species counts based on publication title.
[b]Include giant clams, molluscs, oysters and cockles.
[c]Include abalone, ayu, chum salmon, crab, crayfish, eel, freshwater clam, flounder, goldfish, minnows, mullet, pipefishes, perch, snakehead and trout.

improving farming methods and thereby greatly increasing supplies of prawns over the last 20 years. As prawn farm production was severely reduced by unforeseen disease and environmental problems, SEAFDEC AQD is also in the forefront of research to control and manage production problems as well as identify alternatives.

Much greater research and related investments will have to be made if our industry is to prosper. More investments in research will have to come from the private sector. Larger scale operators will do some of their own research if they can fully capture the benefits.

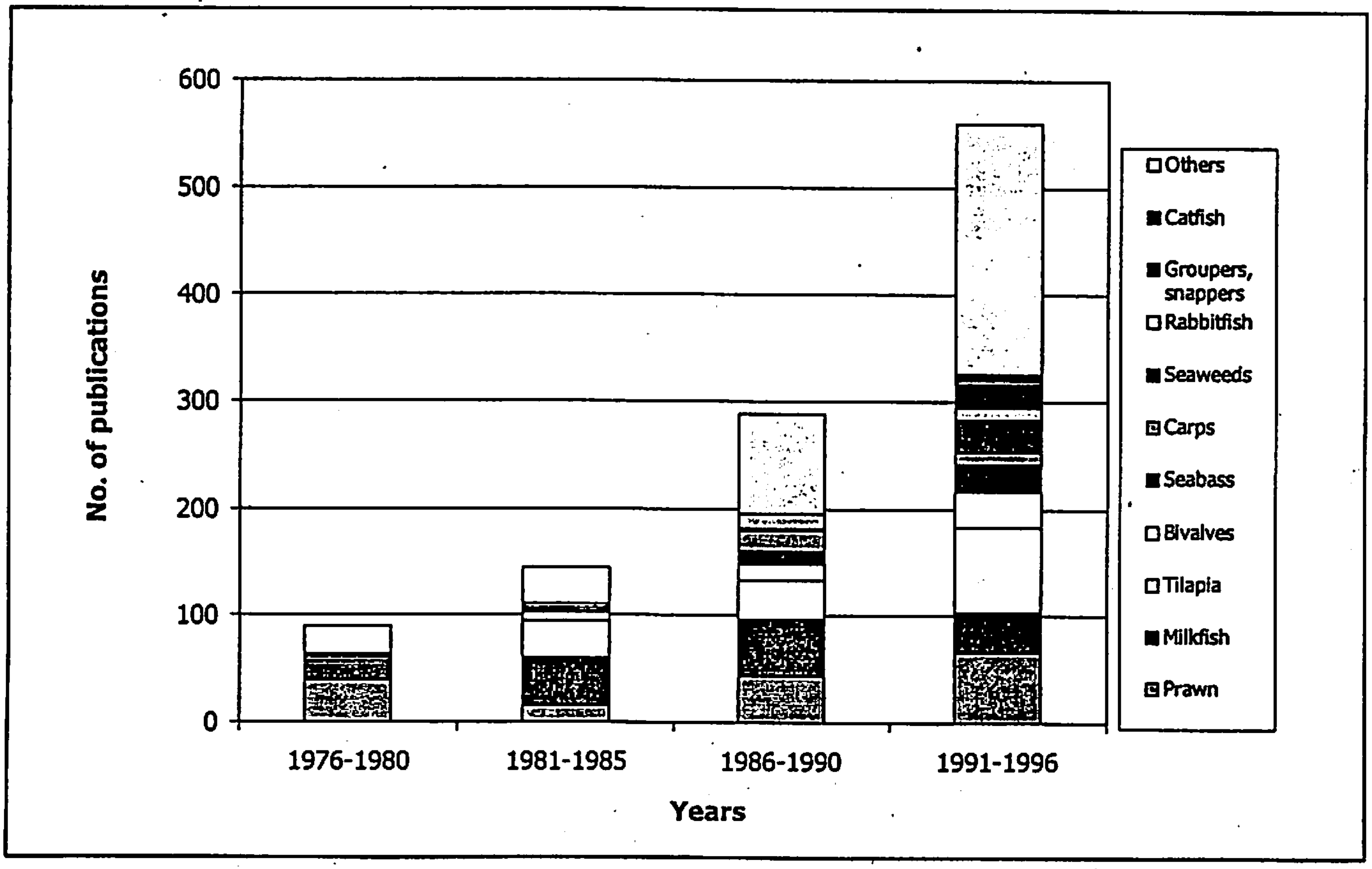


Figure 11. Number of SEAFDEC AQD and ICLARM publications of selected species (1976-1996).

Table 10. Number of SEAFDEC AQD and ICLARM publications on aquaculture by research areas, 1976-1996. (SEAFDEC AQD and ICLARM Annual Reports; ASFA 1978-3/98)

Research areas	1976-1980	1981-1985	1986-1990	1991-1996	Total
Genetics and reproduction	24	26	45	80	175
Physiology	1	5	24	44	74
Nutrition	19	17	58	82	176
Pathology	3	3	19	30	55
Biology and ecology	13	7	45	60	125
Culture system, management and production	23	39	66	117	245
Economics, socioeconomics, policy and research	6	45	41	124	216
TOTAL	89	142	298	537	1066[a]

[a]This total is less than the total in Table 9 because the publication title may indicate more than one species.

Biotechnology, such as disease and feed diagnostic methods, and all forms of genetic technologies including transgenics, will play a bigger role in aquaculture in the future. Here, the research and development being carried out in the private sector dwarfs that carried out by public sector agencies. In future, alliances will be forged between public and private sector agencies using biotechnology. Research agencies will have to adapt to new research funding strategies and develop policies for determining the ownership of intellectual property created. The ownership of fish genetic resources will also become an issue between countries.

Research funded by governments and the international development assistance community will concentrate more on creating public goods, including research on ecological sustainability and socioeconomic and policy goals.

Research centers such as AQD will continue and strengthen their research, technology verification and training programs which are integrated with industry, community and government needs. Collaboration and partnership with other researchers in the region and outside, including developed countries, will strengthen further. Sources of financial support will be broadened to include the private sector. We urge countries to consider how industries could be levied to help support this work, for example, by a tax on export product.

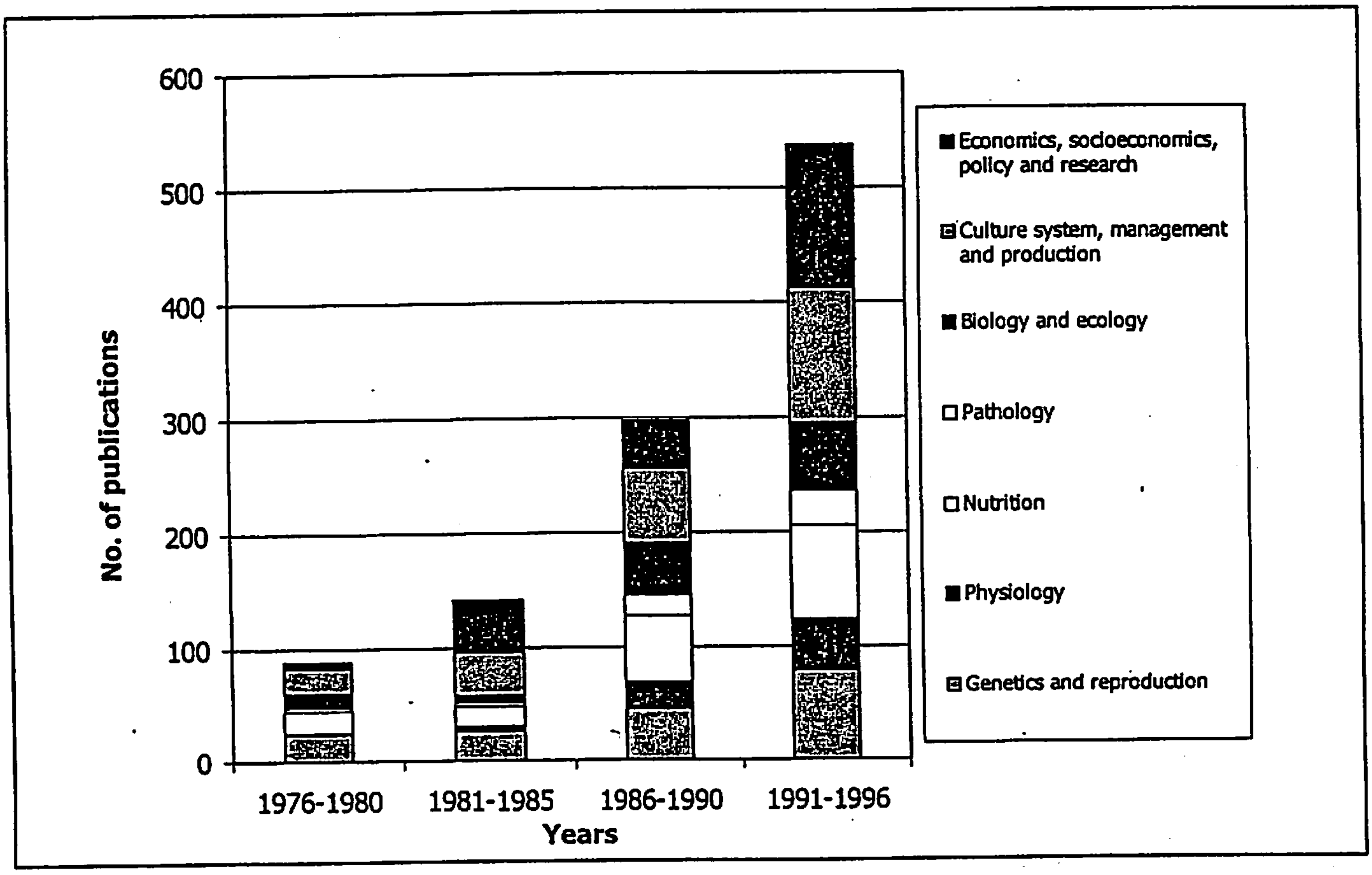


Figure 12. Number of SEAFDEC AQD and ICLARM publications on aquaculture by research areas. (1976-1996).

In private industry many studies have shown that the trick to success is not just doing relevant research and spotting successful innovations but having the knowledge and skill to use them fast and well (Reier 1998). Of course, agencies like SEAFDEC and ICLARM are not the ultimate users of their own research. Therefore, we must work closely with those who will use the research to try to ensure that what we are doing has a high chance for successful application and is available to the end user. To do this means inculcating extra skills into our staff - skills which make them look at the practical and applied aspects of their research. Only then will researchers be truly pushing forward the last frontier in sustainable food security.

Conclusions

We have covered a wide range of issues and it is now time to draw some conclusions.

We started by recognizing that fish is a political commodity, potentially of interest to all people. After fishing down many of our capture fisheries stocks, we seek other sources of fish while these stocks are rehabilitated and as the world population grows. The developments in aquaculture lead us to suggest that it holds great promise as the last frontier or the best bet for meeting the needs of many different stakeholders, such as:

- Consumers can expect more and affordable fish but there is still a question mark over whether aquaculture will lower the price of fish sufficiently to bring it within the reach of the very poor.
- Producers will tend towards agribusiness arrangements, but small and medium scale enterprises will continue to develop and co-exist with the large, vertically integrated sector. New jobs will be created in production but special interventions are needed to involve the very small scale producers. There will be pressure for increased efficiency as well as increased production. The auxiliary industries sector will prosper.
- Environmental sustainability will be a key determinant of business prosperity and risk.
- Governance of the sector will have to develop its own models, incorporating the need for social justice and the environment. Governments will have to improve their performance and knowledge base for regulating the industry.
- Government will be an important actor in helping the industry weather economic crises, such as those caused by the recent currency problems.
- Research and related activities are the key to how aquaculture will contribute to future development. But we must remember, research is a long term investment wherein the returns are available long into the future.

Last but not least, SEAFDEC is well placed to continue and enhance its contributions and partnerships at this last frontier for sustainable food security. We wish AQD a happy 25th Anniversary and a long and successful future in its vital mission.

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Dr. Meryl J. Williams assumed the post of Director General of the International Center for Living Aquatic Resources Management (ICLARM), an international research organization headquartered in Manila, in April 1994. She was previously Director of the Australian Institute of Marine Science and Executive Director of the former Bureau of Rural Resources in the Department of Primary Industries and Energy, Canberra. Dr. Williams also worked as a fisheries scientist with the Queensland Government and with the South Pacific Commission in New Caledonia. In Australia, she was a member of several fisheries management advisory committees and scientific review committees. In November 1997, she became a member of the FAO Advisory Committee on Fisheries Research and in 1998, she was appointed Chief of the FAO Director-General's High Level Panel of External Experts in Fisheries.

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