GOVERNMENT OF JAPAN

INTERNATIONAL CONFERENCE ON SUSTAINABLE CONTRIBUTION OF FISHERIES TO FOOD SECURITY

Kyoto, Japan, 4-9 December 1995

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FOOD AND AGRICULTURE ORGANIZATION
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AQUACULTURE DEVELOPMENT TRENDS:
Perspectives for Food Security

by

J.F. Muir

(Edited C.G. Nugent)

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AQUACULTURE PRODUCTION TRENDS
PERSPECTIVES FOR FOOD SECURITY

EXECUTIVE SUMMARY

Over the past ten years aquaculture has grown at a rate of nearly 10% per year, reaching a total of 19.9 million tonnes with a total value of US$ 33.8 thousand million in 1992. This represents a very significant increase in the importance of aquaculture in food supply by comparison with traditional capture fisheries sources; if one considers only aquatic animal products (fish, crustacea, molluscs) directly used for food, aquaculture doubled its proportion in overall supply since 1984 to some 20% of all food fish supply in 1992.

It is to be expected that the aquaculture sector will continue to grow, although the rate of growth can be expected to slow down eventually as resources and markets become progressively saturated and opportunities for expansion are restricted. Growth in production will come from improving yields and efficiency, as well as from an increase in production infrastructure; the trend towards increasing intensification will continue in many parts of the sector. Against a background of stabilising or even falling catches from the traditional capture fisheries, increasing population and an ever-increasing global demand for food, there is now a major challenge in re-examining the nature and potential of the sector, and to ask just how far aquaculture might go to satisfy the expected increase in demand for its products.

A brief and unavoidably speculative projection has been suggested based on an analysis of present trends and anticipated developments. This suggests that overall aquaculture production of all kinds could reach a total of 47 million tonnes by 2010, of which 33 million tonnes would be of fish, crustacea and molluscs produced for food. Such a prediction is clearly optimistic, while remaining well within the bounds of possibility that are suggested by past experience; resources and markets could accommodate such increases although it is not possible to foresee which constraints might come from outside the sector.

It is important to note that, in historical statistics as well as in making projections for the future, a significant proportion of production is accounted for by fish produced in semi-intensive systems for carp culture in China and to a lesser extent India. China alone accounts for about half of all aquaculture production; consequently, any analysis of aquaculture statistics is inextricably linked to events in this one country, albeit a very large one. The majority of these traditional aquaculture activities are carried out on a small scale and are family operated, while the product provides a significant contribution to local food consumption as well enhancing family financial security.

Aquaculture is a notably diverse activity, and an appreciation of this diversity is fundamental to the understanding of the issues influencing its future development. This applies to an assessment of requirements for resources of all kinds, to the way aquaculture may develop independently from the fisheries sector, to the prospects for producers from all economic levels or locations, or to opportunities for developing new markets. The diversity of the sector is an assurance of a range of benefits involving food, income, employment and social opportunity.

Among these issues, food security is important. Aquaculture can be a significant contributor to local food security providing food directly to the producer or to the immediate community, especially in many areas of Asia. This contribution can also be indirect - as an economic activity which is regular and reliable, especially in comparison with traditional capture fisheries, and as an option for diversification into new opportunities. In those locations where food security is a significant issue, the key producers often operate at a small scale, directly involving families or communities. In terms of policy direction and options for specific development aims, this offers possibilities for involving disadvantaged groups, in targeting activities for the benefit of women, or in helping landless groups where there are under-utilised water bodies.

There has been a trend of increasing influence of the private commercial sector at the expense of traditional public sector involvement. This has brought benefits to the sector in terms of efficiency, competitivity and dynamic expansion, and the private (market oriented) sector will remain the appropriate institutional context for many aspects of aquaculture development. However, there is still a key role for suitable institutions to play in ensuring that the desired benefits are obtained, and they can provide general policy and planning guidance, resource allocation, research support, human resource development and provide a positive legal framework designed to protect producers and consumers, and to safeguard the opportunities for the small operator to enter the sector.

One of the key aspects of institutional involvement concerns the integration of the aquaculture sector into overall management of natural resources, both from the point of view of the sector needing resources in competition with other economic or social uses, as well as protecting the quality of aquatic resources suitable for aquaculture production. Aquaculture must ensure its adequate involvement in resources management through the emerging disciplines of coastal zone and watershed management, which together cover most aquatic resources of importance to aquaculture production. Issues of sustainability and of preservation of adequate biodiversity are particularly important to the long term development of aquaculture.

Attention to human resource development will be important for aquaculture development as the sector continues to experience the considerable changes and growth that are expected. Research support in essential fields of science and technology will be crucial, because although many specific problems can be tackled by commercial producers themselves, small scale producers in the semi intensive sector, who assure the major part of aquaculture production, will continue to need such support.

TENDANCES DE LA PRODUCTION AQUACOLE PERSPECTIVES EN MATIERE DE SECURITE ALIMENTAIRE

RESUME

Au cours des dix dernières années, la production aquacole a progressé de près de 10% par an, pour atteindre en 1992 un volume total de 19,9 millions de tonnes, évalué à 33,8 milliards de dollars E.U.. L'importance de la contribution de l'aquaculture à l'alimentation s'est ainsi sensiblement accrue par rapport à celle des pêches de capture traditionnelle; si l'on ne prend en compte que les produits animaux aquatiques (poissons, crustacés, mollusques) qui sont directement utilisés pour l'alimentation humaine, la part de l'aquaculture a doublé depuis 1984, pour atteindre quelque 20% de l'approvisionnement total en poissons en 1992.

La progression du secteur de l'aquaculture devrait se poursuivre, même s'il est probable que le taux de croissance finira par diminuer car les ressources et les marchés seront peu à peu saturés et les possibilités d'expansion sont limitées. La croissance de la production viendra d'une amélioration des rendements et de l'efficacité, ainsi que d'une augmentation des infrastructures de production; la tendance à accroître l'intensification se poursuivra dans de nombreuses branches du secteur. Compte tenu du contexte actuel - stabilisation, voire même déclin des captures des pêches traditionnelles, croissance démographique et augmentation continue de la demande mondiale de vivres - il est fondamental de réexaminer la nature et le potentiel du secteur et de se demander jusqu'à quel point l'aquaculture pourrait répondre à l'augmentation de la demande de produits aquacoles.

Une brève projection, inévitablement spéculative, est proposée, d'après une analyse des tendances présentes et des perspectives de développement. La production aquacole totale, tous produits confondus, pourrait atteindre 47 millions de tonnes d'ici l'an 2010, dont 33 millions de tonnes de poissons, crustacés et mollusques destinés à l'alimentation humaine. Cette prévision est de toute évidence optimiste, mais elle reste dans les limites du possible si l'on se réfère aux résultats passés; les ressources et les marchés devraient permettre d'absorber cette augmentation, quoiqu'il soit impossible de prévoir les principales contraintes au développement extérieures au secteur.

Dans les statistiques historiques comme dans les projections, le poisson produit dans des établissements semi-intensifs de carpiculture en Chine, et dans une moindre mesure en Inde, représente une part importante de la production. A elle seule, la Chine assure environ la moitié de la production aquacole totale; une analyse des statistiques de l'aquaculture est par conséquent inextricablement liée à ce qui se passe dans ce pays, par ailleurs immense.

La majorité de ces installations aquacoles traditionnelles sont des petites exploitations familiales, et leurs produits contribuent de façon importante à la consommation locale et au renforcement de la sécurité financière des familles.

L'aquaculture est une activité particulièrement diversifiée et il est fondamental de bien s'en rendre compte pour comprendre les problèmes relatifs à son développement, notamment pour évaluer les besoins concernant les ressources de toute nature, pour comprendre comment l'aquaculture peut se développer indépendamment du secteur des pêches, pour déterminer les perspectives pour les producteurs, quelque soit leur niveau économique ou la localisation de leur exploitation, ou pour analyser de nouveaux marchés potentiels. La diversité du secteur est une garantie pour toute une gamme de profits, notamment en termes de vivres, des revenus, d'emplois et d'opportunités sociales.

La sécurité alimentaire est une question importante. L'aquaculture peut renforcer sensiblement la sécurité alimentaire des populations locales, en fournissant directement des vivres au producteur ou à la communauté dont il fait partie, surtout dans de nombreuses régions d'Asie. Elle peut aussi la renforcer indirectement - s'agissant d'une activité économique régulière et fiable, surtout si on la compare avec les pêches de capture traditionnelles, et qui offre aux producteurs la possibilité de diversifier leurs activités. Là où la sécurité alimentaire est une question importante, les principaux producteurs gèrent souvent de petites exploitations, impliquant leurs familles ou leurs communautés. En termes d'orientation et d'options politiques à adopter pour atteindre les objectifs de développement spécifiques, il est possible de faire participer des groupes défavorisés, en choisissant des activités dont les bénéficiaires seront les femmes, ou en aidant des groupes de paysans sans terres là où il y a des plans d'eau sous-exploités.

L'influence du secteur commercial privé tend à s'accroître, au détriment de celle du secteur public traditionnel. Ceci a été bénéfique pour le secteur, en termes d'efficacité, de compétitivité et d'expansion dynamique, et le secteur privé (orienté vers l'économie de marché) restera le contexte institutionnel approprié pour de nombreux aspects du développement de l'aquaculture. Cependant les institutions adaptées ont encore un rôle fondamental à jouer, en veillant à ce que les avantages recherchés soient obtenus, mais aussi en donnant des orientations de politique générale et de planification, procédant à l'allocation des ressources, appuyant la recherche, mettant en valeur les ressources humaines et en fournissant un cadre juridique positif pour protéger les producteurs et les consommateurs et préserver l'accès au secteur des petits exploitants.

L'un des aspects essentiels du rôle des institutions consiste à intégrer le secteur de l'aquaculture dans la gestion globale des ressources naturelles, à la fois en termes d'accés aux ressources nécessaires lorsqu'elles sont en concurrence avec d'autres utilisations économiques ou sociales, et pour protéger la qualité des ressources aquatiques requises pour l'aquaculture. L'aquaculture doit participer comme il convient à la gestion des ressources dans le cadre des disciplines nouvelles telle que l'aménagement des zones côtières et des bassins versants, qui couvre la plus grande partie des ressources aquatiques intéressant la production aquacole. Les questions de la durabilité et de la conservation de la biodiversité sont fondamentales pour le développement à long terme de l'aquaculture. Le développement des ressources humaines sera important pour l'aquaculture compte tenu des changements considérables et de la croissance que devrait connaître le secteur. L'appui de la recherche dans les domaines essentiels de la science et de la technologie est crucial, bien que les producteurs commerciaux soient en mesure de résoudre eux-mêmes un grand nombre de problèmes spécifiques, les petits producteurs du secteur semi-intensif, qui assurent l'essentiel de la production aquacole, continueront à avoir besoin d'un tel appui.

TENDENCIAS DE LA PRODUCCION ACUICOLA PERSPECTIVAS PARA LA SEGURIDAD ALIMENTARIA

RESUMEN

A lo largo de los diez últimos años, la acuicultura ha crecido a un ritmo cercano al 10 por cien al año, gracias a lo cual en 1992 se alcanzó la cifra total de 19,9 millones de toneladas, por un valor global de 33 800 millones de dólares EE.UU. Estas cifras suponen un notable aumento de la importancia de la acuicultura en el suministro de alimentos con respecto a la pesca de captura tradicional; teniendo en cuenta únicamente los productos pesqueros animales (peces, crustáceos, moluscos) destinados directamente al consumo humano, en 1992 la acuicultura duplicó la proporción de su contribución en porcentaje a los suministros de pescado para consumo humano.

Cabe esperar que el sector de la acuicultura seguirá creciendo, si bien a un ritmo que disminuirá con el tiempo, a medida que los recursos y los mercados se saturen y reduzcan las posibilidades de expansión. El crecimiento de la producción se conseguirá mejorando los rendimientos y la eficiencia, así como ampliando la infraestructura de la producción; en muchos ámbitos de este sector seguirá la tendencia a intensificar la producción. En una situación caracterizada por la estabilización o incluso el descenso de la pesca de captura, el crecimiento de la población y una demanda mundial de alimentos siempre creciente, el principal desafío que se presenta en la actualidad es el de examinar de nuevo la naturaleza y las posibilidades del sector y averiguar hasta qué punto puede la acuicultura satisfacer el incremento previsto de la demanda de sus productos.

Tomando como base el análisis de las tendencias actuales y la evolución prevista, se han preparado unas proyecciones escuetas que inevitablemente tienen mucho de conjetura. En ellas se indica que la producción acuícola total podría llegar a ser de 47 millones de toneladas en el año 2010, de las cuales 33 millones corresponderían a peces, crustáceos y moluscos producidos para el consumo humano. No cabe duda de que esta previsión es muy optimista, si bien no se sale de los límites de lo posible marcados por experiencias anteriores; los recursos y los mercados podrían asimilar este crecimiento aunque no es posible prever los factores ajenos al sector que podrían suponer serias limitaciones.

Es importante señalar que tanto en las estadísticas históricas como en las proyecciones para el futuro, una proporción considerable de la producción corresponde a las explotaciones semiintensivas de carpas en China y en menor grado en la India. Tan sólo a China le corresponde alrededor de la mitad de la producción acuícola total; por consiguiente, todos los análisis de las estadísticas de la acuicultura dependen directamente de la evolución de este sector en un sólo país, bien que muy grande. La mayor parte de estas actividades acuícolas tradicionales se llevan a cabo en pequeña escala en explotaciones familiares, y sus productos contribuyen de manera considerable al consumo local de alimentos, así como a mejorar la seguridad económica de las familias.

La acuicultura es una actividad enormemente variada, por lo que es necesario tener en cuenta esa diversidad, para comprender los factores que influyen en su desarrollo futuro. Esta diversidad debe tomarse en consideración para evaluar las necesidades de los recursos de todo tipo, para determinar la forma en que la acuicultura puede desarrollarse independientemente del sector pesquero, y para establecer las perspectivas para los productores de todos los niveles económicos o lugares y las posibilidades de explotar nuevos mercados. La diversidad del sector es la garantía de los beneficios que de él se derivan: alimentos, ingresos, empleo y oportunidades sociales.

Entre estos factores, cabe destacar la seguridad alimentaria. La acuicultura puede contribuir considerablemente a la seguridad alimentaria local proporcionando alimentos directamente al productor o a la comunidad inmediata, especialmente en muchas zonas de Asia. Esta contribución puede ser también indirecta; como actividad económica uniforme y fiable, especialmente en comparación con la pesca de captura tradicional, y como posibilidad de diversificación ofreciendo nuevas oportunidades. En aquellos lugares en que la seguridad alimentaria es un problema importante, los productores principales a menudo desarrollan su actividad en pequeña escala, en explotaciones familiares o comunitarias. Por lo que respecta a la orientación en materia de políticas y las opciones de objetivos de desarrollo concretos, la acuicultura ofrece la posibilidad de involucrar a los grupos desfavorecidos, con actividades orientadas a las mujeres o ayudando a los grupos desprovistos de tierras donde existan cuerpos de agua poco utilizados.

Se ha registrado una tendencia creciente de la influencia del sector comercial privado en detrimento del sector público tradicional. Ello ha comportado ventajas para el sector por lo que respecta a su eficiencia, competitividad y crecimiento dinámico, por lo que el sector privado (orientado al mercado) seguirá siendo el marco institucional adecuado para muchos aspectos del desarrollo de la acuicultura. No obstante, las instituciones del sector público seguirán desempeñando una importante función para asegurar que se obtengan los beneficios deseados y podrán facilitar orientaciones en materia de políticas generales y planificación, intervenir en la asignación de los recursos, prestar apoyo a la investigación, contribuir al mejoramiento de los recursos humanos y ofrecer un marco jurídico positivo para proteger a los productores y los consumidores y defender las oportunidades de los pequeños productores de entrar en el sector.

Uno de los aspectos fundamentales de la participación institucional es el que hace referencia a la integración del sector de la acuicultura en la ordenación general de los recursos naturales, tanto desde el punto de vista de la competencia por aprovechar los recursos entre este sector y otros usos económicos y sociales como desde el de la protección de la calidad de los recursos acuáticos idóneos para la producción acuícola.

La acuicultura debe asegurar su participación en la ordenación de los recursos por medio de las nuevas disciplinas relativas a la ordenación de la zona costera y de las cuencas hidrográficas, que entre las dos cubren la mayoría de los recursos acuáticos y tienen importancia para la producción acuícola. Los problemas de la sostenibilidad y de la conservación de la diversidad biológica tienen especial importancia para el desarrollo de la acuicultura a largo plazo.

Asimismo, para la acuicultura será importante prestar la debida atención al desarrollo de los recursos humanos a medida que el sector siga experimentando los importantes cambios y el crecimiento que están previstos. El apoyo a la investigación en ámbitos fundamentales de la ciencia y la tecnología será de vital importancia, dado que si bien los productores comerciales pueden resolver muchos problemas concretos, los productores en pequeña escala del sector semiintensivo, a quienes corresponde la mayor parte de la producción, seguirán necesitando dicho apoyo.

TABLE OF CONTENTS

1. DEFINING THE AQUACULTURE SECTOR

1.1 Fundamental issues and definitions

Aquaculture, the farming of aquatic species, is a steadily increasing contributor to global food supply, providing a growing and diverse range of high quality products in almost every country in the world. In 1992, a total production of 19.9 m t was recorded, with an estimated value of some $33.8 billion.

Aquaculture can play an important part in the socio-economic resilience of rural areas, potentially offering valuable and skill-based employment opportunities, and in some cases stabilising the economic base of otherwise fragile communities. It has a useful role in many development initiatives, in rural areas, often around coastal margins, and frequently in regions or locations where social, economic and environmental issues are critical.

It is inextricably linked with the issue of natural resource based economic development, is both a user and consumer of natural resources, and in many cases, can be a sensitive indicator of the quality of natural environments. As an economic activity it is important in both the more economically prosperous regions, and in LDCs, where it occupies the dual role of food supply, and of an increasingly important component in international trade and export earning.

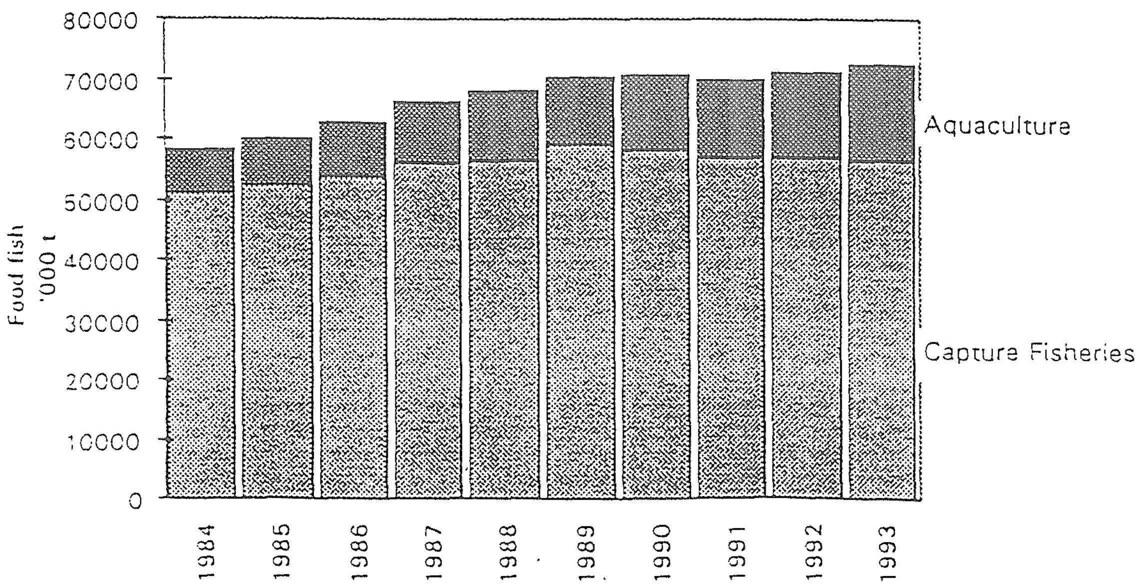


Figure 1.1 Aquaculture/fishery production trends
Source: FAO 1995

Within the fishery sector as whole, production from aquaculture has increased significantly over recent decades (Figure 1.1), and can reasonably be expected to develop and expand further. A number of factors underlie this trend, chief of which are the continuing and developing market demand for aquaculture products, and the increasing scientific, technological and entrepreneurial skill in managing species lifecycles and production environments, and in meeting market and commercial objectives. Institutional and development support has also played an important role, and in particular has brought access to key skills and resources, as well as investment capital support. Aquaculture has developed throughout almost all regions of the world, and is becoming a steadily more important contributor to output in LDCs. Most significantly aquaculture is increasingly being seen as the only means by which declining *per capita* availability of fishery products can be compensated. Indeed recent reviews have suggested as much as a two-fold increase in production being required to meet the growing shortfall in fishery supply.

Before examining the role and potential of aquaculture in further detail, however, it is necessary to consider fundamental definitions; various approaches have been proposed, and a definition has been formalised in FAO for statistical purposes. In summary, this states that aquaculture is:

> "....... the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as common property resources, with or without appropriate licences, are the harvest of fisheries...... "

An additional and emerging area of practice (and definition) is that of culture enhanced fisheries, which involves the use of aquaculture in at least part of the life-cycle of a conventionally fished resource, usually the initial hatchery phase. 'Hatchery based', 'aquaculture assisted' and 'ranching' are other terms used for this type of system, the latter particularly in the marine environment following early work on migrating salmonids.

Though areas of clarification may remain, the basic FAO description will be used to guide this work. As most of the background data for trend analysis is based around this description, it is also appropriate to retain it as the primary basis for discussion. Some important features can be noted at the outset. Firstly, aquaculture concerns aquatic products, and so is closely related to and associated with the fisheries sector, the capture fisheries subsector, and with aquatic resources in the wider sense. However, though commonly grouped within the fishery sector in output terms, and usually aligned legally and institutionally, many of the characteristics and practices of aquaculture are more similar to those of agriculture. Further, the definition draws attention to the essential characteristics of stocking, feeding, managing and harvesting, which in turn imply the various resource demands discussed later in the document.

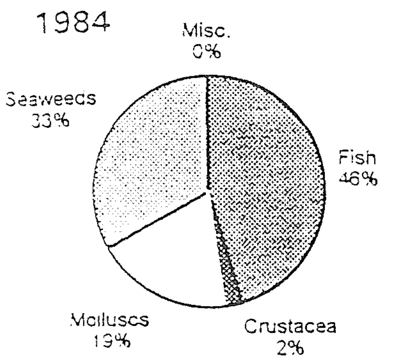
1.2 Major sub-sectoral definitions

The development and use of the FAO definition in the Fishstat/Aquastat system has allowed aquaculture production to be classified at the national and regional level, and its various features and trends to be drawn out, at least in approximate terms. A range of sub-sectoral definitions and descriptions can be employed to allow the range of aquaculture practices, resource features and outputs to be characterised more clearly.

Species definitions

Unlike fisheries, the number of species within aquaculture is relatively modest. Since 1984 the FAO has maintained comprehensive statistics on all the main aquaculture species; this data is commonly presented by major groups of fish, crustaceans, mollusc and (optionally) aquatic plants and 'other species'.

Figure 1.2 describes total production by species group in 1984 and 1992, demonstrating the change in distribution across these groups. As will be discussed later, there are wide-ranging differences in species characteristics - their simplicity and cost of culture, the types of market to which they may be disposed, whether they contribute to local food supply and economy, or are part of the increasing international commodity trade.



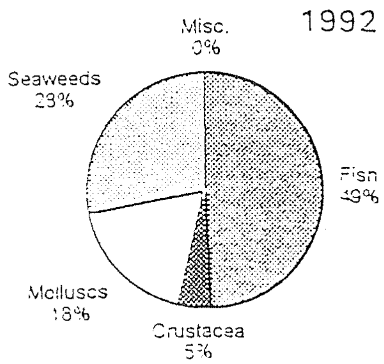


Figure 1.2 Aquaculture production by major species category, 1984, 1992
Source: FAO, 1994

Production environments

Aquaculture is intimately connected with water and its availability, and so can be defined in association with the aquatic habitat, including surrounding land areas, which it occupies or uses. Traditionally, aquaculture has been classified as fresh water, brackish water and marine, with varying definitions of the extent and characteristics of the brackish water category.

This has been reflected in FAO Fishstat data collection forms, which attempt to identify production according to geographical area and environment; FW (fresh), BW (brackish) and MA (marine).

However, the problems of defining brackish water production environments, and the practical absence to date of significant aquaculture production beyond the coastal margins, suggest that a simpler approach may be used, to group all marine/brackish production as coastal, and all freshwater production as inland. For euryhaline species such as molluscs, production can usually assumed to be coastal, unless there is specific evidence to the contrary.

Production stages

Distinctions can also be made between the different life-cycle stages over which aquaculture operates; some enterprises will control the entire life-cycle, others will specialise in particular stages and focus on specialised markets. Hatcheries, in particular may require special skills, may have more specific production requirements and can serve the demands of a considerable ongrowing output. They will therefore tend to be more specialised, and may be more geographically and organisationally distinct.

Intermediate stage and ongrowing units may deal with biomass many times those of the hatchery stocks, and would typically require more significant resource flows, though skill levels may not be so demanding.

System type

Aquaculture is an organised activity, and is carried out in a range of production systems with particular design and operational features: these normally need to locate, contain and protect the stock, provide suitable production environments, allow the required range of management inputs to be provided and applied, and permit partial or complete harvesting.

Two primary forms of aquaculture system can be defined; land-based and water-based, as described in Table 1.1. Indications of major environment (coastal/inland) are also given. Clearly, a production sector can contain elements of each of these systems; several different systems can be used to culture the one species within a single region.

Different systems may also be used for different life-cycle stages; it is thus common for hatcheries, requiring higher levels of control, to be based in land-based tank systems, with ongrowing carried out in simpler land-based or water-based systems.

Table 1.1 Basic system definition

System type	Characteristics
LAND-BASED	*Holding unit established on land, water arranged to be held or to pass through it; requires appropriate land/water site configurations*
- lagoons:	natural water body with controlled water exchange, possible modified environment and management; usually coastal
- ponds:	earth structure formed specifically to hold water; may be sunken/phreatic, elevated, or formed as a barrage; may be inland or coastal; varying degrees of management, water exchange, etc
- tanks:	structure, usually above ground, typically with high-water turnover, highly controlled environment
- raceways:	as above but with a long, linear configuration; often terraced with water reuse
WATER-BASED	*Holding system is immersed within a specific water body, and so tends to be controlled by the water body itself; sensitive to water body characteristics and environmental forces*
- open release:	release of larvae/juveniles into open waters, in some cases with additional habitat - coastal, sometimes inland
- beds:	prepared areas of natural substrate with/out additional structures - usually coastal
- raft/longline systems:	tethered floating structures from which are hung lines/baskets/trays for attachment and placing of molluscs and seaweeds (suspended culture systems); usually coastal
- enclosures (pens):	fenced, netted, structures fixed to the bottom substrate; allowing free water exchange; in some cases (intertidal) may be solid-walled; usually coastal, also inland
- cages:	tethered floating structures from which are hung net bags; inland and coastal

To date, partly due to the above reasons, the formal recording of aquaculture by production system has not been too successful, and reporting of system information under Fishstat has been variable or non-existent.

1.3 Other definitions

Productivity definitions

System intensity, typically described in terms of intensive and extensive culture, is a common descriptor of aquaculture production, and is similar in overall concept to equivalent terms in agriculture.

This approach also offers useful analogies with aquatic ecosystem description, and can be related in a general sense to the range from oligotrophic to eutrophic aquatic systems, corresponding to low and high nutrient levels and productivity, though in nutrient density terms it extends well beyond eutrophic levels in more artificially controlled systems.

In a broad continuum, extensive systems are those which are closest to natural fisheries, requiring minimal inputs and offering relatively low yields, whilst intensive systems require a large amount of inputs to maintain an artificial culture environment, with high yields. Between these extremes are the varying degrees of semi-intensive aquaculture, where definitions are less distinct. One of the simplest such definitions is that used by FAO, in that:

- extensive aquaculture does not involve feeding of the culture organism;

- semi-intensive aquaculture involves partial feeding through fertilisation and/or feeds, and;

- intensive aquaculture is where the culture species is maintained entirely by artificial feeding.

As with system types described earlier, a given species might be produced in a range of intensities. These general descriptions might also be extended to that of aquaculture-assisted fisheries, which typically might involve an intensive aquaculture early life-cycle stage, and the equivalent of an 'extensive' later production stage.

An alternative approach is to classify intensity on the basis of yield. The basic FAO descriptions of three categories translate approximately (on the basis of yield under the regimes defined) as extensive aquaculture yielding from 50 to 1000 kg/ha/yr, semi-intensive systems 500kg to 20 t/ha/yr , whilst intensive systems can produce 10 to 1000 t/ha/yr.

Because of the wide span of yields, additional categories could be defined (see table 1.2), with those producing 500 - 5000 kg/ha/yr, based primarily on fertilisation, termed semi-extensive, and those above around 200 t/ha/yr, typical of high feed/flow/stocking rate systems, described as hyper-intensive. Though this may be helpful in improving discrimination, these terms are not as yet in widespread or formally accepted usage.

Regardless of the classification systems used, there will invariably be some overlap between categories. The general differences between extensive and intensive aquaculture are described further in Table 1.2 and 1.3, which again is a summary of common features rather than a strict definition.

Table 1.2 Characterisation of system intensity and yields. (5 categories).

Intensity	Feeding practices	Management	Water usage	Other
Extensive 0.05-0.5 t/ha/yr	No feeding	Stocking with wild-caught fry, fertilisers may be used	Rain-fed or tidal; little or no management	Typically artisanal ponds, lagoons; also bed culture of molluscs/seaweed
Semi- extensive 0.5-5.0 t/ha/yr	Possibly supplementary feeding with low-grade feeds	Stocking with wild-caught or hatchery reared fry. Regular use of organic or inorganic fertilisers	Rain-fed, tidal and/or some water exchange Simple monitoring of water quality	Normally traditional or improved ponds; some cage systems - e.g. with zooplankton feeding for fry.
Semi- intensive 2-20 t/ha/yr	Regular use of formulated supplementary feeds	Stocking with hatchery reared fry. Regular use of fertilisers.	Some water ex-change or aeration; often pumped or gravity supplied	Normally improved ponds, some enclosures, simple cage systems
Intensive 20-200 t/ha/yr	Complete artificial diet, fully formulated to meet all diet requirements of the species	Stocking with hatchery reared fry, no fertilisers used. Full predator and anti-theft precautions taken.	Usually pump or gravity supplied, or cage based Full use of water exchange and aeration	Normally aerated ponds or simple cage systems
Hyper-intensive >200 t/ha/yr	As above	As above; highly coordinated and controlled production regimes	As above, with increasing levels of control over supply and quality.	Usually flowing water ponds, cage systems, or tanks and raceways.

These generalisations also extend to the assumption that extensive systems are most commonly found in developing countries, and are used for staple food fish, whereas intensive systems are mainly found in developed countries to culture luxury species.

However, this may be to take a simplistic view of the relationships between culture systems, and the biological, environmental, economic, social and market factors which influence overall system design. Thus in Latin America and many parts of Asia, much of the shrimp culture is carried out using "extensive" methods, but is processed for luxury export markets.

Fish species which are regarded as "common food" in one country, may be a prized luxury species in another. Examples of intensive and extensive aquaculture practices can be found in most countries whether "developed" or "developing".

Table 1.3 Generalised differences between extensive and intensive aquaculture

Extensive	Features	Intensive
Low	INPUTS CAPITAL COST OPERATING COST MANAGEMENT PRODUCT VALUE CONTROL	High
High	STABILITY LAND AREA SCOPE FOR MANAGEMENT	Low

Size and structure

A further discriminant of aquaculture production lies in the size and organisational structure of the activity. The size of system is clearly related to the quantity of physical or environmental resource available at a given location, but where these are not directly limiting, is more often associated with the economic and management resources implicit in the structure and organisation, and/or with regulatory regimes. Outlines of scale characteristics are provided in Table 1.4, which describes output at the level of individual units (i.e. ponds, tanks, etc) and total enterprises, and comments on typical aquaculture operations at each scale.

Table 1.4 Scale of output

Scale level	Typical annual output		Notes, etc
	Unit	Total	
Micro	5-500kg	50-500kg	Single small production unit; e.g. cage, pond; also backyard hatcheries; usually individual or family run; low input levels, limited or no external assistance. Own food supply often a motive.
Small	50kg - 1t	500kg-10t	One or more small production units, as above; family or communally run; hatchery output scaled up but simply run; low to moderate input levels, limited external labour. Own food supply may be a motive.
Medium	500kg - 5t	10t - 100t	More organised, usually several production units; family or commercially run, with moderate to high input and management levels. Hatchery may be more specialised. Often some external labour. Own food supply may be a motive
Large	1t - 50t	100t-500t	Fully commercial, multiple units, high level of management input, financial planning; at least partially mechanised, one or more sites; staff employed; hatchery equivalent would be major centre.
Macro	t - 100t	> 500t	Fully commercial, highly organised, high degree of mechanisation, bulk handling, quality control, production planning; agro-industry management approaches; often more than one site;

Clearly, scale and organisational features will vary with the species and production environment, as well as the stage of development and the financial/economic conditions of the aquaculture sector concerned. In general terms, relationships can be described between system, scale, and organisational features, though these may not be definitive. It is more common, however, for larger scale organisations, typically commercially oriented, to show varying degrees of integration, be associated with more intensive, managed systems, and operate using larger scale production facilities. Similarly, individual or family enterprises may be less intensive, and on a smaller scale. While these broad descriptions can often be observed, it can be misleading to generalise, and it may be more important to determine the specific and often localised mechanisms underlying the characteristics of any aquaculture subsector.

Other definitions

A number of other definitions or descriptions have been applied to the various forms of aquaculture which have arisen or been developed. Some of the more common descriptors are provided in Table 1.5. These are not presented in a fully systematic way (i.e. that together they provide a comprehensive overall schema for aquaculture) but rather are given simple descriptions and where appropriate, comparative or synonymous terms.

Table 1.5 Other common definitions

Classification	Definition/description
Socio-economic/development	
Subsistence aquaculture	Operated at small scale, for family or village food supply , typically low input, extensive to semi-intensive.
Rural aquaculture	Carried out in rural areas; more specifically, associated with simple family or co-operative activities, low input, etc., with varied food/profit outputs. Term sometimes used interchangeably with subsistence.
Commercial aquaculture	Carried out for profit, typically more managed, with greater inputs, more intensive, with higher-value products.
Resource usage	
Integrated aquaculture	Sharing resources - water, feeds, management, etc with other activities; commonly agricultural, agro-industrial, infrastructural (waste waters, power stations, etc).
Strategic integration	Where aquaculture is integrated at a broad level, usually as part of a larger management unit; normally commercial.
Specific integration	Aquaculture integrated at the household and small farm level; typically small-scale, food or profit outputs.
Designed integration	Specifically incorporated at the planning/design stage of larger scale system.
Various systems	
Backyard aquaculture	Micro to small scale, for hobby, own food production or commercial output; using own/domestic resources;literally the back yard - with domestic power and water, etc.
Wastewater aquaculture	Using urban or industrial waste waters to provide enhanced nutrient removal/ stabilisation, and a marketable crop.
Hydroponic aquaculture	Linking aquaculture and hydroponic crop production; aquaculture provides nutrients.

1.4 The sectoral context

These definitions describe aquaculture in terms of its basic characteristics, and give some perspective on its differential features. These characteristics will be used as the basis for discussion and analysis in the following parts of the review, in which it is intended to show the range of relationships between production choice, resource implications, and potential for development, whether internally or externally generated. In particular, focus is given to analyzing the primary forces - both positive and negative, which might shape development, i.e.:

- demand; the nature and structure; its relationships with economic opportunity
- production; the structure, capacity for growth, change, demand for resources
- development conditions - political, economic, social, environmental, legal

Assessment will be made of overall trends, in terms of whether they are primarily production or technology led, or driven by factors associated with market demand.

The analysis adopts the fundamental supposition that development within a specific economic sector is driven by primary change in demand and production capability, and that these processes will interact with the political context, and will determine the extent to which various development themes relate and apply. All of these must of course be seen within a wider environment in which aquaculture must compete with other sectors. In an increasingly (but by not exclusively) market-driven world economy, with generally increased levels of internationalisation of most socio-cultural and productive sectors, the context for growth and development may be more uniform than in the past, when national characteristics were more distinctive and economic actions more explicitly directed towards particular sectors. Nonetheless, we might expect sizeable differences in opportunities and constraints; in some cases because of natural resource limitations, in others because purchasing power is inadequate, and elsewhere because the regulatory regime may, intentionally or not, constrain aquaculture.

2. CURRENT PRODUCTION TRENDS

2.1 Introduction

The underlying aim of the review is to describe the potential role of aquaculture in future food supply, and in particular, its ability to address the needs of poorer sectors of society, whether defined on the basis of national average incomes, or as identified in terms of income distribution. The basic definitions and forms of aquaculture have been described in the previous section.

The next stage is to consider the extent and nature of aquaculture activity and production, of whatever species and system type, in the various regions in which it has developed. As noted earlier, aquaculture production takes place in a wide range of environments and economic conditions. Table 2.1 summarises recent production levels by generalised national development category.

This demonstrates the gradually increasing share of aquaculture production (by weight) held by LDCs, and in particular, the growing importance of fish culture. While this is encouraging in *prima facie* terms, the real nature of this distribution, and the extent to which it benefits LDCs requires further analysis. This is discussed in more detail in later sections.

Table 2.1 Aquaculture production by country group ('000 tonnes)

Country group[1]	1984	1986	1988	1990	1992[2]	% annual growth '84-90
Developed	2761 (27.3%)	3069 (25.1%)	3366 (23.1%)	3408 (22.2%)	2600 (18.7%)	3.6
Developing:						
- all species	7357 (72.7%)	9141 (74.9%)	11190 (76.9%)	11915 (77.8%)	11300 (81.3%)	8.4
- fish only	3386 (33.5%)	4811 (39.4%)	6170 (42.4%)	6824 (44.5%)		12.4
TOTAL	10118	12210	14556	15323	13900	7.2

Source: FAO 1992, 1994

There is clearly a range of social, technical economic and developmental issues to be addressed in assessing the development of aquaculture, its potential for the future, and the possible implications for localised benefit and national economic development. It is appropriate therefore to review the recent and current history of development, to examine these characteristics with respect to the principles and philosophies of development, and from this to consider the issues involved if various development objectives are to be met. The milestone Kyoto conference of 1976 provided one of the earliest opportunities for assessing the extent of development of aquaculture, and for offering prognostications of the potential for its growth, and of the prospects for overcoming problems of food supply and economic development.

The primary data described here has been developed on a country/species basis in the FAO/FIDI Fishstat database. These are based on individual country Fishstat/Aquastat returns, supplied annually by relevant national authorities, supplemented with additional information from responsible ministries or agencies, and more recently, modified according to the judgement of individual specialists. The data series for aquaculture started officially in 1984, with the use of the first specialised data forms, which seek information on hatchery and market production, on market value, on culture environments and culture systems. A limited amount of information prior to this has been obtained from various sources.

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1 According to standard UN categories of GDP

2 Excluding aquatic plants.

The main sources of secondary data are those of the FIDI country information files, which include trade press extracts, US Government reports (e.g. from Department of Commerce/ NOAA), extracts from FAO mission reports and other material e.g. from ICES and EIFAC sessions.

The EIFAC Technical Paper 52; Inland Fisheries of Europe, provides comparative and historical figures for inland fisheries and aquaculture in much of mainland Europe The data inconsistencies revealed in this report confirm the general problems involved. Additional information is available from other statistics such as OECD data, producer association statistics, trade press reports, and from species or sector surveys.

Several areas of deficiency can be noted, and cannot completely be eliminated. These include the paucity of data - the lack of returned or correctly completed forms to the FAO system, as well as the problem of standardising species descriptions. In many areas, there are simply not the resources available to assess the extent and nature of aquaculture, or to classify the species accurately, either through lack of commercial or institutional capacity, or the lack of skills in collecting and interpreting local data. Double counting errors are also not uncommon between aquaculture and fisheries, particularly where aquaculture-reared species are stocked for fishery exploitation.

The assessment of the value of aquaculture production, and in particular, the exercise of collating and comparing these within and across national boundaries, is also problematic. The approach taken in the reported figures is to use as far as possible the prices quoted in the national returns, expressed or converted to $US. Where no prices are indicated, where widely varying exchange rate calculations make dollar values too variable, or the data does not appear to be consistent, default values are chosen, either based on the approximate price levels attained over the period concerned, or based on standard default prices.

The result is at best a general approximation, but gives at least some indication of the relative importance of different product groups, and their potential significance at the local and national level.

2.2 General characteristics

Main species groups

For primary definition, aquaculture production is normally separated into major species groups of fish, crustacea, molluscs, and aquatic plants, and other species. Output in each group is normally recorded as gross wet weight.

The actual usable material varies with each group, as indicated in Table 2.2; edible yields also vary according to species characteristics and market size and condition. In value terms it is normally the edible portion which is most significant, though a range of secondary products is also available from aquaculture species (see Table 2.2), and may increasingly contribute to value determination. A range of aquatic products which are not primarily developed for direct human consumption can also be noted; these are not routinely included in the conventional description of aquaculture production and value but are discussed later.

Table 2.2 Production and yield; species group characteristics

Species group	Primary usable form	Typical ratios
Fish	Whole, headed, gutted, skinned, filleted, steaked, dried, smoked	Flesh yield typically 40-60%; fillet yield 30-50%; drying/smoking reduces effective weight to 40-60% of wet weight; roes may have enhanced value; remainder can be used for trash fish/silage feeds.
Crustacea	Whole, tailed/head-off, shell off	Some species have easily usable claw meat; typical shell off yields 20-50% ; astaxanthin, chitin and chitosan recovery possible from shells .
Molluscs	Whole, shelled, dried, smoked	Wide seasonal variation with many species; some flesh parts may be inedible; typical yields 10-25%.
Aquatic plants	Fresh, dried, solvent extracted	May be consumed directly; more commonly dried; yields typically 5-15%; normally further treated for extraction of gel forming compounds and/or mineral extracts.
Other species	Range of forms	Varies with species

The 1992 production and value records are detailed in Table 2.3, which also provides indicative average values per tonne of production.

Table 2.3 Aquaculture production and value by species group, 1992

Species group	Volume, tonnes	% by volume	Value, US$'000	% by value	Avg. value, US$'000/tonne
fish	9 417 153	49	17 318 112	53	1 839
crustacea	981 916	5	6 589 137	20	6 710
molluscs	3 500 719	18	3 669 994	11	1 048
aquatic plants	5 389 789	28	4 902 672	15	910
other	21 836	0	38 287	0	1 753
total:	19 311 413	100	32 518 202	100	

Source FAO, 1994

In terms of quantity and value the most important category is fish, and fish culture has continued to remain the dominant sector over the period of record (see also Figure 1.2 in previous section), in 1992 accounting for some 49% of volume and 53% of value. As noted earlier, fish culture is also more significant in the LDC country category. In 1992 the production level of fish was approximately double that of the next category, aquatic plants (28% by volume).

From 1984 to 1992 fish culture production in overall terms rose fairly steadily and relatively uniformly from under 5 mt to over 9mt, an annualized growth rate of some 7.6%. Other species categories have shown different patterns of development, and though increasing overall have not always shown a steady growth over this time. Thus in the mid 1980's aquatic plants had a total world production level of approximately 3.5mt. However in the late 1980's production fell, only to rise again fairly sharply to reach a level of nearer 6 million in 1992, an overall average annual growth rate of around 7.0%.

This irregularity was generally attributed to poor market conditions and low prices for industrial species in the late 1980s. This was related to a short term over-supply in a highly-competitive sector, whose end-products were in diminishing demand. Natural harvested stocks of these species were also abundant, with costs of exploitation which were generally modest. This situation has gradually improved, as industrial markets have improved and new product opportunities have been identified.

In terms of production volume, molluscs are the next most important category, accounting for some 18% in 1992. In value terms, the group is rather less significant, amounting to some 11 % of the 1992 total; the significance of molluscs in food supply is correspondingly less significant. Production has risen fairly steadily from 3 m to 4 m t since 1984 with only a slight dip in levels in the early 1990's. This represents an average sectoral growth rate of some 3.7% annually. The reason for the intermediate drop in production is not fully clear; there have been substantial variations recorded in some of the more traditional fishery-related mollusc activities, due apparently to short-term environmental conditions - e.g. poor spatfall; there have also been increases in disease incidence (e.g. bonamia) in some stocks, but error in the data record cannot be fully ruled out.

Although the level of crustacean production remains quite low compared with that of other species groups, their value is now the second most important after that of fish. In 1992, crustaceans made up 5% of the total aquaculture production by volume, but accounted for 20% of the total world value. By contrast, aquatic plants made up a much lower proportion of value (15%) than of production (28%) A very small quantity of cultured species do not come into any of the four main categories; these other species make up only around 0.1% of both production and value.

Major sub-groups

The division of major species groups into sub-groups is somewhat arbitrary - using approximate distinctions of taxonomic similarity and/or culture system or environment, but is reasonably useful in defining specific trend components. The fish species category can be separated into six major sub-groups of carps, various freshwater species, salmonids, tilapia, various marine species, various diadromous species. Of these sub-groups, carps are by far the most important, with a production level in 1992 of approximately 6.5 mt, some 69% of total fish culture production, though considerably lower in value terms. None of the other sub-groups have production over 1m tonnes. Production of various freshwater fish has remained relatively static over the previous decade, but the salmonid and tilapia sub-groups have both showed a steady increase in production, which however is as yet insignificant in overall terms.

The values of the salmonid subgroup are notably higher than the overall average, while tilapias are around average for the group. The production of the diadromous subgroup appears to have declined (partly because of the reallocation of salmonids), while the high value marine species sub-group has increased, most markedly for the seabreams, though as with salmonids, the relative level is still quite low.

Four main crustacean subgroups can be considered; marine shrimps (penaeids and metapenaids), freshwater shrimp or prawns (mainly macrobrachium spp), crayfish, and other crustacea (the FAO subgroups include crayfish with freshwater prawns).

In 1984 the level of production was relatively low for all types. Some 90% of the 1992 world crustacean output now consists of marine shrimps and related species. Production has risen from under 2 mt to nearly 9 mt over this period, an average increase of some 20.7% annually. The amount of freshwater and other crustaceans produced up to 1992 has remained consistently low, though there are indications of a more recent upturn in production, though again from a low initial level.

The mollusc group can be separated into five major divisions of mussels, oysters, clams, scallops and 'other' molluscs. Within this group, mussels account for the greatest share in annual production, though are less significant in value terms.

This subgroup has overtaken oysters in importance; in 1984, oysters were more significant in production as well as value terms.

The production of oysters dropped in 1990/1 but has picked up slightly in 1992. Both scallops and clams have shown a notable increase in production in recent years, though overall levels are still not very significant. In terms of value they are generally higher than oysters and mussels.

Aquaculture and other sectors

The patterns of development of aquaculture must be considered in terms of other sectoral trends. The most common comparators, as discussed earlier, are those for the capture fishery sector, with which aquaculture statistics are usually normally grouped (Table 2.4).

The reliability and implications of the capture sector trends are outside the scope of this review, though the prospects of aquaculture increasing its contribution to global production are widely noted. Regardless of the actual level of capture fishery production which may be attainable in the longer term, it is clear that there will be increasing substitution between the two sectors.

Because of the constraints in providing accurate value descriptions it is also difficult to provide definitive comment on the relative values of aquaculture products compared with those in other sectors, though some general comments may be made.

Table 2.4: Fisheries and aquaculture production, 1984-1992 (10^3 tonnes; % total)

	1984		1986		1988		1990		1992		% annual change
Fisheries	77.3	(92.1%)	84.2	90.7%	87.9	(89.0%)	85.1	(87.6%)	86.2	(86.0%)	+ 1.3
Aquaculture	6.6	(7.9%)	8.6	(9.3%)	10.9	(11.0%)	12.0	(12.4%)	14.0	(14.0%)	+ 9.8
TOTAL	83.9		92.8		98.8		97.1		100.2		+ 2.2

Source: New, 1991; FAO, 1992, 1994;

At the level of the major species groups, capture fisheries still contribute substantial parts of the lower value species production, while aquaculture generally occupies the medium and higher value areas. While there are significant areas of competition, particularly in the higher-value sectors, there are also varying degrees of complementarity, with aquaculture supplying markets during out of season periods. For crustacea, shrimp aquaculture has now overtaken fisheries in production and value terms, though overall production in the group is still dominated by fisheries. As with fish production, values in the aquaculture sector are generally higher. In the case of molluscs, an increasing proportion of production is now accounted in the aquaculture sector, though this is subject to the classification of production methods, as many forms of production lie across the boundaries between fisheries and aquaculture. Average values are again rather higher in the aquaculture sector, though some of the higher-value species such as scallops and abalone are still primarily fishery products. Finally, for aquatic plants and other species, aquaculture is becoming particularly important in tropical areas, while wild harvested seaweeds are still dominant in cooler temperate waters. In all areas, the potential use of aquaculture to seed or supplement wild fishery stocks is of increasing interest.

The position of aquaculture with respect to other agro-industrial sectors may also be considered; in terms of production and value, and of the overall context in which the sector has developed. In market and consumption terms, the products of aquaculture can be seen to relate and compete with higher quality protein foods such as meats, eggs, and milk products; similarly, in ecological terms, aquaculture products are often higher in the food chain, so compete for similar type and quality of input. The main exceptions to this are the filter feeding fish species and the mollusc and aquatic plant groups, which occupy far lower food chain positions. Production in most of the equivalent agricultural sectors has increased over the same period, though aquaculture has often been faster growing. The relative significance of aquaculture varies however; in most areas it is relatively small, with the exception of the traditional 'rice-fish' areas of Asia, where it plays a far more important role. In the rapidly growing aquaculture locations, it is usually still relatively insignificant.

[3] Figures exclude mammals and seaweeds.

It is difficult to comment on relative values, though in many cases aquaculture products are priced higher than terrestrial equivalents on a weight or protein level basis. The wider development context is primarily an issue of the resources allocated to aquaculture and the comparative efficiency with which they are used. This is discussed in more detail in the next section.

2.3 Regional/habitat features

In geographical terms there are wide variations in the nature and capacity for aquaculture production, as well as considerable differences in the history and development record of the sector. Regional analyses are therefore useful in exploring the nature and source of these differences, as well as offering explanations and possible development mechanisms for different areas of future potential. Aside from the periodic national or regional sectoral reviews carried out within UNDP/FAO project or programme missions at various stages, and the periodic Regional Office/Fisheries Commission reviews, a range of systematic regional and national analyses has been produced by FAO over the last decade, including the ADCP series of regional aquaculture reviews, and the FIRI series of national aquaculture profiles for Africa. A useful series of regional analyses for Asia has also been produced by the FAO Regional office for Asia and the Pacific (Csavas, 1995). Various national profiles are also produced occasionally by national authorities and by the trade press.

Habitat/environment

Although a wide range of agricultural classifications has been developed to distinguish habitats and agro-ecological zones for terrestrial production, such classifications are simplified in the case of aquaculture to three major categories, marine, fresh and brackish water. Unlike the capture fisheries sector, aquaculture is dominated in volume terms by inland water production (table 2.5). From 1989, inland aquaculture output grew by around 9.7%, while coastal/marine production increased by only 3.1%. In 1992 , some 61% of all aquaculture production (excluding plants) was from fresh water, the remaining 39% from marine and brackish water. The latter sub-sectors however accounted for a higher percentage (46%) of the value of all aquaculture products.

Table 2.5 Fishery sector production 1992, by environment/habitat

Environment	Total output 10[4]t (%total)		Fisheries 10[4]t (%total)		Aquaculture 10[4]t (%total)	
Inland	15.7	16%	7.3	7%	8.4	9%
Coastal/marine	83.0	84%	76.9	78%	5.5	6%
Total	98.7	100%	84.2	85%	13.9	14%

[4] Figures exclude mammals and seaweeds.

For fish culture (Table 2.6), inland waters account for 96% of production and 85% of value, and marine waters 4% production and 15% of value, while for crustaceans, the proportions are reversed, with inland waters supporting only 6% of production and 4% of value. Table 2.6 also indicates the substantial differences in average value for the different habitat groups.

Table 2.6 Freshwater/marine aquaculture production, 1992

Environment	Fish			Crustacea		
	Quantity	Value	$US/tonne	Quantity	Value	$US/tonne
Inland/ freshwater	96%	85%	1 623	6%	4%	4 397
Coastal/marine	4%	15%	7 304	94%	96%	6 868

The majority of species is cultured in one type of environment, corresponding to ecological preference. However, several species can be cultured in more than one environment. For example, species of tilapia (Oreochromis spp) can be cultured in both inland and brackish waters.

In 1992, O. niloticus and *O. mossambicus* had production levels of 280,800t and 23,300t respectively in inland waters, while in brackish water, productions were 21,900t and 22,000t respectively. The rainbow trout (*Oncorhynchus mykiss*) is cultured in brackish, inland or marine water; production in all three environments has increased since 1986.

The majority is however still cultured in fresh water (261,000t in 1992). Other salmonids , eels (*Anguilla spp*), sturgeon (*Acipenser, Huso spp* and their hybrids) red drum (*Sciaenops spp*) and striped bass (*Morone saxatilis*) can all be cultured in fresh or saline waters. The sea bass (*Dicentrarchus labrax*), sea bream (*Sparus auratus*), milkfish (*Chanos chanos*) and mullet (*Mugil* and related species) are described in both marine and brackish waters.

Within the crustaceans, the dominance of the marine shrimp sub-group has already been noted. Many of the *Penaeus* species including *P. monodon*, *P. chinensis* and *P. vannamei*. can be cultured in both brackish and marine waters, though in all cases, productivities are highest in intermediate salinities.

Many mollusc species are classically euryhaline, though the bulk of production is recorded in brackish or marine waters, and as noted earlier, the former category may be used to distinguish more traditional forms of intertidal on-bottom culture from more modern forms of suspended culture.

Most of the reported production of aquatic plants is coming from marine waters.

Regional production

Details of regional aquaculture production are summarised in Table 2.7, which also provides indicative average values per tonne of production.

Table 2.7: Regional distribution of aquaculture production (finfish, crustacea, molluscs) 1992

Region	Volume, '000 tonnes	% of world total	Value, $US million	% of world total	Avg. value $US/tonne
Asia	11 683	84%	21 570	78%	1 846
of which China	*6 856*	*49%*	*8 340*	*30%*	*1 216*
Europe	1 183	8%	3 293	12%	2 784
North America	444	3%	778	3%	1 750
Latin America	325	2%	1 292	5%	3 972
Former USSR	129	1%	302	1%	2 338
Africa	67	0%	169	1%	2 521
Oceania	68	0%	173	1%	2 541
world total:	13 900		27 577		1 984

In 1992, 84% of world aquaculture production by volume originated from the Asia, within which China clearly dominates output. By far the greatest part of this arises from the traditional centres of aquaculture production in Asia, as the Middle East is relatively insignificant.

The region with the next largest aquaculture production is Europe, with 8%. The other regions, including North and South America, Africa, Former USSR and Oceania all produce less than 5% of the total world production.

Although the quantities produced in Asia have grown steadily, and in some sectors very dramatically, there have been sizeable short-term fluctuations in output. These have ranged from the longer-period market-defined production cycles in the Thailand catfish industry over the 1980s, to the heavy but localised impact of disease in inland aquaculture in the region from the mid 1980s onwards, to the more dramatic reversals in the fish culture sector in Taiwan in the mid to late 1980s, and in shrimp culture in Taiwan, Indonesia and Thailand (late 1980s), and China (early-recent 1990s), all of which have been associated with poor environmental conditions, disease and poor production performance.

There have also been significant effects of political instability, with production in Cambodia and Myanmar particularly affected over the past decade. In overall terms, though there is obviously a strong underlying trend for growth, the sector appears to remain very volatile.

The levels of production are reflected in the values of harvest, with Asia accounting for 78% of the world value, equating to US$ 21,570 million in 1992. The reduced value share is associated with the influence of the sizeable quantities of lower value carp and aquatic plant species, but is compensated to some extent by the importance of shrimp production in the region. Marine fish species are also important regionally, but although their value is high, the quantities are insufficient to have much effect on overall value of output. Within Asia, the main producing countries are China, Japan, Indonesia, Thailand and India. On the whole, most countries within the region have shown a steady increase in production with only occasional fluctuations.

The aquaculture industry in Europe is valued at about US$ 3,293 m, some 12% of world value, reflecting the generally higher values of species produced in the region. This in turn reflects on the higher-cost and more intensive forms of aquaculture which occupy a greater share of production, though Eastern Europe has traditionally produced lower value species such as carp.

The most significant countries in the region in 1992 are Norway, France, Italy, Spain, Germany and the UK, though almost all countries have a reasonably active aquaculture sector. The major factors of change in the region have been the significant rise in intensive salmonid production, and more recently the growth of Mediterranean marine aquaculture - mainly of seabass and seabream. However, Eastern European countries such as Albania, Bulgaria, Hungary, and Romania have all shown a recent drop in production, associated primarily with the extensive economic restructuring now taking place (and to some extent, the decline in reporting).

North America produces 3.2% of the world production and accounts for 2.8% of the total world value, a slightly lower than average level of value, which is accounted for by the broad balance between higher value salmonids and shrimp, medium to low value catfish and tilapia, and lower value molluscs, which are still significant in volume terms. The country with the highest production is the United States; other important countries include Canada, Honduras, Mexico, and Panama. These countries have nearly all shown a steady increase over the period up to 1992, but other countries in the region, generally minor producers in the Caribbean, have shown more fluctuation in production levels, quite often with large dips in production.

Production levels are not as high in South America (2.3% of world production) but aquaculture is expanding in the region, and in terms of value the region has a greater share than North America (4.7% of total world value).

This is largely accounted for by the dominance of shrimp culture in the tropical countries of the region, though with the increase of aquaculture in more temperate areas, a wider spread of species (and of market values) may be expected. The biggest producers in the region are Ecuador, Chile, Brazil and Colombia. Production from other countries is fairly insignificant in comparison. Unlike some of the other regions there is a distinct difference in country species focus. In Ecuador over 95% of the production consists of crustaceans, Chile has a large production of salmonids, molluscs and aquatic plants; whereas Brazil and Colombia have their largest production sectors in freshwater fish.

For its size, and its obvious demands, Africa produces an extremely small proportion of world aquaculture output (0.5%), with approximately similar or slightly lower value levels. Within the continent about 80% is produced by just two countries Egypt (tilapia, carp, mullet) and Nigeria (tilapia, carp, catfish).

On the whole, countries within Africa, particularly in the Sub-Sahel region, practice aquaculture on a small scale, usually in simple low-input freshwater pond culture, and many have recorded production levels as low as a few hundred tonnes or less.

However, there is the prospect of contributing to the food supply of vulnerable rural communities in those areas with sufficient resources, especially water.

There has been a very noticeable recorded drop in production from the former USSR, in both aquaculture and the wider agricultural sector, since the fall of communism and the break-up of the state structure. Data has been split into the different countries which make up the former USSR, which makes it more difficult to define the actual patterns of production.

Between 1991 and 1992 the value of production appears to have fallen from US$ 773 m to US$ 302 m, though this may have been due partly to problems of fixing an appropriate and realistic exchange rate. Many of the species traditionally produced, particularly the carps, tend to have a relatively low value, however, and this may have been artificially inflated within the internal price structure of the Soviet bloc. In 1992, Russia was reported to have had the largest production, followed by Uzbekistan and Ukraine.

In the Oceania region, Australia and New Zealand are the only two countries with significant production levels. In both countries the most important species categories are salmonids and molluscs, though crustacean culture is now starting to gain strength in Australia, and small amounts of native species are also produced.

2.4 Production trends

It is clear that overall the aquaculture sector has exhibited significant and relatively sustained growth, but that within this there may be considerable variation. There is a wide variety of species, systems, production environments and socio-economic frameworks, and so some diversity in production history and development pattern might be expected.

However, because of the nature and limitations of the data available, it would not be feasible to construct classical time-series analyses of production and value, or to attempt rigorous functional analysis of component inputs to growth. Instead, a more descriptive assessment is used, based in part on the statistical record, and in part on notable points of change, whose magnitude of effect may not be fully defined, but which can be seen to have acted on various aspects of the sector.

In general terms, various types of production trend may be discerned over more recent time series, and could include any or all of the following features. Examples of these trend forms are given in Table 2.8.

Table 2.8 Typical production trend forms

Production trend	Typical factors/features	Examples/notes
Steady growth, often from a relatively high initial production base	- traditional forms of production, with gradually increasing area and/or output - maturing markets	extensive or semi-intensive fish culture; bed or stake-based mollusc culture; traditional forms of seaweed culture
Recent and rapid growth	- new species, technology, inputs and resources - market opportunities - industrialisation/aggregation	typical of new marine species and systems, of raft and longline production; introduction of particular technologies such as cage systems, marine hatcheries and sub-surface longlines;
Discontinuous production patterns around generally stable trends	- small numbers of producers and unreliable production based on wild stocks, subject to natural fluctuations; - major environmental variability - financial, exchange rate factors; management or marketing difficulties; boom and bust cycles	common in simple artisanal sectors e.g. various marine fish and shellfish production; Thai clarias and macrobrachium industries, affected by rapid supply and price fluctuations; turbot culture in Spain, due to investment and market price problems;
Changes in relative distribution of species	- changing market prices, - more commonly due to changes in species distribution of wild stock.	different mollusc species in bed culture or on longlines; marine fish cage culture in SE Asia
Declining production	- usually in specific zones, most commonly due to disease - environmental problems - regulatory control	fall in production of native European crayfish, due to crayfish plague; native oysters, due to bonamia; localised fall in freshwater fish production due to EUS; heavy metal or domestic sewage contamination
Drastic fall in production	- major environmental disruption, and major shift in risk perception - failure of large corporate structure or major political shift	- e.g. in Chile, an earthquake disrupted much of the traditional on-bottom mollusc culture production. - e,g, Cambodia, Uganda, as a result of political disruption

The reported patterns of production and value may have to be interpreted with some care; certainly it should be noted that the characteristics of sectoral trends within aquaculture may be quite different from those in capture fisheries and other sectors. The following tables extend the outlines given earlier to consider the apparent production trends for species groups. Table 2.9 describes the trends for the major fish species, grouped as freshwater, diadromous and marine.

Table 2.9 General trend characteristics, major fish species groups (tonnes; % total volume; % annual growth).

Species group	1986	%	1992	%	%/yr	Trend/notes
Freshwater						
carps, barbels other cyprinids	4221728	*70.5*	6652305	*70.6*	7.9	steady growth from large base
tilapias and other cichlids	241741	*4.0*	473477	*5.0*	11.9	high steady growth, moderate base
misc. fw fish	592097	*9.9*	854955	*9.1*	6.3	increasing growth from moderate base, dominant effects of channel catfish, also clarias, anabas, trichogaster
freshwater total	5055566	*84.5*	7980737	*84.7*	7.9	steady growth from large base
Diadromous						
sturgeons, paddlefish	180	*0*	437	*0*	15.9	high growth but v small base
river eels	77595	*1.3*	99668	*1.1*	4.3	moderate or levelling, small base
salmon, trouts, smelts	303632	*5.1*	628418	*6.7*	12.9	high growth, moderate base, may be levelling - mainly atlantic salmon and rainbow trout
misc. diadromous fish	313616	*5.2*	352175	*3.7*	2	low growth/levelling, moderate base, primarily milkfish, also lates; mullets in marine category
diadromous total	695023	*11.6*	1080698	*11.5*	7.6	higher early growth, from moderate base, now levelling
Marine						
flounders, halibuts, soles	1965	*0*	12075	*0.1*	35.3	v high recent growth, v small base, mainly paralichthys, also turbot
cods, hakes, haddocks	0	*0*	28	*0*	n/r	negligible, fluctuating
redfishes, basses, congers	39929	*0.7*	95944	*1.0*	15.7	high/recent growth, may be slowing mainly red and gilthead seabreams, also seabass, grouper
jacks, mullets, sauries	167802	*2.8*	179430	*1.9*	1.1	moderate, more or less stable, small fluctuation mainly seriola, also mullet
herrings, sardines, anchovies	3	*0*	0	*0*	-100	negligible/decline
tunas, bonitos, billfishes	60	*0*	123	*0*	12.7	negligible/highly variable
miscellaneous marine fishes	24069	*0.4*	68118	*0.7*	18.9	rapid recent growth, moderate level unspecified, mainly SE Asia/China
marine total	233828	*3.9*	355718	*3.8*	7.2	moderate growth from small-moderate base
TOTAL FISH	5984417	*100*	9417153	*100*	7.8	steady growth from large base

2.5 Species trends

The role of individual species, and the comparative rates of their aquaculture expansion, is of significance not only in their contribution to local and export markets, and national and regional development, but also in terms of the potential for developing various production systems, for the use of resources, and for the planning, e.g. of broodstock, stock quality improvement, and management skills.

Fish species

Details of the main fish species are given in Table 2.10, which ranks production according to 1992 levels. This does not include more general category groups from the statistical data such as 'cyprinids nei' which are composites of undefined species. Two related columns provide the overall percentage increase in production over the 1986-1992 period, and the annual average equivalent.

Table 2.10 Species ranking in aquaculture production

Principal fish species: annual production >100 000t					
Common name	*Species name*	*1986*	*1992*	*%*	*%/yr*
Silver carp	Hypophthalmichthys molitrix	1275315	1616613	26.8	4.0
Grass carp(=White amur)	Ctenopharyngodon idella	439837	1252728	184.8	19.1
Common carp	Cyprinus carpio	802497	1022887	27.5	4.1
Bighead carp	Hypophthalmichthys nobilis	607292	786604	29.5	4.4
Milkfish	Chanos chanos	310866	339289	9.1	1.5
Roho labeo	Labeo rohita	163552	309020	88.9	11.2
Nile tilapia	Oreochromis niloticus	111081	302674	172.5	18.2
Catla	Catla catla	155000	301806	94.7	11.7
Rainbow trout	Oncorhynchus mykiss	204014	296571	45.4	6.4
Mrigal carp	Cirrhinus mrigala	106000	295551	178.8	18.6
Crucian carp	Carassius carassius	93291	257198	175.7	18.4
Atlantic salmon	Salmo salar	59823	241727	304.1	26.2
Channel catfish	Ictalurus punctatus	149244	211067	41.4	5.9
White amur bream	Parabramis pekinensis	147600	181516	23.0	3.5
Japanese amberjack	Seriola quinqueradiata	148788	148988	0.1	0
Principal crustacean species: annual production > 100 000t					
Common name	*Species name*	*1986*	*1992*	*%*	*%/yr*
Giant tiger prawn	Penaeus monodon	89384	388565	334.7	27.8
Fleshy prawn	Penaeus chinensis	82909	207428	150.2	16.5
Whiteleg shrimp	Penaeus vannamei	35144	111075	216.1	21.1
Principal mollusc species: annual production >200 000t					
Common name	*Species name*	*1986*	*1992*	*%*	*%/yr*
Pacific cupped oyster	Crassostrea gigas	763925	795004	4.1	0.7
Japanese scallop	Pecten yessoensis	163601	546222	233.9	22.3
Sea mussels nei	Mytilidae	210670	538900	155.8	16.9
Japanese(=Manila)clam	Venerupis japonica	123037	328031	166.6	17.8
Blue mussel	Mytilus edulis	433377	318047	-26.6	-5.0
Razor clams	Solen spp	126175	198598	57.4	7.9
Principal aquatic plant species: annual production > 200 000t					
Common name	*Species name*	*1986*	*1992*	*%*	*%/yr*
Kelp	Laminaria japonica	1734210	3147258	81.5	10.4
Laver(=Nori)	Porphyra tenera	634155	708350	11.7	1.9
Wakame	Undaria pinnatifida	532055	491734	-7.6	-1.3
	Eucheuma spp	170542	354953	108.1	13.0

The overall dominance of the carp species can again be noted, and the continuing growth of production of key species in this group ensures their continuing significance in global aquaculture terms. It is interesting to note the very high level of production of both silver carp and grass carp, species whose importance is commonly determined by their effectiveness in tsemi-intensive pond polyculture systems, or in open waters, for controlling finer algae or heavier grass and weed growth respectively. Their culture, however, improves the prospects for producing other more highly valued carp species. The dominance of both the Chinese carps and the Indian major carps reinforces the continuing importance of simple semi-intensive pond systems, and also their great significance in these major aquaculture regions.

One of the most economically important species in the western world is salmon, more specifically Atlantic salmon (*Salmo salar*). Aquaculture production makes up 98.6% of Atlantic salmon available on the world markets, and has shown particularly fast growth in Europe and Latin America, and production has quadrupled to over 240 000t in the past ten years. Pacific salmon culture (i.e. all *Oncorhynchus* spp excluding *O. mykiss*) remains at a low level with the exception of coho salmon (*O kisutch*), where production is now at about 48,000 t.

The culture of species such as tilapia (*Oreochromis spp*) and catfish (*Clarias spp*) are much more important in the developing world. Tilapias and other cichlids have a current world production of nearly 500,000 t, which has almost doubled since 1986. Countries where tilapia production is particularly important include Indonesia, China, Egypt, Philippines and Thailand. *Clarias* spp production remains low in relative terms, with a production level in 1992 of 90,000 t compared to 55,000 t in 1986, a growth rate of some 6.3% annually, but these levels may be underreported (Csavas, 1995). The species is known to be increasing in popularity for aquaculture in several regions, and may be expected to show greater increases in the future. The current world leader in production is India followed by Thailand.

Table 2.11 provides further detail of major individual fish species (>=10,000 t annual production), ordered in categories of apparent rate of growth of production, and by overall level of output, with a brief note on the key characteristics underlying the trends concerned. From these it can be seen that several of the major species - primarily freshwater - have steady if not dramatic growth rates, and that this provides the main underlying trend of global fish production. While growth rates for certain marine and diadromous species have been remarkable, the production base is often insignificant.

The possible exception to this - still however only a moderate scale sub-sector, is the salmonids, dominated in particular by the Atlantic salmon. A number of species show relatively static or declining production trends, due to a combination of factors, including poor market demand (or increasing preference for related species), limited seed or other resources, habitat problems and inferior production performance compared with alternates.

Other species, notably the less attractive carp polyculture species, continue to remain in steady, or rising production because of their value in supporting the culture of their more desired associate species, or because of their secondary ecosystem functions.

Table 2.11 Production trends of major fish species, 1986-1992

Fish species		1986	1992	%/yr	notes
Production increase >20%					
Atlantic salmon	Salmo salar	59823	241727	26.2	high market price, competition
Coho(=Silver)salmon	Oncorhynchus kisutch	10416	48379	29.2	good market price
Gilthead seabream	Sparus auratus	745	13414	61.9	v high price, fry available
Giant sea perch(=Barramundi)	Lates calcarifer	2750	12886	29.4	high price, techniques better
Production increase 10-19.9%					
Grass carp(=White amur)	Ctenopharyngodon idella	439837	1252728	19.1	steady expansion, grass control
Roho labeo	Labeo rohita	163552	309020	11.2	regional expansion, markets
Nile tilapia	Oreochromis niloticus	111081	302674	18.2	culture qualities, fry supply
Catla	Catla catla	155000	301806	11.7	regional expansion, markets
Mrigal carp	Cirrhinus mrigala	106000	295551	18.6	regional expansion, markets
Crucian carp	Carassius carassius	93291	257198	18.4	good demand, pond culture
Japanese seabream	Sparus(=Pagrus) major	33497	65950	12.0	good price, simple systems
Mozambique tilapia	Oreochromis mossambicus	16994	45314	17.8	culture qualities, fry supply
Thai silver barb	Puntius gonionotus	10640	19955	11.0	good performance, price, fry
Trouts nei	Salmo spp	8816	15589	10.0	general demand, technology
Flathead grey mullet	Mugil cephalus	4027	11800	19.6	better systems, good markets
Bastard halibut	Paralichthys olivaceus	1865	10327	33.0	technologies, markets
Production increase 3-9.9%					
Silver carp	Hypophthalmichthys molitrix	1275315	1616613	4.0	useful, not popular
Common carp	Cyprinus carpio	802497	1022887	4.1	steady increase, weak markets
Bighead carp	Hypophthalmichthys nobilis	607292	786604	4.4	useful, not strong demand
Freshwater fishes nei	Osteichthyes	300691	517883	9.5	variety of secondary species
Cyprinids nei	Cyprinidae	257393	419185	8.5	variety of secondary species
Rainbow trout	Oncorhynchus mykiss	204014	296571	6.4	}very competitive markets, drive
Channel catfish	Ictalurus punctatus	149244	211067	5.9	} efficiency, price reductions
White amur bream	Parabramis pekinensis	147600	181516	3.5	part of general expansion
Torpedo-shaped catfishes	Clarias spp	54288	83325	7.4	good market interest
Mud carp	Cirrhinus mulitorella	57226	81050	6.0	useful, moderate demand
Japanese eel	Anguilla japonica	36532	55743	7.3	good demand, restricted capacity
Climbing perch	Anabas testudineus	36835	50632	5.4	steady demand
Production -3 to +3%					
Milkfish	Chanos chanos	310866	339289	1.5	declining capacity and profits
Japanese amberjack	Seriola quinqueradiata	148788	148988	0	production problems/cost
Tilapias nei	Oreochromis (=Tilapia) spp	98019	106987	1.5	hybrid demand; others declining
Black carp	Mylopharyngodon piceus	61100	52287	-2.6	useful, not popular
River eels nei	Anguilla spp	36578	36949	0.2	supply constraint
Java barb	Puntius javanicus	22877	23000	0.1	Thai silver barb preferred
Blue tilapia	Oreochromis(Tilapia)aureus	14950	16990	2.2	Nilotica/hybrids preferred
Pangas catfish	Pangasius pangasius	12574	13220	0.8	disruptions, record problems?
Ayu sweetfish	Plecoglossus altivelis	11396	12833	2.0	weak markets
Production drop > 3%					
Snakeskin gourami	Trichogaster pectoralis	17651	14220	-3.5	habitat/production limits

Crustaceans

For shrimps and prawns, the aquaculture species coverage includes Penaeus, *Metapenaeus* and *Macrobrachium* spp, plus various freshwater crayfish and crawfish, and the various other minor decapod shrimp produced in mixed crop aquaculture systems. Other crustaceans such as crabs, lobsters and marine crayfish are insignificant, or not included. Table 2.10 summarises recent production details of the most important species within this group.

Table 2.12 General trend characteristics, crustacean and mollusc species groups (volume, tonnes)

Species group	1986	% of total	1992	% of total	% /yr	Trends/notes
Crustaceans						
freshwater crustaceans	57561	14.8	62433	6.4	1.4	fluctuating around moderate base mainly red swamp crawfish, macrobrachium, also cherax; nei category mainly Vietnam
seaspiders, crabs	3682	0.9	13693	1.4	24.5	rapid recent growth, small base mainly Chinese river crab, scylla
lobsters, spiny lobsters	13	0	62	0	29.7	fluctuating, negligible
shrimps, prawns	312820	80.7	884075	90	18.9	high growth from large base, steadying predominantly penaeids; monodon
miscell marine crust.	13567	3.5	21653	2.2	8.1	moderate growth from small base mainly nei from Korea DPR and China
total marine	330082	85.2	919483	93.6	18.6	good growth from large base
TOTAL CRUSTACEA	387643	100	981916	100	16.8	
Molluscs						
freshwater molluscs	718	0	256	0	-15.8	negligible, strong decline
abalones, winkles, conch.	802	0	1570	0	11.8	negligible, fluctuating, some growth mainly abalones
oysters	937681	39	953529	27.2	0.3	large base, fluctuating/static mainly crassostrea gigas, also virginica
mussels	798512	33.2	1086310	31	5.3	large base, early growth now levelling mainly edulis, also galloprovincalis, smaragdinus, canaliculus
scallops, pectens	164274	6.8	549194	15.7	22.3	good growth from moderate-large base, mainly yessoensis
clams, cockles, arkshells	437507	18.2	764744	21.8	9.8	large base, rapid recent growth, mainly venerupis, solen, also anadara, tapes, merceneria, arca
squid, cuttlefish, octopus	0	0	0	0	n/r	negligible
misc. marine molluscs	65248	2.7	145116	4.1	14.3	moderate base, early growth, levelling, mainly China and Korea DPR
TOTAL MOLLUSCS	2404742	100	3500719	100	6.5	large base, moderate growth, recent upturn

The majority of cultured crustacea (table 2.10) are *Penaeus* spp., by far the most important being *P, monodon* (giant tiger prawn) which has increased in production from 89,000 t in 1986 to 388,000 t in 1992, an annualised growth rate of 27.8% this species represents some 40% of crustacean production by volume. Other *Penaeus* spp, in decreasing order of production level include *P. chinensis*, *P. vannamei*, *P. merguiensis*, *P. stylirostris*, *P. japonicus* and *P. indicus*.

There are distinct geographical patterns of production for these species, with

- *P. monodon*, the most widespread and fastest growing species in the tropical and sub-tropical zones of Asia

- *P. chinensis*, *P. japonicus* primarily grown in cooler subtropical warm temperate climates of China, Japan and neighbouring areas

- *P. indicus* commonly produced in S Asia

- *P. vannamei* and *P. stylirostris* in Central and S America.

P. merguiensis is cultured as a secondary crop in a range of Asian countries, and has shown little increase in production.

However, as Table 2.13 indicates, several of these species exhibited rates of growth in output in excess of 20% per annum over the period reviewed, and *P. stylirostris* showed an increase of 45.6%.

Other *Penaeus* and *Metapenaeus* spp have either small production levels or production has totally ceased (or not been recorded) since the 1980's. There are also usually smaller numbers of minor species which are brought in with wild caught seed, or in the process of water exchange, some of which are recorded in their respective 'nei' categories.

The giant freshwater or river prawn (*Macrobrachium rosenbergii*) is now produced in a large number of countries at a low level, the majority of countries producing under 100 t. The major producer is still Thailand, but production is increasing at some 19.8% annually, and it is expected to become more significant elsewhere, particularly in Asia.

The total world production is relatively low at 19,000 t but may be expected to increase. A number of other *Macrobrachium* species are produced, but in insignificant quantities.

The red swamp crawfish (*Procambarus clarkii*) is only produced significantly in two countries (Spain and USA) with a current world production of over 30,000 t, and is the only main species group to demonstrate a decline in output over the period.

The recent increase in production of the freshwater prawn appears to be associated primarily with increasing regional demand, combined with a relatively well established hatchery-based production technique.

Other crustaceans of note are the mud crab (*Scylla serrata*) which is cultured only in South East Asia, particularly in Malaysia and Thailand. Its production levels have remained static at around 3,500-4,000t since 1986, and although market prices are good, production techniques have limited further development.

Table 2.13 Production trends for major crustacean species

Crustacan species		1986	1992	%/yr	Notes
Production increase > 20%					
Giant tiger prawn	Penaeus monodon	89384	388565	27.8	main Asia shrimp,good market
Whiteleg shrimp	Peaneus vannamei	35144	111075	21.1	main C&S American shrimp
Freshwater crustaceans neil	Crustacea	6000	33670	33.3	mainly crayfish-production led
Blue shrimp	Penaeus stylirostris	1351	12864	45.6	good qualities, C&S American
Production increase 10-19.9%					
Fleshy prawn	Penaeus chinensis	82909	207428	16.5	massive increase in China
Penaeus shrimps nei	Penaeus spp	22181	41994	11.2	general expansion,minor species
Giant river prawn	Macrobrachium rosenbergii	7198	19215	17.8	recent revival in Asia, markets
Production increase 3-9.9%					
Natantian decapods nei	Natantia	32891	56321	9.4	mixed category,species unclear
Metapenaeus shrimps nei	Metapenaeus spp	16775	23537	5.8	secondary to main shrimp prod.
Production -3% to +3%					
Banana prawn	Penaeus merguiensis	27206	28890	1	less interest,poorer growth, price
Production drop >3%					
Red swamp crawfish	Procambarus clarkii	44318	30991	-5.8	control and price problems

Molluscs

Almost all production falls under the general grouping of bivalve molluscs. The main species include Ostrea, *Crassostrea*, *Mytilus*, *Perna*, *Pecten.*, *Chlamys*, *Argopecten*, *Tapes/venerupis*, *Haliotis*, *Tridacna*.

Species entries are grouped according to major production groupings, i.e. oysters, mussels, scallops, clams and fresh-water/marine molluscs, with related nei categories as appropriate.

Associated groups such as cephalopods and echinoderms are not specifically included, though this is not significant, as very little of these groups are as yet produced in aquaculture. Table 2.10, 2.14 provide details of the main cultured mollusc species.

Table 2.14 Production trends for major mollusc species, 1986-1992

Species group	1986	%	1992	%	%/yr	Trends/notes
Aquatic plants						
brown seaweeds	2269880	66.7	3640344	67.5	8.2	large, v rapid recent increase, mainly laminaria, also undaria
red seaweeds	821220	24.1	1132654	21	5.5	moderate, recent growth, mainly porphyra, eucheuma, also gracilaria
green seaweeds & other algae	11040	0.3	17248	0.3	7.7	small, recent growth
misc. aquatic plants	298616	8.3	599543	11.1	12.3	moderate, recent growth, mainly China and Indonesia, also Japan, Korea Rep and DPR
group total	3400756	100	5389739	100	8	large, early fluctuation, recent growth
Other species						
frogs and other amphibians	15	0	884	4	97.3	negligible, high recent growth
turtles	760	2.5	902	4.1	2.9	negligible, fluctuating
crocodiles and alligators	1	0	61	0.3	98.4	negligible, early growth, now stable
seasquirts &other tunicates	23757	78.2	12685	58.1	-9.9	fluctuating, steep recent decline mainly seasquirts nei, Japan and Korea Rep
misc. aquatic invertebrates	5657	18.6	7079	32.4	3.8	small, mid-peak, recent decline, mainly Korea Rep
pearls, mother of pearl, shells	206	0.7	224	1	1.4	negligible, stable
sponges	0	0	1	0	n/r	negligible
group total	30396	100	21836	100	-5.4	small, declining

Molluscs have shown particularly wide variation in production trends, ranging from a marked decline in the case of ark clams (from 58,393 t in 1986 to 20,547 t in 1992), to a dramatic increase for carpet shells nei (from 723 t to 30,055 t). For oysters, formerly the most important group, production levels have been fairly irregular. On the whole, flat oysters (*Ostrea* spp) have decreased in numbers since 1986, and now contribute very little to aquaculture production, whereas cupped oysters (*Crassostrea* spp) have slightly increased, but when added together oyster production has remained relatively static at around 1m t per annum. Though *Crassostrea gigas* now has widespread distribution, and *C virginica* and *O edulis* have also been transplanted, there is a considerable degree of geographical separation for the cultured oyster species, most of which are still cultured around their indigenous range.

Mussels have recently overtaken oysters in volume terms, though not in value. The main genus of mussel is *Mytilus*, of which a number of species is cultured. *Mytilus edulis*, primarily grown in temperate European, N and S American waters, currently has the highest production level (around 29.3% of total mussel output) although this has decreased significantly over the last few years (due in part to the decline in volume in the Netherlands, described earlier). By contrast *Mytilus galloprovincialis* produced in Spain and the Mediterranean, has gradually increased production, to some 10.0% of total mussel production. Other significant *Mytilus* species are the Australasian *M. smaragdinus* and *M. canaliculus* with 1992 harvests of 58,600 and 46,500t respectively.

A smaller number of scallop species is farmed commercially, and though production volume is lower than that of oysters and mussels, total value is the highest in the mollusc group, and production is increasing rapidly. The main genus is *Pecten*, of which the species with the highest production is *P. yessoensis*, cultured in E Asia and Japan, which has the second highest production level of the mollusc species, some 65% of total scallop production. The overall growth rate in production over the period has been 22.3%, and 1992 saw a large rise in production from 378,000 to 546,000 t, an increase of 44.4% from 1991.

Various species of clams and cockles are cultured at significant levels. These include *Venerupis japonica*, *Anadara granosa*, and *Tapes* spp, grown widely in Asia, the N American *Mercenaria mercenaria* and the razor clams *Solen* spp, grown mainly in E Asia, all of which show increasing production levels. *Arca* spp also has production levels over 20,000t but production has fallen significantly. A range of other clam and cockle species is also cultured in smaller quantities, mainly in Asia and N America.

Also of note in the mollusc group are the very high value abalones (*Haliotis* spp), now cultured in a number of regions, which have a small but steadily increasing production. The giant clam (*Tridacna* spp) is moving gradually from experimental production in the Pacific Islands, and the various pearl oysters, though insignificant in volume terms contribute massively to some of the smaller economies of this region. Finally, the related groups of squids, cephalopods and sea urchins are being cultured in a very small scale in various locations, primarily in Asia, where their high market value is attracting some interest.

Aquatic plants and other species

The aquatic plant group is subdivided into red, brown and green seaweeds, and other aquatic plants. Recent production trends are shown in Tables 2.10. and 2.15.

Table 2.15 General trend characteristics, aquatic plant/other species groups

Mollusc species		1986	1992	%/yr	Notes, etc
Production increase > 20%					
Japanese scallop	Pecten yessoensis	163601	546222	22.3	market demand, cost control
Carpet shells nei	Tapes spp	723	30055	35.1	species definitions?
Production increase 10-19.9%					
Sea mussels nei	Mytilidae	210670	538900	15.9	general rise; species definition?
Japanese(=Manila)clam	Venerupis japonica	123037	328031	17.3	market price, simple techniques
Marine molluscs nei	Mollusca	65248	145372	14.3	recording artefact?
Green mussel	Mytilus smaragdinus	23856	58634	16.2	good price, simple systems
New Zealand mussel	Mytilus canaliculus	15636	46500	19.9	market/industry development
Portuguese cupped oyster	Crassostrea angulata	5919	13380	14.6	good prices, species option
Production increase 5.1-9.9%					
Razor clams	Solen spp	126175	198598	7.9	simple techniques
Blood cockle	Anadara granosa	88291	140016	8	wide demand, simple techniques
Mediterranean mussel	Mytilus galloprovincialis	73014	108794	5.7	moderate prices but simple system
Hard clam	Mercenaria mercenaria	19124	29224	7.3	good demand, capacity constraints
Production +/- 5%					
Pacific cupped oyster	Crassostrea gigas	763925	795004	0.7	heavily developed, price problems
American cupped oyster	Crassostrea virginica	130020	113209	-2.3	traditional; declining returns
Philippine cupped oyster	Crassostrea iredalei	16465	15103	-1.4	other species preferred
Clams nei	Bivalvia	12161	13421	1.7	general category
Production drop >5%					
Blue mussel	Mytilus edulis	433377	318047	-5	Netherlands variability
Ark clams	Arca spp	58393	20547	-16	environmental effects?

Brown seaweeds, used mainly for industrial products, accounts for 67.6% of aquatic plant production but a lower proportion of total value. Within this group, Kelp (*Laminaria japonica*) accounts for some 86.3% of this category and has increased by about 10.4% per year over the period. A small but steady increase in production is also to be observed for the three main red seaweeds; *Porphyra tenera*, *Eucheuma spp* and *Gracilaria spp.*, the last of which has recorded the highest rate of increase, 26.9% annually, over the period.

The recorded production of the main 'other species' group, sea-squirts nei, has decreased by around 10% annually over this period, though interest is now widening in the culture of this group, as market prices, particularly in Asia are good.

2.6 System trends

Information on the types of production system employed is requested in the official FAO statistical returns, and is variously if only occasionally indicated. In general, however, not enough information is available specifically or consistently to make convincing descriptions or presentations of trends across all the input sources. There are also problems with system definition, between extensive, semi-intensive, and intensive, between ponds, lagoons, and enclosures, and between ponds, tanks and raceways. Many trout farms use long earth ponds with high water turnover, which in technical terms operate in most respects like raceways. Into what category do they belong? The answer might depend on whether form and materials, or principles of production, were being used as primary criteria. Silos are also defined as a systems category, but are extremely rare, but recycle systems, which are not mentioned, are becoming more common and may be useful to note. Definitions between enclosures, pens (some aquaculturists refer to cages as pens) and barrages also require to be clarified. For barrages (as with lagoons), there is also some question about production being attributable to aquaculture or fisheries. As noted earlier, for molluscs, brackish water and marine environments are used by some sources as substitutes for on-bottom and suspended culture systems.

Despite these uncertainties, it is likely that much of the expansion in aquaculture in the near and midterm will occur around the development of existing systems, either by gradual expansion of production facilities, or by incremental productivity gains, or through a combination of these. Some general comments on trends in system development, based on the major species groups and production regions, are presented in the following section.

Fish culture

The major concentration of fish culture is in Asia and still involves photosynthesis-driven earth pond systems, in inland and coastal areas, traditionally run in various forms of mixed-species culture, either deliberately, or because of inadvertent introduction of wild larvae or fry.

A similarly long tradition of pond culture developed in Central Europe, in more seasonal climatic regimes. These systems have all evolved over centuries of use, and now represent a varied mix of traditional empirical practice and more modern scientifically-based technique.

These systems are normally operated with varying degrees of fertilisation, ranging from *ad-hoc* supply to a regular and organised management system. Ponds vary widely in size, and as production in many areas has gradually tended towards intensification, with more specific and greater levels of stocking, fertilisation and feeding, the average pond sizes tend to be smaller. Systems such as these, which are also used for crustacean culture, are still the dominant form of global aquaculture production.

Many pond systems are rain-fed, or seasonal, and a considerable proportion are used for multiple purposes, including water storage, domestic and animal water supply, irrigation, washing, and waste absorption/dilution. Some systems are integrated with animal and crop production; many of the traditional integrated systems also use human wastes and nightsoil. A notable part of traditional freshwater fish culture production in Asia is also associated with rice production, with fish collected from deeper water areas during dryer seasons; more recently the introduction of fry and fingerlings into oxbow lakes and seasonal water bodies has become significant. More modern systems have also been developed in which aquaculture ponds serve as reservoirs for crop production; alternative arrangements involve irrigation channels.

More intensive pond systems increasingly make use of water exchange and aeration to maintain environmental conditions; some systems also use circulating flow pond mixing, sediment collection and water reuse. Some but not all pond systems use gravity flow water supplies, are drainable, and are periodically dried out and conditioned; others - e.g. channel catfish ponds in N America and intensive fish ponds in Taiwan, commonly use groundwater supplies. Coastal ponds have traditionally been tidally exchanged, though now more commonly have pumped water supply.

In highly industrialised systems, typically for eels, catfish, tilapia and striped bass, and also for intensive fry production of salmonids - mainly in Europe, N America, and in some Asian locations, complete recirculation systems are employed.

For salmonid and marine larval culture, initial levels of development were frequently in the form of government hatcheries, based on pond or tank systems. Stocks were initially released into open waters. The main development phase for intensive commercial inland fish farming - mainly eels, trout and channel, catfish was from 1950-1980, when many farms were established using simple earth ponds or raceways. More sophisticated systems - e.g. recycle units, intensive tank farms, were also developed during the latter part of this period but were rarely commercially viable, except for hatchery production, where they are still widely used. Production during this phase rapidly supplied traditional markets, and cost pressures tended to slow down expansion quite markedly.

These systems are still widely in use, but are being run with increasing mechanisation, management input and control over feed and water exchange. In Japan and E Asia intensive marine larval culture was initially developed for restocking, latterly for ongrowing; intensive land-based marine fish culture, using pumped seawater ponds, tanks or raceways was developed there, in Europe and N America, and was also extended to areas such as the Middle East, for species such as salmon, turbot, dover sole, eels, seabass, seabream, tilapia and grouper.

However, these systems have not developed significantly due to relatively high production costs, and the increasing use of cages. The use of sophisticated (mainly tank-based) hatchery systems has continued however, as the potential value of high quality marine larvae justifies the capital and operating cost.

Simple enclosures and cages have been traditionally used in Asia for freshwater and marine fish culture, in lakes, sheltered bays and inlets, often at the family/artisanal level, commonly with family housing constructed above the culture unit. These systems are still widely used, and as they are relatively cheap and simple to establish, have developed quite rapidly in some localities. More recently, since the mid-80's, larger and more robust cages were developed, widening the possibilities of aquaculture in less sheltered waters. Cages of this type, typically timber, steel, or plastic, form the mainstay of cage aquaculture throughout the world. Engineered enclosures were also developed over this period, but have generally failed to become established because of environmental, maintenance and stock management problems. From the late 1980s the first viable offshore cage culture systems were developed, and from the early 1990s became sufficiently proven to make open-water aquaculture a more practical reality.

Crustacean culture

The early development of crustacean culture, again in Asia, was generally associated with by-crops from tidally-fed coastal fishponds or 'tambaks'. In the 1970s these were adapted towards crustacean monocultures, and used as the basis for expansion during the '80s, but were limited by the availability of seed (hatchery and/or wild seed), and by technical expertise. Original hatchery techniques, based on *P. japonicus* involved large production tanks, but were generally unsuccessful for other species. A range of more sophisticated hatchery systems, using smaller tanks and live feeds, was developed in the 1980s; these have generally been simplified, and have become increasingly effective for most of the main aquaculture species. Ideas for more intensive culture were proposed for penaeids, and for lobsters (*Homarus* spp), during the late 1970s and early '80s, with e.g. intensive recycle systems, and intensive raceway culture, but these were not viable, and little production resulted.

The major period of expansion occurred in the mid 1980's, with existing traditional tambak type areas being moved to shrimp production or intensified, and extensive new areas - often mangrove habitat - being cleared. More recently, pumped systems became the norm, with some movement of sites away from coastal fringes. However, many farms were developed with little idea of site and soil suitability, pond management, water exchange, or environmental control, and as a result, many systems were overloaded, crops failed, and significant coastal areas abandoned.

Sectoral growth rate has now dropped in some regions, with less new area being taken up, though other countries - India, Mexico, Malaysia, Vietnam and China are opening further areas for development.

A recent trend has also seen production of penaeids in cooler waters - either massively as in the case of China, or on a much smaller scale as a part-season crop in e.g. lagoon or salt-pan areas of the Mediterranean.

The latter acts as a 'niche' crop which is valuable enough to justify the effort of incorporation, even if quantities and yields involved are modest. More recently, interest in lobster production has revived, in this case by restocking, sometimes on artificial reefs.

For freshwater crustacea, *Macrobrachium* culture in ponds is the primary focus, the main growth phase occurring in the early to mid-80's, with the successful development of hatchery techniques and their operation at the 'backyard' level. Many countries participated at this stage, and dropped out as market potential proved less than stimulating, but production has recently moved upwards. Interest in pond culture or extensive reservoir stocking freshwater species such as crayfish, and in Australia, the marron and yabby, is continuing, and production from these systems would be expected to continue showing positive though modest growth. The production of *Procambarus* has evolved as an extensive culture system in rice fields in the southern parts of USA and Europe; it is varyingly considered to be an economic benefit or an environmental disaster. There have various attempts at more intensive aquaculture of *Macrobrachium* and crayfish, but none have been commercially viable.

Mollusc culture

The aquaculture of this group has had a very long history, and is a tradition in many parts of the world. Simple artisanal techniques are involved, no food is required, and the euryhaline species are adaptable to a wide range of environmental conditions. In many areas, modern-day approaches using ropes, rafts and longlines (suspended culture methods) and hatchery produced seed overlie many more traditional forms of activity such as natural spat collection, and fixed or on-bottom culture methods such as seabed laying, ground protection and conditioning, and the use of stakes and trestles. The simplest and most traditional of these methods are still widely practised, and account for the bulk of production in many regions, particularly for clam production. Scallops and oysters are also grown widely using on-bottom methods, though in E Asia, particularly Japan, suspended culture methods are also important. Mussels are increasingly being produced on suspended systems, though traditional mussel beds are still operated in some areas, and the large-scale relaying systems in the Netherlands are still significant. The simplest systems are more akin to various forms of fisheries practice, and have often been recorded as such.

In development terms, the simplest practices originated in managing natural stocks of molluscs in tidal estuarine areas, and the development and use of simple spat collection techniques to allow stocks to be set up in favoured or controlled areas; these simple systems were subsequently modified, e.g. in the French development of ponds with restricted water flow, creating warmer temperatures, and locally enriched for better food; in some cases, better growth was obtained with large scale dredging and relaying into more productive habitats.

Traditional spat collection systems were also improved, e.g. in the 1950s and 60s with the Japanese units, using better materials. Hatchery production methods were developed in the 1960s and 70s for oysters, scallops and clams, and provided the first opportunity for independence from the vagaries of natural collection, as well as the means for genetic improvement. However, hatchery production is still not significant in many areas, as the cost of wild spat collection is so low.

The introduction of floating culture systems offered great improvements in terms of simplicity, access to open waters, greater depth of water column, and a great increase in areal productivity, and led to rapid increases in production, particularly for mussels. The development of basket culture techniques allowed oysters and scallops to be grown, though market price constraints in some areas limit the capital cost available for such systems.

The use of such methods, and the development of submerged systems for more exposed areas remove culture locations from the constraints of the traditional intertidal coastal margins, and offer far greater potential for production, as already evidenced for example by the dramatic increases in productivity (as e.g. tonnes/km coastline, or tonnes/km2 coastal margin) attained in China and South Korea.

There are also recent developments in transplanting molluscs from beds to suspended systems to improve final quality; in some areas, the production of part-grown stock is becoming more widespread, allowing greater flexibility of production, and greater control over size and quality. Higher value species such as scallops and abalone are also being produced in managed semi-natural beds, sometimes harvested by divers.

A recent revival in interest in using molluscs to filter out waste materials from intensive fish or crustacean culture effluents has also offered further potential for system development. However many mollusc production areas are under regular threat from problems of environmental quality and disease, and there is likely to be increasing pressure for management in heavily stocked areas with external sources of contamination.

Aquatic plant production

Most systems are very simple, and as cheap as possible, as cost margins are usually very low. Normally, seed material is cut from good specimens or grown from existing stock, which is regularly cropped, placed or tied into position, with sufficient spacing for growth, ventilation and access to nutrients. Stock needs to be tied securely, protected if necessary from predators.

Management is normally very simple - cleaning, partial/ continuous harvesting, transplantation to new areas. A range of systems has been developed . <u>Bed/pond systems</u> are widely used with *Gracilaria* or *Caulerpa*; these are typically conventional small brackishwater ponds, sometimes those too shallow for good fish or shrimp yields, with limited fertilisation and regular water exchange increasing as the stock spreads out.

<u>Stake and line systems</u> are widely used in SE Asia for *Euchema* and *Gracilaria*; simple wood or bamboo stakes knocked into muddy/sandy tidal areas supporting a crossed network of nylon line set at intervals, 30-50cm above the seabed, depending on site and species. Stems of seaweed are tied directly on to the line. <u>Raft and basket systems</u> have also been used in SE Asia, though the systems are relatively expensive and labour intensive.

Containers, e.g. various sizes of tanks or raceways, have also been used, with various matrices for attaching algal material, grown in continuous or semi-continuous flow. However, these also are usually experimental and normally intended for waste nutrient removal.

2.7 Institutional and development features

Aquaculture has moved steadily from extensive semi-natural methods in traditional areas based on static or tidal ponds, lagoons and shellfish beds, towards modern intensive approaches using managed ponds, tanks, raceways, cages, rafts and longlines, in which many new areas and environments are becoming involved (see e.g. ADCP 1989). Such is the pace of development, the growing competition for markets and resources, and the growing economic consequence of success or failure, that structures of planning and development, and the legal and institutional framework in which they exist, have been increasingly challenged in responding to the emerging needs of the sector, or for creating and maintaining an appropriate climate for support, resource allocation, management and control.

The experimental and relatively local small-scale nature of much aquaculture activity has until very recently permitted, and even favoured a liberal development approach, with few restrictions and considerable financial and technical support. Indeed the purpose of the 1976 Kyoto conference had been to highlight the potential for aquaculture and forward the case for an almost unreservedly expansionist approach. In anticipation and response to this and other influences, FAO, through its regional Fisheries Commissions, the Aquaculture Development and Coordination Programme (ADCP) and other regional initiatives, had in the 1980s carried out a range of planning and development exercises aimed at organising and stimulating aquaculture development. This strategic approach has been continued in outputs such as the 1988/89 ADCP regional reviews, which considered a range of institutional factors, Nash's (1992) review of human resource planning in aquaculture, and a more recent series of joint studies through SIFR on regional research needs for the sector.

At this juncture, several key features of development can also be recognised:

- although basic resources may be available, there is sizeable shortfall in aquaculture production in many areas, particularly where the need (in terms of GDP or nutritional status) has been most evident, although considerable development inputs had been committed over the last two decades. As noted in the land-mark 'Thematic Evaluation' study (UNDP/NMDC/FAO,1987), constraints appeared to be social, economic, institutional rather than scientific/technical; this discrepancy continues;

- more recently, a number of areas have seen a rapid development of artisanal aquaculture, associated with a range of development factors, including the rise of an active private sector, changing approaches to agricultural development, and key technical change;

- in areas where aquaculture has grown, and where key sub-sectors have become prominent, the size and nature of the emerging industry, and the scale of individual production units, has started to raise questions concerning physical and economic development, resource demands and environmental protection;

- in areas where commercial aquaculture has been the primary feature, varying degrees of concentration have occurred, as smaller and less efficient producers have gone out of business and/or been absorbed by larger competitors; this has changed the social and economic characteristics of the sector;

In reviewing sectoral status and characteristics with respect to development, it is useful to differentiate the levels of activity attained within producer countries. Table 2.16 provides a simple classification of national status with respect to aquaculture development, which may in turn be used as a basis for identifying appropriate planning and development strategies.

Table 2.16 Country development status categories

Country aquaculture status	Production characteristics	Institutional characteristics
with emergent subsectors; (74 countries noted)	< 1000 t/yr; 1 or 2 species, mainly fresh water, sometimes only R&D level	few small-scale farmers; lack of critical mass, support services or good hatcheries;
with growing subsectors	> 1000t/yr, usually 1 or 2 species, significant small-scale and/or commercial development	critical mass forming, but support services often limited; varies according to whether primarily artisanal or commercial in nature
with established but simple subsectors	1000-200,000t; 1 or 2 products in the same system or environment, usually within a smaller geographical scale	varying levels of support services; sometimes only within industry; good hatcheries, local expertise in major products; moderate-good representation, depending on scale of sector
with complex subsectors	broad range of species in broad range of environments; by definition, of a scale to cover latitudinally or altitudinally a wide range of environments/habitats	usually good levels of support services though coverage limited by complexity; possible conflicts of priorities, e.g. fish/molluscs, inland/ coastal, artisanal/commercial

Source: Developed from Nash (1992)

As will be discussed in more detail later in the review, a table such as this invariably simplifies a rather more complex arrangement of factors, and so it is difficult to make absolute distinctions on the basis of national or sectoral features. The social and political characteristics of the countries involved, and their economic and other policy objectives may all have a particular effect on status and characteristics. The level of development may also depend to a considerable extent on national market and trade features. The general levels of resources available to the institutional sector will also be important. The differences between simple and complex aquaculture sub-sectors may be due as much to accidents of geography as they may be to technical skills, organisation, etc,

Within a context such as this, the respective roles of institutional and private sectors are a critical feature of the nature of development, regardless of the defined country status. Their relationship can vary with the direction of development influenced in different ways: either institutionally driven, private sector driven, or a mixed economy approach.

In practice, many countries exhibit features of each of these categories, depending on the stage of development of the sector, national political and economic evolution, and the needs/features of the different sub-sectors. The areas in which institutional and other factors relate to aquaculture development are discussed in more detail in the following chapters. Though individual countries can be examined in more detail to determine key characteristics, opportunities, and constraints, various thematic issues can be highlighted, which merit review and discussion at the strategic level. Some of these are summarised in Table 2.17.

Table 2.17 Key institutional/development issues

Issues	Characteristics	Key aspects.
Policy issues	Overall approach to aquaculture development, consistency with sectoral and line management objectives	Political process, policy analysis, legislative development
Social/human/development issues	The extent to which aquaculture can be taken up and can satisfy family and community needs e.g. food security	Family, gender, nutrition, skills, techniques, human resource development
Institutional/sectoral context	The role of institutions in support and regulation of the sector; targeting of development, interfaces with other sectors	Institutional capacity, development strategy, efficiency and relevance
Resource characteristics	The nature and extent of resources available, competitive allocation, sustainability objectives	Resource strategies, pricing, sustainability assessments
Demand/market trends	Overall levels of demand, opportunities for growth, income, supply to poorer sectors	Market structures, competition, purchasing power, economic growth.
Production/technology trends	Strategic areas of change influencing production processes, environmental interactions, competition	R&D strategy, technology assessment

Issues such as these require a clear policy overview as well as an informed and responsive system of planning and management, to ensure efficient longer-term development, using resources effectively, to protect the environment, and the interests of other users of resources, and the wider interests of the community. The rise of aquaculture, whether gradual or dramatic, as a new and apparently demanding user of resources has highlighted in many countries the absence of appropriate planning and development frameworks (see e.g. Van Houtte et al, 1989). The probable need to rely even more heavily on aquaculture for the demands of future generations places greater responsibilities on present day decision making and action.

3. DEVELOPMENT ISSUES

This section aims to review the overall issues and trends which may affect the future path of aquaculture, which might determine the nature and characteristics of the choices to be made, and in turn, the real opportunities for various development aims to be achieved. In particular, though it would appear that aquaculture will grow and develop, will or can it do so in ways which might improve food supply and food security for those sectors for which this is most important? And if so, how can such objectives be met? The previous record of institutional-sector development has been mediocre (UNDP/NMDC/FAO 1987, World Bank 1991b); can this be improved? Though the previous sections have focused almost entirely on the aquaculture sector itself a broader perspective is required to understand its role for the future. To illustrate the impact of aquaculture in a global context, Table 3.1 summarises recent production and value trends in developed and developing country sectors respectively.

Table 3.1 General pattern of aquaculture development

	1986						1992					
	Inland		Marine		Total		Inland		Marine		Total	
Country status	Prod'n '000mt	Value US$m	Prod'n '000mt	Value US$m	Prod'n '000mt	Value US$m	Prod'n '000mt	Value US$m	Prod'n '000mt	Value US$m	Prod'n '000mt	Value US$m
Developed	947	2,318	1,526	3,030	2,473	5,349	853	2,580	1,797	5,494	2,650	8,074
Developing	4,833	5,966	1,471	2,299	6,304	8,265	8,199	12,447	3,051	7,057	11,249	19,503
Total	5,780	8,284	2,997	5,329	8,777	13,614	9,052	15,027	4,848	12,551	13,899	27,577

Source: FAO 1994; excluding seaweeds and others.

The value of aquaculture production ($ per tonne) has risen significantly in both developed and developing countries, although this increase has been greater in developed countries. Earlier production was more influenced by lower value species groups such as carps and molluscs; more recently higher value has been obtained through the growth of culture of shrimp, salmonids and marine species. The dependence on market opportunity (and market price) as a primary determinant for growth must be a serious issue, and the possibility of aquaculture offering realistic and substantial prospects for lower cost food production might therefore be questioned.

However, before concluding too unilaterally in favour of market driven development, it would be wise to analyse matters further. It is useful therefore to summarise the range of issues which may be relevant to the sector, and might need to be considered in any more complete assessment of the extent and nature of development. Key issues and their implications for aquaculture are summarised in Table 3.2.

Clearly these objectives and their consequences are not mutually exclusive, and in many instances, developments or activities satisfying one of these may well contribute importantly to others. Nonetheless, where it is feasible to guide development in this way, the choice of particular objectives or sets of these, may have significant effects on the way in aquaculture might be organised and operated, and may determine the nature and characteristics of national and international policy with regard to aquaculture development.

Table 3.2 Summary of key development issues

Development issues	Primary objectives	Implications concerning aquaculture
Primary policy issues		
Economic growth	Output measurable value in conventional terms e.g. GDP, stocks	Maximise output through diversified strategy, or concentrate on simple and easily developed sector
National objectives	Specific aims - e.g. food security, self-sufficiency, region development	Possibly continue development even if inefficient; projects in favoured areas;
Allocation	Equity and access to specific resources; economic efficiency	Mechanisms must be chosen for allocation; competition may affect type of aquaculture
Management	Control over specific sectors, planned development	Possible restrictions for types or scale of development
Human/social issues		
Income distribution	Opportunity for wider sectors of population, redistribution;	Aquaculture targeted to improve conditions in poorer areas; tax laws to encourage investment
Poverty focus	Targeted approach to improve incomes, living standards; health or economic indicators	Use of aquaculture in defined context, usually resource-poor, with new areas of right and access
Role of women	Recognition of gender issues, access, opportunities, empowerment; gender analysis/indicators	Targeting towards female/family groups, recognition of women's' inputs, management
Rural security	Stable rural populations, adequate living standards, health	Aquaculture used as one of a range of measures to gain productive advantage from rural resources
Human resource development	Improved levels of skill, opportunity, capacity, income levels;	Increase success of adoption, better methods, wider and more diverse aquaculture sector.
Natural resource issues		
Biodiversity	Maintenance of species and habitats	May constrain use of species/strains; aquaculture could contribute to restocking, rehabilitation
Sustainability	Bequest of similar levels of welfare to succeeding generations	Focus towards resource-efficient systems, not making heavy demands on ecosystems
Environmental management	Control over various ecosystems, habitats to meet quality objectives	Various degrees of control over installation, activities, methods of operation, possible cost

As the table indicates, a range of development-related issues may apply to the aquaculture sector, and if one or more of these are specifically targeted, the implications for aquaculture will change accordingly.

It is useful to record the existence of at least two major and different perspectives, corresponding in broad terms to the laissez-faire and dirigiste policy/planning approaches, namely that:

- development in the wider sense will occur as a natural consequence of market-generated private sector growth, and that there is no need (or it is wrong) to distort this with specific targeted measures; rather, 'trickle-down' effects - the opening of opportunities to service growth areas - will ensure that benefits extend to any corner of the society, however disadvantaged; a less dogmatic version of this view contains elements of this argument, but identifies restricted or unfair trade arrangements as being the major constraints, therefore focusing on improving trading opportunities as a means to allow such development to occur;

- many forms of market-oriented development will merely improve the economic position of those who have existing access to resources, often, through expropriation or damage of common resources, reducing opportunities for disadvantaged groups; it would therefore be necessary to adopt specific measures to help counteract these effects, and ensure a more balanced and effective longer-term future;

These contrasting perspectives hold different outcomes for aquaculture development.

In practice, though the former view has gained some prominence in the last decade, the scarcity of convincing evidence of its effectiveness has tended to uphold the potential virtues of the latter approach. In fact, many of the poorer countries do not in any case have a sufficiently robust private sector to have any positive significance or effect in the first sense, and so the possibility of the use of this mechanism may be rather academic. The full acceptance of a more interventionist approach is however often tempered by a sense that it should be at least partially market-oriented, e.g. allowing participants to make use and respond to local market signals, rather than providing an unrealistic, expensive and normally unsustainable alternative to the 'real world'. Similarly, development activities themselves should be carried out in an efficient and cost-effective way, and given in practical terms a shortage of development support capital, there should be at least some plausible cost-benefit argument to be made for the intervention.

3.1 Food security/social development issues

Although the underlying aim of the present exercise, food security issues *per se* have here been deliberately understated, to allow broader discussion of the sector. Clearly however, as a food producing sector, the development of aquaculture will have a direct or indirect role in promoting food security, but it would be important to determine, were food security to be the major issue, whether this could be ensured simply by general aquaculture development, or whether it would require specific measures. On a comparative basis, would aquaculture be an efficient means of delivering food security? These issues will be brought into focus, and it is useful to consider some specific points with respect to aquaculture's role:

- aquaculture products, as those of fisheries in general, cannot be considered in absolute terms as 'obligate' nutritional components; i.e. though they are desirable, and contribute meaningfully to the benefits of good nutrition, their absence from dietary intake is not *per se* life threatening; however, fishery products are an important part of diets in many parts of the world, particularly the 'fish rice' cultures of Asia, and have the general potential to contribute further and more widely;

- in most cases, food security in the primary sense is not a major objective of present day aquaculture production. It does, however, contribute with varying degrees of efficiency to the overall food supply system, and broaden the overall opportunity for income and food access within the societies involved. With appropriate identification of targets, there is a substantial area of potential for aquaculture to contribute, both in terms of increased production and economic benefit, and in terms of specific opportunities, perhaps associated with secondary crops, to meet the needs of poorer sectors of society;

- it may be important to distinguish between short and longer-term aspects of supply. The longer-term aspects are those which will determine the general level of food supply to a growing population. The shorter-term aspects will determine whether there are food security risks inherent in the supply system, for example seasonal shortages, which may be addressed by aquaculture production.

- as with other food commodities, there will be pronounced differences in food supply and security features between and within individual countries; though the existence and activity of any food-producing sector will be important, the fisheries sector, and the aquaculture components, will play different roles at the local level; a wide range of institutional and private sector interests concern the sector, and would have to be brought into effect in a suitable manner to ensure objectives could be achieved;

- figures of mean levels of production and its variability may be useful indicators of the reliability of food supply through aquaculture; clearly those species and systems most dependent on ecosystem and habitat will be most susceptible to external change, though highly managed systems will also be sensitive to disruption, sometimes with a more severe consequence; in broad terms though aquaculture is more stable and predictable in output, resource use and production cost than is the capture sector, it is potentially subject to a range of risks;

- clearly some of this variability can be overcome where supply infrastructures and market mechanisms allow sufficient interchange of products, and some degree of buffering is possible between under and over-supply; in general terms, supply will be more reliable when there is greater diversity - of producers, species, locations, product forms in the system;

- aquaculture can potentially be developed in areas where fisheries cannot necessarily provide; either due to lack of stocks or fishing capacity, to overfishing, or where products are exported from the originating community. However, the use of resources by the aquaculture sector requires careful consideration of whether production results in a net gain in food opportunities, or whether the income generated could be distributed effectively enough;

- the primary focus of the role of the aquaculture sector and its products would therefore concern the identification of realistic ways in which food security could be enhanced; not necessarily by making this the primary objective of most forms of aquaculture, but through recognising suitable opportunities and maximising the benefits which might be derived; in particular, the importance of diversity might be highlighted - in terms of locations of production, species and systems, and entities/agents involved;

As Table 3.2 indicates, areas of aquaculture activity can be identified, and their characteristics and potential outlined.

The potential constraints to development must also be recognised, whether social, institutional, economic, or resource based. Resource requirements in particular need to be identified.

Many major areas of existing aquaculture production are changing rapidly in broader economic terms, and while this is very positive in stimulating markets, it also implies increasing competition for resources of all types, and in particular, to changing trends of production - the movement of production from spreading urban areas, the increasing effects of environmental damage, and the increasing difficulties of dealing with disrupted societies.

3.2 Sustainable development: practical concepts

An overlying development issue is that of sustainability, and sustainable development. The aquaculture sector depends on a wide range of input resources, producing a wide range of outputs and impacts. In its more intensive forms in particular, various adverse effects can be identified, which in the longer term might jeopardise the resource base on which the industry depends. Similarly, other forms of development can a have a significant negative impact on aquaculture, and remove otherwise useful and valuable opportunities for food production. While such problems have generally taken second place behind the greater benefit of economic growth and improved supply of high quality food, there are increasing concerns about the balance between environment and development. These in turn increasingly call into question the more simple production-led approaches to sectors such as aquaculture, and require approaches in which the social and environmental context is more clearly expressed. Thus while food security aims might call for increased or better targeted production, there may be little real benefit if this is at the cost of seriously impaired natural resources, and a longer-term failure of their support.

The World Conservation Strategy (IUCN, 1987) first brought the issues of natural resource and environment in the concept of sustainable development, recognising "our responsibilities as trustees of natural resources for the generations to come". The first major recognition of the broader goal of sustainable development - involving both economic development and environmental quality was that of the Bruntland Commission:

> " Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

The UNCED Rio de Janeiro conference of 1992, marked major political recognition of contemporary thinking concerning the human economy and the environment, and the explicit entry of sustainable development into the practical philosophy of political strategy, planning objectives and management action. In common with other areas of human activity, the issues of sustainability are being given particular focus in the fisheries and water resource sector, and may gradually act to change perceptions of desirable forms of aquaculture development and management. However, while sustainability can be described in general terms, its implications for the aquaculture sector need to be clarified, to define criteria by which current activities could be operated and new developments specified.

At a simple level, sustainability might mean that a specific activity can continue or a resource be available for at least the medium term, and is not associated with or dependent upon rapidly depleting inputs. In project development terms a simple definition also involves the extent to which an activity depends and might continue to depend on external (e.g. development support) inputs.

However, in a wider and stricter application, sustainability would require no diminution of future potential, and the provision of "intergenerational equity" in any or all components of the geosphere; it may focus quantitatively on aiming to maintain, and if possible to increase the world's "capital stock" - defined primarily as the quantity of physical and biological resources, but also extendible qualitatively, beyond the immediately utilitarian to include e.g. human skills, technological potential, sources of satisfaction, etc. Such a structure might then allow for depletion of one or more capital stock elements if matched by gain in other areas. Jacobs et al (1987) note five key elements:

- integration of conservation and development
- satisfaction of basic human needs
- achievement of equity and social justice
- provision for social self-determination and cultural diversity
- maintenance of ecological integrity.

According to Pearce (1991) most definitions, including that of Brundtland, suggest as core issues:

- *Futurity:* concern for the well-being of future generations. (inter-generational welfare)
- *Equity:* concern for equity for the current generation (intra-generational welfare)

Though not explicit in the Brundtland definition, but strongly advanced elsewhere, may be added:

- *Environment:* Greater emphasis on the environment.

All these are issues which will affect the direction of aquaculture. The following chapters consider emerging factors which are likely to affect the driving forces in the development of the sector. These are grouped as general development and technical issues, social and institutional factors, and in terms of overall implications for resource use and environmental management of the levels of growth described here and elsewhere. The existing status and overall potential of various regions for aquaculture development with respect to resources and underlying driving forces are also considered.

3.3 Current factors for development

If aquaculture is to develop and provide for current and future needs, and do so sustainably, by whatever criteria used, its interrelations with resource use, human activities and value systems need to be examined. To meet future demands, maintaining present *per capita* levels of fish consumption (i.e. even without satisfying unmet needs of poorer societies and communities), aquaculture production would have to expand significantly (New, 1991, Csavas, 1995). Assuming similar or even reduced levels of fishery production, output might require to rise by some 50% above 1990 levels by the year 2000, and by the following generation, depending on demographic outturns, might easily be required to double. More natural resources would be employed to achieve this, and to varying degrees traded for physical/economic capital, and in turn human and societal benefit.

In the context of such interrelations and the pressures from such rapid change, aquaculture development will have to be carefully guided by a wide range of concerns, including:

- General concerns: sustainabiliy of growth, efficiency, reliability, comparative performance with other food production

- Human/societal concerns: human resource development, equity in allocation of benefits, consumer safety, disease and contamination

- Resource/environmental concerns: resource use, environmental interaction, management and control

Sectoral growth and change

In very broad terms, it is reasonable to expect both quantitative and qualitative change in aquaculture development. That is, overall growth in output will be achieved:

- by expanding its scale - in terms of the land and/or water areas involved, and;

- by developing its productivity - through increased net yields, from productivity gains, higher rates of turnover, and lower levels of loss;

To achieve the kind of expansion that is suggested, the aquaculture sector will have to undergo many changes and seek to remove some of its current constraints; these changes will include, inter alia:

- improvements in production efficiency through better survival, lower feed use, use of artificial early feeds, better environmental tolerance, better disease resistance, development of better-tailored production systems; this will reduce costs and increase effective capacity;

- improvements in overall product quality, through better broodstock, better egg and fry care, disease control, nutritional regime, environmental management; this will reduce losses and improve market-ability of output;

- lengthening of the productive season, through e.g. broodstock selection, out of season spawning, use of other species; this will widen market opportunities, improve utilisation, reduce costs;

- widening the product range from existing stocks, e.g. by producing larger fry, part-grown stocks, different market size stocks, specific genetic strains, single-sex stocks; this will widen market opportunities, improve utilisation, possibly allow premium prices to be obtained;

- diversification, through use of other species, integration with other forms of aquaculture; to spread market or technical risks, widen base of activities, maximise use of specialised skills.

Market development and diversification

The development of markets at all societal levels will be sensu latu an essential determinant in the extent and nature of growth for the sector. Although the importance of wider development objectives has been recognised, these themselves will not be sustainable unless they result in outputs which are desired by individuals and communities.

The present focus might also be assumed to be to derive wider benefits from production, rather than production being an incidental, non-critical by-product of social development. It is obviously difficult to make accurate market forecasts for aquaculture products, and hence for inputs and development needs.

However, the primary model might be that aquaculture expands at various rates, and that provided technical change can compensate for rising real term resource costs there may the potential in the medium term for production to be available at approximately similar real price levels, and possibly cheaper.

In such a way, wider sectors of the community could benefit directly. Gradual replacement of capture fishery demand might result, and the combined resource might be better able to meet future needs across a range of social levels.

Although drawn from medium-high price categories, useful examples for this trend might be found in the trout, salmon and channel catfish culture sectors, which have expanded to a scale many times those of their traditional capture fishery market.

This has been accomplished partly through co-ordinated market development, supported by cohesive producer groups, and partly through significant real price reductions, which have together widened the customer base. This in turn has acted to reduce margins and has forced considerable improvements in efficiency, both in production sectors themselves and in the major support sectors such as feed and seed supply, which have had to become more efficient in their own use of resources. These sectors are continuing to grow, have a sufficient producer base to encourage further research and development, and are confident of widening market opportunities.

While technical constraints clearly apply in any sector, it is instructive to question the wider range of options potentially available in the development of market opportunities. Diversification could involve:

- increasing the variety of output within the same species; including different sizes, production times etc..; this may also include genetic diversification - colour morphs, changed body configuration, single sex species, etc;

- diversifying species within similar groups; usually relying on similarities in system and operational requirements; common areas involve salmonids - Atlantic salmon, rainbow trout, brown(sea) trout and Arctic charr, and carp - common, Chinese and Indian carps in polyculture systems;

- diversifying production systems; using less site-constrained systems for the same species, widening flexibility of operation, product timing etc. For example: offshore cage culture systems, land-based intensive recycle systems, and integrated production systems (e.g. combining intensive tank systems with extensive ponds in coastal areas, combining mollusc culture with cage culture, etc);

- diversifying species and production system; i.e. developing new production concepts, with in some cases, radical departures from current approaches;

Examples of these forms of diversification can be seen in most regions, in both developed and developing countries. Thus Csavas (1995) commented on the emerging importance of newly industrialised countries (NICs), and the increasing Asian markets for medium to higher priced products such as shrimp and marine fish.

Increasing trends towards urbanisation are also likely to change the nature of markets for aquaculture products. However, the potential for major growth is most likely to be found within the current range of species, though many opportunities would exist for building production in the less widely recognised species.

Understanding the nature of the market chain for aquaculture products is important as the sector develops and in particular as it interacts with the traditional capture sector. A range of features can be observed depending on the present market chain characteristics; in some cases it is aquaculture products which will dominate the market, in others aquaculture products will be distributed through traditional fisheries marketing arrangements. It should be noted that the effects of aquaculture will also depend on the scale of output relative to capture fisheries, and the extent to which aquaculture products are different - e.g. if they offer new species or product forms; the more different these are and the greater the scale of aquaculture output, the more likely it is that aquaculture market chains may evolve separately.

A particular concern in aquaculture is that producer price levels for many systems and markets may perhaps lie around the retail price for equivalent capture fishery products, but that adding typical market mark-ups of perhaps 20-50% makes aquaculture products uncompetitive. A policy issue sometimes raise in the context of rural development, and of aquaculture itself, concerns the role of the 'middle-man', which is seen as an exploitative and inefficient relationship which removes the opportunity for improving producer income and reducing consumer prices, and so denies the prospect of growth. While the argument is at first sight plausible, it needs to be considered with some caution, as it commonly fails to recognise the legitimate and necessary intermediary roles played by such agents. However, if this role is used as a basis for non-competitive and market-dominating behaviour, an appropriate policy response may provide practical market means to stimulate competition.

It is unlikely that aquaculture products will receive more substantial degrees of processing in the future, as the preferred product form in many cases is live, fresh or chilled, and as this is often considered to be the main basis of preference (and guarantee of quality). The main exception is shrimp, which normally enters the supply chain in frozen form, which provides a degree of stability of quality, and the potential for development of more sophisticated market systems.

However, there is likely to be further interest in adding value to lower-priced aquaculture products, or extending markets for higher-priced forms by changing the final product form - e.g. by enhancing basic materials to make more desirable products, or by 'diluting' more expensive materials to make composites which can be priced more acceptably. While developments such as these may occur in the middle-higher priced product ranges, they are less likely to affect the lowest price products, which are likely to continue to be sold live or fresh.

A particular area of current interest in developed country and urban markets is the question of whether aquaculture products may be capable of entering the general 'raw material' market - i.e. as a good quality white fish substitute, capable of being used as the basis for various 'value-added' products, ranging from enrobed products such as fish fingers and patties through to more sophisticated pies, sauces and other composite dishes.

Ideally, such material should be neutral in flavour, firm in texture, relatively bone-free (or easily boned) and preferably white in colour, and would need to be available as a standard product of definable characteristics at around $1.50/kg or less.

It would normally be skinned and block-frozen, with lower-grade products made in reconstituted form, and would be stable if properly handled in transport and storage for at least 12-18 months. Recent studies have indicated that certain species - notably tilapia, channel catfish and possibly clarias catfish may meet the general requirements, and are gradually reaching the price level where they may become feasible.

Other species such as silver carp have also been proposed but although potential production price could be attractive, are not able to meet the basic quality requirements. Developments such as these may be important for aquaculture and the fisheries sector in a number of respects:

- the market scale involved is substantial, typically an order of magnitude greater than that for conventional aquaculture markets;

- there may be major opportunities for export markets for tropical or subtropical countries, particularly if (as is most likely) production would be based on systems which are at least partly photosynthesis-driven to be less dependent on external feeding and environmental maintenance;

- the types of product are likely to have an increasing impact in urban and peri urban communities and may maintain demand in lower-middle income groups;

- pressure on certain fishery stocks may be reduced to some extent, particularly if supply and/or quality were becoming erratic;

At present, there are no immediate developments in this direction, as production costs are still too high, though interest is active, and some pilot initiatives have been taken. There are also other areas of longer-term diversification for aquaculture, which are commonly but not always outside the conventional table food production range. Table 3.3 provides an outline of some of these prospects.

Table 3.3 New areas of development for aquaculture products

Area of development	Products, characteristics	Potential
Nutritional enhancement	'High-health' protein or lipid modified products of conventional format	Wide range of current food stocks, primarily well recognised the higher-market value products
Ecosystem support	Closely genetically tailored stocks for habitat support or enhancement; cryo-preserved materials	Wide range of species and habitats, though requires protocols and funding commitments
Raw materials	A range of chemical/pharmaceutical 'natural' products - proteins, enzymes, structural materials from natural or genetically engineered aquatic organisms	Mainly from simple organisms - plankton, etc, capable of high yield and simple extraction - often in high rate photosynthesing systems; extracts from other organisms/body organs may be used
Recreational	Aquatic organisms of interest for aquarium or angling, and facilities associated with them; tourist products - display and interpretation centres, etc	Development of new products, varieties, improving access and involvement; particularly around urban areas and tourist locales

Predictions of the rate of development of these sectors must be rather speculative at this stage, though as the table indicates, the potential and implications might be quite considerable in particular locations. These areas of production might be developed as activities in their own right, or may emerge as part of horizontally or vertically integrated production systems. The prospects for aquaculture producers might vary, as some of these sectors may be highly specialised in their own right, and may require completely new systems approaches and areas of expertise.

Other issues for development

A number of other issues may affect the potential for aquaculture markets to be expanded and for production to be increased. One of the areas of growing effect in developed country markets is that of consumer concern over real or perceived risks associated with various aquaculture processes or products. Similar concerns can also be found in many rural societies. In both cases the more speculative of these might be dismissed by observers as irrational, ill-informed or superstitious, but they represent real constraints to confidence and acceptance, and may unnecessarily restrict the opportunities which may be available. Table 3.4 summarises some of the major current areas of consumer concern, primarily related to public health and quality issues, but also associated with more generalised concern. These are grouped as general areas, and those associated with inland and coastal waters respectively.

As the table indicates, the range of issues is quite wide and could be potentially quite serious in consequence. Effects range from disapproval/doubt about production methods under the general 'green consumer' trend, to serious and sometimes life-threatening public health issues.

Problems arise primarily through consumption of product, but in some cases, contact with water, or the presence of the water bodies associated with aquaculture may be more important. In most cases, specific management approaches can be proposed, some of which are strategic in nature, others more specific, possibly requiring regular monitoring and/or controls over consumption during specified high risk periods. In these circumstances, confidence in the management methods and institutional capacity becomes particularly important. Where resources are unavailable to provide this level of security, there may be major risks to consumers and/or drastic loss in opportunity to produce for local and/or international markets.

Table 3.4 Major areas of consumer/public health concern

Environment	Area of concern
Inland/fresh water	
	Toxic freshwater algal blooms
	Wastewater contamination
	Transfer of human pathogens in integrated systems
	Encouragement of various water-borne diseases
Coastal/marine	
	Cholera and other bacterial/viral disease
	Paralytic fish and shellfish poisoning
	Human intestinal parasites
General	
	Off-flavours and other organo-leptic problems
	Development of drug resistance
	Concentration/accumulation of undesirable materials in products
	Use of 'artificial' chemicals for feeding, growth promotion
	Use of 'genetically engineered' products and stocks
	'Inhumane' methods of production
	Excessive pollution

A range of these issues concern the relationships between aquaculture and the environment, and the need to manage these - a subject of increasing importance. Other issues are more specifically associated with image and public education, but may require to be addressed very seriously. This may be a particular problem for countries exporting potentially high value aquaculture produce to sophisticated and often very competitive developed country markets, in which the smallest hints of concern may be sufficient to create substantial economic damage.

This particular point leads into the area of the growing internationalisation of the aquaculture sector as a whole, whether in terms of international corporate structures, in feed and equipment supplies or the more common feature of international trading of aquaculture product.

While this has primarily applied to major higher-priced products such as salmon, shrimp, sea bream and eels, it is now starting to apply for lower priced species such as trout, mussels and tilapia, and may be expected to extend at least to the point at which transport and distribution costs remain lower than the potential differences in production price. A further incentive for international trade is in the simplicity in obtaining out of season supply, which in turn is associated with an increasing demand for year round supply in major retail chains. Longer term consequences might also be expected in terms of gradual sifting out of the less competitive production locations. Further effects may include the stabilisation of market prices of key aquaculture products, and the increasing standardisation of products and processes. This in turn may reduce risk and uncertainty for investment, and might lead to a greater availability and reduced real cost of investment in further development.

Finally, one of the major questions in the development of the sectore will be that of the pattern of intensity of production. It had been noted that the bulk of aquaculture production is still accounted for in the extensive and semi-intensive sectors. Table 3.5 outlines the main development issues which might be involved at each level of intensity, and which might determine the relative importance of each in the future.

Table 3.5 Critical development areas for production subsectors

Production subsector	Development issues	Critical factors
Extensive	Inland/coastal area availability for new development, pressure on existing areas; water supplies and exchange, environmental capacity, wild seed supply	Extent to which productivity may justify continued use of site areas; possibility for use in semi-natural and/or protected zones;
Semi-intensive	Inland/coastal area availability, pressure on existing areas, fertiliser and feed input costs, water and waste management, improved stock supplies, adoption rates and management skills	Potential for gradual increases in productivity, perhaps with minimal change in input level, but better stock supply and control, better management skills, simple integration.
Intensive	Water and waste management, feed input costs, stock supplies, system development and capital costs, operational efficiency, management skills	Extent to which productivity gains can support possibly increasing feed costs and greater need for environmental control; management skills
Super-intensive	Water and waste management, feed input costs, improved stock, system development and capital costs, operational efficiency, management skills	Extent to which markets justify higher production prices, offer sufficient returns for higher capital requirements of more sophisticated systems

Notes: subsectors as per FAO description, with super-intensive to describe higher yield levels; extensive category includes mollusc/seaweed systems.

As this shows, land and water resources are likely to be critical factors in development, and will apply in varying degrees in specific regions and locations. However, nutrient materials, seed quality and human resource/management skills will also be critical. These points are taken up in the following chapters.

4. RESOURCE AND ENVIRONMENTAL ISSUES

The characteristics of development will have clear implications for the extent and nature of resource use, and decisions or trends in particular directions would create specific and definable changes in resource demand.

In some circumstances aquaculture can be opportunistic in resource use, in others it requires a specific commitment of resources over a defined period of time. While it is tempting to attempt to guide development solely along paths which offer the best marginal returns on the inputs used, the diversity of the sector must be understood since there are many areas of uncertainty and short-term variation which may make practical decisions less straightforward. That said, however, the major resource relationships have an obvious influence over opportunity for development, not least because of the substantial degree of variation in levels of resource involved, and the trade-offs between them.

To illustrate key implications, Table 4.1 shows the typical levels of resource use in producing 10^6 tonnes of aquaculture products using extensive and intensive systems.

Table 4.1 Implications of aquaculture development choice: resource use per 10^6 tonnes

Resource area	Extensive	Intensive	Notes
Land/water area	$1 - 2 \times 10^6$ ha	$0.01 - 0.05 \times 10^6$ ha	based on typical yield rates, varied types
Water exchange	5×10^9 m^3	400×10^9 m^3	variable degrees of quality change, some loss
Food	$0.1 - 0.3 \times 10^6$ t	$0.8 - 1.6 \times 10^6$ t	varies with system, differing quality levels
Fishmeal	$0.02 - 0.1 \times 10^6$ t	$0.3 - 0.8 \times 10^6$ t	from 20 to 50% inclusion; higher in intensive
Devel't capital	\$1 - 3 $\times 10^9$	\$3 - 8 $\times 10^9$	varies according to local conditions
Direct labour	$50 - 100 \times 10^3$	$10 - 40 \times 10^3$	typical ranges; also part-time and service jobs

Though this is clearly a rather crude generalisation, it suggests a wide range of development consequences, and the appropriateness of some degree of selectivity if particular objectives are to be achieved. Current implications for these resources are outlined in the following sections.

4.1 Prospects for area expansion

Scenarios of possible growth of the aquaculture sector have been suggested by various authors (New, 1992; Csavas, 1994). Based on a simple linear extrapolation of the of the current rate of growth, these suggest there would be an increase of some 10 m tonnes in production by 2000, and of some 30 m tonnes by 2025.

As table 4.2 indicates, simple averages can be used to suggest the consequences in terms of land or water areas involved.

Table 4.2 Land area requirements; implications of projected aquaculture production

MAJOR GROUP	1992		2000			2025		
	production 10^6 t	area km^2	prod'n 10^6 t	total area (1) with same yield	total area (2) improved yield	prod'n 10^6 t	total area (1) with same yield	total area (2) improved yield
Fish	9.42	6280	13.78	9190	7250	25.27	16850	8770
Crustacea	0.98	980	1.79	1790	1410	2.70	2700	1400
Molluscs	3.50	1750	5.33	2670	1380	8.23	4120	2140
Aq plants	5.39	1080	8.18	1640	1290	13.84	2770	1440
Others	0.02	4	0.03	6	5	0.06	12	6
TOTAL	19.31	10094	29.11	15297	11335	50.12.	26452	13756

Notes: projections (New 1992, Csavas 1995)

This shows two scenarios of land requirement based around an initial set of assumptions about average productivity: the first (area 1), in which yield levels are assumed to be approximately constant, and a second (area 2), in which productivity is assumed to increase, by 3% annually over 1990-2000, and by 2% annually from 1990 to 2025.

Initial productivity levels are assumed to be 1.5 t ha^{-1} yr^{-1} for fish, 1.0t ha^{-1} yr^{-1} for crustaceans, 20t ha^{-1} yr^{-1} for molluscs, 5t ha^{-1} yr^{-1} for aquatic plants and 2t ha^{-1} yr^{-1} for others. The result indicates a significant increase in demand for land under the 'normal' scenario (1) - some 5000 km^2 by the year 2000 and 16,500 km^2 by 2025, representing a further 50% and 165% of existing areas respectively. Obviously such large changes will have a major impact on the use of this resource.

The second scenario of increasing productivity considerably moderates the impact of aquaculture on land area use, showing 13% and 37% increase in area requirement respectively. The implications of productivity gain however would be a substantial shift in overall intensity, and imply at least some additional inputs of water exchange, fertilisers and feeds relative to output.

The pressures of growing populations result in a steady increase in demand for land, whether for food production or habitation. As is widely recorded, forest land is being cleared at a growing rate, areas of wetland being 'reclaimed' and coastal fringes are being developed and sometimes extended seawards. At the same time, significant areas are declining in productivity due to soil degradation, salinisation and reduced access to ground or surface water. As urban areas expand, many former agricultural areas are being taken over for housing, commercial development and infrastructure.

In coastal areas there are increasing pressures on inshore sites and there are now fewer new sites available. All of these factors will tend to limit access to land for aquaculture, and will tend to make the stable and secure conditions required for aquaculture more difficult to attain.

For these and other reasons, increased production in the future is more likely to come from expansion of existing sites and the development of previously unexploited areas such as inland water bodies and more exposed coastal and offshore sites.

The relationships between land and water use have been noted earlier. Clearly, systems which involve higher productivity will tend to use correspondingly more water; the relationship may not be fully direct, as there is substantial variation between systems which can be primarily photosynthesis-supported, and those which require external inputs.

Tables 4.3 and 4.4 are based on a slightly different set of development scenarios for inland and coastal waters respectively, and illustrate potential use of land and water for additional future production needs, based on assumptions of different productivity levels. These illustrate the trade-offs between land and water usage: the need for land in extensive systems, and for water in intensive and super-intensive production.

Table 4.3 Projected freshwater aquaculture resource use by major species/production system

System	Species involved (est % species total)	Production 10^3t (%totl)		Water usage			Area usage		
				Est.Av '000m³ /t	Total use 10^6m³/yr	% total	Est. Av ha/t-yr	Total use '000ha	% total
Extensive	carp[5](40), tilapia[6](30)	1700	27.4	10	17000	9.2	10	17000	53.5
Semi-intensive	carp(55), tilapia(55), trout(10), catfish(25) ,prawns[7](95), eels(5)	2540	40.9	5	12700	6.9	3	7620	24.0
Intensive	carps(5) ,tilapia(5), ,trout(35), catfish(65), prawns(5), eels(50)	470	7.6	20	9400	5.1	1	470	1.5
Super-intensive	trout(50), catfish(10), eels(40)	180	2.8	20	36000	19.4	003	0.54	min
Total inland		4890	78.7		75100	40.5		25090	78.9

Source/notes: from Muir (1992), based on projections by New (1991) for future demands assuming a basis of 1989 per capita supply, with stable capture fishery production at 100 million tonnes. Net increase in production excludes molluscs and aquatic plants, and is based on species distribution in 1989, with this author's assumptions for percentages of each species group grown in particular environments or systems.

[5] Includes common, grass, silver and bighead carp.

[6] Tilapia also grown in coastal/marine areas but assumed negligible here.

[7] Includes Macrobrachium and red swamp craofish.

Table 4.14 Projected coastal aquaculture resource use by major species/production system

Environment /system	Species involved (est % total)	Production		Water usage:			Area usage:		
		10^3t	%total	Est.Avg '000 m^3/t	Total use 10^6m^3/yr	% total	Est. Av. ha/t-y	Total use '000ha	% total
LAND-BASED									
Extensive	milkfish(70), shrimp(65), eels(5)	590	9.5	30	17,700	9.5	10	5,900	18.6
Semi-intensive	milkfish(30), shrimp(30)	260	4.2	15	3,900	2.1	3	780	2.5
Intensive	shrimp(5)	30	0.5	10	300	0.2	1	30	0.09
WATER-BASED									
Super-intensive	trout[8](5), salmon[8,9](100), yellowtail, etc(100)	440	7.1	200	88,000	47.5	0.003	1.32	(neg)
Total coastal		1320	21.3		109,900	59.3		6,711	21.1
Total inland + coastal		6210	100.0		185,400	100.0		31,800	100.0

Source/notes: as for previous table. Tilapia also grown in coastal/marine areas but assumed negligible here.

Clearly, the amount of land required for additional production will depend on the extent to which productivity might be changed, and whether existing sites can be used effectively - in terms of access to water and other resources. The potential for developing existing and new sites and water supplies will also be influenced by national planning policy. Given mounting pressure from conservationists and other groups to control the development of this and other sectors, planning procedures are likely to become increasingly strict, though not necessarily more equitable. The decreasing availability of 'optimal' sites, and the need to overcome deficiencies of alternate sites - e.g. difficulties of access and security, exposure, poorer growing environments, will probably increase both capital and operating costs. The effect of policies controlling site availability may also act to shift the production cost base upwards. However, against this can be seen the potential effect of technology development, and the possibility that improved methods might be able to overcome some of the constraints.

4.2 Fertiliser and feed resources

The demand for fertiliser and feed resources for aquaculture will also depend on the farming system which will be developed, and their background fertility. As an approximation, Table 4.1 had indicated feed requirements ranging from some 10 to 160% of production tonnage, depending on intensiveness and efficiency; feed quality requirements would also tend to increase with intensiveness.

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8 Onshore (i.e. coastal) production of trout and salmon occurs, but assumed negligible.

9 Salmon are also grown in freshwater, but likely to be insignificant.

Table 4.5 Comparison of estimates of projected feed requirements for aquaculture (major groups)

MAJOR GROUP	1992		2010		
	prod'n m t	feed m t	prod'n m t	feed scenario 1	feed scenario 2
Fish	9.42	2.83	20.8	10.4	6.24
Crustacea	0.98	0.69	1.8	0.9	0.54
TOTAL		3.52		11.3	6.78

To illustrate possible implications of the expansion of aquaculture, Table 4.5 provides estimates of feed demands for two scenarios based on starting assumptions of an overall apparent food conversion ratio (FCR) in 1992 of 0.3 for fish and 0.7 for crustacea. In feed scenario (1), it is assumed that overall intensiveness increases, and the FCR increases to 0.5 and 0.8 respectively.

In feed scenario (2) it is assumed that the overall FCR remains constant, and that increasing yield levels are balanced by improved efficiency of use. These indicate feed demand rising by some 3.26 to 6.78 m tonnes by 2010. The differences in demand for the two scenarios are quite striking and illustrate how the sector might remain competitive where feed resources become scarce.

The use of fertilisers is rather more complex to assess, partly because natural fertility varies so much from one environment and system to another, partly also because the range of fertilising materials is so wide, and relative quantities vary widely between organic and inorganic materials. There are also gradually increasing trends in fertility in many natural waters, due to anthropogenic factors, and the increasing use of feeds in the systems themselves will have a secondary effect in increasing dissolved nutrient levels.

Additionally there are circumstances in which extensive or semi-intensive aquaculture - particularly of molluscs and aquatic plants, might become recipients of fertility from other systems to mutual advantage. Thus while the additional production will require additional quantities of nitrogen, phosphorus and other nutrients, the quantities involved might come at least partially from resources which are already present in or around the system concerned.

While fertiliser inputs might not be so critical, the demand for feed resources is in fact one of the most widely quoted areas of resource concern for aquaculture, in particular the higher quality materials such as fishmeal, which might account for around 20-50% of a typical intensive aquaculture diet for marine shrimp and carniverous fish species. The supply of fishmeal is considered to be broadly static at around 6 $x10^6$ t $year^{-1}$.

On the basis of current input levels, Chamberlain (1993) estimated fishmeal and oil usage for aquaculture to increase by 50% and 77% from 1990 to 2000, at 1.2m and 0.36m tonnes respectively. For the salmon sector alone, demand estimates would suggest the use of some 7% of total world supply of fishmeal by the year 2000.

Tacon (1994) has also reviewed this issue, noting that some 14% of 1990 fishmeal production was used in aquaculture, although the bulk of aquaculture production (87% in 1991) relied on omnivorous/herbivorous species; in the face of a probable decline in fishery supply, development emphasis might be given to these groups, and where necessary the substitution of fish-based materials with other feed sources should be encouraged.

However, it might also be noted that large quantities of bycatch are obtained in various fisheries (Warren, 1994), and as long as the fishery and landing of these species did not jeopardise higher-value opportunities (and it was feasible for vessels to do so), the main need may be to ensure that this resource was not wasted.

In this sense fishmeal production can be a rational way of retaining value, providing stable and versatile inputs to a range of production systems, including aquaculture, which in its higher-value forms may in fact offer premium values for higher quality meals and oils. The issue may then be that of recognising the full value of fishmeal stocks, the importance of the role it plays within the global food supply; and thence the need to consider the marginal value arguments of allocating fish products to aquaculture or other uses.

Aquaculture production will also demand other feed resource inputs, primarily from conventional agriculture production; an increasing range of minor components may be introduced provided they are adequately tested and any toxic materials are removed or counteracted.

In overall quantitative terms this demand is not likely to be limiting, particularly as it may be expected that agricultural productivity would tend to increase. Given also the possibility of improvements in food conversion as a result of improved processing and feeding technology, feed supply in overall terms may not be a dramatic constraint to development, but increased competition for this and other raw materials may affect prices and hence available margins for other inputs. More important however may be access to feed resources at the local level, the timing of availability, and its quality as locally supplied.

A further area of practical import would be the increasing trend towards national commercial feed development, and the gradual move in the more commercial sectors from artisanally produced feeds towards manufactured diets, from wet and moist diets to dry diets, and towards more sophisticated dry diets.

In major markets there has been a substantial degree of competition, resulting in progressive improvements in performance and reductions in real price. Thus FCRs for salmonids show a fall from 2.0 - 3.0:1 in the mid-1970s (Alabaster 1982) to around 0.8-1.2:1 today. In broad terms, though more capital development and industrial energy may be involved, this could be regarded as a positive trend, and offers prospects for improved quality and efficiency of use of raw materials. Dry diets also tend to be more water stable, leading to lower losses and improved water quality.

Against this however must be seen the question of access to the artisanal farmer, and the reduced opportunities to incorporate small-scale local feed resources into aquaculture production. Table 4.6 below outlines the key aspects of feed production in major forms, and indicates the comparative advantages involved.

Table 4.6 Feed producers: characteristics and comparative advantages

Artisanal	Local non-specialist	Specialist producer
Can make use of small quantities of incidental feeds; normally direct use with little or no storage; diets as per material availability	Varying levels of access to raw materials, primarily standard products, some local supplies; often stored; basic standard diets	Access to wide range of standard and specialist materials; may use lowest cost formulations; range of diets, proper storage
Basic manual chopping, mixing and transport equipment, very limited degree of processing, simple moist pellets at most	Equipment typically for agricultural feeds; basic milling, mixing, pelleting, typically occasional batches of aquaculture feeds	Specialised equipment for aquaculture feeds, including fine milling, over-oilers, etc; normally used entirely for aquaculture feeds;
Limited expertise - may either be conservative - missing opportunities, or careless, risking toxicity problems	Varying levels of expertise; aquaculture feed experience often limited, quality control may be poor	Good to excellent levels of expertise, may have R&D to test, improve diets; good quality control, storage and stability
Generally low cost, but very little quality control and supply may be unreliable	Usually higher costs, but some trade-offs expected in quality and availability	Some feeds may be high cost, but efficiency gains may give excellent price/quality

Although food conversions have generally improved, the efficiency of feeding within aquaculture systems continues to merit substantial investigation, both at the level of ecosystem management to optimise yields under natural feeding, and in terms of efficiency of use of external feeds. In the former case, the energetics and trophic relationships of various cultured species are as yet poorly understood, although some advances are being made in understanding the role of grazing on plankton and benthos. In the case of exteranal feeds, the control of losses is obviously important, but can be difficult to estimate.

At the level of the individual system, in theoretical terms (and assuming the aquaculture stock responds to external nutrient sources) the operator would be expected to seek to maximise marginal revenue and would tend to increase nutrient inputs to the point where no further yield gains could be obtained to offset the cost of inputs. In practice this would of course be constrained by other limitations, though examination of many extensive and semi-intensive systems would suggest that inputs and yields could be improved with relatively simple use of local raw materials. In many of the simpler forms of aquaculture, productivity is simply a result of the feeding history of the system, as based on the types and quality of fertiliser or feed that have happened to be available within the knowledge or experience of the operator, rather than based on a specifically targeted intensity level based on known input quality and performance. As well the more common under-resourcing of aquaculture systems, this can also lead to poor yields as a result of periodic overloading, and the creation of poor production conditions. As discussed later, the assessment of knowledge, the use of information, and the development of skills is a critical aspect of this area of resource management.

4.3 Seed supply

As a resource limitation, the supply of seed stock has been a major constraint in the past for many fish and crustacean species. However many, if not most, sectors are now well supplied from hatchery stocks and have sufficient potential to support expected future growth in output. Molluscs and aquatic plants have tended to be less reliant on hatchery stocks, though here too, the potential advantages of genetic selection and managed supply can be expected to increase the relative contributions from hatchery production.

For the species dependent on wild stock, a range of supply risks can also be identified. As is widely documented, early life cycle stages in particular can be highly sensitive to physical and chemical disruption, as well as excess predation, while excess fishing and damage to habitat can also severely impair reproductive success and longer term production. While this does not necessarily mean that those sectors which are more dependent on wild seed will be under major threat, they may become increasingly susceptible to environmental and other consequences of human activity, and may suffer in terms of quality and reliability of supply by comparison with the hatchery supported sector.

Constraints such as these are particularly likely to apply to the fish and shrimp sectors, while for different reasons molluscs and aquatic plants are less likely to be affected. Provided therefore that wild larval supplies are not too widely available and inexpensive, and thereby undercut seriously the cost of hatchery seed, there are usually basic incentives for developing hatchery production in most situations.

The nature of development of the hatchery sector will also be important both quantitatively and qualitatively. The number of hatcheries involved would be difficult to estimate, as additional capacity may be developed through a combination of expansion, new establishments, and better use of existing systems, while management improvements across all sectors might be expected to improve early stage survival and performance in ongrowing, thereby reducing the overall ratio of brood-stock and larval inputs per output level.

As Table 4.7 indicates, current production cost levels vary widely across different species, and there are notable prospects for some of these to reduce in real terms, thereby contributing to an overall reduction in overall production cost.

Table 4.7 Current and potential cost levels for hatchery output

Species/product	Cost/unit	Cost/g.	Notes
Carp fry, 2g	$0.01	$0.005	Simple systems; out of season spawning may improve
Cichlasoma, 10g	$0.10	$0.010	Pilot-scale system; mainly native species interest
Tilapia, 3g	$0.05	$0.013	Example sex-reversed; more expensive but better performance
Seabream fry, 2g	$0.25	$0.125	Standard cycle; price dropping, more out of season production
R trout fry, 10g	$0.15	$0.015	Dropping in price; sex and genetic management more common
At salmon smolt, 60g	$1.50	$0.025	Vaccinated, sex reversed, out of season stock more expensive
Macrobrachium 0.01g	$0.02	$2.000	Increased artisanal production range of qualities
P monodon PL20 0.01g	$0.03	$3.000	Range of suppliers

Source: Inst. of Aquaculture, Stirling.

Although hatchery production offers substantial opportunities for development in the sector as a whole, supply continues to be vulnerable to a range of risks, from physical damage to disease loss, which in turn can jeopardise the financial strength of ongrowing producers, particularly if they have substantial fixed costs. Thus potential hatchery capacity may not in itself be a substantial constraint, but quality, stock health and variability of production might remain serious concerns, and technical measures to reduce risks in these areas would have a positive effect.

The genetic management of stocks to avoid inbreeding and to select for locally desirable traits is extremely important for aquaculture production, particularly for small hatcheries with restricted broodstocks, and limited management capacity. A more recent issue, potentially emerging as a widespread practical constraint, is the concern for biodiversity, and possible implications for genetic management of seed used in aquaculture systems. Apart from additional capability required in selecting stocks and monitoring local species populations, additional facilities may be required, unless technical or organisational systems can be developed to co-ordinate responses and to provide facilities such as cryo-preservation and DNA analysis.

The role of biotechnology in the wider sense is one of the most interesting and challenging areas of future development in this area. Immediate areas of potential include improved stock performance - in terms of growth rate, reproductive control and/or disease resistance, while more speculative prospects involve trans-species gene transplantation, producing dramatic changes in morphological and other characteristics, growth and other physiological performance, cellular defences against disease and external contaminants, tailoring of biomass constituents, and other responses. The introduction of human growth proteins into salmonids has already been carried out experimentally, with startling results; as with all such developments, however, the social acceptability and environmental implications require to be determined before significant practical applications arise. This area is itself the subject of major international policy development and the longer term implications, in aquaculture as elsewhere, could be immense, and could change entire structures of production and resource use.

Genetic and physiological fitness of stock, with better protection against unwanted introductions, is an important issue and a strict precautionary approach is increasingly advocated when considering the development options. However, a pragmatic approach may be required in many circumstances - aiming for some degree of regulatory accord, but accepting the need for development. This may give rise to some uncomfortable and possibly controversial choices.

Because of its technical complexity for many species, and in keeping with the overall development ethos of previous decades, hatchery production has for many countries in the past tended to be concentrated in the institutional sector, often in association with extension services. More recently however, in response to a range of political and economic factors, there has been a notable move in many countries towards commercial production at a range of scales, from the privatisation of larger hatcheries to the creation of a more active market demand to encourage the entry of smaller hatcheries. The increase in activity, and a general growth of the sector as a whole, has stimulated in some countries the development of a very active system of fry distribution and trading.

This is particularly notable in parts of SE Asia, where a considerable level of artisanal employment is involved, and where skill development and information transfer is a critical feature.

Another important consequence of this is the large geographical coverage involved, using larval transport systems ranging from simple baskets, carrying poles and cycle panniers, with hand-paddling of water for oxygenation and periodic stops for water exchange, through to the use of simple oxygen bag systems and rail or road transport for longer distances, and for the larger commercial producers to the use of specialised transport tank systems, well-boats and even helicopter delivery of stocks to remote sites. Using a range of such approaches, effective transport times and distance for fry or larvae have extended from a typical 10-12 hour, 500 km by land or water in the early 1970s to 30-40 hours and 2000 km in the present day. While developments such as these clearly have effects on the scope for access to stocks, on the potential for specialised suppliers to reach wider markets, and on improving competitive conditions for ongrowers, there are also potential problems of disease transfer and of the introduction of undesired stocks.

Table 4.7 shows typical price levels for hatchery products, and indicated some of the trends. In many sectors, hatchery production has been relatively profitable, which has stimulated interest and investment, which for many freshwater species may be relatively modest. Marine hatcheries by contrast are quite capital intensive, though returns are also generally sufficiently encouraging for investment. In general, the availability of investment support for hatchery production is not likely to be a constraint, and expansion in capacity should be relatively straightforward. The use of multispecies and out of season production, with broodstock control, the development of simple and low-cost hatching and satellite nursery techniques, and the possibility of improving broodstock productivity and larval survival rates, would all act to extend production from existing facilities.

The respective roles of the artisanal, commercial and institutional hatchery producers in future development will be difficult to predict with accuracy, though some factors can be noted. For higher-value species requiring specific expertise and higher degrees of quality control, larger commercial hatchery units are likely to continue to dominate production, and are likely to improve efficiency and transport access to reach wider markets more effectively and competitively.

Depending on circumstances, an intermediate nursery sector may develop around this, possibly using artisanal methods, as for example the various backyard shrimp systems. This would combine advantages of lower-cost long distance transport of specialised primary stocks, with a relatively inexpensive local stage, which may also acclimatise stocks more effectively to local conditions.

With improvements in out-of-season supply, this would also create a useful short-cycle business activity suitable both for artisanal and small commercial involvement. The small-scale hatchery sector is also likely to retain its importance, and will probably develop further as artisanal producers become less dependent on public sector hatchery supplies. There might also be some opportunities for local stock development and for restocking with local species and strains.

Though there may be a move towards more appreciation and demand for seed quality from more specialised centres, this might be counteracted by the need to localise production, and to target stocks more clearly to local conditions.

Public sector hatcheries could generally be expected to diminish in importance, at least in output terms, but might increasingly take over more specialist roles, and provide scientific and technical support. While market forces and increased discrimination by purchasers may help to assure a certain degree of quality control in seed supplies, the genetic and physiological quality of production, and the management of disease may become increasingly important issues, and would deserve appropriate support.

4.4 Resource use and environmental management

Resource use by aquaculture has been discussed, and from the sustainability concepts described it is clear that while natural resources can be used for productive output and social benefit, a notable depletion of non-renewable resources (or renewable resource quality) would be generally undesirable.

If aquaculture is to be continued at its present levels, or developed further, it should be done so in ways which do not at least risk compromising natural resource and environmental quality. This section examines some of the critical environmental issues in further detail, and considers ways in which aquaculture systems may be developed to minimise environmental effects.

Environmental impact

The bulk of aquaculture operations, as practised to date in developing countries, carry minimal potential for aquatic pollution while contributing significantly to food supply, income and employment. Problems that have been described are mostly associated with high resource input systems (intensive and super intensive systems), particularly in coastal areas.

More generally, the issue is rather the negative impact on the external environment from other users that is causing problems for aquaculture; aquaculture development is increasingly constrained by reduced access to suitable land and good quality water resources, due to aquatic pollution and habitat degradation.

Expansion of aquaculture areas and intensification of aquaculture production can be managed so as to minimise risks of irreversible damage to the environment. Nevertheless, in some cases, this has not been and the resulting, often serious, damage has been highly publicized, sometimes with negative repercussions on aquaculture in general.

The main environmental issues (Hakanson et al 1988, GESAMP, 1991), associated mainly with intensive aquaculture, include various problems of waste and nutrient loadings such as: outputs of solids, nitrogen and phosphorus loading, vitamins, minerals; outputs of husbandry and disease management chemicals; the effects of waste materials on the adjacent benthos and the water column; their impacts on species and community diversity, and the possible stimulation of blooms.

Other problems include escaped stocks, risks of competition and genetic interaction with wild stocks, disease transmission, directly or indirectly reduced biodiversity. Predation by protected species can also cause damage to farmed stocks and may require controls without compromising conservation interests in the species involved. The key areas and their features are summarised in Table 4.8.

Table 4.8 Potential environmental problems associated with aquaculture

Problem area	Nature of problem
Waste and nutrient loadings	Outputs of solids, N, P, vitamins, minerals, chemicals, antibiotics; impacts of waste materials on the adjacent benthos and water column; on species diversity
Water exchange	In intensive landbased systems, or flushing through cage or enclosures; quantities required, effects of abstraction, build up of "low grade" wastes, at concentrations sufficient to diminish measured quality, but too low for simple treatment.
Escaped stocks	From damaged systems, or through flooding, damaged or ineffective discharge screens; risks of competition with/genetic interaction with wild stocks, disease transmission, directly or indirectly reduced biodiversity
Predation by conservation sensitive species	Causing damage, loss, stress-related disease to farmed stocks, requiring controls without compromising conservation interests;

Table 4.9 Environmental issues related to environmental categories

Environment/system	Significant issues	Implications
Inland		
Extensive pond systems	Silts, predation, local ecosystem changes	Usually minor;traditional,may have benefits
Reservoir cage culture	Nutrient loads, obstruction, visual impact	Vary with location; need control, monitor
Semi/intensive pond systems	Periodic waste discharge; water use, predation	Water/other management may need control
Flowing water tank systems	Solids, BOD and chemical discharges	May need regulation/treatment
Coastal		
Extensive pond systems	Silts, local ecosystems changes, salinisation	Usually minor; traditional, may be restored
Semi/intensive pond systems	Periodic wastes, salinisation, habitat damage	Variable, may need control
Flowing water tank systems	Nutrients, chemicals, salinity, habitat damage	May need management, monitoring
Inshore cage culture	Nutrients, chemicals, visual impact, predators	May need site control, monitoring, regulation
Inshore rafts, longlines	Visual impact, currents, deposits, predators	Minor unless heavily devel'd - poss control
Offshore cage systems	Navigation, system security	Possible site/system control, usually minor

Table 4.9 summarises some of the main problems for specific environments and systems. As noted earlier, nutrient loadings from intensive systems require copious quantities of water for dilution and dispersion. For extensive and semi-intensive (partially fed) systems loadings are relatively lower, but may be significant locally, especially during seasonal draining or cleaning. Normally, requirements are accommodated by supplying quantities of water, and discharging to receiving systems having a high absorptive capacity.

Limitations in either may be tolerable in the short term, but may lead to unacceptable effects. Chua (1993) and Briggs (1993) note the problems of the Taiwanese shrimp industry in 1988, 1992, and 1993, and the collapse of production in central Thailand in 1989-90, with an estimated loss of some $30 m and the dereliction of some 45,000ha of land. Problems have also been noted in the Philippines, Indonesia, Sri Lanka, and in China (Chua, 1993), where production has also been heavily affected. The need to supply the demands for extra water, the increasing need to "fallow" sites, i.e. move production to allow sites to recover from loadings, and increasing management restrictions, provide serious constraint for continuation or development (Jensen 1993).

The consequences of these and other problems if unresolved, can potentially include local and general environmental degradation, mixing of stock and species within aquatic habitats, disruption of human and social activities and reduced social benefit, and direct economic loss, of continuous or catastrophic nature, declining productivity, and foregone opportunity. In turn these can lead institutionally to the imposition of increasingly stringent controls and regulations, including increased charges for site or water use, charges for discharge of wastes, requirements to treat discharges to varying degrees, restrictions on site usage and requirements to carry out expensive monitoring programmes. Regulations such as these may the effect of limiting existing operations and/or preventing new development (see e.g. Rosenthal et al 1993). However, as Muir and Baird (1991) note, it is important to view these effects in context, as it is both irrational and potentially dangerous to focus on aquaculture, often only a minor or moderate component in environmental management, while ignoring other potentially more seriously damaging activities.

Health management

One of the major environmental concerns in the production sector itself is that of disease and its effects. To varying degrees, the problems of disease are specifically related to aquaculture system and the husbandry methods employed, where the primary objective is to maintain healthy, unstressed stocks, with sensibly limited exposure to more dangerous pathogens. However, the use and operation of aquaculture systems, with less than optimal environments, overcrowding, handling stress, variable nutritional state, and risk of cross-infection, naturally lead to risk conditions for disease. Aquaculture operations have also been associated with the spread of disease through stock transfers and transmission through wild populations. The spread of disease through fish and shellfish movements in western Europe and North America has been well documented; although much less studied, serious problems are known to have arisen in the tropics. In particular, the spread of epizootic ulcerative syndrome (EUS) among estuarine and freshwater fishes in Southeast Asia may be connected to fish movements, both natural and anthropogenic.

The economic consequences of health problems can be very significant, and will provide a strong motivation for the sector to identify practical solutions. Estimates of financial loss due to health problems across the broad spectrum of the whole sector are obviously difficult to provide, though if an average figure of 10% loss is applied to the entire sector, this would amount a nominal value of some $2.8 billion annually, a loss level (in percentage terms) which would be broadly similar to that involved in poor post-harvest storage in the fishery sector. Subasinghe and Sharriff (1994) quote losses of $1.36 billion in Asia in 1990 which is broadly in line with the above estimates.

There have been widely publicised losses associated with disease and poor environments in Asia, primarily in the shrimp sector - in Taiwan, Thailand, and more recently in China, where initial unconfirmed losses were estimated at some $0.75 billion (Liao 1992). Recent heavy losses have also been noted in Sri Lanka and in Vietnam, in the Mekong delta (Phillips, 1994), and there have been increasing problems on the west coast of India, and serious losses in Ecuador and Mexico due to Taura syndrome in shrimp.

Though knowledge of the immunology of aquaculture species has advanced significantly in recent years, and developments in biotechnology have considerably widened the range of possible management responses to disease conditions (see, e.g. Newman and Deupree, 1994), there are few realistic prospects that the many causative agents of disease can be eradicated or controlled to the point where risks are significantly and permanently reduced. The objective of sound practice is therefore that disease should be managed, to maximise efficiency of aquaculture systems and optimise resource use.

While many disease problems may be endemic, and are only manifested under conditions of stress in the aquaculture system, there are significant risks from the introduction of new, or new strains of pathogens. Here, the importance of attempting to regulate stock transfers (see also Coates, 1992, Costa-Pierce et al., 1990) and of developing and operating effective quarantine procedures cannot be overstated.

Aquaculture and biodiversity

Beveridge et al (1994) have reviewed some of the general issues concerning aquaculture and biodiversity and note three areas of potential effect; the consumption of resources, the transformation process, and the output of wastes. The use of land, water, feeds and wild seed resources, and the effects of concentrated waste nutrients and treatment chemicals may all have effect in reducing biodiversity, either directly, in terms of habitat destruction or removal of feed supply, or indirectly, in terms of more subtle shifts in local ecosystems.

However, the most common issues of biodiversity relate to aquaculture stocks themselves; there is for example widespread comment on the problems of salmonid genetic diversity, and increasing concern in other areas.

While there are clearly circumstances where aquaculture could pose risks to biodiversity, there is also a need for realism, and to establish rational criteria. In particular, there may be positive challenges in using aquaculture techniques to meet biodiversity conservation objectives, and in the longer term, to use aquaculture as a component in biodiversity enhancement where it is considered necessary and appropriate.

As noted earlier, exotic species have been important in aquaculture development, with species being moved from one continent to another to capitalise on already developed technologies and markets. Domesticated strains will increasingly be selected for the advantages they may offer over wild stocks in terms of growth, disease resistance, colour, shape, etc. However, as already observed, animals may escape from aquaculture systems, sometimes in large numbers.

There is little quantitative information on feral aquatic animals; small numbers of releases go largely unnoticed or unrecorded, during routine farm operations, while occasional mass releases result from storms, overflows, predator damage to cages and other systems, collision and other forms of damage. Insurance records can show tens of thousands of fish being released during a single occasion. Thus from December 1988 - January 1989, some 1.2 million salmon were estimated to have escaped from Norwegian fish farms, equivalent to the year's total catch of wild Atlantic salmon in Norway (Beveridge *et al1994*).

Many exotic species successfully colonise natural waters. According to Beveridge et al (*1994*), approximately two thirds of freshwater species introductions in the tropics have become successfully established. It is estimated that more than 30% of introductions of fish species in European inland waters have come from aquaculture and a similar figure has been attributed to species introductions in tropical freshwaters. While there is little direct evidence of supplanting local species completely, feral exotic species and strains can potentially cause negative impacts such as habitat destruction, disruption of the host community (*e.g.* through competition or predation) and genetic interaction with local stocks, all of which could directly or indirectly lead to loss of biodiversity.

Little is yet known about genetic interactions between wild and feral stocks and what little is available mostly concerns salmonids (Beveridge et al, 1994). Genetically distinct non-interbreeding populations of salmon occur in each water body, but although genetic differences are stable, they are not necessarily correlated with geographic separation. By contrast, farmed stocks differ significantly in genetic composition and have reduced genetic variability (losses in heterozygosity) compared with their wild ancestors, because of selection and inbreeding. Except for some of the more organised, sometimes state-run breeding programmes (e.g. in Norway, Canada, Japan) selective breeding is still practised on a largely *ad hoc* basis by local hatchery producers. Thus in Spain, only 3% of genetic variations among farmed brown trout is accounted for by stock differences, indicating a common stock. There are fears that genetic interactions between farmed and wild stock will adversely affect gene pools through the introduction of non-adaptive genes to wild populations. Evidence from salmonids suggests that a variety of outcomes, ranging from no detectable effect to complete introgression or displacement, may occur. Salmonid studies indicate losses of heterozygosity due to intrusion of fish of hatchery origin. However, whilst genetic markers are useful, it is difficult to assess the impacts of loss of genetic variability in isozyme loci since little is known about the relationship between isozyme variability and individual fitness. The few studies that have been carried out on performance or behavioural traits have only been carried out on salmonids, but results indicate poorer reproductive behaviour, survival and homing performance of farmed compared with wild stocks.

Use conflicts

Aquaculture has been a notable area of development and change in many areas in which land and water are adjoined, whether coastal or inland. Traditionally, many of these have also been areas of human settlement and interest, with a high degree of cultural and recreational value. In many cases the same features which are advantageous for aquaculture site location are also highly desirable for other purposes, and the development of aquaculture, however well considered and carefully executed, may be expected to create conflicts with other users of the same or adjacent resources.

If aquaculture is to develop further, such resource conflicts may become more extreme, and might be expected to lead to further and significant restrictions in potential. This could be the case both for poorer areas, where land is scarce for other productive purposes, and for more prosperous locations, where scenic value and recreational benefit may be more important. Although planning and regulation can assist in resolving such issues, there are also factors to consider such as the relative economic/environmental economic arguments, and the local or national political context in which choices might be made.

Although aquaculture may be suited to poor quality land, unused or marginally useful for agricultural production or other purposes, this is not always the case. Many if not most tropical inland systems are built on arable land of varying degrees of quality and use, though marginal areas may sometimes be used, particularly where land is in short supply. Where fish farming is firmly established, the areas of arable land involved can be substantial. Thus among rice growers in Central Luzon, Philippines, Tagarino (1985) estimated an average of 20% of farm area to be devoted to rice-fish culture. In the Philippines, Indonesia, Thailand, Vietnam, India and elsewhere, productive rice fields have been converted directly to fish ponds. In Taiwan, it was estimated that land devoted to aquaculture doubled between 1965 and 1985 to 70,000 ha (Beveridge and Phillips, 1993), with a major impact on land utilisation. Whilst in several prefectures, much of the land had been either marginal or unsuitable, some change in use of prime agricultural land undoubtedly occurred.

In cases where agricultural land is used for freshwater aquaculture, this is often a commercial decision by the land user (e.g. transfer of rice to fish culture in S E Asia, from cotton, rice or soya to catfish culture in the United States) and is done in full recognition of the comparative benefits. Unlike coastal aquaculture, the areas involved have with some exceptions been rather insignificant in most countries. As noted earlier, productivity increases through intensification have also provided gain without significant change in land use. Thus in Taiwan, production rose from an average of 1.4t ha^{-1} to 3.6t ha^{-1} between 1965 and 1985 (Beveridge and Phillips, 1993). Moreover, changes in land use are not irreversible, being principally determined by economics (Hannig 1988). In Israel, for example, the fish farming area fell from 3,529 ha to 2,818 ha between 1979 and 1988 despite substantial increases in production. A more serious concern may be the abstraction of water to supply land-based systems; thus the recorded subsidence of coastal land in Taiwan and the Philippines (Beveridge and Phillips, 1993), problems of groundwater decline in areas of the southern United States, and the risks of saline intrusion where coastal water wells are used for aquaculture systems. The discharge of water in inland areas may also cause problems and potential conflict, and the difficulties of shared use of such areas in Thailand are well recorded. The potential for conflict in coastal areas is often more serious. In SW Bangladesh, in the Khulna area, there has been competing land use between shrimp farming and seasonal rice and vegetable production; salinised soils have reduced land productivity, which has had an important effect on the food-producing capability of lower-income households. In Thailand, Phillips (op cit) quotes the results of a remote sensing study where the 3344 ha of shrimp pond development were associated with 1168 ha of salinised agricultural land.

A particular concern has also been the extent of use in land area which is not important for agriculture, but may have critical ecosystem value - e.g. salt-marshes, wetlands, mangrove systems - commonly the highly productive and complex water-land interface areas.

In parts of SE Asia, substantial areas of mangrove land have been converted to aquaculture, with extensive destruction of habitat, effects on nursery grounds, destabilisation of soils, etc. Although measures are now being taken to reduce effects - retaining broad shelter belts, reseeding, using pumped sites, etc, many thousands of hectares have already been affected.

However Hambrey (1993) reviewing uses of coastal area in Sumatra, cautions against too ready a condemnation of aquaculture compared with alternative forms of land-use, or against definable ecosystem quality, as the local economic value, and the benefits to communities of at least partially equitable forms of shrimp production can be significant.

Phillips (*op cit*) describes the encroachment of ponds into Kolleru Lake, India, with the consequent loss of wetland and fishing area, and deteriorating water quality. In parts of Africa, 'dambo' land - typically low-lying and marshy lands in general ownership has increasingly been taken over for aquaculture; in some areas of Malawi and Zambia this may be done to establish ownership (Harrison, 1994).

While water-based aquaculture does not use land directly, it occupies areas of lakes and rivers, potentially resulting in similar problems of competition. A widely quoted example is that of the pen culture industry in Laguna Lake, Philippines where rapid and uncontrolled expansion during the late 1970s and early 1980s resulted in some 35,000 ha, equivalent to more than 30% of its surface area, being occupied by milkfish (*Chanos chanos*) pens (Beveridge, 1984). Access to fishing grounds and navigation routes used by lakeshore communities was severely disrupted, causing a great deal of social tension. Fishpens in the shallow inshore areas were also believed to have disrupted fish spawning and nursery grounds, thereby depressing fisheries yields.

The use of cages in multi-use reservoirs is also a potential source of conflict, particularly if drinking water supplies are required. Phillips (*op cit*) describes the use of regulations to restrict aquaculture development, and limit for example the quantity and type of feeds used. Similar regulations are described in Alabaster (1982). However, the role of aquaculture in complex multi-use systems may often be relatively minor. Cages and pens are also by nature temporary and can and have been readily dismantled or moved as environmental, economic and/or political situations change (Beveridge 1984, 1987)

The issues of conflict for aquaculture have become especially critical in certain 'hot-spots' in various areas of the world. Muir and Baird (1991) have described a case in Cyprus, in which a small marine aquaculture installation had been accused by large parts of the tourist sector, of creating massive and unsightly problems of filamentous algal blooms on some of the major beaches.

Although clearly and demonstrably untenable on nutrient supply or ecological grounds (the farm contributed a minute fraction of coastal inputs compared with agricultural fertilisers and coastal sewage discharges), this was not accepted by the proponents of what quickly became a difficult political issue. It was only with the intervention of UNDP and FAO missions to clarify the ecological issues and provide recommendations for an improved legal framework (Van Houtte et al., 1990), plus the fortunate disappearance of the algal growth, that tensions were defused.

There have also been significant problems in highly visually sensitive areas in some parts of the world; in Scotland the continuance of difficulties with site selection, though improved consultative procedures; in Ireland, considerable debate in the last five years concerning the location of salmon farms and the possible impact on seatrout fishing, due to the possible transmission of sealice; in N America, continuing problems with coastal zoning regulations have meant that salmon and shrimp aquaculture have been virtually completely inhibited from further development. Environmental and possible user problems can also be anticipated in Chile, particularly in freshwater lakes currently being used for salmon smolt production. Recent areas of conflict have occurred in shrimp culture in India and Bangladesh, where the claiming of derelict property rights by intending entrepreneurs has led to serious legal problems, and in some cases violent responses.

The extent of conflict in many aquaculture systems will depend to a considerable degree on the nature of water management. Various approaches could be adopted for water resource management depending on the individual situations: open access, command and control regulation, rights based management, user priced management, or simply penalty controlled. A more organised approach to allocation between aquaculture and other users also requires at least some rational criteria for comparative assessment. Clearly, however, an integrated approach to resource allocation is ultimately required.

This situation argues in turn for better integration of aquaculture with other industries or agriculture. There will also have positive effects, reducing potential conflict e.g. where aquaculture may add value to a water resource, e.g. fish production in sewage fed ponds to improve water quality and generate income from a waste material (Edwards et al. 1987; Little and Muir 1987). Work has also been carried out in Scandinavia in attempting to improve water quality in acidified freshwater lakes through selective "pollution" by cage culture (Beveridge and Phillips, 1993).

Mitigation of any negative effects of aquaculture

Aquaculture in many parts of the world is obviously too valuable an activity to be over-restricted or reduced in scale to meet every possible environmental concern. As outlined earlier however, increasing food requirements will place a significant demand on aquaculture production, yet this will depend in turn on good quality environments. There is therefore a longer term mutual benefit to be sought, which requires appropriate mechanisms for realisation. Two approaches can be considered for mitigating the effects of aquaculture, and improving its external interactions: increasing environmental control, and improving efficiency.

In effect, by increasing environmental control, many aquaculture producers are responding by improving efficiency; provided these control measures are not excessive by comparison with other sectors, and that the efficiency changes are not at the cost of other more critical resources, this may become an effective means of achieving change.

It is obviously preferable for aquaculture operations to be set up from the outset to minimise impact, though for various reasons - lack of incentive, absence of awareness of problems and/or site or operational characteristics - many problems may need to be dealt with retrospectively. Table 4.10 summarises the key issues.

Table 4.10 Minimising possible adverse impact of intensive aquaculture operations

Factor	Possible measures to minimise impact
Physical development	
Conceptual approach	Design the system to get best, most efficient production performance from a little as possible environmental cost
Careful site selection	Minimise impact on sensitive areas; visually, in terms of cover/erosion, in terms of ecosystems and/or individual species
Aquatic system capacity	Provide adequate mixing, dilution and dispersal e.g. of wastes, or e.g. self-purification in river systems
Waste and impact management	Careful attention to location, layout, position, visual effects, colour, shading/protection, storage/work areas
Water and effluent management	Collection, concentration and disposal - self-cleaning tanks, solids collection points
Stock security	Design to minimise releases, contact with external water supplies, transfer to other stock, disease contamination
Construction management	Limit construction disturbance, keep top cover as much as possible, don't discharge materials into water courses, etc
Operational management	
Stock management	Care over incoming stock, also genetic consequences; stock density/system management control
Feed management	More digestible and water-stable feeds, better feeding methods, feed control, optimising efficiency of use rather than increased quantities
Disease/loss management	Predator control, changing ways of disposal of morts (dead stock) and wastes; restricting numbers of different stocks and hence possibility of disease transfer
Site management	Using fallow sites; controlling use of chemicals, transfer of resistance
Water management	Reduction of seepage losses, intensification of use, and reuse of water. Integration of agricultural water with aquaculture

The control of environmental aspects of aquaculture production is set to become an increasingly critical management issue. The objective of environmental management is closely associated with efficient production processes, and may also involve dealing with "non-process" matters such as predation or accidental events (Muir and Bostock, 1994). Opportunities for environmental monitoring and control clearly vary with the production system, the degree of management control inherent within the system, its scale and operating environment, and external pressures - financial and/or regulatory, which might affect operation. The main areas of control concern water quality, and in close association, ecosystem quality. Other social and aesthetic impacts considered undesirable might also be controlled. In many cases, monitoring, management and control approaches for aquaculture are as yet only being conceptualised and developed (GESAMP, 1991, Muir and Baird, 1991, Muir et al, 1994).

At the detailed and specific level, they also have to be "tailored" for particular systems and environments. In Europe and North America in particular controls on effluents are being introduced for aquaculture. There is as yet little consistency of approach, either between authorities, or in comparison with other sectors. In part, this is because many authorities relate effluent discharges to the nature of the receiving water bodies. In northern Europe, concerns are about phosphorus loadings, while in southern Europe, solids discharges are considered to be more important. (Solbe 1987, Pursiainen 1988). Regulations governing the quality of effluent discharge may also influence the volume of water required for aquaculture.

Intensification is typically accompanied by increased water use. In common carp and tilapia culture in Israel however, a decrease in water requirements has occurred, (Hepher 1985; Sarig 1988), primarily because of the high cost of water, and priority being given to conservation.

There is also evidence in other regions of improved water use efficiency arising out of increased control, increased real cost, or declining availability. The step from extensive/low-input aquaculture to semi-intensive methods can be taken with very little change in water demands, though nutrient levels will be increased.

Improvements in polyculture techniques usually involve very little change in water management, and may improve overall discharge water quality, but can result in significant gains in yield. The production of species tolerating poor water quality is also possible with little increased water use, and so the recent increase in production of *Clarias* catfish can be achieved with little extra water demand (though creating very concentrated effluents). Routine water conservation is practised in many aquaculture systems and can be implemented in various ways.

Deepening of ponds increases storage and may widen the potential for other uses. (Hepher 1985). Cage and pen culture also offer good scope for improved use of water resources as they do not require water abstraction. Cages have been used successfully in irrigation reservoirs in several countries and in a wide range of lakes, reservoirs and running waters (Beveridge 1987).

Fresh-water reservoir resources are likely to increase significantly suggesting niches for cage aquaculture. Greater understanding of interactions between cage culture and environment and development of models to predict stocking levels should assist optimal use.

There is also an increasing interest in integrating aquaculture with other industries or with agriculture. There may also be benefits where for example aquaculture can add value to a water resource, e.g. fish production in sewage fed ponds, to improve water quality and generate income from a waste material.

The development of dual-purpose reservoirs in Israel has improved utilisation and reduced costs of water for aquaculture. Water loss from ponds can also be reduced by better siting and management, and by increasing pond depth. Integration with agriculture offers scope for improved efficiency, increasing fertility of irrigation water, to maintain or improve yields with lower levels of fertilisation. Pond water has been reported as a fertiliser for maize and for rice and vegetables in the Philippines, and pond sediments and water have been widely used as fertiliser in China (Edwards, 1980).

Fish culture in rice fields is also returning into practice, as low-pesticide approaches are more widely adopted. Marginal water supply and fertilisation costs are very low, but social and economic benefits can be significant, through production of fish and increased rice yields. Integrated aquaculture systems - in which intensive operations are used to fertilise less intensive systems, have also been developed (Muir, 1995, Phillips, *op cit*), and show useful promise.

There is also need to develop effective means for integrating aquaculture demands with others, and preferably arrive at approaches for 'integrated land and water use management' e.g. in which aquaculture can take a complementary and positive role rather than negative and depleting role. Examples include:

- land reclamation in integrated projects;
- the role of aquaculture in water retention, in storage and land stabilisation, e.g. with hillside reservoirs, storage ponds, freshwater retention after monsoons in salinised areas;
- the possible role in managed water systems - e.g. reservoirs for power generation or potable water supply, large and small scale irrigation schemes, regulated river systems with flood control systems;
- the potential role in sanitation, public health, waste treatment, safe use of farm and domestic wastes;
- use in silt retention as temporary phase prior to land reclamation in stabilising downstream landforms;
- use in integrated coastal management, funding protection works, water controls;
- use of aquaculture as a commercial component in scavenger well operations, where groundwater is becoming salinised (Herbert, pers comm), requiring pumping out of saline water; where scavenged water may be used profitably, the viability of development may be greatly improved;

Aquaculture may also be used to improve the quality of water resources, through environmental enhancement or rehabilitation; e.g. improving water quality in acidified lakes through selective "pollution" by cage culture; stocking irrigation canals with macrophyte feeders such as grass carp *(Ctenopharyngodon idella)*, java carp *(Puntius gonionotus)* and *Tilapia zilli* to improve water flow. In warm waters, integration of extensive with intensive cage culture offers scope for minimising eutrophication from intensive cage farming. The management problems of large water volumes and low stock densities may be partly overcome by culture using cages or enclosures within large ponds. Though relatively undeveloped since the mid 1970s, the integration of aquaculture with domestic and industrial waste waters is likely to become increasingly important, particularly where low-cost sanitation is to be developed.

An area of increasing interest in more intensive aquaculture is that of water management and reuse. Such systems commonly involve higher capital costs for water circulation and treatment units, and additional energy cost in circulating water and running treatments. Their record to date has been variable, and commercial ongrowing in particular has been limited by higher than average production costs (Muir, 1992). However they can offer specific advantages, including:

- the control of key water quality parameters;
- relative independence from external water supplies;
- improved flexibility of supply, overcoming seasonal constraints;

An important distinction can be drawn between technological and ecological approaches to water reuse, as outlined in Table 4.11. The former are the most commonly described, but it is valuable to recognise recycling functions within conventional or modified aquaculture systems, as these may often be capable of enhancement through design or management to achieve useful gains in water yield.

Table 4.11 Approaches to Water Reuse

Technological	Ecological
* Water is moved outside culture area * Specific treatments are applied to the process water, with defined water quality objectives * Liquid and gas pumping and energy usually applied; often also heating/cooling * Specifically designed treatment stages, with at least some degree of control * More commonly used for intensive, usually monoculture systems * Typically capital intensive, with "high technology" methods * Typically high energy consumption, though can be controlled	* Water is retained within culture area * Water use is maximised within the culture area, with little specialised treatment * System is driven primarily by photosynthetic energy for water treatment, temperature conditions * Based primarily on biological processes, over which there is limited control * More often used for semi-intensive systems often with polyculture * Usually lower capital input, with simpler technology, where used. * Usually lower energy use, but may be wasted within poorly controlled systems.

A range of methods may be incorporated, from simple in-tank processes, to complex and carefully controlled treatment systems. Another trend involves pond-based recycle systems, which though relatively simple may be potentially more significant for many of the pressing resource challenges facing the main aquaculture sector.

These systems usually operate on low-medium levels of recycle (typically 50-85%), are developed from traditional open-flow systems, use ambient temperatures, and use simple treatment methods. Aeration and solids removal are standard, often based on paddle-wheel aerators, in the Taiwan and Israeli systems, used also to direct water and collect solids. Solids removal is normally by sedimentation, sometimes in production ponds themselves.

Biological treatment is used for higher levels of recycle, through lagoons, sometimes operating as semi-intensive fish ponds, simple rock or gravel filter beds, mollusc culture, macro-algal beds or designed wetlands (i.e. reed-beds).

The choice of system depends on local environmental conditions and preferred management practice. Water is pumped back to the main aquaculture system, on a continuous intermittent, or partial replacement basis. These systems are quite 'ecological' in nature, and are as yet little developed, though broad design and operating parameters have been defined empirically. They offer direct improvements to water quality, and usually also reduce external loadings, thereby benefiting the wider resource system. They may be based on very simple modifications of existing systems; one or more production units may be converted for water treatment, and though productive area decreases, better water quality may result in improved food conversion and higher yields, and some systems produce secondary crops of fish, algae or molluscs.

These systems need further assessment and development, as there are obvious areas of opportunity for optimising production, treatment efficiency, and water management

Rehabilitation and restoration

Human activities have brought about a wide range of effects - including change and damage to natural environments, whose nature and extent have in many cases only recently received widespread recognition and concern for action. The aquaculture sector is no exception to this, and as outlined earlier there are many examples of negative impacts.

An area of increasing interest and action is that of rehabilitating damaged environments, and to varying degrees restoring them to certain defined conditions. There are various aspects of restoration or rehabilitation related to aquaculture, including:

- ameliorating the effects of aquaculture, and restoring systems which have become environmentally unbalanced or damaged;
- landscaping and other visual rehabilitation methods
- integrating of aquaculture with other activities, to reduce environmental impact and establish or restore effectively managed ecosystems
- the use of aquaculture as a specific tool in rehabilitation of threatened, compromised or damaged environments;

Though as yet little explored, there are however ways in which aquaculture and the techniques it embodies, may be specifically targeted towards restoration or rehabilitation objectives. A brief outline of some current examples are given in Table 4.12. There may be constraints to these approaches and the challenge will not therefore be simply for aquaculture and its contributions, but for the acceptance, use and effectiveness of the complete systems in which aquaculture would operate.

Table 4.12 Examples of aquaculture in restoration/rehabilitation

Area of potential	Features/effects
Restocking	Improve utilisation of water bodies, control stock yields and economic value, using culture-based management approaches, possibly using aquaculture hatchery stock.
Water resource and quality management	Integrate with cage culture to reduce eutrophication. 'Controlled eutrophication' through cage farming also suggested to counter lake acidification. Use of ponds for water retention, sediment and erosion control; local storage/supply of water; nutrient control; control salinity intrusion.
Sewage treatment/ sanitation	Direct use of fish culture with wastewater treatment, e.g. as a component in secondary or tertiary lagooning systems; for use as feed or fishmeal resource, or for broodstock; wastewaters in irrigation schemes, with fish culture integrated in supply channels and/or intermediate storage ponds; net effects in all of these to reduce costs of sanitation.
Community support programmes	Shrimp culture in coastal areas in SE Asia (e.g. Sundarbans in W.Bengal, Vietnam) as an integrated component in coastal stabilisation programmes. In other areas, aquaculture based stocking/restocking of rivers (e.g. the Sepik in Papua New Guinea), reservoirs (e.g. Mahaweli in Sri Lanka) proposed to improve food supply and reduce pressure on surrounding farm and forest land.

5. SOCIAL AND INSTITUTIONAL ISSUES

It is clearly important to consider the relationships between natural resource use, economic output and societal benefit. At the simplest level, this can be identified in terms of food security priorities, or of food supply and its distribution, where it is important to note that sustainability arguments involve the widest access to benefits for current as well as future generations, i.e. social equity.

In these respects, issues of resource access, employment opportunity, food supply and social empowerment are all critical. As Harrison (1994) notes, for sub-Saharan Africa, few aquaculture development activities have focused on poorer sectors, or even incidentally improved their livelihood.

Nash (1992) reviewed the employment opportunities associated with a range of aquaculture systems and practices, commenting on the diversity of effect, and in many cases, the rather limited impact in terms of direct employment.

In many regions, opportunities associated with aquaculture may be available only to those who are already privileged, either through ownership of resources, or by being able to afford the produce. There is clearly a substantial challenge in making aquaculture provide for the poorer sectors of society.

In conjunction with this, there is a vital need to involve individuals and communities at these levels, to encourage their participation, and to allow them to adopt activities and economically productive strategies for livelihood. The traditional approach to this, widely adopted in aquaculture, has been to develop production systems and techniques - often from other countries, or within specialised institutions - and to attempt to disseminate these through formal information and extension systems (FAO/UNDP/NMDC,1987). As widely observed in other sectors, these approaches have encountered many difficulties, and a range of largely participative approaches are now commonly advocated (see e.g. Chambers *et al*, 1989, IIED, 1993).

Table 5.1 outlines some of the key elements of the more traditional strategic approaches and those of participative development, and notes their respective advantages and limitations. While these descriptions are obviously at extreme ends of a spectrum, each offers particular if different advantages.

However, while the principles of participative development, and the use of indigenous technical knowledge (ITK) may be seen as having particular relevance and application at the smaller-scale rural level, and indeed within systems in which aquaculture would probably be combined as part of a more complex productive activity, there may also be limitations in its application, and some areas of risk if these approaches are used uncritically (see e.g. Tripp, 1989, Scoones and Thompson, 1994).

This in turn may support the view that an intelligently applied mixed strategy is probably required in many circumstances, as neither can meet all requirements, but they can be operated in a complementary manner to achieve both strategic and local needs. This also relates to the type of agency involved in development - whether institutional, private sector or NGO, as each will have its particular strengths.

Table 5.1 Development strategies; comparative features

General approach	Features	Advantages	Limitations
Strategic/ top-down	Derives from overview, usually planned approach; application of professional expertise; delivers choices, information, support, controls and manages; organised, often centrally managed delivery system	Opportunity for long-term policy development, focus on strategic problems, provides national perspective on local issues and needs, potential for good science/ technology application; selection of appropriate tools, methods	Needs to work well and sensitively to be effective; dissociation from under-standing local needs, not responsive to changing conditions; perpetuates culture of dependence; often expensive but with insufficient resources.
Organic/ bottom up	Derives from participatory involvement at the farmer level,; taken in broad social context; prefers simple and locally based solutions, may seek external expertise; longer term aims for indigenous development capacity.	Explores and develops solutions in local context, implemented within resources and understanding of people concerned; provides evolving system, good communication response. Encourages self reliance and confidence.	May be artificially constrained by knowledge base and attitudes of participants; poor connections with important strategic issues, and key scientific inputs - may be a misplaced anti-technology bias.

5.1 Issues of adoption of aquaculture at the local level

One of the most critical aspects of aquaculture development, particularly in areas which have not shown significant growth or uptake in the past, is that of adoption of aquaculture as an activity, or of improvements to make it more viable and effective.

In the earlier post-Kyoto stages of aquaculture development, it was recognised that extension would clearly have an important role to play, but it was widely assumed that openly demonstrated benefits of aquaculture would require very little additional incentive for expansion.

However, this view proved to be overoptimistic, and as within the agricultural sector, had eventually prompted more recent analysis of the processes of adoption.

Table 5.2 Important adoption issues in aquaculture

Subject	Associated issues	Implications
Entering the sector	Expectations, external incentives, credit/ investment, ownership, family and community, trust in promoter	Fundamental determinant of scale of aquaculture production from new entrants
Choosing species and system	Background beliefs or knowledge; attitudes of peers, wish to be more progressive	Defining the type of system employed, resources used, type and value of output
Increasing productivity	Attitude to risk/allocation of more resources, ability to control system; desire to appear progressive	Level of management input, resource requirements economic activity, output levels and overall efficiency
Using new species or strains	Views of local markets, background beliefs or knowledge, familiarity with species	Diversification, new markets; extent to which improved strains can be introduced
Changing production plans	Extent of confidence that changed practice can result in changed outputs;	Prospects for improving efficiency, productivity, resource use
Environmental management	Understanding of the issues, and concept that there may be local effects	Potential for expansion without environmental degradation, sustainability
Developing new markets	Confidence in existing operations, attitude to risk, ability to communicate outside local context and/or establish trading links	Widening opportunities, better economic returns, food supply benefits
Expanding production	Attitude to risk/allocation of more resources, ability to control system; desire to appear progressive	Determines extent of production growth from existing participants; wider benefits; resource demands; economic returns

Some of the key aspects of the process of adoption itself are summarised in Table 5.2, which is subdivided into critical areas of decision and development, and identifies the types of issue which may contribute to the decision or response to a proposal for change.

5.2 Other social development issues

Aquaculture output may be seen as a primary goal in itself, together with the appropriate targeting methods for those who are seen as being capable of adopting or developing it, or it may be seen as one of several possible vehicles for social change or empowerment. Some of the particular issues are noted below:

Poverty focusing: where aquaculture might be seen as a means of providing economic opportunity for individuals or groups with very little access to resources, in circumstances where aquaculture has relative advantages over other sources of food production. Aquaculture could provide the benefits of food or income, or both together in a mixed strategy. While poverty focusing continues to be a major issue for many development agencies, the effectiveness of many forms of aquaculture in benefiting the poorest sectors might be questioned, as (in common with much of agricultural development) very few examples can be identified of real effect, beyond the opening of opportunities for labour and supply of raw materials (e.g. collection of wild seedlings, trash fish, rice bran and crushed snails for feeds).

The role of women; an ADCP workshop (ADCP, 1987) reviewed some of the issues concerning women in aquaculture development, ranging from their role as owners or operators of fish ponds or cages at the artisanal level, through to their representation in higher levels of research and administration. It has been widely noted that women and families play an important and still under-recognised role in rural activities and food production, that women are closely involved in decision making concerning artisanal enterprises, and that development activities focusing on women are likely to yield particularly important family and community level benefits. Harrison (1994) has also noted the importance of resource ownership. A number of development projects and NGO activities have attempted to use aquaculture as one of the means for specific involvement of women, usually at the group level, either in sharing common-access resources, or in taking advantages of lease arrangements for public land and water bodies. While these have often opened up new opportunities within the context concerned, their record has to date been rather variable, depending partly on the extent to which these are generally considered to be acceptable activities, and partly on the degree to which these are viable activities and feasible for the women's groups to carry out.

Sustainable rural development; aquaculture has been widely advocated as an integral element in development of local community systems which are socially and environmentally beneficial, often with significant degrees of integration of resources, particularly water and fertilising materials, either organised at the level of multiple-families or communities. While these systems are very appealing in concept, the successful incorporation of aquaculture, particularly in new areas, will depend how easily it fits in with traditional activities and customs. Development may also be constrained by problems of access (to resources, markets, extension etc...)

A more complete view of these and other issues might be that aquaculture and its development, both supports and is dependent on the quality of the society in which it operates, and that it is difficult and probably unwise to attempt to separate it from the societal system. Rather it needs to be recognised as one of its elements, and one in which change could be targeted at various points in the systems, and if effectively carried out, could have definable and positive effects within this system. The nature of the system, and the social, economic and environmental relationships therefore needs to be understood clearly.

5.3 Research support for aquaculture

Research will be critical in aquaculture development, both at the initiating phase and during its subsequent evolution. In line with wider development thinking, e.g. in agricultural research, there has been a substantial change in view about its role, methods of operation and objectives, and of the appropriateness of particular types of research for development needs. Table 5.3 provides an initial summary of the different kinds of approach that can be applied to aquaculture research.

There is still considerable debate concerning the role of research in development, and the evolution and application of knowledge, particularly in the agricultural sector (see e.g. Scoones and Thompson, *op cit* Bailey and Skladany, 1990, World Bank, 1992). Although the analyses are often initiated in the context of intensive aquaculture, many of the conclusions are nevertheless relevant to the more marginal, less organised smaller scale aquaculture sector typical in the rural development context. A major element in current approaches is that of participative research, a process whereby cultural and knowledge systems of different forms (e.g. positivist scientific, institutional authoritarian, or rural empirical) are encouraged to interact in pursuit of problem identification and resolution.

Though current thinking about participative-based methodologies has clearly a lot to offer in terms of understanding local constraints and contexts, there are some caveats. Firstly, aquaculture is often a different type of system, and may not really be a tradition about which rural peoples knowledge, etc is established, nor indeed where the transfer agents' knowledge is particularly deep-seated. There is also the interesting consequence that if farmers are inclined to 'pick and mix' in their evolutionary and temporally adaptive approaches to management, the provision of a varied suite of technical choices (rather than a monolithic and dogmatic one) might be a useful contribution. A further area of comment concerns the indisputable point that materialist science does actually have some inputs which are simply unachievable by other means - obvious examples in aquaculture include genetics, disease diagnosis and control, materials and design analysis, and feed manufacture. Inputs from fields such as these can offer discrete change within farming systems, and need to be recognised for their strength and effect. Care must be taken to avoid "twin track" development, with an increasing gap between those trapped in a dogmatic poorly guided participatory approach and those with freer access to scientific support. Such is the power of technology that it can dramatically change the strength of those who can control its use.

Table 5.3 Approaches to aquaculture research

Approach	Key features	Constraints
Conceptual		
Fundamental /basic	Classical 'deep' research, non-purposive, may originate from range of directions, disciplines; does not need local base, nor focused on aquaculture	Expensive, irrelevant, repetitive research may be promoted for alleged potential for aquaculture; difficulties of bridging from key results to next stages
Strategic	Developed with the aim of resolving underlying constraints in adaptive/field research	Although purpose implied, not always clear if needs or methodology-driven; basic research may be called strategic if uses can be identified for its findings
Adaptive	Normally field based, with specific aim of testing prior concepts in local conditions	Usually quite purposive and can be effective, can also include assessment of practical feasibility, but unlikely to elicit fundamental knowledge
Operational		
Research station based	Dedicated facilities, with experimental/demonstration systems, often targeted for local needs/species, aquaculture research staff	Often based on the premise that construction of facilities alone leads to benefit; work becomes facility-led rather than problem led; repetition
Field-based /empirical	Primarily originating from parallel or sequential field-based practical trials, observations; with professional researchers or skilled farmers	Effectiveness depends on design; may be repetitive and trivial; but useful if well planned and run, and representative of broader context
Commercial	Usually simple trials testing out commercial products/systems in real or simulated conditions, by professionals, demonstrators, or farmers	Usually specific and can be effective, can include practical feasibility testing, but not always carried out with adequate experimental design
Opportunistic	Flexible, based on testing ideas, concepts using direct data or re-interpretation/aggregation of other data; usually professional researcher	Can be very effective; depends on opportunity, skills of researcher and data quality available; may not be closely enough targeted for practical use
Participatory	Based around/together with farmers/other participants in development	May be too uninformed, insufficiently designed to provide properly verifiable

A particular institutional issue for aquaculture concerns the nature and extent of useful development research, and the appropriate roles for different parts of the national and international research systems (World Bank 199b) . A further and related issue concerns the potential roles of the public and private sector. While many countries, even those with limited resources, have made or received substantial investments in research infrastructure for the aquaculture and related sectors, there are serious questions to be raised concerning the relevance and effectiveness of output. This problem is further compounded by the effects of structural adjustment and other policy level changes, which have the general effect of reducing funds available for aquaculture research. At least three fundamental areas would appear to be involved;

- the physical, organisational and human resource capacity of the research system
- the nature and appropriateness of the science activities being carried out
- the effectiveness in delivering outputs and communicating with end-users concerning

These and other related issues are developed further in Table 5.4, based on the recent SIFR evaluation exercise, together with respective recommendations for addressing these.

Table 5.4 Research capacity problems in developing countries

Area of concern	Issues	Possible remedies
Past research strategies	Scope too narrow; primarily zoology and technology, intensification; neglect of social and environmental context, short-term in response to funding	Not applicable; though continued post-hoc analysis desirable; focus towards integrated approaches
Present state of research	Wide variation in capacity between regions. Specific needs of different types of development poorly appreciated, inappropriate resource allocation, lack of understanding of farming systems; need for integrated strategies, multi-disciplinary staff resource; lack of long-term funding support, operating funds; low motivation, lack of competition, dynamism, quality of training	Improved procedures for research strategy, selecting priority areas, multidisciplinary approaches, appropriate protocols, co-operation mechanisms and means to integrate plans, skills and outputs; more focus on operating expenditures, improved selection, training, motivation, evaluation, staff conditions, external communication; programme funding continuity
Disparities in distribution of knowledge	Wide regional variation in basic knowledge and techniques available, impeded flow of knowledge, lack of competition, interchange, communication; need for evaluation, need wider participation with developed country activities	Better communication, meeting, exchanges of ideas, network access, external evaluations of work programmes, better regional mechanisms, develop high standard regional scientific journals.
The use of research	Communication gap between public sector institutes, universities, production sector, inappropriate dissemination mechanisms, top-down approaches, unrealistic demonstrations,	Better fora for exchange of ideas, participation; validation under real field and economic conditions, etc; mechanisms for joint financing of research, strengthened user/producer groups, systematic procedures to evaluate development
Institutions	Resources spread across too many institutes, emphasis on capital structures, low priority to innovative research; limited term funding for regional institutions, problems of funding in general for operation and for wider networking.	Develop national entities, with clear priorities co-ordinated linked centres, access to international co-operation; formal structures for regional co-operation and specific action programmes for innovative research

Developed from World Bank/UNDP/CEC/FAO, 1991

A primary recommendation of the SIFR study concerned the development of networks for improving the capacity of research in developing countries, sharing costs and multiplying benefits, improving communication and exchange between workers, improving standards, widening access to information and avoiding unnecessary duplication.

Although not explicitly mentioned in this study, there is a need to educate both the national scientific community and the donor and NGO community concerning the nature of aquaculture research, the mechanisms by which it may be carried out and the potential benefits it can deliver.

There is also a considerable need for institutional change within the research system, with less emphasis on poorly operational replicate field facilities and 'pseudo-research', the not quite repetitive reworking of existing relationships under marginally variant conditions. This is a particular problem in aquaculture research, from which no institution is immune, but is particularly wasteful and irrelevant for development needs. Outside of core strategic programmes, a refocusing towards field level, development-linked situational and adaptive research would provide valuable improvements, with far less need for expensive central facilities. There is also of course a sociocultural issue to be addressed, in the need for greater formal recognition of (and status for) the value and merit of this type of work.

Cost benefit assessments of research options have considerable value in assigning priorities, particularly for research at the applied or adaptive level, but also for strategic research, e.g. within 'foresight' programmes, in which probability adjusted or 'Delphi' techniques can be used to provide a broad concept of potential benefits versus costs (USDA, 1984). Though the unpredictability of strategic research is often invoked against such an approach, the argument works in many ways, and remarkable advances can be made at times almost accidentally and with very little resource. The expense of open-minded and unregulated applied research is ill afforded.

5.4 Human resource planning and development

The issues described in much of the foregoing section have fundamental links with human resources and their development - whether in finding ways to involve individuals or communities, encouraging adoption, or in finding effective mechanisms for developing and communicating cultural or scientific knowledge.

The process of human or social development, within which aquaculture development lies and on which it depends, requires the communication of knowledge, the development of skills and expansion of capability, at a wide range of levels, whether farmer, extension advisor, technician, business manager, scientist or administrator. While much of this may occur incidentally in the course of everyday activities and experience, specific organisation and planning is required if development objectives are to be realistically achieved.

People and their skills are also important in a more general sense, for basic skills and capabilities, potential job satisfaction, productive reward, general motivation, capability for care, for ideas, societal involvement, improvement, and responsibility. The major aspects of the human resource development process include;

- defining the overall objectives and needs for the sector, quantitatively and qualitatively; at the general and strategic level, and in terms of specific production and support targets;

- defining the basic type of skill or resource development required, whether this involves extension (typically evolutionary and interactive raising of awareness and development of skills and capabilities), training (usually the imparting of specific skills), or education;

- assessing the numbers concerned, and their background skills; to determine the scope, extent and resources required to carry out development, and the specific nature of the inputs required;

In overall terms, aquaculture extension activities are usually the most important quantitatively, where inputs usually involve the large number of rural people who are the main 'clients' in the development process. Being on the 'front line', the nature and operation of extension services is one of the most critical aspects of human resource development in the sector, and is closely associated with the development strategies and research processes described earlier. Table 5.5 provides an outline of the main types of aquaculture extension system, and describes their characteristics. Training may also be significant numerically; it may be part of extension, e.g. in developing specific technical skills, and is certainly a need for many of those carrying out the extension process. Education is usually more specialised, involves broader and deeper levels of knowledge, taking a longer time to develop, and is usually less widely dispersed, typically to managerial, support and specialist personnel.

Table 5.5 Aquaculture extension systems and methodologies

Approach/system	Key features	Implications/constraints
Traditional line department extension system	Usually fishery department, with specialists given varying amount of extension training ; focus often on seed supply, stock disease monitoring, technical advice, production records, technology packages, typical train/visit methodologies	Lack of rural development perspective, often poor training, under resourced, lack of linkage/competition with other agencies, etc; conflicts with regulatory or control functions, but sectoral issues may be better understood and promoted
Multiple function extension system	Often agriculture or rural development department, with trained broad-range extensionists, specialist backup if required; usually technical focus, may include farming systems approaches, varied delivery, though often traditional	Usually offers better level of resource, extension skill and capacity; opportunity to fit aquaculture into broader context; specialist inputs may be constraint, not enough support; possible conflicts; ex-tension methods may need improvement
Farm demonstration system approaches	Used by a range of agents, including commercial demonstration, based either in specialist centre or on pilot farms; offers direct evidence and practice	May not be sufficiently typical, and may be over-resourced, artificial; others may be distrustful; can offer practical/realistic conditions if well handled
Participative approaches	Increasingly used by NGOs and some extension services, usually in general rural development context, based on locally expressed needs and problems, local resource capacity	Effectiveness depends greatly on the agents and the process; in some respects simply a properly conducted extension process; can produce important insights into development needs
Broadcast, workshops, and other mechanisms	Commonly used as adjunct/replacement to traditional methods; potential to reach wide audience in impartial or social context with professional quality materials	Less individual focus, more generalised materials with short time period

One of the most striking trends in the present decade in many countries has been the move of extension activities from the formal government sector to the NGOs, a corresponding shift towards more participative approaches, and a far wider and (in many cases) more effective involvement of individuals and communities. Related to this has been a gradual shift from formal fisheries department based aquaculture extension, often with very limited resources and training, towards the inclusion of aquaculture within a more integrated agricultural, rural development or equivalent approach. As well as bringing a far wider resource base into the sector, it provides access to many of the methods of agricultural extension, which have on the whole been better developed and more clearly targeted (Harrison, 1994). While technical expertise is required in some aspects of aquaculture, this can usually be supplied through smaller numbers of subject area specialists. The assessment of needs is essential before the training or extension process is initiated; the mistake is often made of preconceptions, or the use of standardised approaches. In terms of the current and projected aims for aquaculture support, some estimates of overall regional demand can be attempted. Several approaches can be used:

- assumptions of numbers of farmers and extension staff required
- demands based around institution building
- requirements of the commercial sector

Without a detailed sectoral planning exercise it is difficult to identify these numbers with any degree of confidence. However, some indications of the potential scale of demand can be made by considering the present size of the sector, and by making initial assumptions about its characteristics. This could be done at the national or regional level, and could also be extended to consider costs and benefits, as related to gains in welfare and productivity. In Bangladesh alone it is estimated that some 20 million people have at least some form of association with the aquaculture/inland fisheries sector (Rahman, 1991). Clearly much of the wider access is likely to involve indirect approaches, rather than direct contact with sector agents e.g. through institutional strengthening, and through networked and NGO based activities. Nevertheless, it can be assumed that there is already a high level of human resource involvement in the sector, that this will require to be developed to meet many of the challenges of the future, and that a good level of demand for human resource support can be anticipated at all levels.

5.5 Institutional development

The role of institutions in these and related areas has been noted at various points in the discussion. One of the important issues in many cases concerns the improvement and development of institutional capacity to meet the challenges of the sector, whether in terms of organisation, operation, regulation, research, extension, supply, or other support functions. As indicated earlier, there are many institutional participants in aquaculture development, and there are many changes underway in the respective roles of private and public sector institutions. Activities which had traditionally been the province of the public sector, such as seed supply, the provision of technical advice, and in some cases the delivery of extension support are increasingly being taken up by the private sector, either commercially operated, or through NGO activities. In some cases, central institutional functions are themselves being privatised, or contracted out by government to the public sector. Whatever the specific circumstances, in both public and private sectors, in education, support, research or management there is commonly a need to develop skills, organisational capability and responsiveness to external needs.

In many countries and production sectors there is also a need for aquaculture producers to develop a clear identity, to represent the needs of their industry, to carry out co-operative functions such as purchasing, marketing and strategic research, and to co-ordinate and express responses to policy proposals. This is typically achieved through the development of producer associations, usually funded and managed from the respective industry's own resources (e.g. through production levies, etc). As in the research sector the use of networks has also been widely considered for development purposes, to provide institutions (particularly in the public sector) with the means to strengthen capacity efficiently by co-developing various initiatives, comparing and testing planning and policy approaches, and sharing specialist inputs. In all of these cases, as with individual training and educational programmes, institutional development requires thorough analysis of needs and planned responses in terms of organisational and individual development, carried out as far as possible in an integrated and complementary manner.

6. FUTURE SUPPLY FROM AQUACULTURE

Considering the wide range of factors that must be taken into account, predictions in aquaculture are extremely difficult to make, but leaving aside doomsday scenarios of global instability, it seems inevitable aquaculture will play an ever increasing role in global food supply. The trend for intensification is likely to continue, with increased nutrient and energy inputs which will have to be managed with increasing care and efficiency. Shortages of key inputs may arise, and will force substitution or alternative approaches. Efforts will have to be made to minimise initial environmental disturbance, improve nutrient and energy efficiency, and reduce waste output. Supplies will increase from both intensive systems as well as semi-intensive and extensive systems. Increased production will come both from improving yields from existing systems, as well as developing new systems and infrastructure. Integrated systems, capable of fitting in with local resources and activities are likely to have greater prominence. Sustainable resource efficient systems, integrated into farming economies, and based on non-carnivorous species or plant production, will be a favoured option in the context of food security in the main sub-tropical and tropical regions. Diverse intensive systems will supply a wide variety of traded products to an increasingly sophisticated market.

6.1 Projection of aquaculture production to the year 2010

To provide a practical perspective on the implications of aquaculture development, a range of production scenarios have been developed, offering projections for the year 2010. See tables 6.1 and 6.2. Further speculation is offered for the horizon 2050. These are based on the main species groups described earlier, and use selected growth rates for each species group, based in turn on broad assumptions indicated in table 6.3. Here, three test sets of growth rates were applied

- a favorable growth rate from 1992 to 2010, giving anticipated production in the year 2010
- a revised slower growth rate from 2000 to 2010, anticipating a faster slow down of growth over this period;
- a highly speculative growth rate to the year 2050, assuming an adjustment of emphasis between the major species groups.

Overall, with some exceptions, it is assumed that longer term growth rates will gradually reduce, as resource constraints start to apply, and as major production sectors start to stabilise.

The average growth rate for each of the species subgroups is also calculated, as is that of the group as a whole, and the relative percentage contribution of each species group is also provided. The purpose of these tables is to demonstrate typical consequences of the levels of growth rate which it might not be unreasonable to expect in general terms, without making too specific assumptions about determinants for each group. In doing so, the process reverses the approach demonstrated by New (1992), Muir (1992) and Csavas (1995), in which the initiating point is taken as the forecast need for aquatic product supply, to meet current consumption rates projected forwards via population growth estimates towards specified target dates.

The projections presented in table 6.1 and table 6.2 are obviously very tentative, although based on likely scenarios for each species group considered separately table 6.3. A principal scenario is suggested which is essentially optimistic, since it cannot take into account possible uncertainties such as political and economic instability. Low and high alternative projections are also suggested. The lower alternative projection assumes generally slower growth from the year 2000 onwards as a result of market constraints and of the worlds inability to tackle urgent problems of environmental degradation. The higher alternative assumes an early adoption of technologies to increase the production of marine fish at lower cost, leading to faster growth in the marine sector. Growth is expected in most commodities, and the relative proportions of the major species groups is expected to remain broadly similar. However, there are expected to be greater variations in growth between some of the sub sectors as currently expanding species reach the limits of their markets and other species receive greater prominence. These projections anticipate at least a doubling of production by the year 2010 to a total (less plants) of 33 million tonnes, within a range of 27 million tonnes (low) and 39 million tonnes (high). This is an increase of 19 million tonnes over 1992. In order to appraise the credibility of such a projection it is of interest to note that already there is likely to have been an increase of 3 - 4 million tonnes in global production since the 1992 baseline used in these projections (this represents 25% of the increase expected from the "low" projection). The actual calculations were developed using a standard spreadsheet package, which can be adjusted to examine the impacts of various growth rate projections. The examples shown here are therefore simply representative of a range of possible development prospects. The relative importance of these trends will differ according to the social, political and economic characteristics of each region, and on its current state of development. Within regions, individual countries and localities will experience different problems and development priorities.

In the medium to long term up to 2050:

Any projections of future development beyond 2010 become very speculative. New technologies, demographic constraints, absolute uncertainty about economic and political conditions are all against the chances of correct predictions. Aquaculture will probably continue to develop its position as a major source of food supply:

- if environmentally sustainable systems are developed in preference to other solutions
- if aquaculture is effectively integrated into global measures to control and manage fresh water resources;
- if new technologies are developed to increase production from offshore areas
- if genetic innovation can increase the performance of organisms used in culture
- if systems are diversified to include new approaches which target organisms that feed low in the food chain to obtain the maximum benefit from the primary production.
- if a larger proportion of aquaculture production is of aquatic plants for human consumption.

Table 6.1 Scenarios of possible aquaculture production 1992 to 2010

				Assumed growth		Lower growth scenario (a)		Higher growth scenario		Speculative long term growth	
Species group	**1992 Production**	**% of total**	**%/yr 86/92**	**%/yr 92/10**	**2010 tonnes**	**% / yr 00/10**	**2010 (-) tonnes**	**%/yr 92/10**	**2010 (+) tonnes**	**%/yr 92/50**	**2050 tonnes**
Freshwater fish											
carps, barbels, cyprinids	6652305	70.6	7.9	4.5	14691474	3	12713781	5	16009565	2	20978871
tilapias and other cichlids	473477	5	11.9	6	1351464	4	1117067	8	1892023	4	4605031
misc freshwater fish	854955	9.1	6.3	4	1731982	3	1572469	6	2440332	2	2696207
group total	7980737	84.7	7.9	4.5	17770000	3.7	15400000	5.3	20340000	2.2	28280000
Diadromous fish											
sturgeons,paddlefish	437		15.9	15	5408	7	2630	35	96937	12	312699
river eels	99668	1.1	4.3	0.5	109030	0.3	106879	1	119218	1	177499
salmon, trouts, smelts	628418	6.7	12.9	5	1512363	3.5	1309684	6	1793718	2.5	2631678
misc diadromous fish	352175	3.7	2	2	502993	1.5	478873	2	502993	1.5	835197
group total	1080698	11.5	7.6	3.8	2130000	3.2	1900000	4.8	2510000	2.3	3960000
Marine fish											
flounders,halibuts,soles	12075	0.1	35.3	8	48252	4	33083	12	92856	7	611148
cods, hakes, haddocks	28		6	10	156	15	243	40	11953	15	92818
redfishes, basses, congers	95944	1	15.7	8	383394	4	262870	10	533441	4.5	1232431
jacks, mullets, sauries	179430	1.9	1.1	1.5	234576	1	223273	3	305468	2.5	751414
herrings, sardines,											
tunas, bonitos, billfishes	123		12.7	40	52506	10	4708	50	181781	15	407737
miscellaneous marine fishes	68118	0.7	18.9	6	194432	3	145909	19	1559937	6	1999871
group total	355718	3.8	7.2	5.4	910000	3.6	670000	11.9	2690000	4.7	5100000
TOTAL FISH	9417153	100	7.8	4.5	20810000	3.7	17970000	5.7	25540000	2.4	37340000
Crustacea											
freshwater crustaceans	62433	6.4	1.4	5	150000	4	140000	5	150000	4	610000
seaspiders, crabs	13693	1.4	24.5	10	76132	5	47812	10	76132	5	231995
lobsters, spiny lobsters	62		29.7	40	26466	15	3702	45	49776	15	205526
shrimps, prawns	884075	90	18.9	3	1505079	1.5	1299713	4	1790974	1.5	2096619
miscell marine crustaceans	21653	2.2	8.1	5	52111	3	42994	8	86526	3	120248
total marine crustacea	919483	93.6	18.6	3.3	1650000	2.3	1390000	4.4	2000000	1.8	2650000
TOTAL CRUSTACEA	981916	100	16.8	3.4	1800000	2.5	1530000	4.5	2150000	2.1	3260000
Molluscs											
freshwater molluscs	256		-15.8	1	min	0.5	min	10	min	10	min
abalones, winkles,conchs	1570		11.8	10	8729	6	6027	12	12073	7	79462
oysters	953529	27.2	0.3	0.5	1043093	0.5	1043093	0.5	1043093	1	1698140
mussels	1086310	31	5.3	3.5	2017809	1.5	1660111	3.5	2017809	1.5	2576228
scallops, pectens	549194	15.7	22.3	10	3053473	4	1742612	10	3053473	4	5341454
clams, cockles, arkshells	764744	21.8	9.8	8	3055932	4	2095268	8	3055932	3	4246930
squids, cuttlefish, octopus											
misc marine molluscs	145116	4.1	14.3	10	806833	4	460458	15	1795876	4	1411396
group total marine molluscs	3500463	100	6.5	6.0	9980000	3.9	7000000	6.6	10980000	2.6	15350000
TOTAL MOLLUSCS	3500719	100	6.5	6.0	9980000	3.9	7000000	6.6	10980000	2.6	15410000
Aquatic plants											
brown seaweeds	3640344	67.5	8.2	5	8760922	2.5	6884866	5	8760922	4	35405938
red seaweeds	1132654	21	5.5	3.5	2103893	2.5	1909232	3.5	2103893	3	6290082
green seaweeds, other algae	17248	0.3	7.7	4.5	38092	4	36308	4.5	38092	8	1497327
misc aquatic plants	599543	11.1	12.3	10	3333410	5	2093412	13	5410437	4	5831147
TOTAL AQ PLANTS	5389789	100	8	5.5	14230000	4.0	10920000	6.3	16310000	3.9	49020000

(a) Estimated on the basis of a slow down of growth from 2000 (same growth rate from 1992 to 2000)

Table 6.2 Summary of projected aquaculture production 1992 to 2010 (see table 6.1)

				Assumed growth (a)		Lower growth scenario		Higher growth scenario		Speculative long term growth	
Species group	1992 Production	% of total	%/yr 86/92	%/yr 92/10	2010 tonnes	% / yr 00/10	2010 tonnes	%/yr 92/10	2010 tonnes	%/yr 92/50	2050 tonnes
Freshwater fish	7980737	84.7	7.9	4.5	17770000	3.7	15400000	5.3	20340000	2.2	28280000
Diadromous fish	1080698	11.5	7.6	3.8	2130000	3.2	1900000	4.8	2510000	2.3	3960000
Marine fish	355718	3.8	7.2	5.4	910000	3.6	670000	11.9	2690000	4.7	5100000
TOTAL FISH	9417153	100	7.8	4.5	20810000	3.7	17970000	5.7	25540000	2.4	37340000
freshwater crustacea	62433	6.4	1.4	5.0	150000	4.0	140000	5.0	150000	4.0	610000
total marine crustacea	919483	93.6	18.6	3.3	1650000	2.3	1390000	4.4	2000000	1.8	2650000
TOTAL CRUSTACEA	981916	100	16.8	3.4	1800000	2.5	1530000	4.5	2150000	2.1	3260000
freshwater molluscs	256		-15.8	1.0	min	0.5	min	10.0	min	10.0	min
marine molluscs	3500463	100	6.5	6.0	9980000	3.9	7000000	6.6	10980000	2.6	15350000
TOTAL MOLLUSCS	3500719	100	6.5	6.0	9980000	3.9	7000000	6.6	10980000	2.6	15410000
TOTAL AQ PLANTS	5389789	100	8	5.5	14230000	4.0	10920000	6.3	16310000	3.9	49020000
TOTAL AQUACULTURE PRODUCTION (INCL. PLANTS)	19,289,577			5.1	47,000,000	3.7	37,000,000	6.0	55,000,000	3.0	105,000,000
	13,899,788			4.9	33,000,000	3.8	27,000,000	5.8	39,000,000	2.4	56,000,000

(a) For comparison, projecting linear growth on the basis of 1984/1992 statistics predicts production of approx. 31 million t in 2010 (Csavas 1994)

Table 6.3 Broad assumptions behind projections of growth of aquaculture to 2010.

	Supply by 2010	2010 (High)	2010 (Low)
Freshwater fish	continued growth of carps, tilapias and catfish; increased yields from polycultures with new species added; some yield rises from genetic improvements; new species becoming important in South America and Africa .	extra growth through diversification especially more widespread use of tilapias in extensive and intensive systems; expanded market for tilapias in developed countries; introduction of new species to satisfy tastes of local markets	slower growth from carp especially; environmental conditions degrading and yields from existing systems will not expand further
Diadromous fish	growth mainly based on salmon which will slow as markets mature and as other species are introduced; prospects of rapid growth of sturgeon as market penetration progresses; milkfish may receive more attention	better than expected expansion of sturgeon both in intensive culture and in release programmes in the former USSR; salmon remains competitive as costs fall further	most growth still from salmon, while other species fail to establish
Marine fish	lively growth can be expected from this group; growth could accelerate as costs come down and capture fisheries products increase in price; advances in hatchery technology, and reduced feed costs could be very favorable to this group	faster growth in the marine sector as new technologies have an increasing impact; new species will become important, while a few more established species will begin to be traded as salmon is today	costs will remain high, as marine aquaculture has difficulty gaining access to coastal sites increasingly under risk of pollution and overuse
Crustacea	shrimp will continue to dominate and provide most of the increased tonnage; as markets reach their limits, diversification will contribute to growth especially if techniques for lobster culture continue to improve	diversifying markets open new production opportunities for shrimp , lobster and other crustacea; effective solutions for health management and environmental impact remove some constraints in coastal areas.	market and limitation on coastal sites will constrain expansion; continuing health and environmental problems.
Molluscs	the group will continue to show steady growth, although there may be problems of site/environment limitations in the current production centres; expansion in other areas will depend on improvements in a number of factors such as processing and trade; marketing will be a major issue in expansion and scallops in particular may penetrate into much wider markets than is currently the case for molluscs	improved marketing and processing will open much larger markets; molluscs will be actively promoted as an integrated part of water quality management in a number of situations	site limitations will restrict expansion, as will concern from consumers about products from polluted coastal areas
Aquatic plants	the relative proportions of species in this group are likely to remain the same; growth will continue in response to increased industrial demands, although markets for human consumption will only widen slowly; a number of factors may encourage growth; including increased use in nutrient scrubbing systems, and in improving water quality management.	expansion of industrial markets will increase interest in production of particular chemical products; increased use of aquatic plants in water treatment; possible new products for human consumption.	pollution becomes a problem in SE Asia

7. REGIONAL DEVELOPMENT

7.1 Production and country development status

Following the review of current production trends, and the outline of potential growth by species group, the implications are examined for aquaculture development at the level of specific countries or country groups. The primary development concerns would be the resources available, the potential needs e.g. for food, and possibilities of capitalisation for development. The first analysis is therefore to review countries in terms of economic strength, population density and growth, available internal renewable water resources (for inland aquaculture), total coastline length (for coastal aquaculture), recent aquaculture development, and loadings per area, per coastline length and per head of population. Countries are classified according to World Bank GDP levels, using UNDP data on population and resources; FAO aquaculture production statistics are used. While it should be recognised that a broad focus on the poorest country groups will offer the most important insights for food security and associated development priorities, the questions of income distribution (see e.g. UNDP, 1994) will also be important, and many of the middle income and richer countries will also have significant issues of addressing needs of poorer or otherwise disadvantaged sectors.

Table 7.1 Aquaculture development in lowest income countries (1990 GDP > $300)

	Population/km²		f.water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)[1]	length (km)	Total mt	Growth '86-92 %[2]	mt. per '000km2 land area[3]	mt. per km3 water res[4]	mt. per km of coast[5]	kg per head[6]
Mozambique	20	52	1	2,470	30	34.8	0.04	0.38	0	0.002
Tanzania	26	68	1	1,424	5400	135.1	0.42	8.00	3.51	0.220
Ethiopia	42	128	2	1,094	22		0.02	0.20	0	0
Somalia	12	33	7	3,025	0		0	0	0	0
Uganda	69	178	0	0	45	4.3	0.19			0.003
Burundi	193	500	3	0	50	15.6	1.79	15.15		0.009
Lesotho	60	133	1	0	30	3.1	0.87	2.60		0.017
Chad	4	11	0	0	0		0			0
Malawi	72	203	2	0	223	2.9	1.86	22.00		0.026
Zaire	16	38	0	37	730	1	0.31		0	0.020
Sierra Leone	57	139	0	402	20	6.1	0.28		0	0.005
Madagascar	20	44	41	4,828	1677	44.9	1.06	15.63	0.22	0.143
Mali	7	19	2	0	40	26.0	0.03	0.57		0.005
Rwanda	273	885	2	0	53	-2.3	2.04	5.30		0.007
Sudan	10	22	14	853	200	30.2	0.08	1.50	0	0.008
Nepal	134	262	2	0	9371	14.5	66.46	69.41		0.496
Bhutan	30	64	0	0	35		0.74			0.025
Lao PDR	17	42	0	0	16000	21.4	67.51			3.902
Bangladesh	741	1222	1	580	230097	9.4	1452.06	92.73	36.21	2.156
India	258	410	18	12,700	1374787	12.2	407.88	638.38	2.13	1.618
Myanmar	61	103	0	3,060	4425	-4.4	6.53		0	0.106

Notes: 1. Percent of total renewable freshwater resources presently used within the country 2. Percentage growth of aquaculture production between 1786 and 1772 3. Aquaculture production per thousand km² of land area 4. Aquaculture production per km³ of renewal freshwater resources 5. Aquaculture production per km of coastline length 6. Aquaculture production per head of population
(Source: UNDP, 1994; World Bank, 1992; FAO, 1992)

Lowest income countries

The overview starts with Table 7.1, which shows key resource and development features of the poorest group of countries, which (as in the following tables also) are ranked in ascending order of income for each major region.

There are 21 countries in this group, 15 of which are in Africa, the remainder in Asia. The table shows a very wide range of aquaculture production per head - from effectively zero in countries such as Ethiopia, Somalia and Chad to as much as 3.9 kg in Lao PDR, and a similar variation in growth rate for the aquaculture sector. The group includes major aquaculture producers such as India and Bangladesh, moderate level producers such as Nepal, Lao PDR, Myanmar, and Madagascar, the remainder producing less than 1000t.

With the exception of Madagascar, Sudan and India, inland water resources are however relatively lightly exploited, and where coastal resources are available at all, these are often significant. Population densities vary quite widely, from less than 10 km^{-2} in Chad and Mali to more than 100 km^{-2} in Burundi, Rwanda, Nepal, Bangladesh and India. The projected growth of population in all of the countries is high, with the exception of Bangladesh, Myanmar and India, where projected growth is more moderate. Nonetheless Bangladesh is projected to have one of the world's highest population densities, at 1222 km^{-2}, in 2025.

Aquaculture growth rates have been historically extremely varied. However, to the extent that such a disparate group of countries can be aggregated, these countries will all have significant development demands over coming years, with a wide range of capacity with which to respond to these.

For the large Asian countries, the role of the aquaculture has already been significant, and already accounts for significant per capita supply, but there is evidence of considerable resource pressure. While India and Bangladesh clearly have the traditions and capability, and while Bangladesh in particular has significant water resource capacity, a target of increasing production by some 60% over the period to 2025 to meet domestic demand will represent a considerable challenge for resource planning and co-ordination. In both countries, however there are substantial opportunities for extending various forms of inland aquaculture, and encouraging signs of development through NGO and private sector groups, including an increasing interest in the minor species, many of which may also be of biodiversity significance, as well as widening options for purchase. The potential for managed inland capture fisheries on the major river systems of the Indo-Gangetic plain is also being increasingly recognised, and major programmes of flood control mitigation and possible aquaculture-based compensation are currently in hand.

Although there has been a traditional integrated wastewater aquaculture sector in Calcutta and some smaller locations, there appears to be little prospect for this to develop in the medium term, as in spite of growing problems with water and wastewater management there is little institutional support.

The other Asian countries in this group have varying levels of potential, though all will be expected to develop. Nepal has the highest population pressure, and has had a useful aquaculture growth rate, with similar ratios of production to renewable water resource as Bangladesh, but a far lower per capita production.

For both Nepal and Bhutan production may however be restricted by climate and topography. Myanmar's production record has been poor recently, but as with Laos, which is now recording significant production increases, political stability will offer improved opportunities for growth.

In all the countries in the region however, economic growth and industrialisation will put increasing pressure on soil and water resources, and aquaculture development will have to be well co-ordinated.

The major part of the group comprises a range of African countries of diverse geographical, social and political background. With the exception of Tanzania and Madagascar, which have had recent development projects at least partially based on shrimp culture, aquaculture production has been insignificant, though there are major challenges of population growth and food demand.

In overall physical terms (apart from water development in Madagascar and Sudan) resources may be available for further aquaculture development, but there are major problems of adoption and continuation of acceptable forms of aquaculture (see e.g. Harrison, 1994). It is also the case that not all locations will have a suitable combination of resources to make aquaculture feasible (see e.g. Kapetsky, 1994). The need for general infrastructure, institutional capacity and market development has been widely described, and these factors may be expected to limit potential, unless they can be addressed effectively.

Low income countries

Table 7.2 provides a similar presentation for the next category, which contains 36 countries, of which 19 are in Africa, 10 are in Asia, and 7 elsewhere. This group also displays a wide diversity of characteristics.

Variable growth rates of population are projected; in only Egypt, Zimbabwe, Papua New Guinea, Cambodia, Vietnam, Indonesia, Sri Lanka, the Philippines, China, Albania and Haiti is less than a doubling expected; even for these amongst which are already amongst the most populous of the world's countries, the increase is typically 60-75% (i.e. around 1.5% yr^{-1}). By comparison with the previous group, however, population densities are rather lower.

The use of fresh water varies widely but is generally low, though Egypt and Yemen Republic are notable in their heavy dependence (the latter supplied additionally by desalination/groundwater abstraction), Pakistan and Afghanistan also have moderately high utilisation percentages, and Mauritania, China and Sri Lanka have some pressure on use.

Coastline resources vary widely, with Indonesia, the Philippines and China as major world resources, and Egypt, Angola, Namibia, Papua New Guinea, Vietnam, Yemen, Sri Lanka, Pakistan and Haiti all having more than 1,000km. Production of aquaculture, as may be expected, is also variable. Only eight countries record negligible output. Production levels per head follow this pattern approximately, with outputs ranging from zero to 11.99 kg hd^{-1} in the Philippines. Major producers by this criterion are (in descending order) Philippines, China, Indonesia and Vietnam with > 1kg hd^{-1}.

Table 7.2 Aquaculture development in low income countries (1990 GDP $300 - $1000)

	Population. /km2		f. water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km2 land area	mt. per km3 water res.	mt. per km of coast	kg per head
Togo	63	158	1	56	24	17.8	0.42	2.40	0	0.007
Côte d'Ivoire	37	96	1	515	306	6.2	0.95	4.37	0	0.026
Liberia	23	54	0	579	0	-100	0		0	0
Senegal	37	96	4	531	36	1	0.03	0.14	0.06	0.005
Mauritania	2	5	10	754	0		0	0	0	0
Egypt	52	86	97	2,450	38895	4.1	29.17	502.50	3.96	0.747
Cameroon	25	59	0	402	180	6.4	0.38		0	0.015
Guinea	23	61	0	346	5	16.5	0.02		0	0.001
Zimbabwe	25	46	5	0	160	1.1	0.13	2.08		0.016
Ghana	62	142	1	539	440	3.4	1.84	14.67	0	0.030
Angola	8	22	0	1,600	0		0		0	0
Namibia	2	5	2	1,489	0		0	0	0	0
Nigeria	125	276	1	853	16588	20.4	16.86	43.27	1.19	0.144
Kenya	42	110	7	536	1136	31.1	1.29	47.71	0.72	0.047
Niger	6	19	1	0	15	2.4	0.01	0.50		0.002
Zambia	10.8	27	0	0	1120	8.3	1.49			0.138
C.African Rep	5	10	0	0	338	9.8	0.54			0.113
Burkina Faso	33	80	1	0	5	-25.8	0.02	0.25		0.001
Benin	42	89	0	121	75	30.8	0.66		0	0.016
P.New Guinea	8	15	0	5,152	13		0.01		0	0.003
Cambodia	47	77	0	443	7670	21.9	42.38		0	0.902
Afghanistan	0	0	52	0	0		0	0		
Vietnam	201	352	1	3,444	187000	5.5	409.09	264.71	15.10	2.821
Mongolia	1	3	2	0	0		0	0		0
Indonesia	94	144	3	54,716	689747	9	123.04	85.75	8.32	3.871
Yemen, Rep.	21	70	147	1,383	0		0	0	0	0
Sri Lanka	258	364	15	1,340	4200	-0.8	53.03	83.33	0.52	0.247
Philippines	205	337	9	22,540	737501	7.8	329.19	301.27	28.34	11.992
Pakistan	141	302	33	1,046	12670	6.9	15.84	27.13	0.06	0.113
China	119	167	16	14,500	10409190	12.8	520.33	1730.4	374.78	9.182
Albania	114	172	1	418	397	-24.6	3.28	4.75	0.72	0.120
Haiti	232	393	0	1,771	0		0		0	0
Honduras	46	98	1	820	3380	22.8	1.85	1.59	3.87	0.663
Guatemala	84	134	1	400	961	10.5	2.79	4.34	1.64	0.104
Bolivia	7	13	0	0	266		0.07			0.037
Nicaragua	30	69	1	910	60	97.9	0.03	0.04	0.06	0.015

The growth rate of the aquaculture sector has varied greatly, and as with the previous group, countries with an involvement in shrimp aquaculture such as Honduras and Guatemala, and the main Asian producers have had relatively strong growth.

The major producers have also recorded good growth levels, usually in the 5-15% range, though production in Egypt has grown more slowly. Countries such as Côte d'Ivoire, Cameroon, Ghana, Zambia, and Central African Republic have also shown steady growth rates from more modest levels. The averaged level of use of resources for this group is relatively modest in most cases, with the exceptions - all in ascending order - of Indonesia, the Philippines, Vietnam and China (> 100t/'000 km^2 land area); Vietnam, the Philippines, Egypt and China (>100t km^{-3} renewable water volume) and the Philippines (>10t km^{-1} coastline) and China (>300t km^{-1}) demonstrating the overall heavy loading in a small group of countries.

In terms of the overall prospects for further development, the large Asian producers of the group are with their equivalents in the previous group the most important population bloc of the world. Although all very active technically, and (for the most part) demonstrating rapid economic growth, these are also the countries with the most severe concerns for resource use.

This is particularly the case for China, which has had a notable recent history of expansion and intensification and an almost equally notable record of environmental and disease-related 'crashes'. It is interesting to note here, for example, that its internal water loading is more than 2.7 times that of India, itself by far the most heavily loaded of the previous group. Although Bangladesh has a far higher area loading, its water resources are far more generous.

The Philippines and Vietnam also have moderately high loadings, though Vietnam in particular is expanding production rapidly, and as the Philippines' economy starts to pick up, production may be expected to develop more strongly. With the exception of the water-short Yemen, Egypt and Pakistan, most of the other countries are unlikely to be constrained by overall resource access, though specific access and market potential may well be limitations. Egypt and Pakistan, with significant agricultural production and major irrigation systems, may actually have quite useful potential for aquaculture if this can be integrated with these sectors (Haylor, 1994).

In most of the 'middle-range' countries in this group, opportunities for aquaculture may be relatively good, though political and commercial stability will be an important factor, as will the development of suitable and sustainable support mechanisms, particularly for those countries without a strong background tradition.

The prognosis for the 'negligible' producers is variable; countries such as Afghanistan, Mongolia, Papua New Guinea, Yemen and Haiti may not have much potential for development, either for geographical, socio-cultural or political reasons (though very small scale projects have operated from time to time); other countries may have slightly better prospects, while countries such as Angola and Namibia, if political stability can be attained and economic growth will follow, have substantial resources and long term potential.

Medium income countries

Table 7.3 provides the equivalent data for the next income category group, which contains 35 countries, of which 8 are in Africa, 7 are in Asia, 5 in Europe, and the remainder in Central/S America. This group contains a number of countries which may be considered to be quite developed and wealthy; in these countries there is also slightly more stability of development, and population growth levels are generally lower.

Table 7.3 Aquaculture development in medium income countries (1990 GDP $1000 - $3000)

	Population. /km2		f. water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km2 land area	mt. per km3 water res.	mt. per km of coast	kg per head
Algeria	11	22	16	1,183	197	25.3	0.05	6.97	0.06	0.008
Tunisia	50	85	53	1,143	844	29.1	0	0	0.74	0.104
Congo	7	18	0	169	26	-17.4	0.08		0	0.011
Mauritius	550	500	16	177	100	12.2	6	4.80	0.50	0.091
Libya	3	8	404	1,770	80		0.05	114.29	0	0.018
South Africa	29	53	18	2,881	3622	25.2	0.48	11.57	1.05	0.101
Botswana	2	3	0	0	0		0			0
Morocco	56	105	37	1,835	715	30	0	0	0.39	0.028
Malaysia	54	97	.2	4,675	79378	7.5	43.06	30.23	13.94	4.435
Iran	34	101	39	3,180	42420	12.5	25.27	357.77	0.24	0.760
Jordan	36	112	41	26	22	-16.5	0.25	22.00	0	0.007
Lebanon	0	0	16	225	80	-22.7	0	0	0.36	
Iraq	43.2	110	43	58	15142	22.1	34.57	152.18	0	0.801
Syria	67	189	9	193	2800	8.4	14.86	74.93	0.26	0.226
Thailand	108.8	164	18	3,219	359040	18.7	202.20	585.38	79.31	6.434
Czechoslovakia	123	133	6	0	24135	2.2	180.83	239.36		1.537
Bulgaria	79	81	7	354	7900	-6.9	64.86	35.49	1.98	0.898
Poland	122	141	20	491	30200	8.3	83.23	310.12	8.45	0.791
Romania	98	113	12	225	30000	-3.9	126.05	141.71	0	1.293
Turkey	72	117	8	7,200	7687	16.5	0.34	1.34	1.03	0.137
Jamaica	218	273	4	1,022	2697	10.6	241.36	354	0.04	1.124
Dominican	145	225	15	1,288	815	18.1	11.22	27.5	0.21	0.115
Uruguay	18	23	1	660	7		0.03	0.1	0	0.002
Mexico	44	73	15	9,330	40789	-1.4	3.72	20.16	3.59	0.473
Brazil	18	28	1	7,491	29700	18.0	3.05	7.43	0.49	0.197
Argentina	12	16	3	4,989	1202	32.7	0	0	0.24	0.037
Ecuador	36	63	2	2,237	116687	24.9	5.19	5.26	51.50	11.329
Peru	17	29	15	2,414	5404	12.2	0.30	9.58	2.08	0.249
Paraguay	11	25	0	0	70		0.17			0.016
Colombia	28	44	0	2,414	23987	46.6	11.59		4.47	0.743
Panama	31	52	1	2,490	3900	1.7	3.18	1.88	1.47	1.625
Chile	17	25	4	6,435	116269	50.7	0	0	18.07	8.808
Venezuela	22	37	0	2,800	2144	32.0	0.30		0.67	0.109
Costa Rica	55	98	1	1,290	2244	66.3	26.57	9.68	0.69	0.801
El Salvador	248	429	5	307	107	-27.9	1.00	1.05	0.28	0.021

The level of water use varies from an exceptionally high 404% in Libya (exploitation of relict groundwater) to a range of countries including Tunisia, Morocco, Iran, Jordan, Iraq, and Poland, with a use rate of 20% or more of annual renewable resource. Coastline resources vary widely. Aquaculture production is more widely distributed across most of the countries, with (in decreasing order) Thailand, Ecuador and Chile producing more than 100,000 t yr^{-1}, Malaysia, Mexico, Iran, Poland, Romania, Brazil, Czechoslovakia, Colombia and Iraq producing more than 10,000t yr^{-1}. Average levels are slightly higher than in the previous group. The growth rate of the aquaculture sector also varies strongly, with very strong growth recorded amongst middle and larger scale producers, particularly Chile, Colombia, Ecuador and Thailand, and similar levels (15% or more) recorded amongst some smaller scale producers. For coastline loading, only Malaysia, Chile, Ecuador and Thailand (increasing order) have more than 10t km^{-1} length.

The prospects for development in this group appear to be slightly more clear-cut for those countries which have had a notable involvement in the higher value species sectors, such as shrimp and salmon. As might be expected as the only SE Asian entrant, the most diversified country is Thailand, though its growth has not been as great as that of Chile, which though based on salmonids is now starting to diversify. Many of the smaller and medium scale producers are likely to continue to develop, particularly as they have good local markets and/or the prospects of exports. The Middle Eastern and N African countries represent an interesting group, in which there is often a strong government interest in developing aquaculture, but rather limited opportunities, particularly for freshwater aquaculture. However Iran and Iraq both have very diverse environments, and depending on strategic policy, might be expected to develop more strongly in the future. South Africa has excellent natural resources for aquaculture production, but domestic and external markets for commercial production have in the past been limited. This may well change in coming years, as investment interest is already increasing. One of the development themes in this group is the extent to which production in some of the export countries might start also to supply domestic markets. Many of the Central and Southern American producers are primarily focused to the N American, Japanese, or other international markets; while these are likely to remain important trading partners, domestic needs for lower value species are increasing, particularly around urban areas, where there are serious social problems, and in rural areas, where income opportunities need to be increased.

High income countries

Table 7.4 provides a summary of the equivalent resource and development figures for the high-income category group. This contains 9 countries, of which 4 are European, 3 are Asian (2 Middle Eastern).

Table 7.4 Aquaculture development in high income countries (1990 GDP $3000 - $10000)

	Population/km^2		f.water resources	Coastline	1992 Aquaculture production					
	Mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km^2 land area	mt. per km^3 water res.	mt. per km of coast	km per head
Gabon	4	11	0	885	5	8.9	0.02		0	0.005
Oman	8	24	22	2,092	0		0	0	0	0
Korea, Rep.	432	546	17	2,413	943751	-0.8	153.21	241.14	384.8	22.053
Saudi Arabia	7	20	164	2,510	2046	104.5	0.81	791.36	0.1	0.137
Hungary	114	108	5	0	14230	-2.9	152.61	131.42		1.342
Greece	77	76	12	13,676	20890	44.8	2.45	5.56	1.5	2.068
Portugal	113	120	16	1,693	6402	-7.7	0	0	3.8	0.616
Yugoslavia	93	110	3	3,935	0	-100.0	0	0	0	0
Trinidad and Tobago	240	400	3	362	9		0.60	0.45	0.02	0.008

Aquaculture production varies strongly, with Korea the only major producer, but Greece and Hungary medium level producers, and Portugal and Saudi Arabia moderate producers. These patterns are more or less followed in terms of production per head, with Korea significantly higher than others in the group.

Use of land is > 100t/'000km^2 in Hungary and Korea, and use of water >100t km^{-3} in Hungary, Korea and Saudi Arabia. Coastline use is only significant in Korea, which is also high in global terms.

Though these countries are generally able to secure the means of production, the growth rate of aquaculture has been very variable, with only Greece showing substantial growth from a significant base, though Saudi Arabia's growth rate has been much more notable. Production declined slightly in Korea and Hungary, rather more in Portugal, and dramatically in Yugoslavia. Future prospects in these countries are quite diverse. Korea is by far the most significant and has a high fish consumption level, with good markets and generally good economic conditions for growth. However resources are becoming more constrained, and unless more comprehensive management approaches are used, or offshore systems employed, it may be more feasible to import additional needs. The European countries are mainly involved in expanding small-scale markets, with a relatively low growth rate. Saudi Arabia's production may grow a small amount, but changing economic circumstances may reduce the appeal of generally high cost methods of production.

Highest income countries

Table 7.5 provides an outline for the highest income country group. This contains 24 countries, of which 5 are in Asia (3 in the Middle East), 2 in Australasia, 2 in N America and the remainder in Europe.

Table 7.5 Aquaculture development in highest income countries (1990 GDP >$10000)

	Population/km^2		f.water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km2 land area	mt. per km3 water res.	mt. per km of coast	kg per head
Hong Kong	5800	7000	-	733	9333	0.4	4880.00		6.08	1.609
Kuwait	117	222	-	499	5	8.9	0		0.01	0.002
Israel	224	381	88	273	13971	2.2	598.76	5715.45	5.12	2.973
Singapore	3000	4000	32	193	2350	10	0	0	12.18	0.783
Ireland	50	51	2	1,448	31186	15.9	0	0	21.54	8.91
New Zealand	13	15	0	15,134	51310	20.2	0		3.39	15.091
Spain	77	79	41	4,964	170970	-7.1	0.8	3.65	34.36	4.384
U. Kingdom	234	249	24	12,429	56844	15.2	0.2	0.42	4.57	0.99
Australia	2	3	5	25,760	15771	9.4	0	0.06	0.61	0.922
U. A. E.	19	36	300	1,448	2	-18.8	0	0	0	0.001
Germany	223	219	26	2,389	90349	4.3	38.19	86.03	32.11	1.136
Netherlands	403	432	16	451	54370	-7.6	27.03	11.04	118.34	3.649
Italy	192	183	30	4,996	165203	7.2	15.34	24.64	32.14	2.863
Belgium	323	323	72	64	846	8.1	9.68	24.00	8.53	0.085
Austria	98	95	3	0	3605	-2.2	14.29	11.62		0.468
France	102	114	22	3,427	251354	0.4	15.43	46.86	70.86	4.457
Canada	3	3	1	90,908	30852	19.3	0	0	0.34	1.164
United States	27	33	19	19,924	413605	1.8	23.74	90.55	9.59	1.654
Japan	327	339	20	13,685	1397089	1.3	55.98	39.26	100.54	11.312
Norway	13	15	0	5,832	134114	17.8	0		23	31.932
Denmark	119	116	11	3,379	41650	9.3	0	0	12.33	8.167
Sweden	19	20	2	3,218	7143	8.6	0	0	2.22	0.831
Finland	15	15	3	1,126	17909	8.5	0.11	0.29	15.87	3.582
Switzerland	163	171	6	0	1100	26.3	0	0		0.164

These include the major import countries for the higher value fish and shrimp exports from other countries, and also have substantial production in their own right, in many cases also contributing to export markets. Population levels and densities are relatively high in many of this group, particularly so in the case of Hong Kong and Singapore, though in most cases, population growth rates are modest.

Water resource utilisation is variable, though rather more heavily developed than in previous groups, with many countries using 20% or more of the total theoretical amounts available. Particularly heavy use levels are found in Spain, Belgium, Israel and the UAE (ascending order). Coastline resources vary widely.

Production level also varies widely, although the growth rate of production has been generally higher (typically 15-20%) for those countries involved in salmon production, and is in the 5-10% range for Kuwait, Singapore, Australia, Italy, Belgium, Denmark, Sweden and Finland, which have more diversified production. Production levels per head are far less important with this group, as their purchasing power will normally ensure supplies as required. However Japan, New Zealand and Norway all produce more than 10 kg/head/year.

Only in Hong Kong and Israel are water and land loadings of major significance, and only in the Netherlands and Japan is coastal loading > 100t km^{-1} length, though Ireland, Norway, Germany, Italy, Spain and France (ascending order) have loadings > 20t km^{-1} .

In terms of opportunities for further expansion, these are the countries with the highest overall market demands in terms of value, but are also generally those with the most strongly developed concern for environmental values, and for recreational and conservation uses of land and water resources. There are however pronounced local differences in development attitudes, and a steady growth might be expected in many countries, as production systems become more efficient, more intensified, and better managed. There are also likely to be significant trade opportunities with this group, and resource and labour costs should encourage export opportunities from lower cost producers elsewhere.

Overall comparisons

While these tables have given a brief and rather limited overview of the different development and natural-resource related potentials for aquaculture in different countries, there is inevitably a loss of definition at this level of analysis.

It is also rather difficult to prioritise according to development need, as localised variations within countries, income distributions, resource quality and availability, and other competing factors will all determine whether a country has specific prospects or constraints for aquaculture development, and whether that development will have particular significance for food security. To provide a broad context for describing the present status and possible opportunities for aquaculture, Table 7.6 therefore categorises countries according to GDP category and aggregate resource potential.

The development criticality of each country is described according to population density and growth rate, and various other indicators of human development.

Table 7.6 Income, resource and development categories for aquaculture

Category	Most critical countries	Less critical countries
Lowest income		
Limited resource	Ethiopia, Somalia, Chad, Mali, Sudan, Bhutan;	India, Lao PDR;
Moderate resource	Mozambique, Tanzania, Burundi, Lesotho, Malawi, Sierra Leone;	
High resource	Madagascar, Rwanda, Zaire, Bangladesh, Myanmar;	Uganda;
Low income		
Limited resource	Mauritania, Afghanistan, Mongolia, Bolivia;	Yemen;
Moderate resource	Togo, Côte d'Ivoire, Liberia, Senegal, Niger, Benin, Sri Lanka, China, Albania, Haiti;	Egypt, Zimbabwe, Nigeria, Kenya, Papua New Guinea, Cambodia, Vietnam, Philippines, Pakistan, Honduras, Guatemala, Nicaragua;
High resource	Cameroon, Guinea, Ghana, Angola, Namibia, Zambia, Central African Republic, Burkina Faso;	Indonesia;
Moderate income		
Limited resource	Algeria;	Tunisia, Libya, Morocco, Jordan;
Moderate resource	Congo, Iraq, Peru, El Salvador;	Botswana, Mauritius, Iran, Lebanon, Syria, Thailand, Czech Rep, Bulgaria, Poland, Romania, Jamaica, Dominican Rep;
High resource	Mexico, Venezuela;	South Africa, Malaysia, Turkey, Uruguay, Brazil, Argentina, Ecuador, Paraguay, Colombia, Panama, Chile, Costa Rica;
High income		
Limited resource		Oman, Saudi Arabia, Hong Kong, Kuwait, Israel, Singapore, UAE, Germany, Netherlands, Belgium, France, Denmark;
Moderate resource	Gabon, Trinidad and Tobago;	Sweden, Finland, Switzerland, Korea, Rep, Hungary, Croatia, Spain, UK, Italy, Austria, Japan, Norway;
High resource		Greece, Portugal, Ireland, New Zealand, Australia, Canada, United States;

Notes: in lowest income countries India considered less critical due to rising average income, Lao PDR because of improving political/economic circumstances, Uganda due to inland fisheries resources, improved economy; in the low income category group less critical countries either have diverse and/or growing economies, or have little cultural link with aquaculture; in moderate/high income category, 'more critical' countries are chosen mainly on social/economic development grounds.

While outlines such as this can be criticised as being rather arbitrary, they do highlight the primary areas of need and sectoral opportunity. The UNDP review on indicators of human development (UNDP, 1994) provides more detailed national criteria for development in terms of human welfare, and the World Bank (1992) study provides a similar perspective of development and the environment, from which a more detailed description could be developed. It is useful however to compare this broad assessment with that of the UNDP review, where Afghanistan, Angola, Haiti, Iraq, Mozambique, Myanmar, Sudan and Zaire have been highlighted as 'countries in crisis' due mainly to a combination of political and food supply problems. All of these countries are located in the 'most critical' category of Table 7.6, predominantly at the low income/low resource level. Another dimension of need is given by the category of the ten countries with two-thirds of the world's poor, which comprise Bangladesh, Brazil, China, Ethiopia, India, Indonesia, Nigeria, Pakistan, Philippines and Vietnam.

Of these, only Ethiopia, Bangladesh and China appear in the 'most critical' category, as the others, while clearly in need of significant development response, appear on basic indicators to be less constrained by natural resource potential and/or engaged in recent and more positive economic growth.

While it is potentially possible to build up a more complex matrix-based analysis of comparative need and potential, using UNDP Human Development Indices (HDI), and food dependency indices, as well as more specific natural resource, conservation/biodiversity needs, and productive competition indices, it may be misleading to do so at the national level, as there will be significant variance both in terms of needs and social priorities, and in terms of actually usable resource. There are variable levels of use of existing surface waters, a wide range of coastline length, and substantial differences in climatic/environmental quality with respect to habitation and food production, though no distinctions are made here of quality. Similarly, UNDP (1994) note the substantial regional disparities in HDI. This emphasises the importance of strategic resource assessments, and the use of GIS and other approaches to clarify the actual potentials and needs within a region or country.

The possible rise in aquaculture production in many countries may be sufficient to keep up with population growth, at least in the short to medium term (say 10-15 years), though the largest population centres will have the greatest difficulties. Commonly it is the poorest and largest countries which also have the highest population growth rates, and hence the greatest development challenges. This is further compounded if aquaculture is to expand to improve food supply in these countries, if per capita food levels are threatened. One of the main characteristics of the poorer countries, apart from an obvious lack of development capital, is their limited surplus of agricultural products, and hence a potential constraint for developing production and yields even in existing systems.

There is also the important question of whether aquaculture production can really contribute effectively to food security needs, or will be predominantly market-price driven, that is the point of whether aquaculture products would simply be affordable. Thus (assuming that aquaculture and other forms of development can make only gradual changes to income levels and purchasing opportunities) an annual income level of \$300 per head provides less than \$1.00 a day on average for total consumption. Assuming the poorest sectors have 50% of this, and spend around 60% on food, this amounts to some \$0.30 per day, most of which at this level would have to be used for basic staples - primarily carbohydrate foods. The purchase of lowest-cost aquaculture product - say an amount equivalent to 50g per person, at \$0.60-1.00/kg uses \$0.03-0.05, which is perhaps feasible for occasional purchase, perhaps alternated with wild caught fish, miscellaneous other foods, home-produced foods, etc. It is also uncertain whether it would be feasible under current conditions to consider large parts of aquaculture production being sold at such price levels.

However, it might be possible for say 15-20% of production to be sold at low price levels, providing the remainder was able to attain higher prices. Thus, e.g. in a polyculture system, or a main cash crop system with secondary low value species (such as silver carp and smaller local species) with a main crop average of \$2-3/kg and a yield of 3 -5 tonnes/ha, it may be acceptable to target for a gross revenue of \$6,000 - 15,000 per ha, with an additional return at perhaps 0.5 - 1 tonnes/ha at \$0.6-1/kg, of \$300 - 1,000/ha, whereas entire production at lower value might gross only \$2,000 - 5,000, which may not be feasible in many circumstances. Lower cost systems such as mollusc culture could of course add to this potential.

The implications of this, apart from the question of the development capital needed to satisfy these requirements at the individual country level, may be that only a limited fraction of potential aquaculture output could be available for supply to poorer sectors, and an increased supply to this sector might require a total output change of several times this amount. Issues such as these highlight the need for strategic development planning, based on realistic, rather than theoretical development possibilities.

7.2 Regional features

The regional characteristics of the aquaculture sector have been widely noted. There are obvious differences in traditions, skills, resource availability, population levels and distribution, economic development and distribution, social and political characteristics, which all contribute to different constraints for development and food supply, and for different potentials for the sector.

Table 7.7 Regional perspectives for aquaculture development

Region	Food security significance	Positive development features	Potential constraints	Overall prospects with respect to food security
Asia	Very high; significant and growing populations, wide income distributions	Traditions, skills, water resources, markets, innovation, economic growth	Industrialisation, population pressure, pollution, legislation management	Important; needs very careful planning and management of resources
Australasia	Limited except in specific communities	Natural resources, stability, increasing skills	Markets, environmental/ conservation aims	Possible supply source; local initiatives
Africa	Very high; growing and increasingly stressed populations, low incomes	Natural resources	Politico-economic stability, traditions, skills, infrastructures, markets	Critical: needs substantial stimulation, better structures, stability
Europe	Very limited except in specific communities, and export income source	Markets, skills, traditions, technical capacity, stability, finance	Environmental regulation, natural resources, conservation	Not critical, but source of export potential
Former USSR	Depends on political outcomes, may be serious	Natural resources, local skills, response to new techniques	Pollution, management structures, financial and market development	Uncertain; needs political economic stability, better resource management
N America	Very limited except as export income source	Natural resources, markets, skills, technical capacity, stability, finance	Environmental conservation regulation, legislation	Not critical, but source of export potential
S America	Quite high; growing populations, wide income distributions	Natural resources, increasing skills	Politico-economic stability, infrastructures, markets, finance, conservation	Important, needs better structures, stability, balanced resource use

The major regional differences with respect to aquaculture development and food security are summarised in Table 7.7, though it is important to note, as indicated earlier, the substantial diversity within each region, and within individual countries. This confirms the relative importance of Africa, Asia, S America and possibly the former USSR group of countries as the primary targets for attention for food supply and food security, and in conjunction with Table 7.6, the main areas of concern within these regions. It also outlines the relative development priorities and constraints. However, as noted earlier, the substantial level of variability within regions and within countries emphasises the importance of strategic resource assessments, linked in with clear views of the economic feasibility of different development options. The use of techniques such as GIS could be particularly important for spanning the regional to local perspectives (Kapetsky, 1994) , but with more developed approaches for finer discrimination of capacity and for priorities.

8. STRATEGIC APPROACHES

8.1 Aquaculture in broad management systems

The previous chapter has reviewed some of the key features of individual countries with respect to their needs and their apparent potential for development. While individual project initiatives can and will be developed for specific locations, strategic approaches will be increasingly important, in which socio-political, environmental and resource related issues are addressed, and in which economic development and sustainability objectives can be defined. Here are reviewed some of the strategic issues which will concern aquaculture development, and which will determine its future prospects. One of the major themes in the natural resource sector has been that of adopting systems based approaches, as individual subject/sector approaches are to an increasing degree inadequate for dealing with complex and interlinked development and resource issues. Systems can be defined at several levels or orders; individual components might form part of a set of larger, higher-order multiple-linked systems and management approaches. In the case of aquatic based production and management, the important major systems would be:

- watershed management; within which inland fisheries and aquaculture would take place

- coastal area management; which would involve coastal and marine aquaculture, coastal and lagoon fisheries;

Table 8.1 outlines some of the important issues concerning these two major systems, and provides a brief summary of the implications for aquaculture. While these need not be inhibitory, they may change the criteria within which aquaculture might develop and operate. Though systems approaches are increasingly advocated for aquaculture and other natural resource management areas, the context and implications have rarely been noted. These focus on function and links rather than individual organisms and their processes. However, in most environmental systems there is only incomplete and partial knowledge of the system to be understood and controlled.

To satisfy the needs of sustainable development, systems have to be drawn across broad bounds, directly involving the questions of human and societal welfare, as well as ecological/environmental features, and must be capable of making links across the physical through to the social and spiritual or ethical realms.

Table 8.1 Major strategic issues

Major system	Primary issues	Implications for aquaculture sector
Inland	water retention, local albedo effects and soil stabilisation; sediment collection, maintenance of nutrients and productivity; groundwater use, reuse and quality management; multiple use of reservoirs, lakes, the development of multi-use ecological and economic models; incorporation in large scale projects for flood control, irrigation, water supply and waste water treatment.	adapting aquaculture systems and operations within overall water management context; including water quality/suspended materials management; interfaces with conservation/wetland areas, (environmental) economic criteria applied for use/discharge; selective use of aquaculture/enhancement for rehabilitation and other purposes; multiple use systems
Coastal	physical development, water exchange, coastal processes, sedimentation and salinisation, groundwater use, nutrient and chemical management, ecological management, multiple use system/economic models, coastal area/zone management theory	clearer strategies for desirable aquaculture locations; use in coastal control systems; more integrated nutrient balances, environmental capacity; use of ground-water control systems; more detailed strategic and local coastal planning; stronger biodiversity targets;

8.2 Strategic resource approaches

The aquaculture sector involves the use of a range of resources, and results in a range of consequences, not all of which may be desirable with respect to the environment in which it is supported. It must also compete for resources - either explicitly in terms of other users, or indirectly in the sense that environmental change may come about as a secondary consequence of other forms of activity. Various approaches could all contribute to lessening the potential impact of aquaculture in terms of external resource use and undesirable impacts. Primary consequences could include:

- the potential to increase production, with a lower cost base, within the existing resource allocated;
- better acceptance of the aquaculture sector within the overall public opinion and regulatory environment, and the locational/resource planning context, with improved predictability of impact, and better opportunities for "fine-tuning";
- the ability to adhere to increasingly rigorous external controls without undue financial penalty or competitive disadvantage;
- investment and development confidence, and the continued opportunity for sustained longer-term growth.

An initial approach in strategic resource management would be to model potential impact and define local capacity. This could be used to determine suitable locations, define forms and combinations of aquaculture which might be practicable, and describe possible relationships with other activities. The levels of change involved could also be used if required in a cost:benefit approach.

Ideally, development would be assessed in an integrated context, incorporating other activities, as aquaculture may only represent part of the resource/environment system loading, and will be only part of the social and economic system.

Thus in Denmark, Sweden and Finland, marine aquaculture was estimated to account for less than 1% of the total load of nitrogen entering coastal waters (Hakanson et al. 1988), the remainder attributable to agriculture runoff and industrial and domestic effluents. Muir and Baird (1991) found similar conditions in coastal environmental planning for Cyprus.

In many rural areas in particular, aquaculture activities may contribute strongly to local economies, in some cases offering almost the only employment, and in many others offering critical support to small communities (see, e.g. Garvey and Bennett, 1991). In Norway, the NW of Scotland and W of Ireland, aquaculture is a major economic element; very similar characteristics can be seen in regions of Java and Sumatra, SW Bangladesh, NE Thailand, Ecuador and S Chile. However, the more complex the model, the more expensive in terms of data collection and computation, and the greater the inherent uncertainty.

Most aquaculture models have been carried out for specific site location exercises or localised environmental impact assessments; mainly for salmonid culture (e.g. Gowan et al, 1989), though carrying capacity models have been worked out for the mussel and oyster farming in Canada and France (Carver and Mallet, 1990; Heral, 1991).

However, with the exception of the ecosystem modelling of Folke and Kautsky (1992), there have been few attempts to integrate environmental capacity in terms of input ecosystem support and social benefit, for sustainability assessments.

Sectoral level modelling was developed in Norway, in response to the rapid expansion in coastal aquaculture during the late 1970s and 80s. LENKA, a three-year project to develop a coastal zone GIS (geographical information system), was established in 1987 to help planners at both a national and local level (Kryvi et al, 1991). It incorporated data on:

- environmental conditions (depth, salinity, temperature, exposure, water quality);

- existing resource use (settlement, recreation, port development, fisheries, etc);

- infrastructure (roads, electricity, availability of trash fish, etc);

- presence of special areas (nature reserves, spawning grounds, existing fish farms, etc.).

The output was a gradation of the potential of each area of the coastline for aquaculture development. In the absence of predictive models, the production capacity of each area was estimated by classification based on water exchange, in turn related to water volume, the presence or absence of restrictive sills in the area and tidal range. Areal aquaculture production capacities were then estimated for each type of area, designed to avoid environmental degradation.

Final assessment of production capacity took into account loading from other users. The outputs from LENKA included gross national estimates of potential salmonid production and maps and tables detailing specific areas of greatest potential. GIS based systems such as these have now been developed further using a range of techniques, and have been applied at scale ranging from local to continental (Kapetsky, 1994).

8.3 Concepts of integrated management

The need for more strategic perspectives for managing aquaculture has been increasingly recognised, particularly for environmental management, and issues have been highlighted in a number of reviews (e.g. NCC, 1989, Pullin et al 1993). Aquaculture development has received particular attention in the context of coastal planning and management (Barg ,1992, Clark, 1992). Environmental management of inland aquaculture has also been considered, in flow-through systems (Alabaster, 1982) for cage culture (NCC, 1989) or in terms of water resource management (Muir, 1992). Though there is a considerable literature on integrated coastal area management (ICAM) or coastal zone management (ICZM), there are varying definitions and interpretations of the concepts involved. Much of this concerns the approaches for planning for multiple use objectives, and doing so in a way which satisfies shorter-term financial/economic criteria as well as longer-term sustainability goals. In this sense, apart from the fundamental questions of locational characteristics, capacity definition, and the social and political objectives, this is again an issue of environmental management.

The scope and opportunity for integrated management will clearly vary with the regulatory and management environment, the aquaculture production system, the degree of management control inherent within the system, its scale and operating environment, and the external pressures - financial and/or regulatory, which might affect the sector.

As aquaculture is intimately dependent on water resources, the main areas of control would normally concern water quality, and in close association, ecosystem quality. Other undesired social and/or aesthetic impacts might also be brought into control. In many cases, approaches to integrated management are as yet only being conceptualised and developed, and may have to be "tailored" for particular systems and environments. Planning and management inputs to improve the efficiencies of aquaculture systems may be expected to have a profound influence on the relationships between aquaculture production and environmental impact.

The following recommendations were amended by Muir and Baird (1991) from the equivalents for coastal aquaculture as addressed by GESAMP (1991):

- aquaculture has the potential to produce food and to generate income contributing to social and economic well-being;
- planned and properly managed aquaculture development is a productive use of natural resources if undertaken within the broader framework of integrated management plans, according to national goals for sustainable development and in harmony with international obligations;
- the likely consequences of aquaculture developments on the social and ecological environment must be predicted and evaluated, and measures formulated in order to contain them within acceptable, pre-determined limits;
- aquaculture activity must be regulated and monitored to ensure that impacts remain within predetermined limits and to signal when contingency and other plans need to be brought into effect to reverse any trends leading towards unacceptable environmental consequences.

A set of specific actions for environmental management consequent on these principles was also identified (see also Clark, 1992)as summarised in Table 8.2.

Table 8.2 Suggested actions for environmental management

Recommendation	Implication/effects
Aquaculture development and management plans should be integrated into overall area management plans; integrated area management plans should be formulated;	Linkage of aquaculture with other activities; rational bases for assessment of comparative costs and benefits; better foundation for development
The capacity of the ecosystem to sustain aquaculture development with minimal ecological change should be assessed; the environmental impact assessment (EIA) process should be applied to all major aquaculture proposals; monitoring for ecological change.	The need for a system of evaluation; ideally these should be linked to provide strategic resource information; the EIA should also make clear the social and economic benefits; other activities should also be subject to the same level of assessment and monitoring;
Incentives and deterrents should be used to reduce environmental degradation from aquaculture; management of aquaculture operations should be improved; standards should be defined for control of effluent discharge and use of bioactive compounds;	Management control of aquaculture systems is required; this would vary in extent and severity with type of system; similar levels of management and control should be applied to other systems.

Source: Developed from GESAMP, 1991, Muir and Baird, 1991

In practical terms, Muir and Baird (1991) suggested that the management of aquaculture, though stringent and tough if needed, should not be over-elaborate and burdensome. It should be:

- simple; as easy to operate as possible, clear and understandable to all those involved, including the public;
- rational; based on logical and scientific foundations, providing testability and, once operational, offering predictive power;
- equitable; operating fairly on all those involved with 'using ' the resources, according to the degree of use; this should extend to apply to all users, as well as aquaculturists;
- workable; within the capacity of the institution(s) involved; with at most a modest amount of training and/or equipment, whether established within the public or the private sector, or both;
- cost-effective; not be too burdensome, overloading or excessively inhibiting the activities it is designed to cover, or placing too great an imposition on the agencies responsible for its operation.

In a properly integrated approach, these criteria should apply to all sectors for which management might be appropriate, and there should be an effective rationale for integration, with specific system-based rules for decision and management. To date, most integrated management approaches have concentrated almost entirely on environmental interactions of single projects (i.e. on a case by case basis), primarily nutrient-based, though sometimes modified by criteria for genetic interactions and management needs for conservation and/or scenic amenity.

A wider balance involving development, employment, social and other components has rarely been attempted, though various EIA recommendations have suggested such an approach., and environmentally modified forms of social cost benefit analysis might be considered.

8.4 The legal environment

The development of legislation provides an important instrument by which development planning and policy can be effected, and through which emerging issues for the aquaculture sector might be resolved. An effective legal framework is essential for the sector to develop and be protected, for investment to be made, and for effective planning to be carried out. It may also impinge on food security issues where legal status can protect the small scale food producer, or can secure access to production resources for poorer elements of a community.

The history of much recent aquaculture development however (e.g. Howarth, 1990, Van Houtte et al, 1989) suggests that legislative issues are often complex and that aquaculture in its more recent forms is often in an anomalous position vis-à-vis existing provisions and/or interpretations. This has resulted in some conditions of the legal environment being surprisingly favourable, but others unjustifiably restrictive or discouraging. Unfortunately, the process of development of the law may take considerable time, and while those involved may in the expectation of change informally choose not to exercise apparently unjust or questionable areas, this does not necessarily provide a secure environment for the industry.

One of the most critical constraints for overall environmental management has been the absence of an effective legal framework (Van Houtte et al, 1989). This problem is by no means confined to aquaculture, and many sectors are only now being brought within environmental legislation and its associated assessment and control procedures. The underlying need for rational and uniform cross-sectoral approaches has also highlighted the importance of economic criteria, both in terms of conventional resource allocation decisions, and concerning the questions of economic instruments for pollution (and natural resource management) control, including licensing procedures, loading-related charges, and environmental recovery taxes.

Many of these approaches, based around the "polluter pays" principle, and based also on the ideas of maximising economic rent for natural resources, are starting to come into planning and regulatory approaches. Indices such as net economic output per unit of organic loading, and other comparators, are of increasing interest in making or influencing strategic and allocative decisions.

Aquaculture is in many areas a relatively new activity, and often cuts across a range of established interests and planning/legal boundaries. Where inappropriate laws are enforced the fully legal clearance for development of aquaculture may be extremely complex, and may unnaturally distort the type and nature of development that can be carried out. In several countries, steps have been taken to simplify this process, either by amending legislation to rationalise procedures, or to instruct e.g. development agencies to co-ordinate clearances and assist developers in making submissions. It is difficult to predict future trends in legislation concerning aquaculture. Van Houtte et al, (1989) has provided reviews of current legislation and proposed needs for change in a number of countries. New laws are being formulated specifically for aquaculture in several countries (e.g., Canada; Wildsmith 1985).

There is also increasing demand in Europe for consistent regulations which treat aquaculture on a fairer basis, although this basis has yet to be defined. It seems inevitable that aquaculture will face increasingly tight restrictions over development, as concern over environmental impact and competition for resources grow.

8.5 Management information

A very important constraint to planning and development in aquaculture is inadequate knowledge concerning potential areas for development or expansion (Kapetsky et al, 1987, Barg, 1992). As suggested earlier, effective management requires knowledge of the functioning of the complete system, together with specific details of individual areas. However, the information typically available is collected on an ad hoc basis, primarily to obtain site-specific information, and does not therefore provide an organised basis for assessing the current state of the particular environment. The development of a system and procedures for regulating and monitoring provides an ideal opportunity to develop a strategic approach to managing the marine coastal environment.

An area of particular interest in land-use planning is that of GIS (Geographical Information Systems), often based on thematic, large scale data inputs, e.g. from remote-sensing systems, but also usable at a more localised level. GIS formats incorporating a range of remote sensed and localised data can provide a useful tool for regional aquaculture planning and site selection. The increasing variety and complexity of natural resource data, and the need to assess and represent changes through time, have stressed the value of systems that permit storage, management and analysis of data in an easy, reliable and rapid manner. Widespread use of GIS has until recently been rather limited, primarily due to the high investment and operational costs involved. However, the development of PC-based GIS packages is now making the technique more widely available, and it is increasingly being brought into area management applications (Ross et al, 1993, Meaden and Kapetsky 1991, Kapetsky et al, 1995). There is also a growing application of computer analysis in the support of environmental and resource management decisions. Decision support systems (DSS) encompass a range of implementations from the more ad hoc use of microcomputer database, spreadsheet, statistics and graphics programs, to dedicated software packages. These systems are used to store, sort, analyse and present information in a way which allows a manager to make informed decisions. The basic principle behind most systems is the construction of a numeric model which represents the major variables of the system under study, which can then be analysed using methods such as optimisation, risk analysis, goal seeking and sensitivity analysis, in order to examine the implications of different management strategies. The emphasis of DSS is therefore the manipulation of factual (mainly numeric) information to assist the human decision maker. Although these systems are only now being developed to the point of access and usability, they may be expected to find a greater place in aquaculture and natural resource management, and combined with improved GIS systems with better logical functions, are likely to contribute to an increasing degree to strategic and local area management.

8.6 Development strategies

The previous parts of this section have covered many of the factors involved in the current development of aquaculture, from the artisanal to the commercial sectors, involving private, NGO and institutional sectors. They have also identified the main contexts and locations in which aquaculture may be significant for food security, and have confirmed the potential for the aquaculture sector to be developed, at least in output terms, in many circumstances. While it is clear that there are many mechanisms available for the commercial development of aquaculture, and there are also many processes by which aquaculture might be adopted at the rural, artisanal level, there has been little comment on the ways in which aquaculture development might be stimulated, or which forms of intervention might be appropriate.

It may in fact be argued that specific intervention might be a rather suspect response to perceived needs, given the previous record of development projects in the aquaculture sector, and the apparent problems of the traditional 'transfer of technology' approaches. The role of the private sector is becoming far more significant, even in countries where this had previously been poorly developed, and there are far more activities which can successfully be taken up in the commercial context, often at the very small scale level. Table 8.3 summarises initiatives which may be involved in development, particularly in the smaller-scale, rural sector where food security is likely to be most important.

Table 8.3 Potential initiatives in rural aquaculture development

Approach	Aims/prospects	Constraints
Organisational		
Privatisation	- Selling / leasing assets of institutional hatcheries, service functions etc	- Commitment of government, quality of facilities, local capability etc;
Social targeting	- Use of poverty ranking, other methods to focus on key groups such as food security vulnerable	- Rapid rates of change in rural areas, difficulties of communication;
Rural credit systems	- Improving access for low-asset borrowers, using group schemes, etc	- Group organisation, collective responsibility, commercial returns;
Local producer groups	- Provide group support, organisation, market and technical support functions	- Group organisation, social context, shared interests, leadership, benefits;
Farming systems	- Better understanding of resources, local econ. decisions, social contexts	- Quality of knowledge, ability to test concepts;
Novel extension systems	- Use small-scale traders, others to carry extension message	- Number and type of agents, comparative social status
Selective infrastructure development	- Better targeted inputs into critical support areas	- Institutional capacity, commitment to appropriate quality, quality control
Production oriented		
Rice-fish culture	- Major development prospects in many low-income tropical countries (IPM)	- Areas involved, deep water rice systems, IPM training
Other integrated aquacult.	- Improve fertility and yields	- Local resources, other demands, management skills, co-ordination.
Improved polycultures	- More valuable/efficient production; local species, low price species	- Understanding benefits, management skills, availability of seed stock
Small-scale hatcheries, nurseries	- Improve local opportunities, more flexible supply structure	- Genetic management, management skills, quality and disease control
Small-scale cage culture	- Opportunities for landless groups, nurseries and ongrowing, use open water bodies	- Areas available, group organisation, costs of materials, viability, risks
Intermediate/service functions	- Opportunities for local supply, aquaculture and other processes contracted out locally as part of strategic management schemes	- Extent of demand, skills and materials available, quality of products/services
Demand-oriented		
Market development	- Improve local and other marketing systems	- Purchasing power, ability to finance developments, inflexibility of markets
Quality control	- Improve product quality to increase returns	- Sensitivity of markets, costs of development
Other development	- Human/social development to improve living standards, market/economic power	- Cultural and institutional responses

One of the primary levels of change in development effectiveness has been that observed in the procedures of the donor and implementing institutions. Better awareness of wider social development and environmental issues, including concern for poverty focus, the role of women, environmental impact, and biodiversity and an espousal of the principles of sustainability, are all creating change. There has also been a notable change in the nature and operation of development projects from the traditional project idea. New development approaches are often based on more clearly specified objectives and encourage greater clarity, focus, and purpose, and offer the potential for measuring performance, change and effectiveness of specific types of development approach. While systems such as this have been criticised for their lack of flexibility and responsiveness to changing circumstances, a system of rolling revision can be used to overcome any such constraints. While approaches such as these have done much to develop the management capability of many of the institutions concerned, it remains to be seen whether it becomes a genuine basis for longer-term change, and in particular giving agencies the confidence to support longer-term programmes when they are necessary.

There is also a need for a greater degree of co-ordination between the main donor and development groups and better linkages with the NGO sector, to ensure an appropriate and balanced level of input to the needs of a developing sector, and the appropriate co-ordination with external sectors such as water management. Associated with this there is a need to develop a stronger and more integrated concept of development, and to provide a forum for the exchange of ideas and experience. This extends also to the need for a well defined social and economic context for development, and effective, rational and analytically based methods for development formulation, monitoring and evaluation at both the project and sectoral level. Although the private sector may tend to focus on the more commercial areas of the aquaculture industry, there are also important reasons for involvement and co-ordination - e.g. technical and market developments, access to critical skills; better networks of organisation and co-operation might be proposed. Table 8.4 summarises some of the respective roles involved.

Table 8.4 Potential roles of aquaculture development sectors

Sector	Strategic	Specific/project based
Private	producer groups, representation	most project activity, range of scale, market objectives, etc.
NGO	involvement in dialogue, integrated initiatives in target areas, infrastructural support, donor consultation	range of project activity, usually with social, community development context
Institutional	main policy development, formulation, general consultation, development co-ordination, some infrastructural support	critical support and regulatory functions only

The development of aquaculture is not inconsistent with needs for food security for vulnerable groups, but has not been a significant direct component, being more important in its role in the overall food supply system.

The extent to which aquaculture might be developed specifically towards food security issues depends primarily on the extent to which the appropriate policies can be articulated and taken up, and the extent to which it is considered that these issues are determined by supply-side measures rather than say, addressing primary structural issues such as income distribution, human rights, access to opportunity, and thus creating a more positive environment for a demand-led response for aquaculture or any other food supply sector. In reality, the aim may be a combination of both approaches, with varying degrees of intervention (preferably economically efficient) to encourage supply for poorer groups or provide income opportunities, together with a range of human and social development actions.

9. CONCLUSIONS

9.1 Introduction

The aim of this study has been to consider the nature of aquaculture with respect to its possible implications for food security. As such the aim had not been to identify exactly how to target aquaculture to these objectives, nor to attempt to make a spurious and distorted justification for aquaculture development on such grounds. This is entirely appropriate, as it is more realistic to consider aquaculture to be a broader entity, which if developed and managed in particular ways will offer food security gains along with its other development outputs.

The aquaculture sector is clearly an important component within natural-resource based economic development, and can contribute effectively to local and regional food supply and to the promotion of wider social well-being. In quantitative terms, however, by comparison with major agricultural commodities and with capture fisheries, it ranks as moderate in scale. Nonetheless, it has a critical role to play in terms of its delivery of quality foodstuffs, in providing valuable exportable materials for international trade, and in terms of complementing other rural based activities. Its diversity, which makes it far more difficult to characterise and develop than a single commodity, offers it unique strengths, in that aquaculture techniques and products may be introduced in a wide variety of contexts, for a wide variety of objectives. Although negative environmental impacts have been a cause for justified concern, proper attention to site location and system management can do much to limit these. Thus, if properly understood and carefully managed, aquaculture might be expected to play a vital role in sustainable development and greater security of food supply. The Kyoto Conference of 1976 had created a significant change in awareness of aquaculture and its potential; many of the projections for aquaculture and its growth have come about, though understandably not always in the manner or to the degree expected. There is now, nearly 20 years later, a major challenge in re-examining the nature and potential of aquaculture, considering what will be its prospects and its promise, and how might these be shaped to meet the formidable needs of the next century.

This review has attempted to define the basic characteristics of aquaculture and its relationships with its functional environment, to describe the recent development of the sector and its key elements, and to consider the factors underlying its scope for expansion, in particular to meet potentially increasing needs for food supply. However, the lack of comprehensive and fully reliable data has required a significant element of interpretation and speculation, much of which may be well founded in principle and intuitively reasonable, but may need to be further examined or corroborated, or indeed monitored along the future path of the sector.

9.2 General points

As noted in the introduction, the aquaculture sector is diverse, and these diversities need to be recognised in any analysis or prescription for development. Amongst the basic definitions given for aquaculture are those which distinguish it from fisheries. This is not mere semantics, but serves to determine the important features of management control, ownership and output which characterise aquaculture. The point is also made of the similarities between aquaculture and agriculture, and the validity therefore of applying many of the principles and approaches of agriculture to that of its aquatic equivalent. As noted later, this can have important consequences for some of the development methodology with may be applied.

The aquaculture sector has considerable potential for growth, and will increasingly be expected to meet shortfalls in production from other sectors, notably that for capture fisheries, with which it is commonly grouped. However, its potential lies primarily in respect of its fundamental differences from fisheries, in that far greater levels of control can be exerted between inputs and outputs, and that the necessary inputs can be obtained from a range of sources, both terrestrial and aquatic, in raw material or processed form.

There are many different forms of aquaculture, with many different environments, systems and species involved. These naturally result in a range of consequences, not all of which may be desirable. Aquaculture needs to be seen in context, with a full appreciation of costs and benefits concerned, and a comparative perspective when judged with other sectors.

It is important to recognise that aquaculture activities are associated with the culture, society and landscape of the locations in which they operate; individuals, communities and social organisations are critical in defining the nature and extent of aquaculture, irrespective of the technological context. As a result, there are substantial differences in the pattern of development of the sector in various parts of the world, and evidence suggests that standardised approaches will not be effective.

The aquaculture sector has been the subject of notable scientific and technological development in recent decades. Although there have been very few 'breakthrough' developments, improvements in genetics, nutrition, disease management, reproduction control and environmental management can all be expected to widen choices for aquaculture, improve its efficiency and cost effectiveness, and optimise resource use.

Although a substantial part of modern aquaculture makes use of sophisticated scientific and technical development, and is increasingly operated along intensive 'agro-industrial' lines, by far the greatest amount of production is still in relatively simple, low input systems which can be reasonably ecologically efficient, and which can produce a range of outputs at relatively low cost. Indications are that this overall trend will be maintained, and that this will be the primary area of development for lower cost production.

There are many respects in which aquaculture may be operated in a complementary manner with other activities. Examples of these have been given in the report, and include agricultural, industrial, wastewater and other linkages. However, at present, there are rather more technical opportunities than there are social or other organisational incentives to carry out such integration.

The need for integrated approaches to planning and development are emphasised throughout the text; steadily increasing pressures on natural resources and their sustainable use will require far greater skill and diligence, and a better degree of conceptual, system-based understanding. This will apply regardless of the objectives of aquaculture production, and will affect both aquaculture and its adjacent activities and functions.

9.3 Major development aims

As with any other economically active sector, aquaculture can provide a range of benefits involving income, employment, and social opportunity. As a producer of high quality food materials, these benefits may extend further to include opportunities for local food supply and the associated health and social development benefits involved. However, not all forms of aquaculture are suited for local supply, particularly for lower-cost markets associated with lower income groups. Development objectives therefore need to be defined carefully, and mechanisms for the use of aquaculture need to be focused clearly.

There are substantial needs for food supply and income in many of the countries and communities where aquaculture has been or can be carried out, and there are important opportunities for helping to meet these needs using aquaculture, or aquaculture-based activities. However, a clear distinction needs to be made concerning the objectives of aquaculture production. In most cases, a market economic view needs to be taken, modified as appropriate by local social and societal constraints and motivations. However, there is little point in promoting aquaculture production unless it offers obvious benefits to participants, taking into account all the relevant issues of rural security and social context.

Food security issues are clearly significant; aquaculture can be an important contributor to food security, and can offer a diverse range of products, though its value is usually that as one of a range of possible food supply inputs. However this would be consistent with trying to improve the diversity of economic activity and of food supply within any given location or economic context. To a certain degree aquaculture is predictable in output, and once established, with skilled operators, can provide a reasonably reliable source of food and income. However, with the exception of the highly mechanised intensive production of a small number of luxury species, there is as with any natural-resource dependent process, a certain level of external variability which must be accommodated in any planning or projections.

Smaller scale aquaculture activities may involve any members of families or communities; there are therefore many opportunities for involving disadvantaged groups, in targeting activities for women, and in involving children in economically useful, but relatively safe and undemanding family work. Landless groups, often the poorest in any community, can be targeted in many areas if under-utilised water bodies are available for access (e.g. through government allocation). The effectiveness of mechanisms of individual or group level activities need to be considered carefully, however, and depend greatly on the social context and on the economic/structural characteristics of the aquaculture sector proposed..

Though aquaculture may offer useful opportunities for the resource poor in areas where it has not developed, and where the resources are therefore not strongly demanded, it is important to ensure that access to resources is secure and can be maintained. There are many examples where resources have been appropriated by the wealthier members of societies if opportunities are expected.

The extension of control through social mechanisms or through credit, or other relationships, also needs to be given careful consideration.

There is an increasing awareness of the requirements for sustainability and sustainable development. Some of the key parameters are discussed in the text, and include environmental, social and economic development issues. Though precise sustainability criteria (as with any other sector) are difficult to define, it is possible to identify in broad terms those forms of aquaculture and types of operation which are more likely to meet these, and those others which are unlikely to be acceptable.

However more work needs to be done to understand how sustainability choices might apply in practice; most critically, the effects of intensification need to be understood, so that rational strategic decisions can be taken concerning the 'mix' of aquaculture development which might be suitable in a particular location or context. The use of environmental economic techniques is likely to become increasingly important.

Associated with this, is the increasing concern for the quality of natural resources, and in particular, for biodiversity; this may be expected to increase the demands for control and conservation, and may impose various restrictions on the location and/or methods of management for aquaculture and other natural resource dependent processes. However, aquaculture skills and techniques may have an important role to play in maintaining and even improving natural resource quality.

There has been a substantial degree of organic growth in the aquaculture sector, though much of this has taken place in more overtly commercial and profitable sectors. There still remain substantial needs for development support in terms of finance, raw materials and technical support. The sustainability of development and its support also needs to be considered carefully, though there have been various examples where this has been achieved, and guidelines can be proposed to increase the probability of continuing development effectiveness.

Human resource development is of course a critical area for aquaculture development, as for any other activity, particularly in circumstances where it is less traditional and/or requires development in new ways. However, many of the traditional 'transfer of technology' concepts, which are still being applied in spite of substantial reservations concerning their effectiveness, should be reviewed. The development of human resources in the fuller sense requires careful assessment and planning, with clearly defined objectives, in which aquaculture may be only one of several development areas.

9.4 Sectoral growth and its determinants

The volume growth rates of the sector of the last decade have been examined, using FAO aquaculture production data. These have demonstrated a generally positive growth in most sectors over the period concerned, though with obvious differences for the more recently developed, high value species, which in many cases have demonstrated dramatic increases in output.

However, the major subsectors, particularly the Chinese and Indian carp assemblages and systems, continue to dominate production and are likely to remain the major constituents of total output.

Analysis of relative values of aquaculture production does not indicate such clear trends, though species which have been internationally traded, and for which better quality commercial data has been available, have tended to demonstrate gradually falling real term price levels. However, because of substantial market development, the price response appears to have been relatively modest in many cases.

The quality of the data on aquaculture production, which though improving in many areas, still offers many areas of doubt and possible misinterpretation. However, there are increasing opportunities for cross-correlation, and greater levels of regional and subsectoral data collection, which combined with a better awareness of aquaculture characteristics, should gradually improve the recording, transmission and analytical context of information.

Major determinants of growth have been examined in the text, to consider the relative importance of markets, technology development and institutional environment. The most appropriate representation of long-term growth may actually be a multiple curve system, in which growth is constrained at a series of levels, to be overcome by successive combinations of market and technical development and changes in the institutional conditions.

There are clear examples of the importance of institutional support in specific cases, but much of the more recently growing section of the industry appears to have been a result of market opportunity and technical feasibility, with a relatively laissez-faire institutional environment. Where regulation has been a factor, aquaculture has tended to be located in areas where its benefits are clearly preferred to any disadvantages it may be thought to bring.

There appears to be a substantial potential for organic growth in most sectors, particularly once an active private sector has evolved, whether at smaller scale or larger commercial level. Many existing enterprises are expanding from their original production bases, either by intensifying production, or expanding their area of operation.

In aggregate terms, as well as encouraging new entrants, this is also an important route of growth for the sector itself, and for those sectors which were less vulnerable to external risk, could easily be responsible for an underlying growth of 3-5% annually. However, a number of thresholds can be recognised in different circumstances, ranging from local market and economic constraints, to resource or environmental limitations, production process constraints, system stability factors and changing social and institutional environments. Systems which have a substantial degree of external control - e.g. dependence on wild seed, highly variable environmental conditions will clearly be more specifically constrained.

The markets for aquaculture products are extensive, and range from lower priced items essential to local diets, to highly specialised and expensive products. There are opportunities both to supply existing markets, and to develop others.

Apart from the potential levels of output in the future, the management of supply (in terms of size grades, quality and timing) in the aquaculture sector confers particular advantages. Some higher value markets for aquaculture products have grown very strongly, often leading to greater efficiency and lower prices, which are however still well above those for subsistence food supply. The bulk of demand is at lower price levels and only the lowest cost forms of aquaculture can be expected to compensate for major shortfalls in fishery sector supply.

There is however a major potential for simple and relatively inexpensive increases in yield in many systems. As the trend for intensification is likely to continue, efforts will have to be made to minimise environmental disturbance, improve nutrient and energy efficiency, and reduce waste output. Shortages of key inputs may also arise, and will force substitution or alternative approaches.

Integrated systems, capable of fitting in with local resources and activities will have greater prominence in the longer term, but need to be developed in realistic circumstances - i.e. where practical and cost-effective gains can be demonstrated, rather than theoretical ecological efficiencies.

Technical changes will also have an increasing impact on the viability and competitiveness of aquaculture enterprises. Effects of technical change will also be found in the lower value sector, particularly for nutrient supply and management, for seedstock type and quality, and to a varied extent, environment and disease management. As in other productive sectors, there will be an important challenge in making sure that technical developments are communicated to the smaller and less prosperous sectors of the industry, to ensure they are not overridden by technical change.

Because of the weighting of major aquaculture species (outputs of 10^5 - 10^6 t yr^{-1} or more), even modest rates of growth will maintain their dominance over coming decades. Though other species have shown very high growth rates, many are reaching at least the first levels of market saturation, and will be expected to slow their rates; there are therefore few other species which are likely to reach more than a medium level of output (i.e. of the order of 10^4 - 10^5 t yr^{-1}). While diversification into other species will be a feature of aquaculture development, as techniques become more widely applicable, the effects in output terms are expected to be modest.

Although this is a potentially valuable area of development, the role of aquaculture in enhancing capture fisheries will be rather variable, until financial returns can be guaranteed to those who have committed investment. This requires fisheries which can offer a bioecological basis for securing returns (i.e. in terms of yield gains), and most importantly, a management regime which provides sufficient control, and the appropriate mechanisms of cost recovery. There are however many examples of these systems, and if conditions are appropriate, there will be further opportunities to develop these.

There are also several areas where aquaculture development or the use of aquaculture techniques will offer important benefits to conservation and rehabilitation of stocks and ecosystems; these include the provision of alternatives to wild species, the restocking of native species and local strains, and the provision of management techniques for complex systems. These and other unconventional areas of demand are likely to increase in the future.

9.5 Social/economic issues

It is important to recognise that social determinants and social impacts are critical in aquaculture development, but they are not the only issues and need to be assessed in an overall context.. Preliminary review would suggest that rural, small scale aquaculture, more commonly associated with lower value production, is more subject to social factors but may also be more significant in terms of change and social benefit that it brings. By contrast, larger scale and more commercial aquaculture may have a greater economic role at the community and national level, is less dependent on social constraints, but may be more likely to bring negative social impacts.

At both artisanal and commercial levels, aquaculture development may engender social change, create changes in the significance of specific resources, and so change relative power and opportunity within a given social frame. Various social mechanisms may operate to regulate these, or they may break through existing structures, requiring new forms of adaptation and response.

There had been a widespread disappointment in the development of aquaculture in many rural areas, and increasing attention is now being paid to the processes by which aquaculture is adopted and sustained within poorer and more marginal communities. With a greater understanding of these, and with greater technical skill, economic understanding and social awareness, more effective approaches to rural aquaculture, supporting local communities, may be identified.

The potential of participative approaches aimed at introducing aquaculture as an additional option of community development has been demonstrated, and this broader approach is also reflected in the question of extension and support services, which had traditionally been delivered by fisheries departments and their equivalents. In areas where support is most needed, these have commonly been under-resourced and too little involved in anything outside the purely technical issues of aquaculture. There is a small but potentially growing trend to incorporate aquaculture development into wider agricultural or rural development systems, where a better-resourced, broader-ranging and often more experienced development support can be provided. There are opportunities for exploring new mechanisms for delivery of social-benefit oriented development. There should be more emphasis on local area development, on local networks, indigenous support mechanisms, and less reliance on public-sector support. Associations between commercial and rural/artisanal sectors (if non-exploitative) can also be developed, to provide a heterogeneous but well-linked sectoral structure.

An issue which is particularly important for poorer sectors, but also influences commercial aquaculture, is that of social stability, and the access to rights for land, water and other critical inputs. Where these cannot be secured, it is essential that they be established, whether through basic legislation, fixed period licensing, or change of practice

9.6 Market and associated issues

Market opportunities have clearly driven the development of many aquaculture sectors, and have encouraged very rapid, if not always balanced, development to meet major demands. More mature industries however face highly competitive conditions, and far smaller margins, usually with declining real term market prices. This has widened the overall availability of aquaculture products, and tended to reduce overall price levels.

Aquaculture produces a range of outputs occupying a considerable spread of price levels in most societies. However, many of its products are in the middle to higher price levels for equivalent foodstuffs, and while these products are important in satisfying overall demands, and will contribute to consumption for many levels of society, they may not directly or routinely benefit the poorest and most vulnerable groups..

The relationships between aquaculture and fisheries products and markets can be quite complex, and are not uniform. In some cases, the two are closely associated, with aquaculture products increasingly entering the fishery marketing chain, and alternatively substituting or complementing capture fishery production.

In other cases, aquaculture is developing as a more discrete market element, and in the higher value sectors particularly has developed new market areas and linkages.

The opportunity for aquaculture to provide low-cost fishery raw material is rather limited, though the implications for development of these markets are very large. There are however a few potential candidate species, mainly produced in tropical systems with lower-level ecosystem requirements, which might fill some of the gaps in supply for basic product for the low-middle range processed sector - e.g. fish fingers, coated products, fish/sauce products. Should price, availability and quality range become suitable, there could be a useful additional export potential from many countries, though at present, there is still too large a gap between aquaculture and fishery products to make this feasible. Additionally, the activity of aquaculture within an area can offer important opportunities for access to wider communities, e.g. through family-based production, and through the availability of secondary products, offgrades and surplus materials.

Quality and health issues relate to market and environmental issues; the aquaculture sector will be increasingly sensitive to both real and potential risks, and will need far greater support and security in this respect. The rise of issue-based political processes may affect aquaculture at a range of levels; consumer issues and concerns may increasingly affect marketability, and may damage prospects for developing country supplies. Environmental and disease management, and social practice/labour conditions, may all affect the image of particular producers and countries, and may affect the associated market opportunities.

Better understanding is required of market dynamics, the role of market intermediaries, the role of information and the market power relationships. Wider access is also required to market information in general, particularly in rural areas and in many developing countries.

9.7 The role of science and technology

A wide range of scientific and technological developments can be observed to apply to the aquaculture sector, and have done much to extend and expand its capability. Though many of these have been focused around the higher value sectors and been stimulated by its demands and potential, the longer terms effects may be expected to apply in other areas, even benefiting the simplest forms of aquaculture. However the rate and effect of this process will depend on the effectiveness of communications and application.

The role of science and technology in the growth and development of the sector has been variable. While these have clearly been associated with opportunity for expansion, and have often created the initial focus for development, they then support rather than drive most growth, and supply the means for periodic change in overcoming constraints. Thus technological change has generally been incremental in effect rather that ground-breaking.

System technologies are primarily associated with the 'hardware' of aquaculture production. Their primary effect has been to extend management control and operational efficiency, and to widen the potential availability of resources - particularly sites - for aquaculture production. The most important current developments concern exposed-water production systems, water reuse systems, and large-scale management systems using mechanised and data-managed systems. These have primarily focused on higher value, intensive systems, though products such as aerators and pumps, and materials as soil reinforcers and plastics are becoming more important in simpler operations.

Biotechnologies are more 'software' oriented, and involve areas such as genetic management, reproduction control, feed development, disease identification and control, and environmental manipulation. Here, the potential for change is far wider, as techniques can potentially be developed and extended across a wide range of species. In many cases, the result of sophisticated and complex research can be made available as a relatively simple and easily applicable product, potentially able to reach a wide range of beneficiaries.

As technologies are developed, more attention should be given to processes by which aquaculture is adopted and sustained within poorer and more marginal communities. The commercial sector is likely to play an increasing role in many technical developments, which may generally be welcomed, though there may be a corresponding need for sources of impartial advice;

The need for more sustainable forms of natural resource use actually calls for a substantial body of knowledge about ecosystems, their components and their behaviour. Without more specific background data it is impossible to understand or predict the nature and extent of development-induced change. Research in this field will also extend to physicochemical and socio-economic features of systems, and we might expect subjects such as aquaculture to be described and analysed as part of a wider systems perspective.

A clearer concept of research frameworks needs to be adopted and applied, and a more rational and objective oriented approach used for setting priorities and for management of research. Scientific and technical advances need to be viewed within a proper production systems and economics framework, to identify and test implications of technology change and to clarify development priorities. Techniques of technology assessment will require to be used more widely, and can be applied at both local and strategic levels to view the implications of specific developments.

9.8 Infrastructure and investment: the public and private sectors

The aquaculture sector is in most countries and locations of low to moderate significance in terms of fixed capital and economic scale, though in specific localities it may be more dominant. In most cases aquaculture does not need highly specialised infrastructure, beyond the normal agricultural sector requirements for transport and communications.

A range of organisational features can be noted, from international and national public sector institutions, through various private sector bodies, from multinational to local businesses, various communal structures, family enterprises and individual entrepreneurs at a range of scale. The role of the public sector is variable; in many poorer countries this had been the major source of support for the aquaculture sector, though this is changing, as the private sector gathers strength. Likewise, the larger-scale institutionally managed sector, typical of the command economies, is declining in most cases, to be replaced by corporate equivalents.. Developments such as these increasingly call into question the need for public sector involvement, and a redefinition of the role it should play.

The nature and characteristics of investment in the sector are evolving as the private sector plays an increasing role, particularly in the development of intensive aquaculture. The financial rates of return in some sectors can be extremely good, though the cashflow characteristics of many enterprises may increase risks and the difficulties of financing. In economic terms, investment in public infrastructure specifically for aquaculture has been variable, and often disappointing.

For commercial investment, aquaculture requires at least moderate levels of security of ownership. In many aquaculture systems the bulk of the financial value lies in the stock, which may not always be considered as collateral. This can be a constraint for investment access, particularly for smaller enterprises, where the risks of securing other assets may be too great. Self-generated investment has been an important factor in many areas.

As with any economic activity, there may be a range of financial and other barriers to entry for intending participants. In its higher value forms in particular, aquaculture is a relatively complex subject, and at various stages may have been constrained by the availability of expertise. Increasingly however the barriers are becoming structural, in that better established and larger groups are now gaining in efficiency and commercial strength. At this level, larger scale investment is likely to become available preferentially, to the detriment of smaller-scale operators, who will find their terms of business to become increasingly expensive and uncompetitive, thereby accelerating the dominance of larger groups.

At the smallest scale, while larger commercial groups may not threaten competitively, the problems of investment primarily concern access and security. For poor or landless individuals or groups, the absence of significant collateral, or the understandable reluctance to commit basic resources to new and possibly uncertain ventures, may deny many useful opportunities. Development methods such as those employed by the Grameen Bank in Bangladesh, and other NGO credit systems maybe effective in some circumstances, but need to be applied carefully in the local context.

Given the emerging role of the large corporation in the commercial sector there will be an increasing need to understand the implications in terms of competition, trade, resource access, etc. If a diverse production sector is desired, with a range of opportunity for small and large scale producers, it will be necessary to try to maintain a diversified market and supply chain system.

9.9 Resource use and environmental management

Aquaculture has notable requirements for land and water, and varying levels of demand for fertilisers and feeds. Seedstocks are also important, and are critical in freeing production from the primary constraints. Demands for labour can also be defined for different systems. Wider resource implications, including energy analysis, ecological footprint analysis, and generalised sustainability assessments may also be applied to measure the resource demands of aquaculture, and compare these with the potential benefits. In such a way, preferred options for development could be identified.

The trend for higher production intensity leads to increased nutrient and energy inputs, lowered transfer efficiencies and higher waste discharge levels. Potential shortages of major resource inputs such as fishmeal have already been identified. Significant efforts will have to be made to develop practices which minimise initial environmental disturbance, are efficient in nutrient and energy use, and have as a consequence less waste output. Associated with this will be the development of integrated systems more capable of fitting in with local resources and activities, and of improving overall efficiency and reducing cost; more accurate local level inventories of production need to be taken. The effects of alternative development strategies have been noted, in that extensive aquaculture will generally require more land, but have less environmental impact and employ or beneficially involve more people. However investment may be higher, and profitability and output per resource use may be lower, and hence conventional economic benefit may not be maximised.

It is clear that any means to reduce demands on resources would be potentially beneficial, and various approaches may contribute to lessening impacts in terms of external resource use and undesirable effects. Primary consequences of this could include the potential to increase production, with lower costs, within the existing resource allocated; better acceptance of aquaculture within the overall public opinion and regulatory environment, and the location/resource planning context, with improved predictability of impact, and better opportunities for 'fine-tuning'; the ability to adhere to increasingly rigorous external controls without undue financial penalty or competitive disadvantage; investment and development confidence, and the continued opportunity for sustained longer-term growth.

9.10 Prospects for development

Growth rate projections have been made for the major species groups to provide estimates for production to the year 2010 and beyond. These were based on the existing growth rates, together with a subjective estimate of the level of maturity of the specific market and the technical status and development potential in terms of opportunities, site areas, etc. In most cases, lower growth rates were assumed for the longer time period. These projections were aggregated for major species groups.

Similar targets for development had been developed by others, based on slightly different assumptions and more explicit regression-based projections, derived from a longer time-series of production data.. Though there is some difference between the projected figures, the overall trends are broadly similar. The present projections, based to a degree on the expectation of varying constraints, are however rather lower, with the implication that per capita supply might decline. To achieve otherwise will require a major co-ordinated approach to stimulate development, linked in turn to a major level of concern and action for undernutrition - a problem which is already increasing steadily, with potentially disastrous consequences for large parts of the world's population.

The primary feature of the projections, which are largely based on trends in existing growth rates, has been that the bulk of additional production will come from the major species groups - i.e. the Chinese and Indian carp assemblages, mainly through gradual intensification of production, the bringing in previously under-utilised water bodies, rain-fed ponds, etc. Other groups will also grow substantially - e.g. tilapia, various species of catfish and would increase significance, but would not reach the production levels of the carp species. There will be wider opportunities for diversification, with particular focus on multiple cropping, more efficient polycultures, and greater emphasis on 'minor species' both for market and biodiversity aims.

While there have been substantial developments in coastal and marine areas, inland aquaculture is likely to continue to provide a major share of output, and will be particularly important for poorer communities. Here there will be significant opportunities in the use of seasonal water bodies, in rice/fish culture as IPM (integrated pest management) approaches become more widely adopted, and in reservoir stocking/cage culture. The stocking of open water bodies in general will become more important. Coastal and marine aquaculture is likely to continue with higher-value species, but will come under increasing pressure for environmental control and social benefit, in which case multiple-species approaches will become more common, and will offer lower trophic level species, often cheaper, for more diversified markets.

Although technology will increasingly permit open-sea aquaculture, this is likely to be limited by its capital and operating costs, though improved forms of stock containment or release/recapture, coupled with suitable legal and management conditions may widen the prospects for managed production in open environments.

With the increase in aquaculture production there will be inevitable resource implications, though these are well within the overall capacity of most current producing areas, and in most cases projected increases could be achieved sustainably with proper management. As noted earlier, a considerable degree of endogenous growth might be expected through improvements in productivity, though additional areas of production will also be involved. The displacement or supplementation of other activities by aquaculture will also be expected to change local and larger-scale social and ecological systems, though such effects need not be negative and/or irreversible.

There are wide-ranging differences between individual countries, depending on resource access local and export markets, and institutional capacity. Potential for aquaculture is not specifically related to current GDP/head levels, and is more generally related to political stability, social context and institutional characteristics.

Aside from the countries which are recognised as having critical development problems - due e.g. to military conflict, major environmental crises, social instability - and the countries which are clearly constrained in water resources, most countries have significant potential for aquaculture, at least in strategic terms. This would have to be clarified in terms of specific resources and their potential and mechanisms for development, but there is a reasonable potential for growth in many areas.

There is also however a need to determine whether resources are likely to be employed for local food production or for export income, as the distributional effects are likely to be very different.

The relative importance of the various development trends will differ according to the social, political and economic characteristics of the area involved, and on its current state of development. Within regions, individual countries and localities will experience different problems and development priorities. Allowing for the inevitable generalities, the following general patterns might be expected;

- Asia, particularly East and South-East: will see continuing growth and technological development, an increasing amount of which will be commercially originated; there is likely to be a substantial pace of science and technology input; increased output will be associated with greater demand on resources and a far greater need to reconcile conflicting demands. Some products are export-oriented, and there will be an increasing need to maintain, support and develop quality/consumer acceptability issues; local markets are also developing strongly, and may require different products and product forms. Rural aquaculture for local markets will also develop, though economic changes may reduce incentives for non-urban activities; rice/fish culture and other forms of integrated aquaculture will become more important, and local species will receive greater attention. Institutional involvement will become increasingly specialised, e.g. scientific support, specialised training, monitoring and regulation, and in some cases may link with private sector development to provide exportable services.

- Australasia/Oceania; will demonstrate steady growth and wider diversity of production, particularly in coastal/marine aquaculture, but will be limited by the size of domestic markets and/or the costs of market access/transport for exportable products; Australia and New Zealand may become major producers in some species,; conservation and biodiversity issues will become more important and may increasingly control the nature and extent of development. Expertise and experience developed in these issues may become increasingly valuable for other regions.

- Indian subcontinent: will develop greater amounts of commercial aquaculture, but with increasing environmental and social consequence, and an increasing need for planning and management; greater private sector involvement in hatcheries and aquaculture supply should lead to improved efficiency and rapidly increased capacity; aquaculture supported fisheries - e.g. in floodplains and reservoirs may become increasingly important in rural development; NGO activities will be very important in developing rural aquaculture, and in involving the very large populations of poorer people, usually as part of broader programmes. Public sector institutional involvement will gradually lessen, if deregulating trends continue, but modern, effective and equitable regulatory levels and mechanisms need to be developed to avoid the old bureaucratic problems, but provide the necessary level of strategic capacity and resource protection, and to stimulate and make more effective the very capable national scientific institutions.

- Former Eastern Bloc countries; will demonstrate variable responses to political and economic changes, depending on the effectiveness of emerging management structures, the institutional strengths of the entities carrying out production, and the extent to which access can be gained to open market conditions. The transfer towards 'Western' systems will be variable, and new ventures may be constrained by legal and political uncertainty and by financing risks. There may also be serious environmental problems and difficulties with quality control for export markets. Production opportunities are variable, as climatic conditions will constrain many options, but resources are significant, and could be developed to a far greater degree. There are also important areas of potential with managed water bodies, and the development of high quality and potentially valuable recreational fisheries for European and other markets.

- Middle East; in many areas constrained by climate, though local market demands will be good and in some areas will support more sophisticated production systems, including offshore aquaculture, intensive recycle systems and integrated arid-zone aquaculture production. The economic strength of the region may decline in relative terms, and may change social and market characteristics, possibly reducing the practical opportunities for indigenous production. Some of the larger countries in the region do however have very large and varied resources for aquaculture, and given a reasonable degree of political stability may be expected to develop and expand production quite considerably. Institutional involvement will be variable, but is in many cases likely to be a major input in stimulating and managing development.

- Africa: aquaculture by its nature demands stability and security, and its potential will depend on structural and societal stability as much as on technical and economic viability.

Though the needs are arguably the greatest in many areas of Africa, and good resources potentially available, the region offers many structural constraints to development. This is obviously not just a problem for aquaculture, but as a relatively recent introduction in many cases, is a particular difficulty, and one which may not be easily overcome. There is therefore a need to evolve systems which are workable within the local context, less dependent on the very low capacity of many national institutions, to find ways to widen the range of local opportunities, e.g. with short-term production cycles, and lower risk strategies. Around urban areas in some countries there may be an increasingly potential for private aquaculture industry, and in some coastal countries there may be further opportunities for export-based production. The roles of institutions will vary, but with one or two exceptions will probably be rather marginal. Institutions and other structures may need to be developed to become rather more diverse, selective and effective.

- Latin America: although there are considerable areas of physical and resource potential, developments to date have been relatively patchy, with active export-oriented production of a small number of high value species contrasted with a rather poor or intermittent growth of production of other species for domestic markets. In many cases, local economies have been badly affected by recent trade and finance conditions, and export-oriented production, though important, may not be the only solution to national economic needs. However any change will depend on the state of local demand, and on the extent to which local economies can be developed. There is increasing interest in rural aquaculture, and approaches might be developed further for assessing potential and developing effective methods. Indigenous species may have an increasing role for aquaculture, but will need to be evaluated realistically within a proper techno-economic framework, and may be more important as components in broader biodiversity initiatives. Local institutions are very variable in capacity, but in many cases private sector and NGO development may be more important and more effective.

- N America and W Europe; will continue to develop in higher-market value aquaculture production, but are likely to be increasingly controlled by environmental and other regulatory pressures. However, a considerable degree of scientific, technological, and management skill development may be expected, and this will extend via commercial and trading relationships to other regions. Local aquaculture production, is likely to grow relatively slowly, but will increase in efficiency, reduce in environmental impact and may concentrate into the hands of a smaller number of major producers. Opportunities for specialised areas of production, for recreational fisheries, and for stock enhancement are likely to increase, and may widen options for smaller producers.

9.11 Strategic perspectives

Aquaculture is a diversified activity, and national approaches need to take account of this. It is also closely interdependent with other areas of activity, in social, economic and environmental terms, and requires some form of framework in which to develop.

In many countries, the increasing sophistication of the aquaculture industry, its growing economic importance, and the increased potential for social and environmental impact, are likely to require a greater organisational and regulatory capacity than were previously considered necessary.

Good policy and planning should improve the prospects for equitable and efficient development and should support the industry, while its absence will increase the risks of wasted physical and economic resources, of social conflict and of environmental damage. However, it will be important not to over-regulate and make procedures unnecessarily complex, inhibitory or expensive. Planning approaches need to consider not only technological improvements and constraints but also institutional and social limitations, and the wider context of general development trends affecting the role of Government and the private sector.

New strategies and policies should be formulated to engage both the public and private sectors in sectoral growth and management, and new mechanisms sought for collaborative association towards common goals.

In resource management terms, aquaculture must be seen within the overall context A broader and more systems-oriented perspective will be required, involving understanding, management and rehabilitation - of individual ecosystems such as lake and river systems, lagoons, mangroves and coastal reefs , with approaches such as .

- watershed management; involving issues such as hydrological management, water retention, local climate effects and soil stabilisation; sediment collection, soil nutrients and productivity; groundwater use, reuse and quality management; multiple use of reservoirs, lakes, multiple-use ecological and economic models; incorporation in larger scale projects for flood control, irrigation, water supply and waste water treatment.

- coastal area management, involving brackish water and marine aquaculture, coastal and lagoon fisheries, including issues such as spatial characteristics, land use, water exchange, coastal processes, economic and physical development, sedimentation and salinisation, groundwater use, nutrient and chemical management,

Such approaches, rather than presenting aquaculture production as a creator of environmental problems, would seek to develop ranges of solutions, capable of allowing improved management of aquatic resources, and would increasingly be seen as the units of management, rather than individual activities and processes.

Finally, the issue of sustainability has been discussed at various points in the review, and the broad themes introduced in the planning and development contexts. The whole issue of aquaculture and its role in food security can be interpreted as a matter of sustainability, in which natural resources are used in specific ways to meet societal objectives, and in particular to satisfy intra-generational equity requirements. The broad concepts would indicate that aquaculture could be developed and expanded within conventional sustainability criteria, to meet these social goals, though market forces will act to favour some forms of development and resource use over others.

9.12 Sectoral support

In previous periods, support for the aquaculture sector has come from the institutional sector, NGOs and the private sector. The main areas of direction for the post-Kyoto period have been in the institutional sector, partially because of recognised weaknesses in these areas, but partly also because of the view that this sector would play the most important role in providing the conditions for development of aquaculture.

Many of the subsequent analyses have suggested otherwise, however, as the role of the private sector has appeared in many instances to be more prominent and effective, and more flexible in addressing real needs and issues.

The role of traditional development agents has also changed; whereas formerly they have been important in developing pioneering activities, in institutional strengthening, training management and 'brokering' information and helping to articulate and formulate policy, there are now many other agents in this process, and many potential and possibly competing sources of authority. These include NGOs, Universities, commercial service companies, individual advisors and increasing range of computer-network based information sources. Many countries now have at least an embryonic aquaculture industry and local institutional capacity, and the issues of concern are developing and becoming more complex and sophisticated.

Development agencies may need to establish new strategies to assist in development, exploiting their specific comparative advantages,. Networks may have a particularly useful role in this context, and the use of computer-based communications can have an important effect on information exchange, where this is feasible.

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AQUACULTURE DEVELOPMENT TRENDS:

perspectives for food security
Graphs and tables

Figure 1.1 Aquaculture/fishery production trends (FAO 1995)

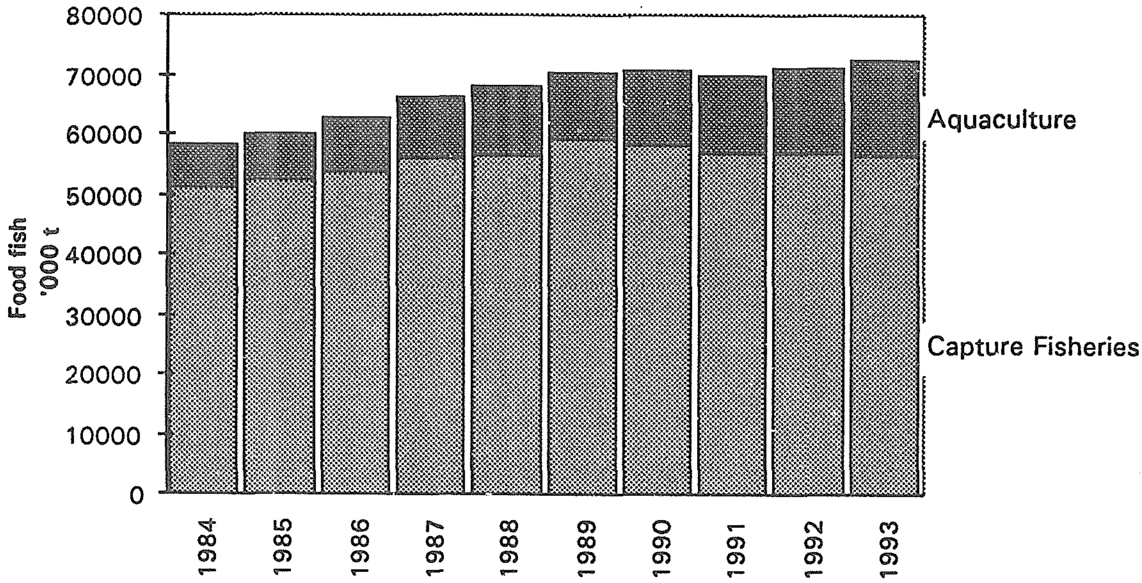
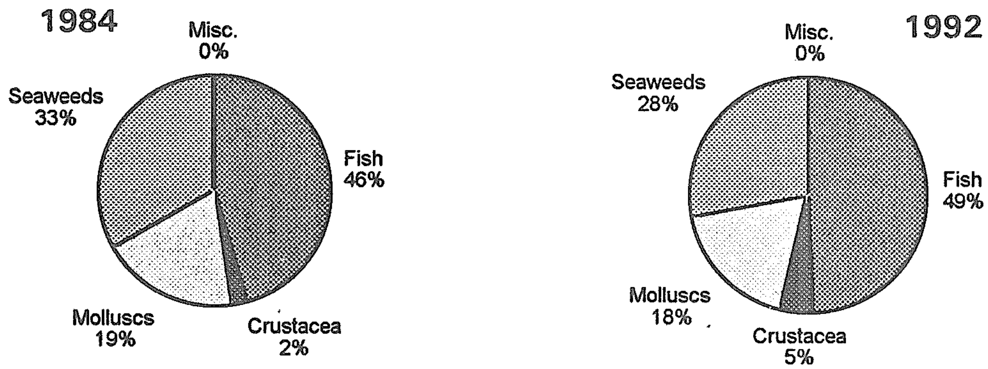


Figure 1.2 Aquaculture production by major species category, 1984, 1992



Source: FAO, 1994

Table 2.9 General trend characteristics, major fish species groups (tonnes; % total volume; % annual growth)

Species group	1986	%	1992	%	%/yr	Trend/notes
Freshwater						
carps, barbels other cyprinids	4221728	*70.5*	6652305	*70.6*	7.9	steady growth from large base
tilapias and other cichlids	241741	*4.0*	473477	*5.0*	11.9	high steady growth, moderate base
misc. fw fish	592097	*9.9*	854955	*9.1*	6.3	increasing growth from moderate base, dominant effects of channel catfish, also clarias, anabas, trichogaster
freshwater total	5055566	*84.5*	7980737	*84.7*	7.9	steady growth from large base
Diadromous						
sturgeons, paddlefish	180	*0*	437	*0*	15.9	high growth but v small base
river eels	77595	*1.3*	99668	*1.1*	4.3	moderate or levelling, small base
salmon, trouts, smelts	303632	*5.1*	628418	*6.7*	12.9	high growth, moderate base, may be levelling - mainly atlantic salmon and rainbow trout
misc. diadromous fish	313616	*5.2*	352175	*3.7*	2	low growth/levelling, moderate base, primarily milkfish, also lates; mullets in marine category
diadromous total	695023	*11.6*	1080698	*11.5*	7.6	higher early growth, from moderate base, now levelling
Marine						
flounders, halibuts, soles	1965	*0*	12075	*0.1*	35.3	v high recent growth, v small base, mainly paralichthys, also turbot
cods, hakes, haddocks	0	*0*	28	*0*	n/r	negligible, fluctuating
redfishes, basses, congers	39929	*0.7*	95944	*1.0*	15.7	high/recent growth, may be slowing mainly red and gilthead seabreams, also seabass, grouper
jacks, mullets, sauries	167802	*2.8*	179430	*1.9*	1.1	moderate, more or less stable, small fluctuation mainly seriola, also mullet
herrings, sardines, anchovies	3	*0*	0	*0*	-100	negligible/decline
tunas, bonitos, billfishes	60	*0*	123	*0*	12.7	negligible/highly variable
miscellaneous marine fishes	24069	*0.4*	68118	*0.7*	18.9	rapid recent growth, moderate level unspecified, mainly SE Asia/China
marine total	233828	*3.9*	355718	*3.8*	7.2	moderate growth from small-moderate base
TOTAL FISH	5984417	*100*	9417153	*100*	7.8	steady growth from large base

Table 2.10 Species ranking in aquaculture production

Principal fish species: annual production >100 000t					
Common name	***Species name***	***1986***	***1992***	***%***	***%/yr***
Silver carp	Hypophthalmichthys molitrix	1275315	1616613	26.8	4.0
Grass carp(=White amur)	Ctenopharyngodon idella	439837	1252728	184.8	19.1
Common carp	Cyprinus carpio	802497	1022887	27.5	4.1
Bighead carp	Hypophthalmichthys nobilis	607292	786604	29.5	4.4
Milkfish	Chanos chanos	310866	339289	9.1	1.5
Roho labeo	Labeo rohita	163552	309020	88.9	11.2
Nile tilapia	Oreochromis niloticus	111081	302674	172.5	18.2
Catla	Catla catla	155000	301806	94.7	11.7
Rainbow trout	Oncorhynchus mykiss	204014	296571	45.4	6.4
Mrigal carp	Cirrhinus mrigala	106000	295551	178.8	18.6
Crucian carp	Carassius carassius	93291	257198	175.7	18.4
Atlantic salmon	Salmo salar	59823	241727	304.1	26.2
Channel catfish	Ictalurus punctatus	149244	211067	41.4	5.9
White amur bream	Parabramis pekinensis	147600	181516	23.0	3.5
Japanese amberjack	Seriola quinqueradiata	148788	148988	0.1	0
Principal crustacean species: annual production > 100 000t					
Common name	***Species name***	***1986***	***1992***	***%***	***%/yr***
Giant tiger prawn	Penaeus monodon	89384	388565	334.7	27.8
Fleshy prawn	Penaeus chinensis	82909	207428	150.2	16.5
Whiteleg shrimp	Penaeus vannamei	35144	111075	216.1	21.1
Principal mollusc species: annual production >200 000t					
Common name	***Species name***	***1986***	***1992***	***%***	***%/yr***
Pacific cupped oyster	Crassostrea gigas	763925	795004	4.1	0.7
Japanese scallop	Pecten yessoensis	163601	546222	233.9	22.3
Sea mussels nei	Mytilidae	210670	538900	155.8	16.9
Japanese(=Manila)clam	Venerupis japonica	123037	328031	166.6	17.8
Blue mussel	Mytilus edulis	433377	318047	-26.6	-5.0
Razor clams	Solen spp	126175	198598	57.4	7.9
Principal aquatic plant species: annual production > 200 000t					
Common name	***Species name***	***1986***	***1992***	***%***	***%/yr***
Kelp	Laminaria japonica	1734210	3147258	81.5	10.4
Laver(=Nori)	Porphyra tenera	634155	708350	11.7	1.9
Wakame	Undaria pinnatifida	532055	491734	-7.6	-1.3
	Eucheuma spp	170542	354953	108.1	13.0

Table 2.11 Production trends of major fish species, 1986-1992

Fish species		1986	1992	%/yr	notes
Production increase >20%					
Atlantic salmon	Salmo salar	59823	241727	26.2	high market price, competition
Coho(=Silver)salmon	Oncorhynchus kisutch	10416	48379	29.2	good market price
Gilthead seabream	Sparus auratus	745	13414	61.9	v high price, fry available
Giant sea perch(=Barramundi)	Lates calcarifer	2750	12886	29.4	high price, techniques better
Production increase 10-19.9%					
Grass carp(=White amur)	Ctenopharyngodon idella	439837	1252728	19.1	steady expansion, grass control
Roho labeo	Labeo rohita	163552	309020	11.2	regional expansion, markets
Nile tilapia	Oreochromis niloticus	111081	302674	18.2	culture qualities, fry supply
Catla	Catla catla	155000	301806	11.7	regional expansion, markets
Mrigal carp	Cirrhinus mrigala	106000	295551	18.6	regional expansion, markets
Crucian carp	Carassius carassius	93291	257198	18.4	good demand, pond culture
Japanese seabream	Sparus(=Pagrus) major	33497	65950	12.0	good price, simple systems
Mozambique tilapia	Oreochromis mossambicus	16994	45314	17.8	culture qualities, fry supply
Thai silver barb	Puntius gonionotus	10640	19955	11.0	good performance, price, fry
Trouts nei	Salmo spp	8816	15589	10.0	general demand, technology
Flathead grey mullet	Mugil cephalus	4027	11800	19.6	better systems, good markets
Bastard halibut	Paralichthys olivaceus	1865	10327	33.0	technologies, markets
Production increase 3-9.9%					
Silver carp	Hypophthalmichthys molitrix	1275315	1616613	4.0	useful, not popular
Common carp	Cyprinus carpio	802497	1022887	4.1	steady increase, weak markets
Bighead carp	Hypophthalmichthys nobilis	607292	786604	4.4	useful, not strong demand
Freshwater fishes nei	Osteichthyes	300691	517883	9.5	variety of secondary species
Cyprinids nei	Cyprinidae	257393	419185	8.5	variety of secondary species
Rainbow trout	Oncorhynchus mykiss	204014	296571	6.4	}very competitive markets, drive
Channel catfish	Ictalurus punctatus	149244	211067	5.9	} efficiency, price reductions
White amur bream	Parabramis pekinensis	147600	181516	3.5	part of general expansion
Torpedo-shaped catfishes	Clarias spp	54288	83325	7.4	good market interest
Mud carp	Cirrhinus mulitorella	57226	81050	6.0	useful, moderate demand
Japanese eel	Anguilla japonica	36532	55743	7.3	good demand, restricted capacity
Climbing perch	Anabas testudineus	36835	50632	5.4	steady demand
Production -3 to +3%					
Milkfish	Chanos chanos	310866	339289	1.5	declining capacity and profits
Japanese amberjack	Seriola quinqueradiata	148788	148988	0	production problems/cost
Tilapias nei	Oreochromis (=Tilapia) spp	98019	106987	1.5	hybrid demand; others declining
Black carp	Mylopharyngodon piceus	61100	52287	-2.6	useful, not popular
River eels nei	Anguilla spp	36578	36949	0.2	supply constraint
Java barb	Puntius javanicus	22877	23000	0.1	Thai silver barb preferred
Blue tilapia	Oreochromis(Tilapia)aureus	14950	16990	2.2	Nilotica/hybrids preferred
Pangas catfish	Pangasius pangasius	12574	13220	0.8	disruptions, record problems?
Ayu sweetfish	Plecoglossus altivelis	11396	12833	2.0	weak markets
Production drop > 3%					
Snakeskin gourami	Trichogaster pectoralis	17651	14220	-3.5	habitat/production limits

Table 2.12 General trend characteristics, crustacean and mollusc species groups (volume, tonnes)

Species group	1986	% of total	1992	% of total	% /yr	Trends/notes
Crustaceans						
freshwater crustaceans	57561	14.8	62433	6.4	1.4	fluctuating around moderate base mainly red swamp crawfish, macrobrachium, also cherax; nei category mainly Vietnam
seaspiders, crabs	3682	0.9	13693	1.4	24.5	rapid recent growth, small base mainly Chinese river crab, scylla
lobsters, spiny lobsters	13	0	62	0	29.7	fluctuating, negligible
shrimps, prawns	312820	80.7	884075	90	18.9	high growth from large base, steadying predominantly penaeids; monodon
miscell marine crust.	13567	3.5	21653	2.2	8.1	moderate growth from small base mainly nei from Korea DPR and China
total marine	330082	85.2	919483	93.6	18.6	good growth from large base
TOTAL CRUSTACEA	387643	100	981916	100	16.8	
Molluscs						
freshwater molluscs	718	0	256	0	-15.8	negligible, strong decline
abalones, winkles, conch.	802	0	1570	0	11.8	negligible, fluctuating, some growth mainly abalones
oysters	937681	39	953529	27.2	0.3	large base, fluctuating/static mainly crassostrea gigas, also virginica
mussels	798512	33.2	1086310	31	5.3	large base, early growth now levelling mainly edulis, also galloprovincalis, smaragdinus, canaliculus
scallops, pectens	164274	6.8	549194	15.7	22.3	good growth from moderate-large base, mainly yessoensis
clams, cockles, arkshells	437507	18.2	764744	21.8	9.8	large base, rapid recent growth, mainly venerupis, solen, also anadara, tapes, merceneria, arca
squid, cuttlefish, octopus	0	0	0	0	n/r	negligible
misc. marine molluscs	65248	2.7	145116	4.1	14.3	moderate base, early growth, levelling, mainly China and Korea DPR
TOTAL MOLLUSCS	2404742	100	3500719	100	6.5	large base, moderate growth, recent upturn

Table 2.14 Production trends for major mollusc species, 1986-1992

Mollusc species		**1986**	**1992**	**%/yr**	**Notes, etc**
Production increase > 20%					
Japanese scallop	Pecten yessoensis	163601	546222	22.3	market demand, cost control
Carpet shells nei	Tapes spp	723	30055	86.1	species definitions?
Production increase 10-19.9%					
Sea mussels nei	Mytilidae	210670	538900	16.9	general rise; species definition?
Japanese(=Manila)clam	Venerupis japonica	123037	328031	17.8	market price, simple techniques
Marine molluscs nei	Mollusca	65248	145372	14.3	recording artefact?
Green mussel	Mytilus smaragdinus	23856	58634	16.2	good price, simple systems
New Zealand mussel	Mytilus canaliculus	15636	46500	19.9	market/industry development
Portuguese cupped oyster	Crassostrea angulata	5919	13380	14.6	good prices, species option
Production increase 3.1-9.9%					
Razor clams	Solen spp	126175	198598	7.9	simple techniques
Blood cockle	Anadara granosa	88291	140016	8	wide demand, simple techniques
Mediterranean mussel	Mytilus galloprovincialis	78014	108794	5.7	moderate prices but simple system
Hard clam	Mercenaria mercenaria	19124	29224	7.3	good demand, capacity constraints
Production +/- 3%					
Pacific cupped oyster	Crassostrea gigas	763925	795004	0.7	heavily developed, price problems
American cupped oyster	Crassostrea virginica	130020	113209	-2.3	traditional; declining returns
Philippine cupped oyster	Crassostrea iredalei	16465	15103	-1.4	other species preferred
Clams nei	Bivalvia	12161	13421	1.7	general category
Production drop >3%					
Blue mussel	Mytilus edulis	433377	318047	-5	Netherlands variability
Ark clams	Arca spp	58393	20547	-16	environmental effects?

Table 2.15 General trend characteristics, aquatic plant/other species groups

Species group	1986	%	1992	%	%/yr	Trends/notes
Aquatic plants						
brown seaweeds	2269880	66.7	3640344	67.5	8.2	large, v rapid recent increase, mainly laminaria, also undaria
red seaweeds	821220	24.1	1132654	21	5.5	moderate, recent growth, mainly porphyra, eucheuma, also gracilaria
green seaweeds & other algae	11040	0.3	17248	0.3	7.7	small, recent growth
misc. aquatic plants	298616	8.8	599543	11.1	12.3	moderate, recent growth, mainly China and Indonesia, also Japan, Korea Rep and DPR
group total	3400756	100	5389789	100	8	large, early fluctuation, recent growth
Other species						
frogs and other amphibians	15	0	884	4	97.3	negligible, high recent growth
turtles	760	2.5	902	4.1	2.9	negligible, fluctuating
crocodiles and alligators	1	0	61	0.3	98.4	negligible, early growth, now stable
seasquirts &other tunicates	23757	78.2	12685	58.1	-9.9	fluctuating, steep recent decline mainly seasquirts nei, Japan and Korea Rep
misc. aquatic invertebrates	5657	18.6	7079	32.4	3.8	small, mid-peak, recent decline, mainly Korea Rep
pearls, mother of pearl, shells	206	0.7	224	1	1.4	negligible, stable
sponges	0	0	1	0	n/r	negligible
group total	30396	100	21836	100	-5.4	small, declining

Table 7.2 Aquaculture development in low income countries (1990 GDP $300 - $1000)

	Population. /km2		f. water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km2 land area	mt. per km3 water res.	mt. per km of coast	kg per head
Togo	63	158	1	56	24	17.8	0.42	2.40	0	0.007
Côte d'Ivoire	37	96	1	515	306	6.2	0.95	4.37	0	0.026
Liberia	23	54	0	579	0	-100	0		0	0
Senegal	37	96	4	531	36	1	0.03	0.14	0.06	0.005
Mauritania	2	5	10	754	0		0	0	0	0
Egypt	52	86	97	2,450	38895	4.1	29.17	502.50	3.96	0.747
Cameroon	25	59	0	402	180	6.4	0.38		0	0.015
Guinea	23	61	0	346	5	16.5	0.02		0	0.001
Zimbabwe	25	46	5	0	160	1.1	0.13	2.08		0.016
Ghana	62	142	1	539	440	3.4	1.84	14.67	0	0.030
Angola	8	22	0	1,600	0		0		0	0
Namibia	2	5	2	1,489	0		0	0	0	0
Nigeria	125	276	1	853	16588	20.4	16.86	43.27	1.19	0.144
Kenya	42	110	7	536	1136	31.1	1.29	47.71	0.72	0.047
Niger	6	19	1	0	15	2.4	0.01	0.50		0.002
Zambia	10.8	27	0	0	1120	8.3	1.49			0.138
C.African Rep	5	10	0	0	338	9.8	0.54			0.113
Burkina Faso	33	80	1	0	5	-25.8	0.02	0.25		0.001
Benin	42	89	0	121	75	30.8	0.66		0	0.016
P.New Guinea	8	15	0	5,152	13		0.01		0	0.003
Cambodia	47	77	0	443	7670	21.9	42.38		0	0.902
Afghanistan	0	0	52	0	0		0	0		
Vietnam	201	352	1	3,444	187000	5.5	409.09	264.71	15.10	2.821
Mongolia	1	3	2	0	0		0	0		0
Indonesia	94	144	3	54,716	689747	9	123.04	85.75	8.32	3.871
Yemen, Rep.	21	70	147	1,383	0		0	0	0	0
Sri Lanka	258	364	15	1,340	4200	-0.8	53.03	83.33	0.52	0.247
Philippines	205	337	9	22,540	737501	7.8	329.19	301.27	28.34	11.992
Pakistan	141	302	33	1,046	12670	6.9	15.84	27.13	0.06	0.113
China	119	167	16	14,500	10409190	12.8	520.33	1730.4	374.78	9.182
Albania	114	172	1	418	397	-24.6	3.28	4.75	0.72	0.120
Haiti	232	393	0	1,771	0		0		0	0
Honduras	46	98	1	820	3380	22.8	1.85	1.59	3.87	0.663
Guatemala	84	184	1	400	961	10.5	2.79	4.34	1.64	0.104
Bolivia	7	13	0	0	266		0.07			0.037
Nicaragua	30	69	1	910	60	97.9	0.03	0.04	0.06	0.015

Table 7.3 Aquaculture development in medium income countries (1990 GDP $1000 - $3000)

	Population. /km2		f. water resources	Coastline	1992 Aquaculture production					
	mid-1990	2025	% used (all uses)	(km)	Total mt	Growth '86-92 %	mt. per '000km2 land area	mt. per km3 water res.	mt. per km of coast	kg per head
Algeria	11	22	16	1,183	197	25.3	0.05	6.97	0.06	0.008
Tunisia	50	85	53	1,143	844	29.1	0	0	0.74	0.104
Congo	7	18	0	169	26	-17.4	0.08		0	0.011
Mauritius	550	500	16	177	100	12.2	6	4.80	0.50	0.091
Libya	3	8	404	1,770	80		0.05	114.29	0	0.018
South Africa	29	53	18	2,881	3622	25.2	0.48	11.57	1.05	0.101
Botswana	2	3	0	0	0		0			0
Morocco	56	105	37	1,835	715	30	0	0	0.39	0.028
Malaysia	54	97	2	4,675	79378	7.5	43.06	30.23	13.94	4.435
Iran	34	101	39	3,180	42420	12.5	25.27	357.77	0.24	0.760
Jordan	36	112	41	26	22	-16.5	0.25	22.00	0	0.007
Lebanon	0	0	16	225	80	-22.7	0	0	0.36	
Iraq	43.2	110	43	58	15142	22.1	34.57	152.18	0	0.801
Syria	67	189	9	193	2800	8.4	14.86	74.93	0.26	0.226
Thailand	108.8	164	18	3,219	359040	18.7	202.20	585.38	79.31	6.434
Czechoslovakia	123	133	6	0	24135	2.2	180.83	239.36		1.537
Bulgaria	79	81	7	354	7900	-6.9	64.86	35.49	1.98	0.898
Poland	122	141	20	491	30200	8.3	83.23	310.12	8.45	0.791
Romania	98	113	12	225	30000	-3.9	126.05	141.71	0	1.293
Turkey	72	117	8	7,200	7687	16.5	0.34	1.34	1.03	0.137
Jamaica	218	273	4	1,022	2697	10.6	241.36	354	0.04	1.124
Dominican	145	225	15	1,288	815	18.1	11.22	27.5	0.21	0.115
Uruguay	18	23	1	660	7		0.03	0.1	0	0.002
Mexico	44	73	15	9,330	40789	-1.4	3.72	20.16	3.59	0.473
Brazil	18	28	1	7,491	29700	18.0	3.05	7.43	0.49	0.197
Argentina	12	16	3	4,989	1202	32.7	0	0	0.24	0.037
Ecuador	36	63	2	2,237	116687	24.9	5.19	5.26	51.50	11.329
Peru	17	29	15	2,414	5404	12.2	0.30	9.58	2.08	0.249
Paraguay	11	25	0	0	70		0.17			0.016
Colombia	28	44	0	2,414	23987	46.6	11.59		4.47	0.743
Panama	31	52	1	2,490	3900	1.7	3.18	1.88	1.47	1.625
Chile	17	25	4	6,435	116269	50.7	0	0	18.07	8.808
Venezuela	22	37	0	2,800	2144	32.0	0.30		0.67	0.109
Costa Rica	55	98	1	1,290	2244	66.3	26.57	9.68	0.69	0.801
El Salvador	248	429	5	307	107	-27.9	1.00	1.05	0.28	0.021