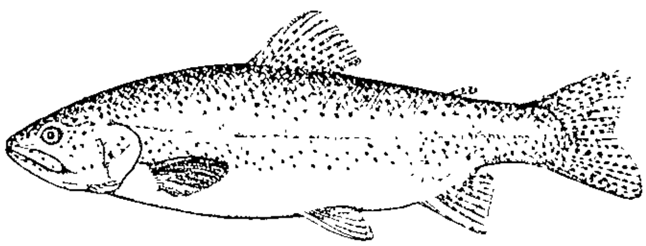
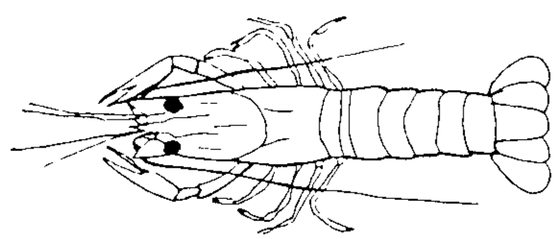


Aquaculture in South Africa: A cooperative research programme

O Safriel and M N Bruton

A report of the Working Group for Aquaculture
National Programme for Environmental Sciences



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SUMMARY

During the past few years the National Programme for Environmental Sciences has been involved in assessing the potential of aquaculture in South Africa and in formulating a research policy which will provide the information needed to place the industry on a sound footing. An Aquaculture Working Group was appointed by the CSIR in 1981, which developed a research strategy, identified needs and suggested priorities for research on major problem areas in aquaculture.

Aquaculture aims at the human-controlled cultivation and harvest of aquatic organisms for commercial utilization. The successful implementation of aquaculture is determined by environmental conditions, human resources and economic factors on the one hand and the appropriate utilization of available technology on the other.

Although fish culture has been practised for over 2000 years, it is only during the past few decades that aquaculture has developed into a commercial activity which is dependent on advanced technology and coordinated scientific research. Aquaculture offers a controlled and relatively stable means of increasing food production. The contribution of aquaculture to the world food supply, which increased by over 50% between 1975 and 1980, is especially meaningful in view of recent events in South Africa and elsewhere which demonstrated the limited and unpredictable nature of the ocean as a sole source of aquatic products. It should be borne in mind, however, that aquaculture in South Africa must be seen as a complementary development to the harvest of natural resources. Aquacultural products are likely to be valuable for import replacement and as commodities for local consumption and export.

In rural areas, the integration of aquaculture into agriculture could contribute to a more rational use of water and land so as to increase yields and profitability per production unit. Aquaculture also offers a possible means of utilizing environmental pollutants, such as thermal effluents and wastes, for food production.

It is proposed to initiate an aquaculture research programme aimed in particular at the following objectives:

1. To provide the scientific knowledge necessary to facilitate the production of food and other commodities in controlled aquatic systems. This production will complement food production based on the harvesting of natural resources;

2. To provide scientific information to support and promote existing aquaculture activities;

3. To provide the knowledge necessary to facilitate more rational and optimal use of available resources such as water and effluents within existing systems;

4. To generate knowledge which may improve the selection and adaptation of available technologies related to the practise of aquaculture in South Africa; and

5. To generate and support problem-orientated research in such a way that aquaculture research will integrate with research in other scientific and commercial disciplines.

Research needs for the aquaculture programme may be presented in a two-dimensional matrix in which the horizontal component includes generalized information and research needs which apply to all culturable species in terms of i) aquaculture systems; ii) economics and marketing; and iii) supportive research. The vertical component includes specific requirements for species which are either currently in culture or are potentially culturable. These species are listed in three groups:

1) <u>Current commercial species</u>

Rainbow trout	Waterblommetjies
Pacific oyster	Ornamental fish

2) <u>High potential candidate species</u>

Marine prawn	Abalone
Freshwater prawn	Marron
Tilapia	Brine shrimp
Sharptooth catfish	Nile crocodile
Turbot	

3) <u>Other potential candidate species</u>

<u>Priority species for research</u>

American channel catfish	Marine crab
Black mussel	Dover sole
Brown mussel	Atlantic salmon

<u>Lower priority species for research</u>

Cape stumpnose	Flathead mullet
Blacktail	Butter catfish
Sea catfish	Moggel
Kob	Common carp
Rabbitfish	Grass carp
River bream	Silver carp
Milkfish	Bighead carp
Agulhas sole	African freshwater eel
Spotted grunter	Spirulina

The research needs identified are summarized in the table overleaf.

PRIORITIES FOR AQUACULTURE RESEARCH IN SOUTH AFRICA

CANDIDATE SPECIES	SURVEY OF LITERATURE	AQUACULTURE SYSTEM				ECONOMICS PROCESSING AND MARKETING	SUPPORTIVE RESEARCH
		HATCHERY	PRODUCTION SYSTEMS	NUTRITION AND FEED	PATHOLOGY AND DISEASES		
Current commercial species	Survey of relevant literature with special reference to local conditions and ecological requirements	Genetic selection of strains and hybrids to improve their adaptability to local conditions	Development of optimal production systems relating to local conditions	Determine specific nutritional requirements Formulation of diets	Diagnosis/control/treatment/prophylaxis	Market research and feasibility Processing technology of aquaculture products	Biology Physiology Behaviour
High potential candidate species		Mass production of seed and juveniles according to demand	Selection of appropriate sites Development of optimal management techniques	Feed preparation (in particular least-cost feed)			Immunology Endocrinology Pathology
Other potential candidate species			Technological aspects of production systems				Genetics Ecology

INTRODUCTION

BACKGROUND

During the past few years the CSIR has been involved in assessing the potential of aquaculture in South Africa and the formulation of a research policy which will provide the information needed to place the industry on a sound footing. An Aquaculture Working Group was appointed in 1981, and identified needs and suggested priorities and a strategy for research on major problem areas in aquaculture.

This document proposes a national cooperative programme of research in intensive aquaculture. Following a brief description of aquaculture in general and in South Africa in particular, this report focuses on the rationale, objectives, users, scope and structure of a proposed aquaculture research programme. It is envisaged that the research programme will develop with the aquaculture industry and that positive feed-back will occur between the scientific community and the users of the research findings.

Aquaculture in its broad sense aims at the controlled cultivation and harvest of aquatic organisms for commercial utilization. Aquaculture products include a wide range of saleable commodities such as food, fodder, hides and ornamental fishes. The practise of aquaculture is based on the assumption that proper management of systems by optimal input of high quality water and feed can provide higher yields than is possible in unmanaged natural systems. Skilled management is also required in aquaculture in order to overcome the limitations of local abiotic environmental conditions, human resources and economic factors on the one hand and to make best use of available technology on the other.

Fish culture has been practised for over 2000 years, but it is only during the past few decades that intensive aquaculture has developed in certain parts of the world into a commercial activity which is dependent upon advanced technology and scientific research.

In recent years the world has become increasingly aware of the finite nature of its natural resources and of the importance of food production in controlled systems. Aquaculture offers a means to increase that production. Annual worldwide aquatic catch in recent years stands at around 70 million tonnes. It is not anticipated that the world protein supply from natural resources will continue to keep pace with demand. Alternative methods of food production such as aquaculture must therefore be sought.

Total worldwide aquaculture yield increased from about 6,1 million tonnes in 1975 to 9,4 million tonnes in 1980. The total yield for the year 2000 could be as much as 50 million tonnes. While the contribution of aquaculture to aquatic production increased by nearly 54% between 1975 and 1980, the rate of growth of sea fisheries declined.

The greatest growth of aquaculture has occurred in countries with a long established tradition of fish farming and/or high levels of technology, rather than in poor and protein-short nations. Of the total world aquaculture production of 6,1 million tonnes in 1975, China and Taiwan produced 2 617 396 tonnes, Japan 945 220 tonnes, India 494 000 tonnes, USSR 210 000 tonnes, USA 151 393 tonnes, Indonesia 143 840 tonnes, the Philippines 125 008 tonnes and Thailand 106 300 tonnes.

THE VALUE OF AQUACULTURE TO SOUTH AFRICA

Aquaculture in South Africa began more than one hundred years ago with the introduction of trout, mainly for angling purposes. The commercial production of trout has been based mainly on imported technology aimed at producing a highly priced product for a well-defined market. This industry has not been supported by local research and has encountered many difficulties in adapting to local conditions.

Today the culture of rainbow trout *(Salmo gairdneri)*, oysters *(Crassostrea gigas)*, waterblommetjies *(Aponogeton distachyos)* and ornamental fishes (mainly goldfish, *Canassius auratus)* are the only commercially viable aquaculture industries in South Africa. Oyster culture depends on government support for seed production. In 1982 South African aquaculture production did not exceed 550 tonnes and the contribution towards the gross national product was approximately R4 million.

Attempts to culture various other species in South Africa have mostly not developed beyond an initial research stage. Moreover, the research was most often of an academic nature and did not necessarily answer the questions posed by the commercial grower. Shortage of skilled manpower has also been a limiting factor. The trout example, as well as other attempts to develop aquaculture, have demonstrated that the industry should not be approached as a mere "off the shelf" technology but as an activity which involves original scientific research in order to determine the most cost-effective ways of culturing various organisms under local conditions.

Today the marine industry in South Africa is almost exclusively based on the harvest of the oceans. However, marine catches and biomass have generally declined during the last few years. In spite of the large quantities of marine products which are locally available, fish, molluscs and crustaceans costing R102 million were imported into South Africa in 1981. There is wide scope for import replacement as well as for additions to exports, mainly in the highly priced species in a market with an increasing demand for freshness and quality.

Recent events here and elsewhere have demonstrated the limited and unpredictable potential of the ocean as a sole source of aquatic products. Aquaculture offers a controlled and therefore more stable means of increasing that supply. The potentially high quality products of aquaculture also offers a valuable complement to the harvest of quantities of low-cost marine fish.

Scientific research should play a key role in attempts to achieve the optimal utilization of water resources in South Africa. Recurring droughts emphasize this urgent need. It seems likely that the integration of aquaculture into agriculture could contribute to a more rational use of water and land and to increased yields and profits per production unit.

Aquaculture also offers a possible means of utilizing environmental pollutants, such as thermal effluents and organic wastes, for food and fodder production. The use of warm water from power stations could facilitate year-round aquaculture in areas where climatic conditions are unsuitable or allow only seasonal production. The use of thermal effluents could therefore increase the profitability of culturable species and allow the successful culture of new candidates.

The aquarium fish trade is worth about $1,8 billion retail worldwide and is a potentially lucrative market which deserves more attention in South Africa. At present Africa accounts for only 2% of the international trade, despite the wealth of its fish fauna. South Africa has many suitable indigenous marine and freshwater fishes for the aquarium trade and in addition, many alien species could be bred here for resale. Whereas food fishes in aquaculture are selected for good conversion ratios and other factors associated with low maintenance costs and good growth, aquarium fishes are selected for their attractive colours, rarity and interesting behaviour. A major problem is that numerous species lose colour in captivity, usually as a result of a poor diet and incorrect physico-chemical conditions in the aquaria. The principles of warm water hatchery and pond management for food and ornamental fishes are very similar and the aquarium fish industry should therefore be regarded as part of any aquaculture initiative.

Producers require scientific information on an ongoing basis to facilitate aquaculture within prevailing human, economic and environmental constraints. Since the task is a large one and the small research community is widely spread among different organizations, it is necessary to coordinate and harmonize existing scientific efforts, to define the aims of the research programme clearly and to generate new research and encourage the training of scientists and technologists interested in entering the field of aquaculture.

AIMS OF RESEARCH

Research is equired with the overall objective of providing the scientific information necessary for the practise of aquaculture by a diverse group of users including commercial fish farmers, agriculture authorities, farmers, the marine industry and agencies involved in economic planning and development. This broad objective has been divided into the following five programme objectives:

1. To provide the scientific knowledge necessary to facilitate the production of food and other commodities in controlled aquatic systems. This production will complement food production based on the harvesting of natural resources;

2. To provide scientific information to support and promote existing aquaculture activities;

3. To provide the knowledge necessary to facilitate more rational and optimal use of available resources such as water and effluents within existing systems;

4. To generate knowledge which may improve the selection and adaptation of available technologies related to the practise of aquaculture in South Africa; and

5. To generate and support problem-orientated research in such a way that aquaculture research will integrate with research in other scientific and commercial disciplines.

SCOPE AND STRUCTURE OF THE PROGRAMME

Research needs in aquaculture identified by task groups of scientists, producers and regulatory and development agencies are presented here 'horizontally' and 'vertically' in the form of a two-dimensional matrix. As the 'horizontal' component, generalized research needs and priorities have been identified which apply to all candidate species. As the 'vertical' component, specific requirements for the most obviously important species are identified.

Although the task groups tried to confine themselves to scientific research needs, it became clear that the identification of candidate species also needs priority attention. Some important questions are raised which relate to economics, environmental regulations and policy. These problems are interrelated and need to be examined within a wider framework.

SUPPORTIVE RESEARCH

Intensive animal production, including aquaculture, is an advanced skill which requires a thorough scientific knowledge as well as skilled technical personnel to develop the appropriate technology. The research may be either fundamental, ie leading to an understanding of how an organism or system functions, or applied, ie putting fundamental information to practical use. Both types of research may be problem-orientated. Fundamental research will usually be conducted in academic institutions whereas applied research will be carried out at hatcheries or in field rearing facilities which may or may not be close to academic institutions. There is clearly a need, therefore, for pure and applied researchers to be in regular contact in order to facilitate the overall coordination of aquacultural research and development.

The many scientific disciplines which contribute to aquacultural research include:

1. Biology and ecology of fish
2. Comparative physiology
3. Comparative endocrinology with special emphasis on reproduction
4. Immunology and pathology
5. Genetics
6. Biochemistry
7. Nutrition and feed formulation
8. Sociology, economics and marketing

9. Engineering
10. Reaction of fish to capture conditions
11. Hydrology and water quality control

The integration of local and overseas expertise in these fields towards developing a scientifically sound base for South Africa's aquaculture industry will be a key function of the proposed cooperative programme.

PHASING OF THE RESEARCH

The planned aquaculture research programme is intended to develop the horizontal and vertical axes of the matrix discussed above in three phases over a period of ten years. The first year will be regarded as a period of planning and consolidation of the research programme according to available facilities and prevailing constraints, such as human resources and budget. The principal components of each phase are as follows:

Phase 1

1.1 The review of on-going research, taking into account priorities set in this document so that existing and new research can later be harmonized and integrated.

1.2 The survey of existing literature related to the culture of high potential candidate species (Group B). The relevance of available information to local conditions needs to be critically investigated.

1.3 Market feasibility studies on current commercial species (Group A) and on high potential candidate species to ensure that research efforts are directed at species with proven economic value.

1.4 Research projects on priority problem areas of current commercial and high potential candidates.

1.5 Supportive research to provide a meaningful scientific basis for aquaculture development.

1.6 The selection of appropriate sites for aquaculture.

1.7 The reassessment of research priorities.

1.8 The evaluation of the achievements of phase 1.

Phase 2

2.1 Continue research activities on priority species.

2.2 Continue supportive research.

2.3 Continue selection of appropriate sites.

2.4 Establish demonstration facilities for the successful implementation of aquaculture which will ensure that there is information transfer between researchers and aquaculturalists.

2.5 Survey the literature on additional candidate species.

2.6 Re-evaluate existing production systems and examine new systems such as the warm water effluents of power stations.

2.7 Reassess research priorities.

2.8 Evaluate achievements of phase 2.

Phase 3

3.1 Continue research on candidate species.

3.2 Continue supportive research.

3.3 Increase research output to existing commercial activities.

3.4 Up-grade pilot and experimental systems.

3.5 Review the literature on new candidate species (Group C).

3.6 Conduct market research on new candidates.

3.7 Initiate research on selected commercially viable candidate species in Group C.

3.8 Reassess the need to continue the cooperative research programme for an additional period.

AQUACULTURE SYSTEMS

HATCHERIES

The purpose of the hatchery is to produce seed of culturable species when necessary and to provide means to ensure a high percentage survival throughout the larval stages. In intensive systems, the culturable organism lives in a highly controlled environment throughout its life cycle. The selection of broodstock should be aimed at narrowing genetic variability and at the improvement of predetermined desirable qualities.

Wild and domesticated broodstock of some species reproduce naturally in captivity but produce an inadequate quantity or quality of eggs and larvae. The spawning of other species must be induced by the administration of exogenous hormones or by the manipulation of factors such as temperature and light which trigger the release of endogenous hormones which induce spawning. Specific feed is required at different larval developmental stages to provide for essential nutritional requirements and to ensure fast and adequate growth. Trace elements and vitamins may play an important role in determining the survival rates of larvae.

Priority research areas for existing hatcheries are genetic selection, manipulation of water quality and its associated effects on fish growth and survival, and management. For various potential candidates the knowledge on hatchery requirements is somewhat fragmented and if available usually bears little relevance to local conditions and specific constraints. Research needs therefore range from detailed studies on the natural history and biology of the species through genetic selection, reproduction and spawning, larval rearing and feeding, to water quality and management.

The following research areas are of greatest importance for existing and future hatcheries. Specific needs are discussed under the relevant section for each species.

General -

- Survey of the relevant literature
- Studies on the natural history of the species
- Determination of water quality requirements (physico-chemical; dissolved oxygen, including rate of flow and methods of aeration; temperature; pH; conductivity; transparency; nitrates; nitrites; ammonia; phosphates; fluorides; total hardness; alkalinity; mineral elements; salinity; suspended solids; bacterial and microorganism loads; nutrients; toxic elements and metabolites)
- Hatchery management
- Hatchery design

Alternative technologies to reduce operating costs and improve efficiency
Feed technology
Diseases and immunology
Quarantine of imported species
Stress (environmental, physiological and behavioural)

Broodstock and genetic selection -
- Environmental and physical requirements
- Anaesthetics, handling and stress factors

Spawning -
- Endocrinology - production of monosex populations
- Artificial (induced) and semi-natural spawning
- Hormones - steroids and gonadotrophic preparations
- Release of sperm and eggs
- Spawning techniques, conditions for spawning, stripping and natural spawning, short-term preservation of spawn
- Off-season spawning
- Delayed spawning

Incubation techniques -
- Controlled and uncontrolled
- Prophylaxis
- Chemical treatment

Larval rearing -
- Physico-chemical hatchery requirements
- Nutritional requirements
- Feeding regimes
- Algal cultures
- Prophylaxis
- Stocking densities

Fry rearing -
- Physico-chemical hatchery requirements
- Feeding requirements
- Feeding regimes
- Algal cultures
- Prophylaxis
- Stocking densities
- Acclimation to rearing conditions

Overwintering

EXPERIMENTAL FACILITIES

A fish farm has two main components - a hatchery and a growing-out facility. After juvenile fish have reached a certain stage of development in the hatchery, they are tranferred to the growing-out ponds, where they are usually subjected to quite different of environmental conditions.

Intensive culture facilities are of two kinds. In through-flow systems the water is passed through the fish-rearing units without being recycled, whereas in recirculating systems all or part of the water is passed from rearing units through reconditioning units and back to the rearing units.

In developing and refining techniques for aquaculturea, it is necessary to construct facilities in different climatic zones which test the advantages and disadvantages of these two types of systems. It is also necessary to construct experimental facilities which allow for the performance of replicate experiments so that conclusive, verifiable results can be obtained.

In general, recirculating systems offer more control over the culture environment than through-flow systems, and are more suitable for experimentation. However, techniques also need to be developed for through-flow systems, which are usually less expensive to build.

In addition to experimental aquaculture facilities, it is necessary to build a series of small-scale commercial fish farms in the different climatic zones in South Africa, where techniques can be tested on a cost-benefit basis. Ideally, a network of experimental and small-scale commercial units should be developed in parallel.

MONOCULTURE VERSUS POLYCULTURE SYSTEMS

Management methods for aquaculture systems are determined by production targets, environmental constraints and socio-economic factors. For the production of low-cost fish, energy and/or financial input must be low. Therefore natural food will mainly be utilized and its production rate will be increased by fertilization of the water. However, fish density and yield per unit area will be limited. For the production of highly priced species, higher quality food, aeration and recirculation systems are used. The stocking density can be increased in such systems and higher yields per unit area are obtained. Production can be further increased if management skills are improved and effective extension services are established.

Chinese aquaculturists have long recognized that yields can be increased by stocking ponds with several species that occupy different ecological niches. The classic example is that of the Chinese carps, of which the grass carp is fed wastes, while the other species subsist on undigested faecal matter and the planktonic and benthic communities of organisms supported by the residues of the herbivore. The techniques of polyculture have been applied in other countries to other combinations of species including oysters and lobsters, oysters and rabbitfish, grass carp and freshwater shrimp, catfish and tilapia, and silver carp, common carp and tilapia.

The most important consideration in polyculture is the probability of increasing production by better utilization of natural food. The selection of candidate species and stocking density is determined according to the system available. Therefore, polyculture is not a practical solution for the culture of most upmarket species which are presently in greatest demand in developed countries.

Whereas in polyculture the availability and utilization of natural food may dictate the choice of species and the stocking density of the culture, in monoculture the pond productivity plays a minor role in production and a well-balanced food is supplied to the cultured organism. Aeration of the water makes it possible to increase stocking density and yields. In addition, monoculture of a single species and of a more or less uniform size fish saves sorting and grading and makes the culture simpler. In South Africa monoculture is indicated as the preferred management system for the culture of highly priced species, while either monoculture or polyculture could be practised where aquaculture is integrated with agricultural irrigation.

NUTRITION AND FEED

Fish have a low conversion ratio of feed into flesh. Specific nutrient requirements are known for only a limited number of species, and even these requirements do not take into account the interaction between nutrients during intensive production. The economic success or failure of an aquaculture operation is directly dependent upon the nutritional state of the stock and the cost of feeds. Therefore more information is needed on specific nutrient requirements and nutrient availability. Future research should focus on adequate feed substitutes, especially those which can replace costly components without offsetting the nutritional balance of the diet.

Specific nutrient requirements should be related not only to the species but also to size, environmental temperature and growing conditions. Much attention has focused on the nutrient requirements of rainbow trout. This information has been used, in many cases, to formulate diets for other species of fish cultured under different environmental and growth conditions, with varied success.

The technology that caters for larval feeding integrates the techniques of feed science, engineering, nutrition and commodity processing. The production of larval feed requires an approach which ensures inter-nutrient component binding in order to produce a stable compound that is nutritionally adequate and capable of being micropulverized and separated into stable larval food.

The particle size of most fish feed which is mass produced is too large for many larval forms to use. Research is needed on the formulation of optimal food to rear larvae to a size that can consume industrially produced diets.

PATHOLOGY AND DISEASES

The study of diseases in aquaculture has in the past been concerned almost exclusively with the taxonomy of pathogenic organisms of freshwater species. A more holistic approach has recently been adopted in which disease is defined as an imbalance between the fish and its total environment. Infectious diseases involve not only the pathogen and its host, but also the interplay of the nutrition, physiology and genetic constitution of the host with an array of environmental factors.

The working model below provides the general framework for research needs on pathology and disease in aquaculture. It emphasizes the interaction between the three components and indicates where control measures can be used.

Pathogens ⟶	Physiological responses	⟵ Aquatic environment
Fungal	stress and other	Temperature
Viral	defence mechanisms	Dissolved gases
Bacterial		pH
Neoplasia		Hardness
Genetic		Salinity
Metabolic		Turbidity
Parasitic		Overall water quality

The health of organisms in aquaculture systems can be maintained by:

1. Preventative measures, including maintaining water quality and reducing environmental stress (low O_2, temperature extremes, build-up of waste products);
   providing optimal nutrition;
   selection of pathogen-free and disease-resistant stocks;
   improving management practises;
   developing vaccines for immunological protection;
   manipulating environmental conditions (for example, growing oysters in water which has salinity levels which are too low for the survival of pathogens);
   enforcing legislation which prevents the national or international transfer of pathogens from one population to another;
   providing chemical prophylaxis.

2. Diagnosis, including the understanding of the life cycle and ecology of pathogens.

3. Treatment by the application of chemicals or drugs, optimally combined with preventative measures.

The use of chemicals or antibiotics for the control of pathogenic organisms may have negative effects on biological filters in recirculating systems (particularly on nitrifying bacteria) as well as on algal food, and may leave toxic residues in cultured animals.

The diagnosis and treatment of diseases in the medical and veterinary sciences is largely directed at individuals. In fish health science, however, the diagnosis is directed at populations and the treatment is usually administered to the environment and only in rare cases to the individual fish. Measures that minimize diseases offer increased margins of profit and can often mean the difference between success and failure. The technology of disease control has paralleled the development of fish culture in freshwater. Treatments have progressed from simple chemical measures through sulphur drugs to antibiotics and nitrofurans. The control of disease should concentrate on prophylaxis (the maintenance of adequate food and water quality as well as a reduction of stress) rather than treatment. Chemical prophylaxis should be considered as a secondary method of disease control.

ECONOMICS AND MARKETING

When an industry such as aquaculture is being developed, it is necessary that cognisance be taken of economics and marketing so that research is not conducted on species that are not suited for commercial exploitation ie they are not marketable. In the past, local aquaculturalists have generally identified marketing problems as the principal cause of business failures. Certain knowledge concerning the market can be gained by studying the present pattern of consumption of marine fish in South Africa. The South African market for table fish displays a number of features rooted in a peculiar geographical and historical situation. The main source of tablefish, the trawling industry, arose from monopolistic origins and consequently has always been vertically integrated and concentrated. As a result, the fish auction never became a South African institution and middlemen have always experienced restricted access to the products. As the main urban areas for marketing (the Vaal triangle) are at least 1600 km from the fishing ports, an ability to distribute has always been the key factor in the industry as long as frozen fish comprised the main product. Fish were the germinal product of the frozen food industry and today 99% of tablefish traded outside of the western Cape are sold frozen at the wholesale level. However, recent trends indicate an increased preference for fresh products by consumers.

With the exception of high value species such as sole, kingklip and selected line fish, the South African market is relatively free of supply constraints. However, the market is fairly limited in variety. In 1980, five species - anchovy, hake, pilchard, horse mackerel and snoek contributed 88,4% of the South African commercial marine catch, with the first two species accounting for 76,4%. The white fish used in processed products is cheap (R0,48 kg^{-1} FOB wholesale equivalent) so that this sector provides no conceivable aquacultural market opportunities for comparable products at the present time, except in the immediate vicinity of large captive markets.

Consumers are generally very discriminating about quality. The industry operates under the SABS compulsory standard specifications for frozen fish and delivers a high quality product to the market. The unit price attained depends on relative scarcity, appearance, texture, palatability, size and filletability.

The available data indicate that:

- there are no soft markets for fish

- tablefish are distributed by a few efficient concerns at low cost

- fish products are distributed partly in bulk to wholesalers but usually as a minor but important part of a full range of frozen food and perishable products

- frozen and processed fish are generally oversupplied at price levels relatively lower than other meat products

- there are few identifiable real shortages of fish but the top end of the wholefish market lacks variety

- most consumers are demanding, discriminating and conservative. South African quality standards for frozen fish are exceptionally high

- the inland market is geared to a frozen product

- fish are sold through a narrow range of outlets

- ownership and trade in the retail sector is concentrated among large self-service stores

- the present market for frozen products is in the large towns and cities.

The future aquaculture industry will be faced with various marketing problems. Selling adequate volumes of aquacultural finfish domestically poses difficulties relating especially to price levels and distribution. There are many cases of aquacultural projects being launched on a high cost/price basis but failing when unit revenue dropped as volume of output increased. In most developed countries the real price of aquacultural products has declined since about 1973. Even in South Africa with its minimal production, the real price of trout has fallen over the past three years although the nominal price has risen slightly. The probable explanation is that demand for a species of fish tends to be price inelastic.

For its development, intensive aquaculture should concentrate on highly priced products and hope to reduce production costs through research and to reduce distribution costs by using existing channels. It would be wise not to encourage low margin enterprises in the initial stages of development. Paradoxically it may be a good idea to establish high volume production units capable of realising scale economies.

Most fish growers will be isolated from large concentrations of consumers, thus limiting the prospect for gate sales, which are normally considered to be a prime outlet for aquacultural products. The total amount of farmed fish sold will be made up of many small contributions from producers scattered over relatively wide areas. The economics of fish distribution may exacerbate the problem further in that the scattered production and the well-established marine fishing industry may preclude independent middlemen from playing an effective role in disposing of the products. The application of compulsory standards for processed fish, as administered by the SABS in terms of the Standards Act (33 of 1962) and the Foodstuffs, Cosmetics and Disinfectants Act (54 of 1972), raises a further difficulty in that compliance significantly raises the average costs for low volume producers.

Having identified such target outlets for aquacultural products as restaurants, self-service stores and, to a lesser extent, fishmongers, the ultimate strategy might be to channel fish through one or any of three distribution modes: (a) large integrated frozen food distributors (b) intermediate wholesalers specializing in restaurants, hotels and catering outlets and (c) in-house distribution by the large supermarket chains. Intermediates could be used for the restaurant trade. Wide penetration of this market sector through intermediate wholesalers entails a considerable sacrifice of revenue for small cost savings. The difficulty posed by many isolated small production units trying to feed their products into the system remains. The situation suggests that substantial economies may be derived from joint processing - economies that may be vital to the long-term success of aquaculture.

Agricultural cooperatives serve farmers well and are very much an accepted part of agriculture in South Africa. These cooperatives may provide the best means of obtaining the abovementioned economies. In terms of the Cooperative Societies Act it seems that freshwater cultured fish products can legitimately be handled by any agricultural cooperative. However organized, processing combines would still have to contend with the problem of access to the distributing network.

Aquaculture possesses intrinsic advantages which can be harnessed for successful marketing. Compared to capture fisheries, aquaculture is better able to deliver products of exceptional quality on schedule in standard sizes. These advantages arise from the capability for controlled cropping and the fact that butchering, processing, packing and freezing can occur simultaneously for practical purposes. The edge enjoyed by some types of grown fish could be consolidated in retail outlets through branding.

Experience shows that while output volume is low in terms of the global market, it is not difficult to dispose of products at favourable prices by taking advantage of special situations. However, the problems listed will constitute serious obstacles to growth for a large volume activity. Perhaps the soundest approach to marketing as far as the State is concerned is to take advantage of special situations and not to compete with the marine fish industry.

A national aquaculture development programme must take into consideration the economic constraints arising from the dominant role of marine fisheries. Opportunities for successful fish farming arise in situations where under-utilized production farms are available, where markets are isolated from the main channels of marine fish distribution, where supplies are imported and where attractive new varieties of fish are offered to the market.

The following aspects must be taken into consideration when a new aquaculture venture is planned:

1. <u>Market</u>

    Consumer preferences
    Demand for the product
    Price of the product
    Market segment at which the product is aimed
    Prices of other comparable foods

Size of market
Market development and entry
Distribution of product (nationwide and overseas)
Market structure and organizational forms of the market

2. Production costs

Scientific and technological inputs to production and their relationships
Relevant biological information
Cost of feed and quality of feed
Diseases, health, maintenance and predation
Production methods, technologies and management
Cost of labour
Capital investment and return
Health regulations affecting production and processing
Cost of processing
Choice of aquaculture sites

RESEARCH NEEDS: CANDIDATE SPECIES

Current and potential culturable species are listed in Table 1 in three groups:

- current commercial species (Group A)
- high potential candidate species (Group B)
- other potential candidate species (Group C), several of which are important commercial capture species

The following information, where available, is briefly summarized for each of the species in Groups A and B:

- selection and propagation
- environmental constraints
- nutrition
- diseases and factors inhibiting growth
- management
- marketing, processing and distribution
- production systems
- research needs

For species of Group C, the following information is provided where available:

- present annual catch and capture method
- form in which the fish are presently marketed
- present market value
- biological knowledge, especially that relating to adaptability to mass rearing conditions
- environmental tolerance, (water quality, temperature, salinity)
- dietary requirements, growth rate and food conversion ratio
- potential aquaculture technology
- overall assessment

Table 1. Candidate species for aquaculture which are considered in this report (for explanation see text)

Current commercial species (Group A)		
A.1	Rainbow trout	*Salmo gairdneri*
A.2	Pacific oyster	*Crassostrea gigas*
A.3	Waterblommetjies	*Aponogeton distachyos*
A.4	Ornamental fishes	Numerous species
High potential candidate species (Group B)		
B.1	Marine prawn	*Penaeus monodon*
B.2	Freshwater prawn	*Macrobrachium rosenbergii*
B.3	Tilapia	Indigenous species and hybrid tilapia
B.4	Sharptooth catfish	*Clarias gariepinus*
B.5	Turbot	*Scophthalmus maximus*
B.6	Abalone	*Haliotis midae*
B.7	Marron	*Cherax tenuimanus*
B.8	Brine shrimp	*Artemia salina*
B.9	Nile crocodile	*Crocodylus niloticus*

Other potential candidate species (Group C)

Priority species

C.1	American channel catfish	*Ictalurus punctatus*
C.2	Black mussel	*Choromytilus meridionalis*
C.3	Brown mussel	*Perna perna*
C.4	Marine crab	*Scylla serrata*
C.5	Dover sole	*Solea solea*
C.6	Atlantic salmon	*Salmo salar*

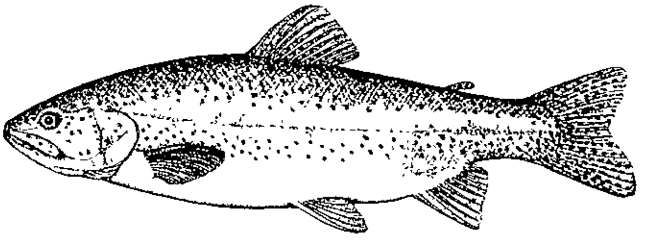
Non-priority species

C.7	Cape stumpnose	*Rhabdosargus holubi*
C.8	Blacktail	*Diplodus sargus*
C.9	Sea catfish	*Galeichthys feliceps*
C.10	Kob	*Argyrosomus hololepidotus*
C.11	Rabbitfish	*Siganus sutor*
C.12	River bream	*Acanthopagrus berda*
C.13	Milkfish	*Chanos chanos*
C.14	Agulhas sole	*Austroglossus pectoralis*
C.15	Spotted grunter	*Pomadasys commersonnii*
C.16	Flathead mullet	*Mugil cephalus*
C.17	Butter catfish	*Eutropius depressirostris*
C.18	Moggel	*Labeo umbratus*
C.19	Common carp	*Cyprinus carpio*
C.20	Grass carp	*Ctenopharyngodon idella*
C.21	Silver carp	*Hypophthalmichthys molitor*
C.22	Bighead carp	*Aristichthys nobilis*
C.23	African freshwater eel	*Anguilla mossambica*
C.24	Spirulina	*Spirulina platensis*

A. CURRENT COMMERCIAL SPECIES

There has hitherto been an inadequate appreciation for the quality and quantity of scientific information required by trout and oyster producers to ensure better utilization of available resources, the propagation of ova and seed on demand, adaptation to local conditions by genetic selection, increased yields at lower costs, disease control and enhanced market expansion by the diversification of products.

A.1 RAINBOW TROUT *(Salmo gairdneri)*



Trout farming is a large scale activity in both Europe and the United States. The countries of the European Salmon Culture Federation alone expected a production exceeding 71 000 tonnes in 1978. Trout *(Salmo* spp) were introduced into South Africa a hundred years ago, mainly for angling purposes. Today the rainbow trout *(Salmo gairdneri)* is farmed intensively in various parts of South Africa by 60 producers. The total production amounted to approximately 400 tonnes in 1982.

Selection and propagation

Trout ova for the production of fingerlings are either imported (50%) or produced locally. In season, ova are mostly produced by the provincial conservation authorities and sold to individual farmers. In 1981, these sales amounted to about five million ova. In 1982 sales dropped to around two million ova due to unfavourable climatic conditions. A few private farmers also produce ova for sale. During summer, trout ova are imported from Europe, mainly Italy, as well as the USA. A demand for South African ova has been expressed by trout farmers in the northern hemisphere. This potential export market for ova should be exploited. Exported and internally distributed ova should not only be of superior stock, but certified as disease-free, especially of viral diseases.

No genetic selection programmes have been launched in South Africa to improve the stock.

Environmental constraints

For seven to eight months of the year water temperature conditions are ideal for the raising of trout in many parts of South Africa. The summer months are sub-optimal, leading to many management problems. In the summer-rainfall areas, the months of September to October can be critical due to low water levels in rivers and consequent high water temperatures. Cooling towers may be used to reduce water temperatures and extend the growing season.

Nutrition

Only dry balanced rations are being used for table fish production. Fingerlings and fry are currently raised on wet rations (liver, etc) at provincial hatcheries in the Transvaal, but elsewhere dry feedstuffs combined with *Daphnia* are used. Pellet sizes of 3 and 5 mm are available, while complete diets can be purchased containing protein levels ranging from 36 to 48%. The food conversion average is 2:1.

According to overseas literature, correct feeding programmes and diets should make it possible to lower the conversion ratio to 1,3:1. Warm water feeding programmes (over 20°C) are lacking. Feed companies are unable to supply a proper size range of pellets due to the small demand compared to the chicken and other industries. The main protein source in trout pellets is fish meal which is becoming increasingly expensive.

Diseases and factors inhibiting growth

Cold and unpolluted waters are prerequisites for trout farming. These conditions are continually being threatened by other activities such as forestry and associated industries. Besides sub-optimal environmental conditions, disease is a major constraint on trout production. Outbreaks are usually associated with an unfavourable environment. The most common diseases arise from parasitic protozoans, crustaceans, flatworms and internal and external bacteria. Fortunately no viral diseases have been positively identified. Extension work concerning the identification and treatment of fish diseases is presently performed by various institutions in South Africa, but disease prophylaxis and the treatment of fish have been gravely neglected. Disease treatments are often hampered by incorrect identifications of the causative organisms.

Management

Trout farming is presently a small-scale operation usually involving one manager and a few labourers. Trout production is rarely the sole source of income to the farmer as it is usually integrated with other farming activities. In a few instances trout are being farmed by a company. Most producers are members of the South African Trout Farmers' Association, which is a useful forum through which to disseminate knowledge and lodge complaints and requests with government bodies.

Processing and marketing

Trout are presented to the consumer in a variety of forms (gutted with head on, filleted, or smoked whole). Live trout (300 to 500 g) are also sold by producers for angling purposes.

Most trout farmers in the Transvaal market their fish through one of three centralized marketing organizations. Some producers scattered through the country also sell trout to local retailers whereas others run profitable roadside stalls. No fish marketing company is involved in distributing trout countrywide. The market preference is for trout from 200 to 350 g, depending on the outlet.

Production systems

Production methods include raceways, circular ponds (concrete and other), Danish type earthen ponds as well as larger ponds and cages (very few producers). Water is fed by gravity into the ponds, and only one experimental recirculating unit is presently in use (in Grahamstown). Aeration techniques have recently been introduced.

The cost of producing 1 kg of trout (live mass) lies between R2,00 and R3,00 depending on the level of skill of the manager and the production method applied.

Potential

Should it be possible to lower the production costs of trout through improved management, a larger section of the consumer market will become available. Trout are, however, unlikely to become a staple food on the market due to production and environmental constraints.

Generally, the outward appearance of fresh trout on the market can be improved substantially. Production could be increased by making more use of cage culture techniques. Closed-circuit production units show promise, but require a high level of skill and there is a high risk capital factor.

Research needs

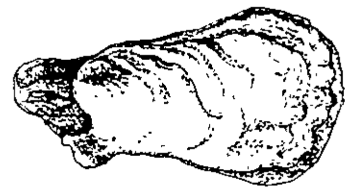
1. Local propagation of ova on demand, especially disease-free ova.
2. Genetic selection of strains for high water temperature tolerance and disease tolerance.
3. Influence of stocking density and environmental factors such as temperature and dissolved oxygen on assimilation, conversion ratio, growth rate and production.
4. Nutritional requirements and feeding schedules under local environmental conditions.
5. Substitution of highly priced components, such as fish meal, in the diet by cheaper and more readily available protein sources, including waste.
6. Biological and technological aspects of cage culture of trout in ponds and dams.
7. Identification of clinical symptoms and diagnosis of pathogenic conditions.
8. Prophylactic treatment of trout diseases.
9. Corrective treatment of stress-induced infections.

10. Economic evaluation of trout farming in South Africa.

11. Technological and economic implications of product diversification.

12. Market research to evaluate the potential in South Africa and overseas of trout products.

A.2 PACIFIC OYSTER *(Crassostrea gigas)*



The farming of oysters has been practised for thousands of years. Currently the United States, Japan, Korea and France lead in oyster production, while more countries without a history of oyster culture are entering the field. The development of farming practises has mainly concentrated on mechanized, off-bottom culture (because of the advantages of the three-dimensional effect) and tray design (coated wire baskets and mass produced polyethylene trays). The establishment of commercial oyster hatcheries during the early 1960's in the USA and early 1970's in Europe was mainly for the purpose of breeding disease-resistant stock and to replace or augment natural seed supply. The further development of cultureless techniques and oyster nurseries has made it possible to supply seed as loose units at a time and size which suit the specific needs of oyster farmers. Hatcheries are mainly needed where reliable natural spatfalls cannot be obtained.

Worldwide, only about eight species are farmed, of which *Crassostrea gigas, C virginica* and *Ostrea edulis* are the most important. The first organized attempt to farm an indigenous South African marine animal originated with the Knysna Oyster Company founded in 1948. The services of an experienced Dutch oyster farmer were obtained for the purpose. Because of the continual problems encountered with indigenous as well as certain foreign species, and the lack of a practical cultivation system, the Fisheries Development Corporation (FDC) initiated a long-term programme in 1963 to promote oyster culture in the Knysna estuary. A semi-culture system was developed for *Crassostrea margaritacea* which consisted of the collection of seed oysters on abalone shells in nature and their onqrowing on anchored rafts. In the 1970's the Pacific oyster *C gigas* replaced *C margaritacea* as the main commercially cultured species.

At the World Aquaculture Conference (Venice 1981), the following were identified as the main constraints on oyster culture:

- access to space in suitable areas
- shortage of seed
- inadequate market development and research
- inadequate transfer of ongrowing technology
- disease and predator control
- lack of genetic improvement

Selection and propagation

Only one oyster hatchery is operational on the African continent, that o, the FDC in Knysna. Using certain maturation and retardation techniques, gonadal development can be controlled and seed oysters *(C gigas)* produced throughout the year independent of natural cycles. Seed oysters are at present supplied to two commercial farming enterprises (one in Knysna and one near Port Elizabeth) at a size of 8-10 mm for further ongrowing. Small quantities of *C gigas, O edulis* (European flat oyster) and *O atherstonei* (red or False Bay oyster) are also produced by the hatchery at Langebaan for experimental purposes.

The seed production target for 1982 was approximately four million, which is only 50% of the needs of the present industry. The rest were imported from approved overseas hatcheries.

Selection at this stage is based on fast growth only and no detailed studies have been done.

Water quality problems occasionally hamper production at Knysna. If these problems can be solved, the FDC hatchery should be able to supply the total seed oyster needs of the present industry. With little extra capital investment, it should be possible to produce at least 15 million seed per year. Possible export markets for seed oysters could be found during the northern hemisphere spring when locally produced seed oysters are scarce.

Hatchery technology is well developed especially in the USA, Britain and France and the techniques have been published widely. Most of the very successful hatcheries are private enterprises, each with its own secrets. Selection programmes are currently undertaken by certain State and university hatcheries in the USA and Britain.

Seed production problems are mainly attributed to poor water quality and larval diseases. The production of high quality algae as food for larvae will remain a high cost and risk activity until a cheap artificial particle feed is developed.

Environmental constraints

Due to the unfavourable bottom conditions of most South African estuaries, any form of bottom cultivation is impossible. An intertidal rack system has to be used, which is more expensive than bottom cultivation.

Temperature and salinity conditions in most estuaries with suitable space for cultivation are within the tolerance range of *C gigas*. A better quality product is obtained in cold water (10-20° C), such as at Langebaan Lagoon, than in the warmer Knysna estuary. It is expected that estuaries in Natal will produce an even lower quality product.

All estuarine and rivermouth systems are State property but a few hectares of the Swartkops and 50 hectares of the Knysna lagoon have been allocated for aquacultural activities. Only the FDC experimental activity is at present allowed in the Langebaan lagoon.

Oyster culture requires control of space in estuaries that are desired for other uses. The importance of allocating space for food production in these areas should be recognized by the authorities.

Pollution and siltation of estuaries is a potential problem.

Nutrition

In hatchery production throughout the world only a few species of diatoms and flagellates are currently used for feed. A combination of species is normally used for feeding larvae and post larval stages. Most of these micro-organisms are, however, very sensitive to high temperatures.

A selection of the most important isolates (mainly aliens) is kept in stock in Knysna. Starter cultures can readily be obtained overseas from, amongst others, the Culture Centre for Algae and Protozoa at Cambridge University.

At the nursery stage most overseas nurseries utilize either areas with a high primary production or enriched man-made lagoons. In Knysna mass algal cultures are grown in shallow outdoor tanks to supplement natural algae. Only one of the species in stock is hardy enough to withstand these conditions.

For ongrowing under natural conditions, bivalves are totally dependent on food transported to them by currents. No intensive commercial ongrowing culture system based on feeding with cultured algae exists anywhere. Continuous indoor culture systems for algae would cut operating costs as well as increase volume per unit area.

Other problems include the following:

- low water quality that affects the quality of algae as food for larvae;

- shortage of algal species resistant to relatively high temperatures.

Disease and factors inhibiting growth

The origin of the seed and the previous management history in the hatchery and nursery stages are of great importance for further ongrowing. Mortalities of imported seed have been observed in South Africa but could be traced to specific batches or bad management.

The main problem, especially in Knysna, is the occurrence of the shell parasite, *Polydora* (mud blister worm), which thrives in silted areas. To eliminate *Polydora,* oysters have to be grown at mid-tide level or slightly above low neap tide. This causes a substantial decrease in growth rate. Further ways in which *Polydora* could be controlled include:

making areas with low siltation and low *Polydora* incidence such as Langebaan Lagoon available to oyster farming, and culturing the indigenous *C margaritacea*, which is more resistant to *Polydora* than *C gigas*. Although certain chemicals can be used to eliminate *Polydora*, their use is not practical, and the only known elimination procedure is that of exposure to air.

Management

The ongrowing of oysters is regarded as a low technology operation and no special managerial qualities are required. Hatchery operation is, however, a highly skilled operation.

Most northern hemisphere oyster farming operations are family activities, or one- or two-man operations employing casual labour at peak activity. These operators normally utilize special distributors and marketing agencies for their product. In contrast, large enterprises cover the whole spectrum of functions. The largest company in South Africa employs a manager, a production manager and a work force of about 15 labourers. The skill of labour is extremely low, and more basic in-service training is necessary.

Marketing, processing and distribution

Oysters are supplied to the South African market only in the fresh form for the half shell trade. No processing seems to be necessary due to the constant demand for fresh oysters. An unknown amount of processed products (smoked and canned) are imported, mainly from the East, but recently frozen oysters in the half shell have appeared on the market from Australia and New Zealand and are cheaper than the fresh South African product.

The main clients are hotels and restaurants, who prefer a well-shaped oyster weighing about 60 g. Oysters are supplied to two distributors, one in Cape Town and one in Johannesburg. Both also handle other marine products. 1983 wholesale prices on site were as follows:

	Price per 100	
	Cultivated (*C gigas*)	Coastal oysters (*C margaritacea*)
Extra large	R33,00	R34,00
Large	R28,00	R29,00
Medium	R25,00	R23,50

Approximately 40% is added to this price by distributors.

Production systems

During 1982 nearly 2,5 million marketable *C gigas* were produced. This figure should reach the 3 million mark by 1983. Production is approximately 20-25 t ha^{-1} yr^{-1}. An unfortunate development during the last two years has been the tendency of the main grower to over-stock containers, thus sacrificing quality for quantity.

Production methods have changed recently from wooden trays covered with plastic mesh to plastic mesh bags. Nursery production is being geared to accommodate about 2,5 million seed oysters of all sizes at one time.

Marketing prospects are good as it will take some time for the present fresh oyster market to be saturated. Thereafter, excellent opportunities exist for a frozen pack. In addition, the European market is at present under-supplied.

Future growth will depend mainly on the availability of farming areas as well as on market research and development. Genetic improvement, the selection of species or strains for a specific environment and the improvement of culture techniques should also make a positive contribution.

Research needs

1. Water quality control and improvement.

2. Genetic selection and evaluation of existing strains.

3. Proper monitoring of pollution.

4. Identification of areas suitable for shellfish culture.

5. Selection of species or strains for a particular climatic condition.

6. The identification of potential culture sites.

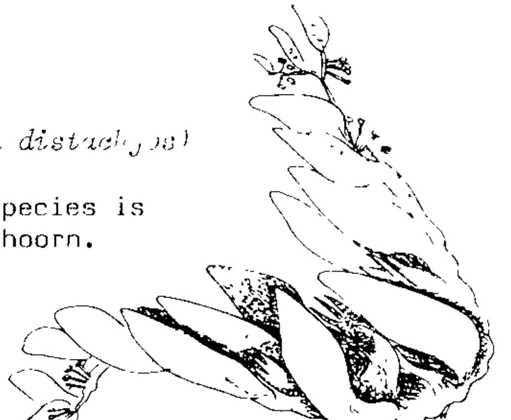
7. Development of algal cultures, especially of species tolerant to high temperatures.

8. A detailed study of *Polydora*.

9. The selection of *Polydora*- resistant species.

10. Market research to evaluate the potential of oysters in South Africa.

11. Product processing and presentation.



A.3 WATERBLOMMETJIES OR WATER HAWTHORN *(Aponogeton distachyos)*

The natural distribution of this freshwater plant species is limited to the south coast from Mossel Bay to Oudtshoorn.

Flowers of this plant are prepared to form a traditional Western Cape dish which was originally prepared by the Cape Malays as a substitute for vegetables. Thirty-two varieties of this species are known throughout the world, but the only known commercial harvesting is in the western Cape. Attempts by Langeberg Co-operative Ltd in South Africa to culture the plant intensively are very recent.

Environmental conditions

The plants are grown in dams built on a slight slope. This helps to empty the dam more rapidly at the end of the growing season (November) so as to cause the buds to become inactive in summer. The depth of the water must be kept at about 1 metre and the pH between 7,5 to 8,5. Optimal growth takes place at 14°C and water temperatures should not exceed 18°C. The best results have been obtained in slow-flowing water.

Selection and propagation

Seeds must be collected as early as possible and left in water during August to develop roots, after which they are planted into shaded water beds. Small bulbs can be taken out during March and planted individually in dams. Old bulbs that have more than one eyelet are cut in half, which results in higher production since the larger the nodule the higher the production. Presently there is no selection programme to improve the genetic stock.

Harvesting

The flowers are harvested manually every 8 - 11 days between the end of April and the beginning of November. They must be picked with the stem on to stimulate the production of additional flowers by the nodule. Optimally flowers should already have formed seeds but the scale leaves must still be soft. The flowers are too old when the seed is beginning to fall off. Yields of 6 - 16 t ha^{-1} are obtained.

Processing

Flowers must be delivered to the factory fresh, without the stem and free of algae. Flowers which are too young or too old are unsuitable for processing. Young flowers disintegrate when cooked.

Market

Approximately 20 tonnes of waterblommetjies were marketed in the 1982/83 season as fresh produce (70%) and in canned form (30%). The price paid to the producer ranges between R1,20 - R2,00 per kg depending on the quality, the seasonal demand and the marketing channels.

There is currently a growing demand for waterblommetjies in both fresh and processed forms in South Africa but no market research has as yet been conducted to determine their future potential. Currently it is a seasonal product, with market demand starting toward the end of April and increasing throughout the winter. Demand decreases during October and prices decline accordingly.

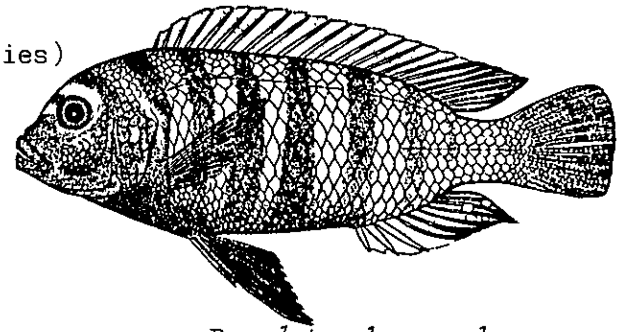
Research needs

1. Genetic selection of strains for desired qualities.

2. Biological and technological aspects of optimal production.

3. Market research to evaluate the potential of waterblommetjies in South Africa and overseas.

A.4 ORNAMENTAL FISHES (numerous species)



Pseudotropheus zebra

The culture of ornamental fishes for the aquarium trade is a potentially lucrative industry as domestic and foreign markets pay high prices for these fishes. Ornamental fishes may be alien or indigenous, marine or freshwater.

The ornamental fish trade requires attractive, hardy fishes which readily adapt to feeding (and preferably also breeding) in a small aquarium or pond. Many fish groups are popular among aquarists, including mormyrids, minnows, goldfish, catfish, killifish, livebearers and cichlids (all freshwater species) as well as seahorses, cardinal fishes, moonies, angelfishes, butterflyfishes, surgeonfishes, glassies, emperors, seabreams, damselfishes and wrasses (marine species).

The culture of these species requires specialist knowledge of life histories and the physico-chemical and nutritional requirements of the species concerned, as well as meticulous attention to the maintenance of good water quality.

Several indigenous South African freshwater species have potential as ornamental fishes, including *Petrocephalus catostoma*, *Hemigrammocharax machadoi*, various *Barbus* minnows (especially *B multilineatus*, *B fascilatus* and *B afrovernayi)*, *Eutropius depressirostris*, *Amphilius uranoscopus*, *Clarias theodorae*, *Chiloglanis* species, *Synodontis zambezensis*, *Aplocheilichthys katangae*, *Nothobranchius orthonotus*, *Pseudocrenilabrus philander*, *Tilapia sparrmanii*, *Ctenopoma ctenotis* and *Mastacembelus frenatus*. These species are attractive or unusual forms which readily adapt to aquaria.

In addition, numerous attractive species are found in neighbouring countries. Lake Malawi has over 500 endemic cichlid species, of which various *Pseudotropheus*, *Trematocranus*, *Cyrtocara* and *Aulonocara* species are most suitable for aquaria. These species could be bred in South Africa and have the advantage that they are very unlikely to survive in our rivers and lakes due to their high temperature preferences and specialized breeding requirements. The ornamental fish industry in Malawi is a major earner of foreign currency (R275 000 in 1977). Numerous tropical fishes suitable for the aquarium trade also inhabit the Okavango Swamps in Botswana, the lower Pongolo River in Zululand and the eastern Transvaal lowveld.

While indigenous southern African species will cater for specialist aquarist interests, imported or locally bred aliens, especially the goldfish *Carassius auratus*, are likely to be the mainstay of the industry, as large numbers are regularly sold through petshops and supermarket chains. Four commercially viable goldfish and 'tropical' fish farms already exist in South Africa.

Prices of up to R400 per 30 g fish can be realized for rare, attractive species such as *Cyrtocara moorii* from Lake Malawi, but the market is subject to wide fluctuations according to prevailing trends in the Americas, Europe and Asia. The annual value of the retail and wholesale trade in aquarium fish worldwide was conservatively estimated at about $1,8 billion and $600 million respectively in 1982. The major importing countries are the United States, Japan, the Federal Repubic of Germany, the United Kingdom and The Netherlands. Estimates of the 1982 value of the wholesale trade in aquarium fish, including coldwater fish, are given below:

North America	$325 million
Japan	$50 million
Western Europe	$125 million
Other	$100 million
Total	$600 million

An estimated 85% of all tropical aquarium fish sold in industrialized countries are imported, and in some countries this figure is reportedly as high as 95%.

There is an increasing demand for tropical aquarium fish in the north temperate industrialized countries, which must be met mainly by imports from tropical or subtropical countries. At present, various south-east Asian countries account for over 60% of the total export trade, and South America caters for nearly 30% of the market. The aquarium fish trade in Africa is extremely poorly developed (2% of the current share of international trade) despite the wealth of suitable species in its inland waters and adjacent oceans.

In addition to the aquarium trade, ornamental fishes are also sold for use in decorative outdoor ponds. Highly domesticated strains of goldfish, especially koi, are mainly used for this purpose. Japan is the largest exporter of coldwater pond and aquarium fishes, many of which are bred commercially in other industrialized countries as well.

Ornamental fishes appear to have good potential for import replacement and export, as well as for local sales to the unsaturated South African market.

Research needs

1. Development of techniques for the breeding of ornamental fishes in captivity, based on a knowledge of their natural breeding behaviour.

2. Maintenance of broodstock under aquarium or pond conditions.

3. Determination of the impact of escaped alien ornamental fishes on indigenous species and ecosystems, so that potentially harmful species can be blacklisted.

4. Improvement of techniques for the intercontinental transport of ornamental fishes.

5. Review methods for the prevention of the importation of infectious water-borne diseases.

6. Genetic selection for brilliant colours and rare polymorphs (unusual colour forms) of a species.

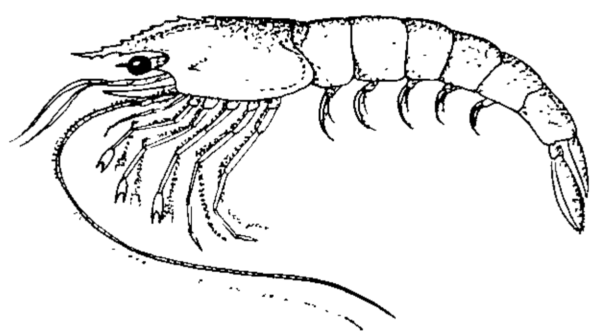
7. Review the success and failures of ornamental fish culture in Europe, North America and Asia.

8. Market research to evaluate the commercial potential of ornamental fishes in South Africa.

B. HIGH POTENTIAL CANDIDATE SPECIES

Scientific information is required on candidate species with high commercial value and culturable species on which pilot work has been done and shown promising results. While both the marine and the freshwater prawn are grown in monoculture, tilapias and catfish can be produced by either monoculture or polyculture under certain conditions. The culture of these species can also be integrated into existing systems such as agriculture, recycled waste treatment and thermal effluents of power stations.

B.1 MARINE PRAWN *(Penaeus monodon)*



Penaeus monodon is rated as one of the most lucrative marine products on the market. In 1982 1100 tonnes of prawns were imported into South Africa. In addition, an estimated 400 tonnes were imported illegally from Mozambique and this figure is likely to rise. Prices depend on size and appearance. The range is between R11,00 kg^{-1} for queen prawns (35 g) to R21,00 kg^{-1} and more for tiger prawns (55 g).

The culture of marine shrimps has been economically profitable in Japan since the 1950's. Techniques for the mass production of larvae and for growing of shrimps to marketable size have been developed in other countries such as the USA, based on the Japanese model.

In South Africa laboratory scale attempts by the FDC did not advance beyond the experimental stages. The problems encountered included inadequate reproductive control, inadequate knowledge of nutritional requirements, unsuitable climate for year-round production, high cost of food, and legal and social constraints related to site and water access.

Selection and propagation

The maturation and spawning of marine prawns has not yet been developed under culture conditions. Wild gravid females used as spawners must be collected and transferred to hatcheries where spawning is induced. The survival rate of the larvae is greatly affected by the procedures used for the induction of spawning.

The dependence on wild spawners inhibits the genetic improvements necessary to develop culturable strains. Egg incubation and hatching procedures are routine for marine prawns when high quality seawater is available and good hatchery management procedures are used. Rearing procedures are well established for marine prawn larvae and involve careful control of temperature, salinity, oxygen and other water quality conditions. Algae and brine shrimp are required as food.

Larval rearing procedures are expensive and contribute significantly to the cost of raising prawns. Older, less expensive rearing methods can be used but these require greater initial capital investment and are less dependable.

Environmental constraints

Very few suitable natural sites for marine prawn culture exist in South Africa as *P monodon* requires high water temperatures and good water quality.

Nutrition

Major costs are associated with both the algae and brine shrimp, which constitute the main larval food. The development of suitable artificial feeds and of efficient systems for the mass production of brine shrimps would improve the efficiency of larval culture.

Production systems

Two distinct systems (semi-natural rearing ponds and raceways) are used in the USA to rear marine prawns after they have been removed from the larval rearing tanks. Raceways are used to increase the survival rate and to enhance temperature, thereby extending the length of the growing season. The growing season will be about seven months in natural ponds in the warmer parts of South Africa. Either system can be used to rear juvenile prawns at high densities, thereby reducing space requirements.

Ponds are stocked with 11 - 22 prawns per square metre and the animals are fed formulated dry rations at set rates. Typically, some water is exchanged during the growout period and predator control is exercised by the filtration of incoming water. The universal problem with marine prawn farming is that either a large poundage of small prawns or a small poundage of large prawns can be produced, but not a large poundage of large prawns. Occasional production rates of up to 4500 kg ha^{-1} per crop of large prawns have been reported in the USA.

Few studies have been conducted to identify ecological conditions optimal for marine prawns. Most public research facilities do not have adequate pond space for such studies and commercial firms have apparently avoided such work because of the practical difficulties of controlling pond ecology. However, major increases in production might be realized through the refinement of methods of environmental control.

Harvesting is accomplished by draining and collecting the prawns in nets as they leave the pond outlet. This procedure is well established, relatively efficient and requires little improvement. Processing methods used by the shrimp industry are generally suitable.

Potential

There seems to be good reason to believe that thermal effluents might offer a means of overcoming the scarcity of good sites for marine prawn culture in South Africa.

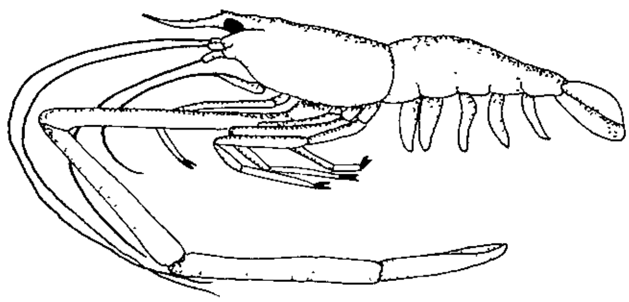
Marketing and processing

The market for prawns in South Africa is under-supplied. Almost all *P monodon* imported into South Africa are purchased by top class catering establishments (hotels and restaurants) and very few go to the frozen retail market (supermarkets etc). Only bulk processed *P monodon* are retailed. There is ample room for market enlargement and import replacement of *P monodon*. Locally produced prawns would probably have an advantage over imported products since size, appearance, freshness and coloration determine the market appeal and price of the final product.

Research needs

1. Production of domestic broodstock.
2. Mass production of larvae under controlled conditions.
3. Selection of low temperature tolerant strains.
4. Formulation of a reasonably priced pellet feed.
5. Acquisition of suitable areas for cultures including the development of a system for thermal effluents.
6. The use of water from thermal discharges for year-round production.
7. Methods to ensure freshness of products.

B.2 FRESHWATER PRAWN *(Macrobrachium rosenbergii)*



Freshwater prawn culture is a profitable industry in Hawaii, Puerto Rico and several other countries. Several pilot scale operations have been started in South Africa. However, lack of local expertise, rising production costs and the scarcity of appropriate sites may inhibit development.

Research on the culture of freshwater prawns was initiated by the Food and Agriculture Organization (FAO) in Malaysia in 1959. A system for raising laboratory produced larvae to commercial size in seven months was subsequently developed in Hawaii.

Selection and propagation

Freshwater prawns mature, mate and spawn naturally in captivity without special handling. Maturing males and females are placed in tanks where mating and spawning occur. Females incubate the eggs, which are attached to their bodies after spawning. When the eggs hatch, the larvae are free-swimming and can be collected from spawning tanks. Successful hatching depends on the control of the quality, temperature and salinity of the water. Freshwater prawns are easily reared at low densities, but problems arise at high densities. Larvae and young require brackish water which can be produced artificially, but juveniles are grown out in fresh water. Larvae are reared in tanks designed to keep them suspended in the water column and brine shrimp and algae are provided as food. At present brine shrimp are essential for larval culture. The high costs associated with algae and brine shrimp as food for marine shrimps are also a problem in *Macrobrachium* culture.

Environmental constraints

Pond temperatures must be above 20°C for good growth. This limits production in South Africa to Natal and the Transvaal lowveld. The development of temperature controlled systems using solar heating would extend the length of the growing season.

Diseases and factors inhibiting growth

Disease problems are frequently encountered during the larval stages. Research aimed at rearing larvae in high-density conditions and developing acceptable artificial feeds for larvae would decrease the costs of larval rearing. Predators, mainly clawed toads *(Xenopus)* and water birds, present a major problem in production ponds.

Production systems and management

Juvenile and adult prawns are stocked together in ponds and the stock is replenished at intervals of two to four weeks. Chicken feed or similar organic feed-fertilizers are provided. Pond management is difficult because of the aggressive behaviour of the male prawns. A small percentage of large prawns dominate the other males and grow more rapidly, the largest becoming territorial and developing blue claws. If the dominant group is removed, others become dominant. Hence, prawns of marketable size must be removed from the pond at regular intervals.

When the larger prawns are removed for marketing and the remainder are returned, smaller prawns are frequently injured or killed. The development of better techniques for harvesting large prawns would be of great benefit.

The eutrophication of ponds through poor food binding presents a problem in production ponds.

Marketing, processing and distribution

As for the marine prawn, the market for freshwater prawns is under-supplied. There is ample room for import replacement by locally produced fresh products. The price range is similar to that for *P monodon*. Emphasis should be placed on freshness control of products.

Research needs

1. Genetic selection of broodstock for cold-tolerant strains.

2. Determination of the water quality requirements of *P monodon*.

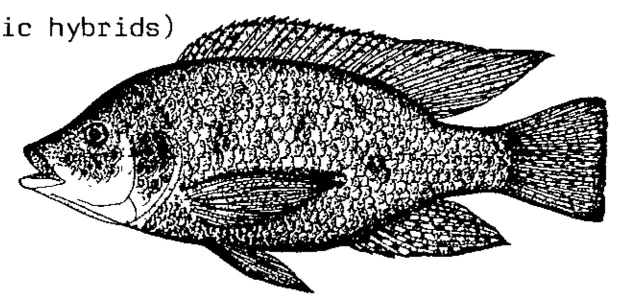
3. Development of a better feed binder to minimize the eutrophication of ponds.

4. Development of a local feed based on low cost components.

5. Predator control (mainly of *Xenopus* and water birds).

6. Selection of suitable sites to ensure optimal environmental conditions or, alternatively, the use of solar energy for year-round production.

B.3 TILAPIA (indigenous species and exotic hybrids)



Oreochromis mossambicus

The culture of tilapias dates back to about 2500 BC with evidence in a bas-relief found in an Egyptian tomb showing tilapia being netted in an artificial pond. No significant progress in fish culture is known to have occurred on the African continent until more recent times, with the first constructive attempts to culture tilapia having been made in Kenya in 1924. Gradually interest in tilapia culture spread to northern and southern African countries, extending as far south as Zimbabwe in 1950 and South Africa in the early 1950's.

The species cultivated were initially those indigenous to each area. The natural distribution of *Oreochromis mossambicus* extends from East Africa and the Zambezi system along the east of the continent to near Algoa Bay, while *Tilapia rendalli* occurs naturally from the Congo system to the Cunene River in the west, across to the east coast and as far south as northern Zululand. Both species have been introduced widely into rivers, ponds and impoundments beyond their natural range.

Several tilapias have proved to be very suitable for intensive culture. These are farmed in all the major tropical and sub-tropical freshwater fish culture countries. The current trend in the world is to utilize hybrid tilapias for commercial production. Hybrids have been shown to possess added growth vigour. Males grow faster than females, especially in monosex culture, and overbreeding can be prevented by using all-male progeny which can be produced either by crossing pure strains of certain species or by hormone treatment.

The following alien tilapia species also have potential in aquaculture:

> *Oreochromis aureus, O niloticus, O macrochir, O nigra, O mortimeri, Tilapia zillii, O andersoni, Sarotherodon galilaeus*

Of the indigenous species, *T sparrmanii* is only cultured as a fodder fish for bass and *T rendalli* is mainly stocked to control aquatic weeds. *O mossambicus* is therefore the most important indigenous tilapia available for culture. Although this species has good potential, its phenotype (the external expression of its genetic makeup) is highly variable in response to differences in the natural environment. Despite rapid development in other countries, tilapia culture has remained limited and unsophisticated in South Africa due to the limitations imposed by using unselected natural stocks.

Selection and propagation

Tilapias in general are prolific spawners and can easily be propagated in virtually any pond provided that the water temperature is suitable. All juveniles sold in South Africa spawn naturally in ponds and are netted for distribution when they reach the required size. In other countries it is common practise to hatch eggs in funnels or remove juveniles at two-weekly intervals to tanks or small ponds where they are fed artificially with food containing hormones for sex reversal.

Three different techniques have so far been developed for the production of all-male populations of tilapia, the oldest being by hand-sexing mixed populations of males and females and the other two by means of hormonal treatment and by hybridization.

Hand-sexing of mixed populations involves the selection of males from a mixed population of juveniles. Technically, this is a simple technique and only requires adequate supplies of mixed male and female fingerlings weighing 30-50 g and with well-developed reproductive organs. Because of the extensive work involved in this system, however, it is practically impossible to avoid mistakes. Sexed populations usually have 75-85% males. Another serious disadvantage is that the discarded females are of little value although their production cost is the same as that of the males.

The hormonal treatment of tilapia fry for sex reversal has been carried out successfully with some tilapia species using various androgens and estrogens. In several cases 100% male populations have been obtained. This procedure requires homogeneous batches of larvae which must be fed with hormone-treated food as soon as they are able to eat. Optimal results can be obtained only if the mixture of the hormone with the food is carefully done and if adequate measures are taken to prevent the fry from ingesting any food other than the treated food.

The Natal Parks Board has been involved in methyl testosterone treatment of *O mossambicus* since 1979. This method of producing all-male populations can be improved, however, as only 73% male cultures were produced.

Hybridization between tilapia species (mainly female *O niloticus* and male *O aureus)* has been widely used since 1960 to produce all-male progeny. Other crosses have produced 90-100% male populations and this system has now been developed to a stage where it is possible to produce millions of such hybrids for commercial use. For success, pure parent strains are essential.

Considerable progress has been made in Taiwan and elsewhere in selecting strains of hybrids with greatly increased growth rates and improved appearance. The most notable of these is the red tilapia which has a bright red body colour and lacks the black colour on the peritoneum. Red tilapia resemble sea bream *(Chrysophrys major)* and are highly preferred by consumers in many countries. Red tilapia are hybrids produced by crossbreeding *O niloticus* and the red mutant of *O mossambicus*. At least two strains of red tilapia are cultured in Taiwan and the Philippines. The latter show more polymorphic characteristics and probably originated from a Taiwanese strain. Neither produce an all-red progeny. The Philippine strain is claimed to produce 70% red progeny and the Taiwanese strain less consistent results.

Particular problems with tilapia culture in South Africa include the following:

- small fish are only available late in the production season and provincial hatcheries generally do not overwinter juveniles for distribution early in the following season;
- hatcheries do not provide all male or sterile juveniles so that growth is inhibited by uncontrolled reproduction;
- parent fish are not genetically selected;
- lack of information on techniques for the high density overwintering of juveniles;
- predation by birds and *Xenopus* species on juveniles.

Environmental constraints

Most tilapias with culture potential are sensitive to low temperatures. However, recent research has shown that tilapias could do well in areas with low winter but high summer temperatures provided that they can be grown to a marketable size within the growing season. This could be achieved, for instance, by overwintering large juveniles or by using a fast-growing hybrid. It is important, furthermore, to carry out genetic selection to produce cold-tolerant (less than 14°C) strains.

In general, tilapias have wide tolerances of most other environmental factors such as dissolved oxygen, salinity and non-ionized ammonia. Some species are not seriously affected by overcrowding and are ideally suited to intensive cage or tank culture and could also do well in polyculture. Tilapia could therefore be cultured in South Africa in any area with high summer temperatures and would adapt to almost any type of culture, including wastewater aquaculture and mariculture in the case of *O mossambicus*, which is euryhaline.

Nutrition

The potential candidate species are either microphagous planktivores or detritivores, obtaining much of their nutrition from diatoms, bacteria and free amino acids. Small fish (3 - 5 g) are particulate feeders on zooplankton or benthos. In some planktivorous species the nutritional requirements apparently change at a size of 100 - 150 g. It is therefore important to consider size in nutritional studies of this group. Food intake and energy expenditure rates are also related to size. Natural food can also be a component of the feed in pond or cage culture.

Unfortunately much of the research on commercial pellets has been done by private companies who do not share their secrets. Pellets normally contain about 25% protein and include substances such as fish meal, soya meal, rice bran or wheat, oils, gluten, NaCl and a vitamin/mineral premix. Recent studies demonstrated that unlike the common carp, tilapia show poor ability to utilize oils. This has important implications in the formulation of balanced rations with an adequate energy content.

Diseases and factors inhibiting growth

Tilapias are fairly resistant to diseases and parasites if water temperatures do not decrease below 14°C, although populations of *O mossambicus* in the eastern Cape tolerate temperatures below 10°C.

Management

In South Africa tilapia are mainly cultured in poorly managed earthen ponds. The success of commercial culture will depend on the proper management of propagation and production processes, including selection, genetic sex reversal, sterilization, hybridization, overwintering, correct stocking, recirculation, aeration, balanced nutrition etc.

Marketing, processing and distribution

Tilapia have a good market potential in South Africa. Processed fillets of large fish can cater for the luxury market, while smaller specimens can sell at a lower price as whole fish. The development of marketing and processing is at present largely dependent on private initiative and will only succeed on a commercial scale if larger quantities are produced.

Production systems

Tilapia can be grown in extensive, semi-intensive or intensive systems depending on stocking density, and in mono- or polyculture. They are also grown in floating net cage culture.

In Taiwan, 3 - 4 t $pond^{-1}$ $crop^{-1}$ or 600 - 800 t ha^{-1} yr^{-1} are produced from octagonal ponds of 100 m^2 each. At the highest density of 100 fish m^{-2}, two annual crops of 6 t $pond^{-1}$ each have been achieved. This system is well suited for red tilapia. This type of tilapia culture makes good use of intermediate nursing or stepwise manipulation by shortening the rearing period of fish in the pond by transferring fish from pond to pond once every few weeks. This has the advantage of avoiding the ageing of the pond substratum and increasing the annual production per unit area of the pond. Available production figures for tilapia in various systems vary from less than one to more than 20 t ha^{-1} yr^{-1} without water replacement and up to 100 t^{-1} ha^{-1} yr^{-1} with recirculation (no biological filtration). Production is related to the degree of sophistication. Sex reversal, hybridization, selection and artifical feeding all improve production. Selected strains can grow from egg to 600 g in six months.

The biology of red tilapia is very similar to that of the common mouth-brooding tilapias. Red tilapia are also omnivorous, fecund and euryhaline and are highly resistant to disease. Because of their high market value, red tilapia are produced in highly intensive monoculture systems. Culturing red tilapia in sea water and in brackish water usually results in lower fecundities and higher growth rates.

An estimated 12 and 18 tonnes of tilapia were produced commercially in South Africa in 1980 and 1981 respectively. No sales figures are available. Considering the good qualities of tilapia, their potential is very high and this resource is grossly underutilized at present.

Potential

Certain alien tilapias and their hybrids are high potential culture species, in particular strains of red tilapia and hybrids that produce all-male progeny. In most cases, larger fish can be sold for a better price, and therefore fast growers have an advantage over slower growers. A proper choice of species for tilapia culture is therefore important. In this respect, the propagation of slow-growing strains of *O mossambicus* instead of faster-growing *O aureus* and *O niloticus* and certain hybrids is not recommended when commercial production is considered.

It seems likely that in modern facilities, high stocking densities and sophisticated culture techniques could make intensive tilapia culture both possible and potentially highly productive in South Africa.

Research needs

1. Selection of optimal tilapia species for aquaculture in South Africa, bearing in mind market considerations, environmental constraints, life history traits and conservation aspects.

2. Determine the impact of the introduction of red tilapia on indigenous fish populations in South Africa. Development of practical measures to prevent escape into natural habitats.

3. Evaluation of the potential for culture of red tilapia in fresh, saline and brackish waters.

4. Production of all male or sterile offspring.

5. Development of techniques for overwintering juveniles in colder areas.

6. Investigate temperature tolerances of different strains and selection or hybridization for temperature tolerance.

7. Determine the influence of environmental factors such as temperature, dissolved oxygen and ammonia on food intake, assimilation and growth rates by different size groups.

8. Investigate parasites and diseases of tilapia grown in different salinities.

9. Evaluate present health measures especially those associated with manuring of ponds.

10. Investigate methods of reducing predation.

11. Development of a suitable food pellet for different culture systems, including cage culture.

12. Investigate the relationship between stocking density, growth rate, conversion ratios and production under various environmental conditions.

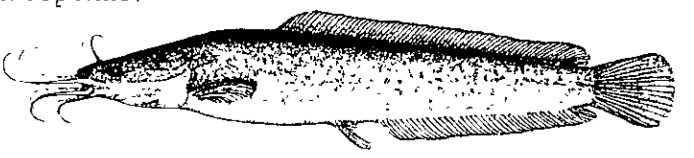
13. Development of practical culture systems such as:

    - cheap durable cages which are otter resistant;
    - closed recirculating units utilizing solar energy for heating and pumping;
    - possible implementation of the Taiwanese system whereby water is recirculated but not treated;
    - the most suitable production pond for intensive mono- or polyculture with reference to shape, depth, protection against predation etc.

14. Adaptation of existing processing technology for tilapia in South Africa.

15. Market research to evaluate the commercial potential of tilapia in South Africa.

B.4 SHARPTOUTH CATFISH *(Clarias gariepinus)*



Clarias species are widely accepted food fishes in several African countries (eg Cameroon, Uganda, Kenya, Zambia, Zimbabwe, Egypt, Chad, Ivory Coast, Tanzania) and in northern South Africa, and make up 20% of the pan-African freshwater fish yield. Detailed studies of the biology and ecology of *C gariepinus* have revealed that this species is an excellent aquaculture candidate. For example, under natural and culture conditions *C gariepinus* can attain up to 30 cm or 800 - 1 000 g in one year. It is a hardy, omnivorous species tolerant of water temperatures ranging from 8°C to 35°C, low oxygen concentrations due to its efficient air breathing organs, a wide salinity range (0 - 10%), a wide pH range and high sibling densities.

Selection and propagation

Under natural conditions *C gariepinus* spawns at the outset of the summer rains in recently inundated shallows. The average fecundity is approximately 45 000 eggs for a 2 kg fish. Several workers have demonstrated that natural spawning is not practical for the large scale production of catfish fry but that it is possible to induce spawning artificially with the aid of gonadotropins in spring and summer. Winter gonadal maturation still needs to be achieved for year-round spawning. Hatching success ranges from 30 - 70%. However, hatching techniques need to be refined to increase the average success rate.

Larval survival rates of up to 80% have been achieved under carefully controlled conditions, but in the first 20 days the average survival is usually between 30 and 45%. Survival also appears to be linked to the general condition and origin of the parental stock. These facts point to the necessity for continued research on larval and fry nutrition and on the genetic selection of broodstock.

Environmental constraints

As for other culturable species, poor water quality, low protein food and diseases are the main growth inhibiting factors.

Nutrition

Work has been done on food and feeding requirements during the primary nursing period of the larvae, followed by studies of some of the dietary requirements of catfish larvae during the first two weeks after the start of the first food intake. However, dietary requirements of juveniles are not known. Conversion ratios range from 1:1,3 to 1:3,2. Presently food costs contribute 50 - 60% to production costs.

Problem areas for research include the determination of minimum amino acid, vitamin and mineral requirements and protein/energy requirements.

Diseases and factors inhibiting growth

Metabolic disorders and diseases induced by pathogenic organisms, such as viruses, protozoans, bacteria and trematodes, under culture conditions need to be investigated, in addition to methods of treatment and prophylaxis.

Marketing, processing and distribution

Two feasibility studies have been undertaken so far in the northern Transvaal and eastern Cape. Prices obtained for catfish ranged from R1,00 to R8,00 kg^{-1}. A preliminary processing study undertaken by the Fishing Industry Research Institute revealed that *Clarias* flesh can be processed in a variety of ways to produce tasty, white fillets.

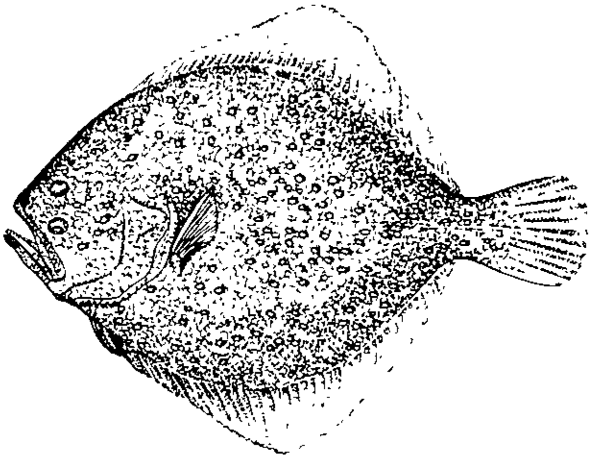
Production systems

Production rates of 3 to 12 t ha^{-1} yr^{-1} under pond conditions are anticipated. Under closed system and cage culture conditions yields could be increased to more than 20 ha^{-1} yr^{-1}.

Research needs

1. Develop techniques for year-round spawning under controlled conditions.
2. Increase hatching percentage and larval survival in the hatchery.
3. Genetic selection of broodstock.
4. Diagnosis, treatment and prophylaxis of diseases.
5. Determine dietary requirements in hatchery, nursery and production ponds so that optimal standardized diets for all stages of the life history can be developed.
6. Develop alternative food sources (including wastes) to reduce production costs.
7. Determine water quality requirements, especially in terms of metabolic load.
8. Determine physico-chemical tolerance limits under culture conditions.
9. Perform market research to determine the commercial potential of catfish in South Africa.
10. Optimize processing and presentation of the product.

B.5 TURBOT *(Scophthalmus maximus)*



The turbot is a flatfish commercially harvested off the coasts of Europe. It is considered to be an upmarket species, and should not be confused with halibut.

Between 10 000 and 12 000 tonnes are caught annually in Europe. Turbot are marketed whole on ice at £3,50 kg^{-1} (R5,80) wholesale. For comparison, the wholesale price of farm-raised salmon is R7 per kg. The landed value in British ports in 1982 was £2055 per tonne.

Commercial cultivation of turbot is in its infancy, with two commercial companies in Britain and one in France. One farm in Britain is producing 60 - 70 yr^{-1} but is expanding its facilities and also exporting juveniles and technology to a company in Spain. Research on the cultivation of turbot has been carried out in the UK since the early 1970's.

Obtaining ova and rearing larvae until they could be fed on formulated foods has been the major constraint for many years. Maturation can now be manipulated by photo-period. The larvae are weaned off natural feeds after 20 days. After a further 9 weeks, the juveniles (2 g in weight) are transferred to ongrowing farms. Whereas the hatchery technology is fairly sophisticated, ongrowing is straightforward. The turbot adapts well to domestication and can be kept in tanks or cages at high densities (30 - 40 kg per m^2) if sufficient water is supplied.

The fish grow from 2 g to 2 - 3 kg (when they are harvested) in 30 to 36 months at 14 - 19°C, which is regarded as optimal. Little if any growth takes place below 10°C and mortality appears to increase above 20°C. Mortality during on-growing is normally around 15%. Pelleted feeds are used as well as whole sprat and sand eels. Conversion on the latter varies from 4:1 to 2,5:1 above 200 g while a conversion of 1:1 is claimed for pelleted feeds.

One report mentions a hybrid between turbot and brill - a closely related species of more northern distribution. The hybrid larvae are said to be more hardy.

The production costs of a land-based, pumped water system in the UK are R4,50 per kg in the round and would be similar in South Africa, although costs may be reduced if a hatchery was established locally to replace imported juveniles (R1,30 each including air freight).

Research needs

1. Economic evaluation and market research on the potential of turbot culture in South Africa.

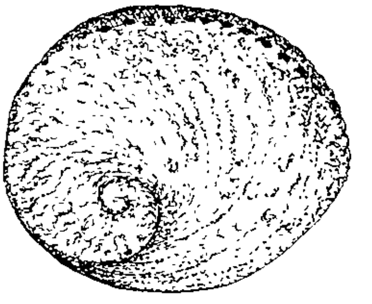
2. Development of local hatchery technology based on available knowledge.

3. Determine nutritional requirements and formulate feed with local materials.

4. Adaptation of production technology to local conditions and needs.

5. Disease monitoring under intensive growing conditions.

B.6 ABALONE OR PERLEMOEN *(Haliotis midae)*



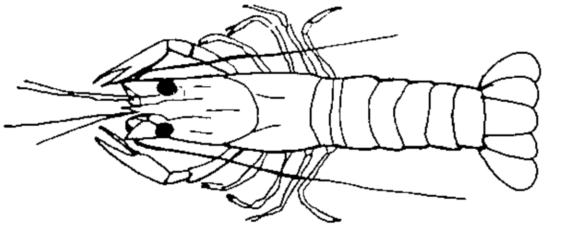
Published information on growth, management and hatchery procedures is available. The commercial catch in South Africa in 1982 was approximately 730 tonnes (whole animal), and the quota for 1983 was 660 tonnes. There are five factories licensed to process abalone and each has a fixed annual quota. Private divers take an unknown amount in addition to the commercial catch, probably 10% to 50% of the commercial catch. Until recently, virtually the whole commercial catch was exported. There has been a recent attempt to increase the share on the local market to 20%.

Abalone divers receive about R1,50 kg^{-1}. Restaurants are, by law, only allowed to buy abalone from factories, but animals dived for privately are also purchased. A restaurant might pay R9,13 kg^{-1} for legal abalone, R5,00 - R9,00 kg^{-1} for private abalone. The minimum legal size is 11,4 cm (shell width), which corresponds to a mass of about 300 g and is reached only after about 13 years of growth.

The Japanese have cultivated abalone for many years, mainly for reseeding natural stocks. The American abalone *Haliotis rufescens* is successfully cultured by several commercial farms in California. However, the seed has not been grown to market size in commercial quantities.

Young abalone graze on seaweeds. Systems that provide artificial feed have yet to be tested.

B.7 MARRON *(Cherax tenuimanus)*



In view of the worldwide increase in demand, freshwater crayfish could prove to be a viable alternative to marine crustaceans such as lobsters, over which they have a number of advantages. Freshwater crayfish are usually faster growing and mature at an early age, some as early as their first year.

They feed primarily on plant detritus which is readily available at low cost. They convert this food into high quality protein, thus making the economics of feeding crayfish more attractive than that of rearing many other culturable species which convert protein to protein. As they are cultured in freshwater, crayfish can be farmed inland close to the markets. The economic advantages of being able to supply freshly harvested crayfish to the market on an ongoing basis are significant.

There are some 300 species of freshwater crayfish worldwide (Africa being the only continent where they do not occur). They vary in size from the miniature *Cambarellus shufeldti,* which attains a length of 25 mm, to the giant Tasmanian crayfish *(Astacopsis gouldi),* which can attain a mass of 6 kg.

Freshwater crayfish are farmed to varying extents in the USA, Europe and Australia. The most extensively cultured species in the USA is the red swamp crayfish *(Procambarus clarkii)* which attains a length of 7,5 to 10 cm. Louisiana is the centre of production, which in 1980 was estimated at some 10 000 t with a value of $6 million. *P clarkii,* which is considered to be a pest in some areas, has also been introduced into Spain, Italy and, more recently, Zimbabwe.

The signal crayfish *(Pacifastacus leniusculus)* is one of the larger North American species which has also attracted the interest of aquaculturists. *P leniusculus* has also been introduced into Europe where it is preferred to *Astacus astacus* or *Austropotamobius pallipes,* which are fairly widely cultured in Europe and marketed when they reach a mass of 25 to 50 g.

Freshwater crayfish are considered to be an upmarket species in Scandinavia and France where they sell for $17 to $25 kg^{-1} (1981 prices). To meet local demand, Sweden imports approximately 2 000 t of freshwater crayfish annually, mostly from eastern Europe and Turkey.

Crayfish farming has developed rapidly in Australia, which has a rich variety of freshwater crayfish (9 genera with 97 species). The three largest freshwater crayfish occur in Australia, namely the giant Tasmanian crayfish *(Astacopsis gouldi,* 6 kg), the Murray crayfish *(Euastacus armatus,* 4 kg) and the marron *(Cherax tenuimanus,* 2,7 kg).

Of the three largest species the marron is the most suitable for aquaculture. Beside its large ultimate size it has a higher processing yield (recovery of edible flesh) than any of the other freshwater species. The large, broad tail constitutes 40% of its total mass and the claws an additional 19%. In this respect the marron is comparable to the western marine lobster *(Homarus americanus)* to which it is more closely related than are the southern rock lobsters or marine crayfish *(Jasus* spp). The marron is frequently termed a "freshwater lobster" and has a clear commercial advantage over other freshwater species in which the edible yield is often only 20% of total mass.

Marron are native to a small area of south-western Western Australia where they frequent perennial pools and streams between Perth and Albany. They are highly regarded as a sport species and gourmet food by the locals. In 1975, the Western Australian authorities legalized marron farming by exempting licensed farmers from certain regulations pertaining to the capture, sale and translocation of marron. This gave impetus to marron culture, and there are currently 17 licensed farms in Western Australia, organized as the Marron Growers Association.

Sales of juvenile marron in 1981 (30 000) showed a 210% increase over the preceding year. Marron are readily marketed through the restaurant trade in Australia and in 1982 growers were paid \$16 kg^{-1} for live marron. Since the lifting of an embargo on the export of live marron in 1980, marron have been exported to the USA, Japan, Europe and South Africa.

Water quality

Although marron inhabit perennial rivers and streams, they can be successfully reared in open ponds and farm dams and tolerate a wide range of water qualities. They can survive salinities up to about half seawater strength - ie about 17 000 ppm, and may survive for about 53 hours in full seawater. However, the affect of high salinities on the survival of eggs and larvae has not been determined.

Marron do not thrive in water which is rich in lime. In the George area they have been bred and reared in peat-stained water which has a low lime content (about 10 ppm) and a pH between 5 and 6,5.

Dissolved oxygen is a most critical factor. Marron will not survive at oxygen concentations of less than 40% saturation at 20°C. Growth at concentrations below 70% saturation is slow. Marron are bottom-dwellers under sub-optimal conditions when they crawl up the pond sides into shallower water. This can lead to overcrowding and fighting. Anoxic conditions may also result from algal blooms, especially during the night and early morning. Failure to maintain optimal dissolved oxygen levels on pond substrata is the most frequent problem in marron culture.

Optimally ponds should be 1 - 1,5 m deep, located in open areas and built so that their long axis is parallel to the prevailing wind, which helps aerate the water and break down stratification. Any South African venture should give careful consideration to local conditions such as soil type and extreme water temperatures.

Temperature

Marron originated in a temperate climate and temperature extremes in South Africa would probably be one of the limiting factors to their culture. The optimal water temperature range is 17° - 30° C. They show very little growth at temperatures below 12°C and cannot tolerate temperatures higher than 30°C. At this temperature death usually occurs at moulting, when the animal is extremely vulnerable.

Breeding

Marron breed easily under natural conditions in spring. In the George area the first "berried" females are observed at the end of August and most females (196 out of 204) were in berry by the last week of October.

Marron carry their eggs attached to the pleopods or swimmerets beneath the tail. On hatching the young pass through two brief larval stages, during which they remain attached to the pleopods and the parent cares for them. When they are finally released 12 to 16 weeks after spawning, the juvenile marron are miniatures of the adults, and require the same care and attention as adults. In a commercial venture it is vital to separate the juveniles from the adults in order to reduce losses from maternal predation.

While some species of freshwater crayfish spawn in their first year, marron start spawning in their second year when about 25% will breed. Most females breed by their third year. The number of eggs produced is directly related to the size of the parent.

Management

Growth and survival are the two crucial issues determining the economics of marron farming. Both depend on stocking rate, shelter and feeding.

Fifty percent of the population survives from year to year, when commencing with an initial stocking rate of 15 juveniles per m^2. Thus 5 to 7 will survive at the end of one year and about 2,5 animals after two years. This stocking rate should yield 2100 kg ha^{-1} after one year and 3175 kg ha^{-1} after two years. A lower stocking rate (5 - 7 juveniles m^{-2}) could prove to be a better economic proposition. There is a wide variation in the growth rates of individual animals.

Feeding

Marron are primarily detrital feeders. They ingest detritus and digest the micro-organisms. They are placed low on the food chain and thus it is possible to support large populations under natural conditions. Marron thrive on compost which has been decomposed to past the heat stage when the growth of micro-organisms has reached a maximum.

Disease

To date there have been no recorded mass mortalities of marron from disease. However, marron kept in indoor aquaria in George have been found to be susceptible to the fungus *Saprolegnia*.

Predators

Otters, cormorants, platannas (*Xenopus* species) and a number of fish species, such as bass and trout, are potential predators. Precautions against predators are essential.

Research needs

1. Production of juveniles "on demand" out of season.

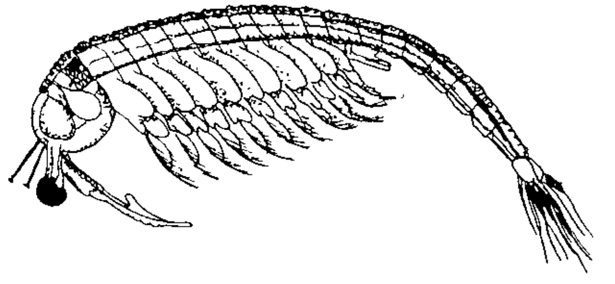
2. Genetic selection of strains for higher growth rate and to eliminate variations in growth rate.

3. Determine nutrition requirements and preparation of optimal feed.

4. Adaptation of available production and management technology to South African conditions.

5. Market research.

B.8 BRINE SHRIMP *(Artemia salina)*



Early efforts at intensively culturing large numbers of young fish were often thwarted by the lack of a suitable live food. In 1933 Seale found that *A salina* larvae are an excellent live food - the cysts can be transported and stored easily, and can be hatched within 24 hours when the early instar larvae are needed. Many marine animals are now fed on brine shrimps either together with other foods or, more often, as a sole diet. Early instar larvae are also used in the aquarium trade.

All the commercially available cysts for early instar larvae are obtained by harvesting wild populations. Initially cysts were only harvested in the USA, but a serious shortage of cysts in the mid 1970's led to the opening up of several new sources of supply. Currently the world's brine shrimp needs are supplied from a limited number of countries and the annual production in the late 1970's was in excess of 100 tonnes. All of South Africa's needs are imported, but no exact figure is available as the breakdown of imports in the Foreign Trade Statistics is not sufficiently detailed. Both eggs and freeze-dried flakes are available through the aquarist trade in this country. Freeze-dried flakes wholesale and retail at R76 kg^{-1} and R114 kg^{-1} respectively.

South Africa has an indigenous brine shrimp occurring in the salt pans of the western Orange Free State, the northern Cape Province and in evaporation pans along the coast. They occasionally reach pest proportions in inland pans from which salt is harvested.

Selection and propagation

Little work has been done in this field, mainly because a large volume of the trade is aimed at using first and second instar larvae as food for small fish, and these are hatched from cysts harvested from natural populations. There are many strains or subspecies of *Artemia salina*, which are variably susceptible to diseases and have different hatching rates. There is thus scope for genetic selection, and the strains to be cultured should be carefully tested.

Environmental constraints

The production of brine shrimps is limited to the warmer months due to climatic constraints. In many of the inland areas the rainfall is irregular, so that systems which rely entirely on surface water may dry up. However, there is an extensive reservoir of underground waters that are too saline for conventional agriculture in the Karoo and northern Cape and may be suitable for the intensive culture of brine shrimps.

Research needs

1. Compare the performance of the strains occurring locally with that of other strains as documented in the literature.

2. Optimize production both in extensive and intensive systems.

3. Test available sources of cereal and maize bran as well as cultured algae as food.

4. Investigate pathogenic factors affecting local *A salina* strains.

5. Determine the effect of temperature and salinity on the cultivation of local strains.

B.9 NILE CROCODILE *(Crocodylus niloticus)*

Crocodilian hides are used to make a variety of luxury leather articles such as handbags, shoes and purses. In addition, live crocodiles may be sold to restock game reserves and game farms. Crocodile farms themselves can be important tourist attractions.

The present world trade makes use of approximately 1,5 million hides per annum. Due to the depletion of crocodile populations throughout the world, this demand can no longer be met from wild stocks. As a result crocodile farms have been established in several tropical countries, but it will be many years before these farms will produce sufficient hides to reduce pressure on wild populations.

The Nile crocodile was formerly widely distributed in Africa, but indiscriminate hunting and habitat destruction have reduced their populations and the species is regarded as threatened outside conservation areas. There is therefore an urgent need to grow crocodiles in captivity to produce hides for the leather market. Fifteen crocodile farms currently operate in South Africa, holding stocks from less than 100 to over 2000 animals.

Selection and propagation

The breeding biology of the Nile crocodile is now well-known and techniques have been developed for the incubation and hatching of eggs and the growing-out of juveniles and adults in captivity. Adults will normally only breed in an unstressed situation. No genetic selection has taken place.

Environmental constraints

Crocodiles are tropical/subtropical cold-blooded animals and require moderately high temperatures to grow and reproduce. The eggs and young are susceptible to various infections and parasites. In general, earthen ponds are preferred to cement ponds due to the abrasion caused by the latter.

Management

Management techniques are fairly well developed, having been adapted from methods used in the American alligator industry.

Marketing, processing and distribution

Several marketing problems need to be overcome. The Nile crocodile is an endangered species and there are therefore local and international barriers to the sale of crocodile products. There is no adequate tanning facility in South Africa and hides have to be sent to Europe for processing. This results in a loss of revenue.

At present, crocodile farmers are very dependent on tourist revenue, but will need to become more independent of the tourist trade in future when this market becomes saturated.

Production systems

Outdoor earthen ponds are generally used, although egg incubation and juvenile rearing may take place indoors. In Asia individual farms with hundreds of ponds holding over 30 000 crocodiles have been established.

Research needs

1. Refinement of crocodile rearing and husbandry techniques.

2. Local development of techniques for processing crocodile hides.

C. OTHER POTENTIAL CANDIDATE SPECIES

Biological and technological information needs to be generated and supplemented on a number of candidate species which have long-term potential and on species which do not have high commercial value, but are important within polyculture systems. It is envisaged that due to the current dynamic development of aquaculture, certain species in this group, mainly marine finfish, crustaceans and molluscs, will become high priority species in the future.

The availability of many desirable species of marine food fish will probably continue to decline as long as wild stocks remain the principal source of supply. The need for marine fish aquaculture may, therefore, increase. However, many biological and technological problems need to be solved before aquaculture can provide reliable alternative sources of marine food fish.

In southern Asia finfish, principally milkfish and mullet, account for more than half of the total aquaculture production. Several kinds of flatfish have been sucessfully cultured in Great Britain and France. Japanese fish farmers have established profitable culture systems for a number of marine fish species, including sea bream and yellowtail. In the United States, commercial attempts to raise pompano were unsuccessful, apparently because growers lacked adequate information, because the growing season was too short and because operations depended on capturing young from the sea. A tropical species, the rabbitfish (*Siganus* species), shows some promise in Palau and Guam.

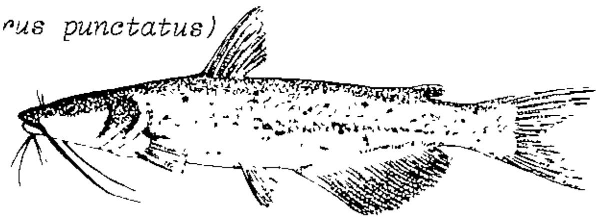
The many species of marine fish that can potentially be cultured will require production systems that are appropriate to their individual needs, but some generalizations can be made.

Frequently, artificial spawning has not been achieved when marine fish are kept in captivity. This problem can be overcome by collecting juveniles from natural waters and raising them in captivity to marketable size, as is done in Japan with the yellowtail. Once spawning has occurred, fertilized eggs can be collected and procedures are available to hatch them.

During their larval stages, marine fish are usually fed plankton. The food requirements of larvae are fairly well understood, but the technology for the commercial production of larvae is generally undeveloped.

Although problems associated with growing juvenile marine fishes in captivity are often less difficult to solve than problems associated with larvae, information is needed pertaining to nutrition, disease control and environmental requirements. Considerable research and development work is required before commercial-scale operations will become profitable. There is little experience with growing marine organisms for food in South Africa and many attempts at culturing larvae and juveniles have not advanced beyond the initial experimental stages. Off-the-shelf technology relevant to each species will need to be adapted to local needs.

C.1 AMERICAN CHANNEL CATFISH *(Ictalurus punctatus)*



The catfish industry in the southern and eastern USA has developed very rapidly in recent years. Farm sales have risen from $100 000 in 1960 to $90 million in 1981. Ancillary industries and services approach $1 billion annually. The American catfish can be regarded as the most recent aquaculture success story. Production yields have increased from 1,5 tonnes ha^{-1} in 1960 to over 6 tonnes ha^{-1} in 1982 and the increase is ascribed to the research effort which has been put into channel catfish nutrition, production techniques and, more recently, disease diagnosis and treatment.

The technology of selection and propagation is well developed and hatchery techniques are highly refined. The dietary requirements for all stages of the life history have been established. Water quality has been an important limiting factor for further intensification of American catfish production since this species requires high saturations of dissolved oxygen under intensive stocking densities. Problem areas also include wide pH ranges and high ammonia and nitrate levels. Processing, distribution and marketing of this species is receiving much attention in the USA.

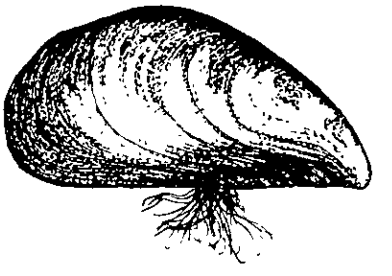
The potential of *Ictalurus* culture under strictly controlled conditions should be investigated in South Africa. Simultaneously, research should be undertaken to assess the possible effects which this species may have on indigenous fishes. Some trials have been undertaken in West Africa, but the results are not available. Preliminary trials on larvae in an indoor recirculating system in Grahamstown revealed that *I punctatus* grew significantly slower than *C gariepinus* during the first four months.

Research needs

1. Determine the ecological implications of the introduction of *Ictalurus punctatus* into South Africa.
2. Refine artificial propagation under South African conditions.
3. Rearing of fingerlings to sexual maturity under local experimental conditions.
4. Establish their dietary requirements under local conditions.
5. Establish their water quality requirements under local conditions.
6. Conduct comparative nutritional studies using imported feed and locally produced pellets.
7. Conduct comparative production studies in ponds, recirculating systems, raceways and cages.
8. Perform comparative marketing research with *Clarias* to establish its possible acceptance by the market.

C.2 BLACK MUSSEL *(Choromytilus meridionalis)*
C.3 BROWN MUSSEL *(Perna perna)*

Mussel culture dates back to 1235 AD when farming of *Mytilus edulis* began in France. Today mussel farming is widely practised with the main producers being Spain, the Netherlands and France. Spain's contribution is in excess of 40% (300 000 tonnes plus) of the current world mussel production. Yields of 300 tonnes/ha have been obtained in the Galician bays of Spain.



Black mussel

Different systems of mussel farming are used depending on the hydrographical, social and economic conditions of the country concerned. In Spain mussels are mainly cultured off the bottom on rafts, whereas in the Netherlands they are cultured on the substratum.

Brown mussel

Mussel seed is obtained in nature by collecting natural sets on rocks or by placing artificial collecting substrata in the natural habitat during the spawning period, which is normally autumn to spring.

The basic requirements for mussel culture are good quality water, a sheltered shore and the availability of food and seed stock. Phytoplankton as well as dead organic matter of the correct particle size form the main food source. In general, mussel farming is a most efficient method of converting organic matter produced by organisms low on the food chain into edible protein.

Until recently no commercial exploitation of mussels was allowed in South Africa although individuals may collect up to 25 in the Cape Province (free of charge) and 50 per person per day on the Natal coast (for which a R10 permit is required). During 1980 a total of more than 55 000 such permits were issued for *Perna perna* collection, apart from general bait licences which allow 20 mussels per person per day.

Recently the Marine Development Branch of the Department of Environment Affairs and Fisheries granted the first permit to a company for mussel *(P perna* and *Choromytilus meridionalis)* farming in a tidal pond at Saldanha. Seed mussels have recently been artificially reared by the Fisheries Development Corporation in the Knysna Lagoon.

Black and brown mussels are probably the most abundant and least exploited edible molluscs in South Africa. Although they form the main food source of rock lobsters, research has indicated that only 22% of the mussel mass is actually available to the lobsters, with the remaining 78% comprising mussels which are too large to be eaten. Furthermore, large areas of South Africa's coastline are without a rock lobster population.

It is very difficult to extract statistics on mussel imports as all molluscs and crustaceans are lumped under "shellfish". One company imports mussels to the value of R200 000 per year. *Mytilus edulis* from Norway, Denmark, The Netherlands, France and Spain dominate the South African market. Recently, frozen *Perna canaliculus* (New Zealand green-lip) also made their appearance on the Cape market.

The brown mussel, *P perna,* occurs from Walvis Bay to Delagoa Bay and is most abundant between False Bay and Durban. Large colonies occasionally occur on the west coast. During 1974 the mussel population in Saldanha Bay consisted mainly of *C meridionalis,* while *P perna* is the dominant species there at present.

P perna has no strict preference for a specific substratum and can be found in dense populations attached to rocks, wood, buoys, ropes, steel structures etc. Their vertical distribution extends from approx. 1,3 m above MLWS to a depth of more than 5 m. Although strong wave action or water movement appears to be necessary for settlement, excellent growth can be obtained in quieter waters. Settlement density varies markedly from year to year and in different areas.

Mussels in general display a gregarious tendency which can result in a surface coverage of more than 90%. This leads to overcrowding, high mortalities, poor shape and a loss of condition. In a culture system this would be prevented by thinning and relaying.

The growth of *P perna* even under unfavourable conditions, such as exposure to heavy sand-laden surf, is very satisfactory. After one year an average length of about 5 cm for intertidal and about 7 cm for subtidal mussels can be expected. After two years, the growth rate of natural populations decreases rapidly. In South Africa, with its lack of protected waters, the development of a mussel industry should be seen as a combination of an inshore fishery and a farming activity.

There is evidence that *P perna* shows morphological variation throughout its wide distribution along the coasts of South America, southern Africa and the Mediterranean Sea, and the taxonomic status of the group needs to be investigated.

Research needs

1. Re-examine *P perna* systematics.

2. Conduct market research on:
   a) species preferences - the flesh of *P perna* is more attractive than that of *C meridionalis.*
   b) product preferences - frozen in shell, canned in brine, smoked etc. The brown mussel is more appetizing in its raw state than the black mussel.

3. Determine resettlement patterns along the coast and the effect of controlled harvesting.

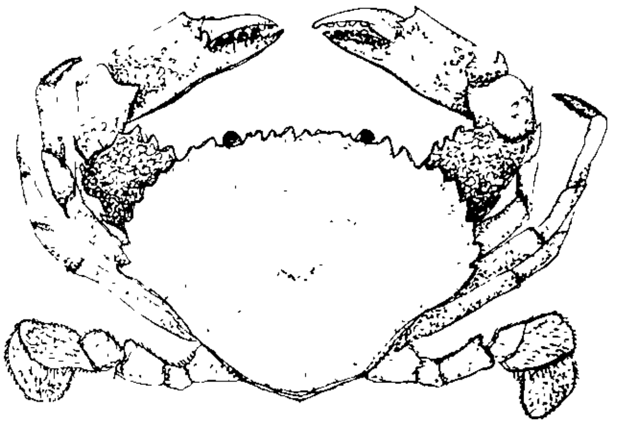
4. Identify natural nursery areas.

5. Develop farming systems by utilizing natural seed. If this is not allowed, large-scale artificial rearing of seed mussels should be attempted.

6. Identify protected waters with a potential for mussel farming.

7. Investigate species competition and interactions.

C.4 MARINE CRAB *(Scylla serrata)*

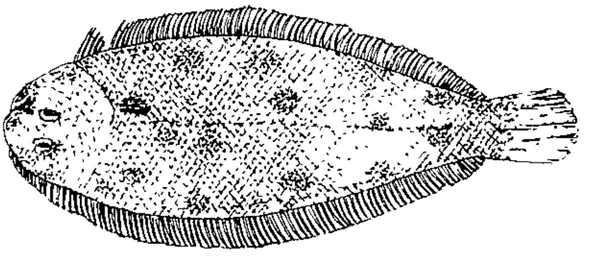


Scylla serrata is a large edible crab found in the brackish water of river mouths, mangrove swamps and estuaries along the east coast of Africa, Mauritius and the Indo-Pacific region to Australia and Japan. On the South African coast it is found as far south as Knysna and rarely to the Great Brak River. Local populations differ in their biology from the same species in the Indo-Pacific region where it is an important part of the fishery. Although the meat of *Scylla* is considered to be a delicacy locally, its numbers are too low to warrant commercial exploitation. The life history of *Scylla serrata* is well documented and the larval stages have been described. The larvae have been successfully reared through to the crab stage.

Between 1968 and 1970 the Fisheries Development Corporation conducted a study on the morphological characteristics, feeding, growth, reproduction and larval rearing of *Scylla serrata* at the Knysna Oyster Research Laboratory.

A considerable amount of work still needs to be done before a reliable commercial project could be initiated. The principal problems to be overcome would be the combating of cannibalism and the curbing of mortality during larval rearing. The former is a major problem in intensive aquaculture. Another important factor is the availability of food constituting a balanced diet. It has been shown that the adult can be cultivated in captivity with promising results. Mating was successful and larvae can be obtained during five to six months of the year.

C.5 DOVER SOLE *(Solea solea)*



The Dover sole is a marine flatfish of the north-eastern Atlantic Ocean and Mediterranean Sea. It passes through pelagic egg and larval stages which drift with the currents. The larval stage in the sea lasts 1 - 2 months, depending on temperature and food, after which the metamorphosed soles seek out shallow, sandy coastal areas. Spawning is in spring. Wild fish reach 35 cm and 250 g after 4 years growth.

Dover sole at first-feeding have a sufficiently large mouth to take *Artemia nauplii* and have been reared through the larval stage in captivity with remarkably high survival rates. Weaning metamorphosed sole onto inert foods is reportedly difficult, and mortality increases significantly during this period.

On-growing Dover sole require a sandy substratum and cannot tolerate a stocking density as high as that tolerated by turbot. A marketable sole of about 35 cm (250 g) can be produced in 18 months under near-optimal farming conditions.

Unlike the case with Atlantic salmon, detailed information on sole farming, particularly the financial aspects, is not freely available. The results of research on this species in the UK, Germany and France are obtainable by contracting with the relevant agencies or companies.

Data that are available suggest that, with a good site and good management, sole (or turbot) farming could be a rewarding economic proposition in South Africa. The MSc thesis by G de F Retief (1978, "A feasibility assessment of sole farming in South Africa, UCT) provides the best review and analysis of the information that was freely available at that time.

Potential for aquaculture in South Africa

Temperatures of 15°- 20°C are suitable for Dover sole. Sites along the southern coast of South Africa would therefore be more suitable than west coast sites.

The South African indigenous sole, *Austroglossus pectoralis,* has not as yet been reared from the egg in captivity. As the first-feeding larvae are smaller than those of *S solea,* and the adults have a restricted depth and geographical distribution, *A pectoralis* may not survive and grow as well in captivity as *S solea*. A closer look at the problems associated with Agulhas sole rearing is required.

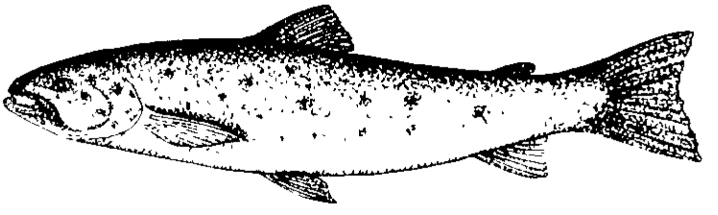
Retief's feasibility study concluded that an expertly managed farm producing 125 tonnes per annum would be a viable proposition in South Africa, but that the venture would not be without financial risks.

Because of the scarcity of suitably sheltered areas on the South African coast such as Langebaan Lagoon, Knysna Lagoon, and several Natal estuaries and the competition for those areas from other users (especially for recreation), the cheapest fish farm layout (floating net cages or fixed net enclosures) has very limited application in this country.

The only alternative is tanks or ponds on land, into which water must be pumped. In certain circumstances, tidal exchange might be employed to partially defray expenses. The farm location must have access to sea water of suitable year-round quality and temperature. The farm must be sited where there is good road access, where electricity is available, and where the relevant authorities can be persuaded to supply the necessary permits.

Fish food typically accounts for approximately half the operating expenses of a farm and a dependable supply of fodder at an acceptable price is obviously essential. A variety of high quality foods specifically developed for particular fish species are obtainable in North America, Europe and Japan. In South Africa, the marine fish farmer must develop his own rations or acquire a suitable recipe (which he must adapt to local conditions) from abroad.

C.6 ATLANTIC SALMON *(Salmo salar)*



Atlantic salmon are native to both sides of the north Atlantic Ocean and an introduced population has become established in New Zealand. Eggs are spawned in shallow depressions in the gravel of a stream bed (redd), where they are fertilized by the male and covered with a few centimetres of gravel. The alevins remain in the gravel until most of the yolk has been absorbed and then emerge. They live in fresh water for about two years, when physiological changes (smolting) occur which prepare the fish for life in sea water. Time spent at sea may vary from one to five years, at which time they return to their home stream to spawn.

Production of Atlantic salmon has reached a high level of sophistication in northern Europe and it is likely that the technology could be exported to any place with satisfactory rearing and marketing conditions.

Procedures for stripping and incubating the eggs and rearing fry (stocking densities, foods, water flow rates etc) are well documented and this information is widely available.

A dependable supply of smolts is vital. Under near-optimal water temperature and feeding conditions, a high percentage of fish can smolt at one or two years after hatching. Since smolts grow faster in sea water than in fresh water, it is advantageous to transfer them to sea water as soon after smolting as possible. A one year old smolt weighs about 30 g.

Production of Atlantic salmon beyond the smolt stage is carried out either in floating net cages, in netted enclosures or in tanks and ponds on land. Net cages are the preferred method at present. Ocean ranching, as is practised with Pacific salmon species, is not yet a reality, but shows promise in some areas, notably Iceland.

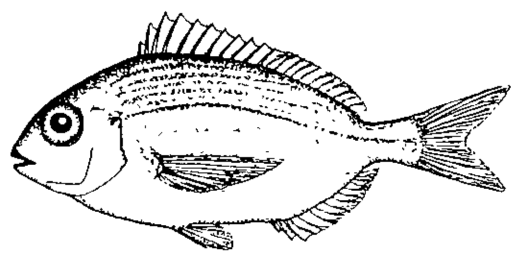
In sea water, cultured fish attain a market size of about 4 - 5 kg two years after smolting. They should be harvested before they attain sexual maturity (become grilse) because of the decrease in growth rate at that stage.

Potential for aquaculture in South Africa

Conditions suitable for shore-sited Atlantic salmon culture are present along the west coast of South Africa and on the south coast west of Cape Agulhas. Since the species does not live naturally in South African waters, broodstock must be maintained locally or eggs must be routinely imported. Repeated importation of eggs greatly increases the probability of introducing alien diseases, however, and should be avoided. In general, cultured Atlantic salmon are less prone to disease than either rainbow trout or the various Pacific salmon species. Their market value is greater than that of rainbow trout.

The economic success of a salmon farm in South Africa should be established by a full scale feasibility study. However, the partial successes of the sea water rainbow trout operation on the Cape west coast are encouraging to anyone considering salmon production in this country.

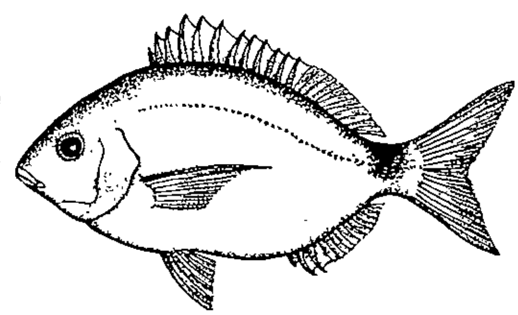
C.7 CAPE STUMPNOSE *(Rhabdosargus holubi)*



Approximately five tonnes are taken annually by line fishing in South Africa. Stumpnose are marketed either fresh or frozen at a size of about 0,5 kg. The price presently paid to fishermen ranges from R1,00 to R2,00 kg^{-1} for unprocessed fish.

The biology of this species, including its growth rate in nature, is fairly well known. Juveniles live mainly in estuaries. They ingest or scrape aquatic vegetation from which they remove diatoms, crustaceans and other digestible matter. Adults occur at sea and feed mainly on benthic molluscs.

C.8 BLACKTAIL *(Diplodus sargus)*

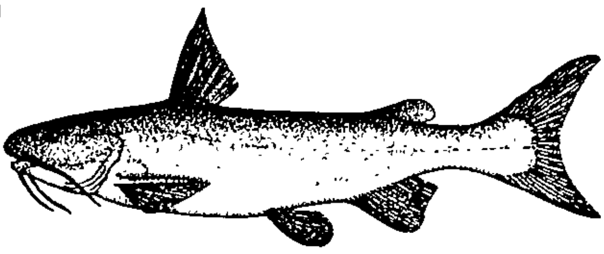


Approximately 10 tonnes of this species are taken annually by line and speargun, and two tonnes by beach seine. Blacktail are marketed either fresh or frozen at a size of 0,5 - 1 kg. The price presently paid to fishermen ranges from R1,00 to R2,25 kg^{-1} for unprocessed fish.

This species has been reared in South Africa and France, with high survival rates. Blacktail spawn throughout the year but especially during winter. They are omnivorous, hardy fish that adapt well to aquaculture conditions, and have wide salinity tolerances (8 - 35 g l^{-1}) and water temperature tolerances. Blacktail are suitable for estuarine cage culture and brackish water pond culture. The closely related *D cervinus* (zebra) has also been reared from the egg. Although its maximum size is greater than that of *D sargus,* juvenile growth and survival rates in captivity are lower. *D cervinus* is also more sensitive to low oxygen concentrations than *D sargus.*

Research needs include breeding and feeding biology, and studies on controlled spawning, hatchery procedures and fingerling production.

C.9 SEA CATFISH *(Galeichthys feliceps)*



Between 2 - 10 tonnes are taken annually by beach seine, lines and trawls off the eastern Cape coast. Fish of 0,2 - 1 kg are marketed in salted, dried or smoked form, and a few are sold fresh or frozen. The price presently paid to fishermen ranges between R0,50 - R2,50 kg^{-1} for unprocessed fish. Sea catfish have an excellent taste but there is some market resistance due to their appearance.

This estuarine and marine species is omnivorous and a mouthbrooder with a low fecundity. Sea catfish have wide water temperature tolerances and a salinity tolerance of 6 to 35 $g\ l^{-1}$. They are suitable for estuarine cage culture and brackish water pond culture.

Research needs

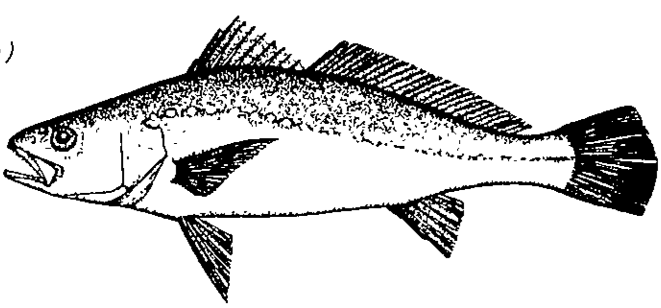
1. To maintain and rear broodstock in captivity.

2. To develop artificial spawning techniques (either by hormonal treatment to induce gametogenesis and spawning, or by the capture of ripe individuals in eastern Cape estuaries, which are then induced to spawn artificially).

3. To investigate spawning and incubation behaviour.

4. To develop fry-rearing techniques.

C.10 KOB *(Argyrosomus hololepidotus)*



Between 300 - 1000 tonnes are taken annually by trawl and 10 tonnes by beach seine and line. The total catch was 165 tonnes in 1980 and 143 tonnes in 1981. Kob are marketed in fresh or frozen form at about 3 kg. The price presently paid to fishermen ranges from R1,50 to R3,00 kg^{-1} for unprocessed fish.

The natural history of the kob has been well documented and allows the species to be identified as a potential aquaculture candidate. No attempt has as yet been made to investigate its culture potential.

This species is carnivorous, feeding mainly on fish and squid. Sexual maturity is attained at between three and four years. Kob grow to one kilogram in two years under natural conditions, and reach a large size. They have wide water temperature tolerances and a salinity tolerance of 5 - 35 $g\ l^{-1}$. Kob often enter estuaries and live well in aquarium tanks. They are suitable for estuarine cage culture and brackish water ponds. The entire culture technology needs to be developed.

Research needs

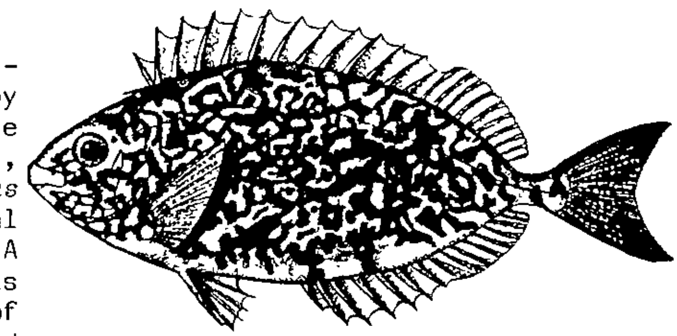
1. To develop artificial spawning techniques.

2. To investigate the mechanism of spawning.

3. To develop larval rearing techniques.

4. To maintain and rear broodstock in captivity.

C.11 RABBITFISH *(Siganus sutor)*



The potential of siganids in mariculture has been pointed out by several authors. Three species are found along the South African coast, of which *S sutor* and *S canaliculatus* are considered to be potential candidates for mariculture. A considerable amount of work has already been done on the culture of these species in Israel, Germany and western Samoa. These studies will serve as baseline data for the development of techniques suitable for local conditions.

The rabbitfish is omnivorous and oligohaline. Under culture conditions in Israel it attained marketable size in two years. The most suitable type of culture for rabbitfish is a recirculating system of ponds and cages. From a survey of the relevant literature it would appear that larval rearing, including nutrition, presently forms the bottleneck to the development of siganid culture.

Research needs

1. To develop artificial spawning techniques.

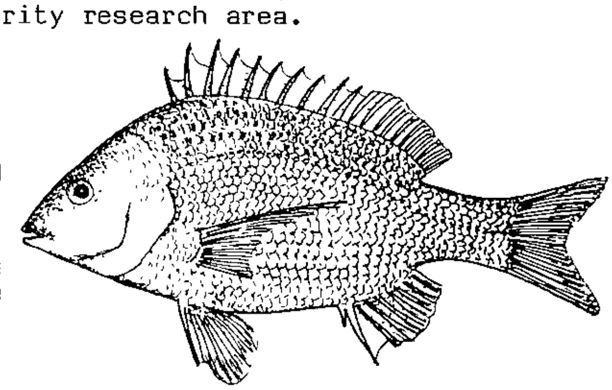
2. To investigate the mechanism of spawning.

3. To develop larval rearing techniques.

4. To maintain and rear broodstock in captivity under local conditions.

Although some research into food requirements has already been undertaken this aspect should be regarded as a priority research area.

C.12 RIVER BREAM *(Acanthopagrus berda)*



This species is a popular Natal angling fish. River bream are marketed fresh or frozen at 0,5 - 1 kg. The price presently paid to fishermen ranges from R1,50 to R2,50 kg^{-1} for unprocessed fish.

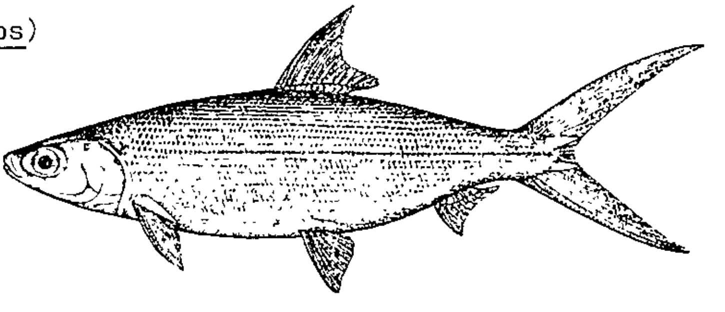
A berda is an omnivorous, warm water euryhaline species. Spawning occurs at the mouths of estuaries during winter and the juveniles return to estuaries. The most suitable type of culture for river bream is estuarine cages or recirculating systems.

Research needs

1. The biology of this species has to be thoroughly studied whereafter culture technology has to be developed starting with hatchery procedures and fingerling production.

2. Adapt the technology developed for another sparid, *Sparus aurata* in Israel, to the culture of *A berda* in South Africa.

C.13 MILKFISH (Chanos chanos)



The milkfish is widely distributed in the subtropical and tropical regions of the world. In South Africa it is fairly common as far south as the Swartkops River near Port Elizabeth. This euryhaline species is cultured extensively in the Philippines, Indonesia, China and Taiwan in brackish water ponds under recirculating conditions. In these regions it is an important food fish and is cultivated from the fry stage. However, the availability of fry is almost totally dependent on the capture of wild fry stocks. Attempts have been made to induce spawning but success has been limited. Similarly, little success has been attained with the rearing of the larvae and fry. Milkfish grow to 700 - 900 g after one year under culture conditions.

Their diet consists mainly of detritus, diatoms and other micro-organisms which live in mud. This species reaches sexual maturity at 4 yrs (50 cm) in females. Spawning occurs at sea and the larvae are pelagic.

Research needs

1. To maintain broodstock under culture conditions.

2. To develop technology for the artificial spawning and rearing of the larvae.

3. To study larval nutrition and larval maintenance under culture conditions.

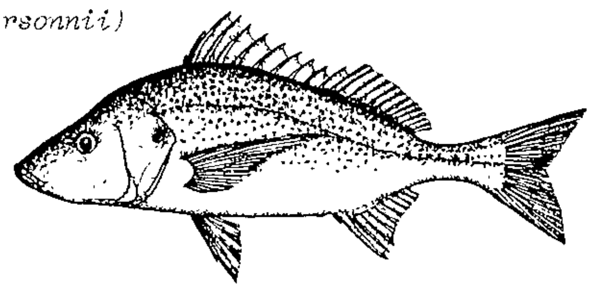
C.14 AGULHAS OR EAST COAST SOLE *(Austroglossus pectoralis)*

The distribution of this species is limited to muddy substrata along the south coast between Port Elizabeth and Cape Agulhas at depths from 10 - 100 m. The trawl quota for 1983 was 950 tonnes, but the market potential is well above this figure. Fish of 0,25 - 0,5 kg are marketed fresh or frozen. The price presently paid to fishermen is approximately R2,00 kg^{-1} for unprocessed fish.

This species is cold water tolerant but its growth is slow; a 12 - 24 months old fish has a total length of 10-17 cm and a mass of 10 - 20 g. Females reach sexual maturity at 33 cm at an age of 4 years. Their food includes small bottom-living worms and crabs. Agulhas sole have not been reared in captivity.

C.15 SPOTTED GRUNTER *(Pomadasys commersonnii)*

Spotted grunter are marketed in fresh or frozen form at a size of approximately 2 kg. The price presently paid to fishermen ranges from R1,50 to R2,50 kg^{-1} for unprocessed fish. This is a very popular angling species.



The spotted grunter is a warm water, euryhaline marine and estuarine species which spawns in late winter in the sea. Fry and adults return to estuaries to feed. Under natural conditions this species attains 1 kg (320 mm) in two years. Sexual maturity is attained after three years. The juveniles usually enter estuaries. Spotted grunter feed on worms, crabs, shrimps, prawns and molluscs. Although this species has not been reared through the larval stages, two related species *(Haemulon parrii* and *H sciurus*, both of the tropical western Atlantic) have been reared successfully.

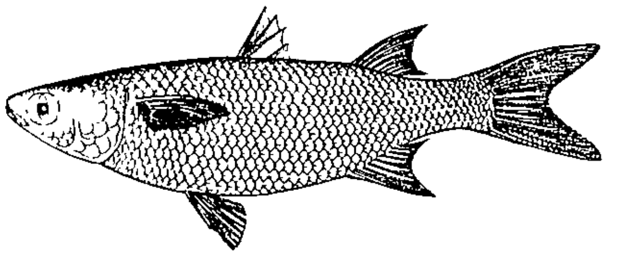
There is no existing aquaculture knowledge. The types of culture suitable for this species are estuarine cage culture and brackish water ponds.

Research needs

1. To develop hatchery procedures and fingerling production techniques.

2. To develop culture technology.

C.16 FLATHEAD MULLET *(Mugil cephalus)*



Approximately five tonnes of this species are taken annually by beach seine. Mullet are marketed in fresh, frozen and smoked forms at a size of approximately 1 kg. The price presently paid to fishermen is R1,20 kg^{-1} for unprocessed fish.

The flathead mullet is commonly found along the South African coast and in estuaries. Sexual maturity is reached after 3 - 4 years at 45 cm, and spawning occurs in the sea in winter or spring. Juveniles feed on plankton and adults on benthic diatoms and invertebrates.

Mullet culture, using both intensive and extensive techniques, forms an important component of the aquaculture industry of many countries. In South Africa the market acceptability of mullet is largely unknown (apart from its popularity on the west coast).

In the last decade there has been an intensive research effort in countries such as Hawaii, Taiwan, Israel and elsewhere, towards perfecting techniques for the artificial spawning and propagation of mullet. However, high larval mortalities during the first two weeks of larval development have largely impeded the successful mass propagation of grey mullet larvae in hatcheries. A major problem has been the specific feeding requirements of the newly hatched larvae. Only live food has to date been used with any success, with organisms of optimal size and nutritional value required at various stages of larval development. An adequately equipped larval food production system is therefore an essential part of any mullet hatchery. High standards of water quality are also required during the first critical weeks. Recent research using pelagic microcopepods as larval food has increased the survival of mullet larvae. These can be cultured artificially or collected from wild populations. Although an anticipated overall survival of five per cent of the original number of eggs at 50 days is given, the high fecundity of female mullet (over one million eggs per female) does offset this problem to some extent.

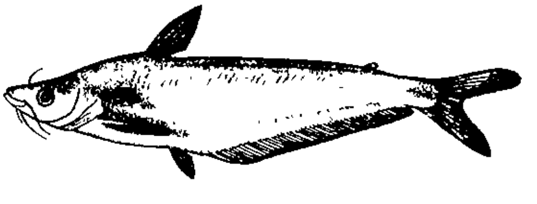
Research needs

1. To develop artificial spawning technology.

2. To study overcrowding problems associated with larval nutrition and survival under local conditions.

3. Market research to evaluate the commercial potential of this species in South Africa.

C.17 BUTTER CATFISH *(Eutropius depressirostris)*



Representatives of the freshwater fish family Schilbeidae are restricted to the African continent. In southern Africa only two species occur, *E depressirostris* and *Schilbe mystus* (although a recent taxonomic study has concluded that these two species are synonymous). The butter catfish has excellent organoleptic qualities and an attractive appearance. It is a warmwater species with variable growth rates. Little is known of its biology.

Fecundity is high and consequently only a small breeding stock is needed. Recently success has been achieved in artificially propagating the butter catfish. Males can be stripped and need not be sacrificed. Females survive the handling and stripping. Cannibalism may be a problem and will have to be considered.

The fry grow satisfactorily on brine shrimps and zooplankton, and there is a close correlation between stocking density and growth rate. No rearing of fish to table size has been undertaken as yet.

Limited marketing studies indicate that butter catfish are readily bought for R1,50 kg^{-1} whole gutted.

Research needs

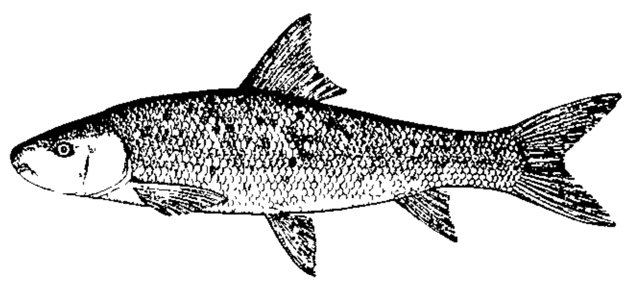
1. To improve on hatchery techniques.

2. To investigate preferred physico-chemical conditions.

3. To establish nutritional requirements throughout the life cycle.

4. Market research to evaluate the commercial potential of this species.

C.18 MOGGEL *(Labeo umbratus)*



Of the nine *Labeo* species occurring in South African fresh waters only one, *L umbratus*, has been cultured experimentally and none have been cultured commercially. *Labeo* species are commonly used in polyculture in India (eg *L rohita* and *L calbasy)* and elsewhere. The biology of *Labeo umbratus* is well documented but aquaculture knowledge is limited.

Propagation

Eggs have been hatched and the larvae reared to fingerlings of approximately 30 g in six months. Sexual maturity is attained after three years. Under natural conditions moggel grow to 280 mm in two years. They are suitable for culture in ponds and in recirculating systems.

No research has been performed on the artificial propagation of *L umbratus*. It is a floodplain spawner with slightly sticky eggs and has a high fecundity, an average mature female producing over 250 000 eggs. Mature ovaries contain one size range of eggs but all the eggs are not always spawned simultaneously in nature. Spawning females are easily stripped of eggs, and successful artificial spawning therefore seems to be feasible. Fertilized eggs have been successfully hatched and reared in an aquarium, showing that this aspect would probably not hamper propagation. Small fish are readily available in natural systems.

Environmental constraints

L umbratus can tolerate temperatures well below 10°C but the critical minimum is unknown. Moggel are apparently less tolerant of low oxygen concentrations than common carp and tilapia. Mass mortalities occur in impoundments for unknown reasons.

Nutrition

L umbratus feeds on organic detritus which is apparently digested with the aid of enteric bacteria. Moggel readily take artificial pellets.

Production and management

The following results give an indication of the production potential of this species. *L umbratus* with a mean mass of 49,2 g were stocked together with five other species (total 23 000 ha^{-1}) at a density of 2400 ha^{-1} in a pond enriched with piggery waste. Over 106 days the mean mass increased to 145,6 g, giving a daily growth rate of 1% of body mass, a daily production of 2,2 kg ha^{-1} and an overall production of 231 kg ha^{-1} (assuming no mortality). This is about 10% of the theoretical total production. Their growth rate in the pond was higher than that reported for natural populations.

This species may be suitable for polyculture.

Marketing and processing

Moggel have good quality flesh but contain many small bones in the fillet. They are therefore more suitable for marketing in processed forms such as canning, as fish sausages etc. High densities of this species occur in state dams which have been opened for commercial utilization. Moggel are presently exploited commercially at Lake Mentz.

Research needs

1. Develop suitable methods for artificial spawning, hatching and raising of juveniles.

2. The selection of fast growing broodstock.

3. Determination of the influence of temperature, dissolved oxygen, ammonia and crowding on growth and survival.

4. Investigation of parasites and diseases.

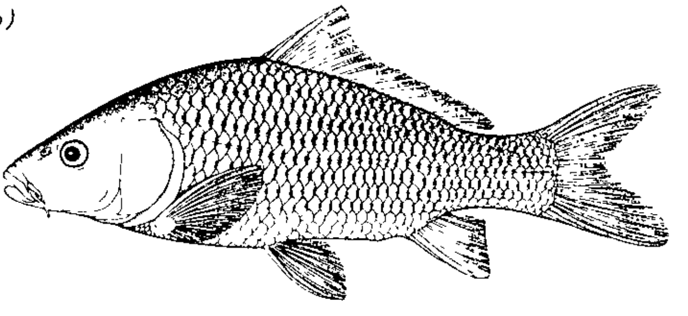
5. Determination of dietary requirements under culture conditions.

6. Determination of the relationship between stocking density, growth rates, conversion ratios and production rates under various environmental conditions.

7. Development of processing and marketing methods.

8. Conduct market research.

C.19 COMMON CARP *(Cyprinus carpio)*



Carp farming has a long history in both Europe and the Far East. By means of meticulous selection various strains have been developed which are suitable for pond culture. A main contributor to the refining of techniques in recent years is Israel. The re-appraisal of carp as an aquaculture species in Britain is noteworthy.

Although carp were introduced into South Africa as ornamental fish in the eighteenth century and for angling over a century ago, it was only in 1955 that a specific strain was imported for culture purposes. This is the Aischgrund variety from Germany, which was released in ponds of the Lowveld Fisheries Research Station at Marble Hall. More recently (1977) the Dor 70 strain was imported from Israel. To date commercial carp farming is practised by a few private farmers only.

Propagation

Fingerling production is undertaken by the provincial hatchery at Marble Hall. In the near future fingerlings will also be available from the Lebowa Government Service and the Umtata Dam Fisheries Station in Transkei. Natural spawning techniques as well as artificial propagation through hormonal stimulation are practised. Annual fingerling sales in South Africa vary from 200 000 to 300 000. As carp are prolific breeders and fry can be raised without great difficulty, it should be possible to cater for the demand for fingerlings.

Environmental constraints

Carp can tolerate, and even thrive, over a wide range of environmental conditions. Water temperatures between 20° and 30°C are ideal, although lower and higher temperatures can be tolerated for extended periods. Sustained carp growth is dependent on water temperatures higher than 15°C. An active growth period of 8 - 9 months can be expected in South Africa. Dissolved oxygen levels should not decrease below 20% saturation and pH should range between 5,5 and 11.

Dissolved oxygen levels can be maintained in production units by artificial aeration of the water using paddle wheels and other techniques. The addition of lime buffers excessive pH changes in the water.

Nutrition

The dietary requirements of carp are well documented. In extensive farming practises, besides organic and inorganic fertilization of the water, supplementary feeding with low grade maize is undertaken. This results in a food conversion of about 6:1. In intensive carp farming a balanced ration with a crude protein content of 25% is administered with or without the aid of demand feeders. With this method a food conversion ratio of 3:1 is attained.

By applying improved aeration techniques as well as higher stocking densities, it should be possible to raise the yield appreciably above the 2 - 3 tonnes presently achieved.

Feeding costs contribute at least 50% of the total production costs, therefore every effort should be made to optimize feeding efficiency and to develop least-cost feeds. Specific carp pellets are presently only available in the Transvaal.

Disease

The carp is a hardy fish but under conditions of stress it may be attacked by a wide variety of external and internal parasites. Infectious viral diseases such as VHS and IPN have fortunately not occurred to date in South Africa. Various chemicals for the treatment of diseases are available.

Indiscriminate importation of new carp strains can endanger the present stocks should adequate quarantine measures not be applied.

Although disease treatment methods are described in the literature the techniques should be adapted to suit local water conditions. A disease diagnostic service embracing the whole spectrum of potential diseases is lacking. At present Onderstepoort is being furnished to handle bacterial and viral diseases, while other aspects are dealt with by bodies of the provincial authorities and various universities.

Management

In South Africa, carp farming is practised together with other agricultural endeavours. The relatively unsophisticated methods used need only low level management. Provincial Nature Conservation authorities aid carp farmers to a limited extent in planning the construction and management of a fish farm.

Production

In the mid 1970's carp farming experienced an upsurge in the Transvaal due to the increased efforts of the provincial authorities. Unfortunately, adequate marketing studies were not performed and the venture was, on the whole, unsuccessful.

Carp yields for the Transvaal were 28 tonnes in the 1974-75 season but have since declined to under 10 tonnes. Figures for the country as a whole are not available.

Processing and marketing

Although large areas of South Africa are climatologically suitable for carp farming, actual production will be regulated by market constraints. Presently, carp raised in ponds are mainly used as rations for farm labourers. Limited quantities are sold in urban areas. There is also a small demand for live carp by the Jewish community. One supplier in the Transvaal is active in this field.

No processing other than cleaning and gutting is performed. In 1975 a marketing cooperative for warmwater fish farmers was established in the northern Transvaal but was soon dissolved due to marketing difficulties.

Carp does not lend itself to instant cooking and preparation methods, but when properly prepared it makes a tasty dish. In a processed form (eg smoked) it may have higher potential to penetrate the local market.

Research needs

1. Development of techniques for the overwintering of broodstock to ensure adequate fingerling production at the onset of the summer growing period.

2. Identification of areas most suitable for carp culture, taking into consideration other land uses such as agriculture, conservation of indigenous fauna and flora, etc.

3. Adaptation of available techniques of prophylactic and therapeutic treatment of diseases to local conditions.

4. Investigation of means of supplementing fish meal in carp rations with locally available feedstuffs, especially agricultural wastes.

5. Examination of means of integrating carp farming with agricultural practises in order to ensure a sensible use of water.

6. Evaluation of the economics of carp farming in terms of construction costs, working capital and market prices for the product.

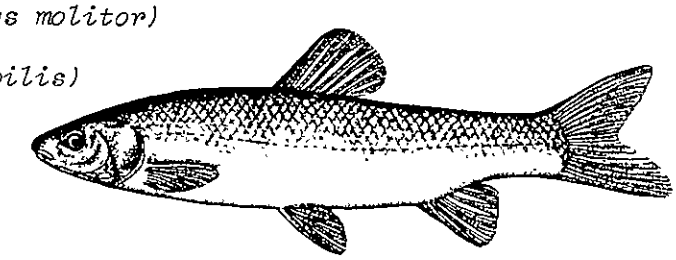
7. Evaluation of the market potential of carp in South Africa in order to guide future management and production policies.

C.20 GRASS CARP *(Ctenopharyngodon idella)*

C.21 SILVER CARP *(Hypophthalmichthys molitor)*

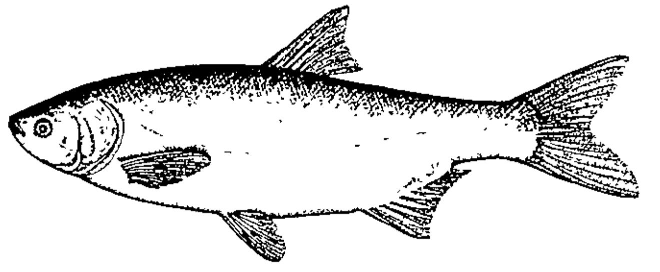
C.22 BIGHEAD CARP *(Aristichthys nobilis)*

These species are mainly grown in polyculture. They are almost unknown to the local market. Their market potential in the fresh form is fair.



Grass carp

Propagation



Silver carp

Propagation techniques are available and adapted to local conditions, although physiological ripeness must precede artificial inducement to spawning. These species will almost certainly not breed in the wild in South Africa and would therefore not pose a danger as invasives.

Nutrition

All three species feed on plants or plankton. The grass carp can utilize pelleted food. Food conversion efficiency is low.

These carps require eutrophic conditions, which pose the problem of nocturnal oxygen depletion. They are used in stagnant pond polyculture.

Research needs

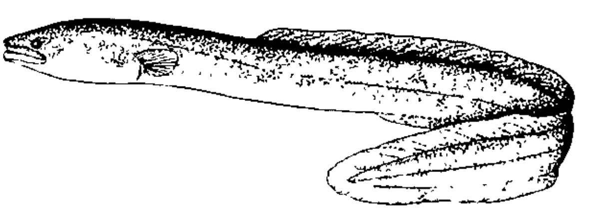
1. Development of techniques for the hormonal inducement of gametogenesis.

2. Evaluation of the market potential of these species in South Africa.

3. Development of processing methods in order to achieve wider market acceptability.

4. Investigation of the potential of these species in polyculture.

C.23 AFRICAN FRESHWATER EEL *(Anguilla mossambica)*



Approximately 1 tonne of this species is taken annually. Eels are marketed in fresh, frozen or smoked forms. The price presently paid to fishermen ranges between R5,00 and R18,00 kg^{-1}. The biology of this species is poorly documented. Like the European eel, it is carnivorous. The freshwater eel has a wide tolerance of salinity (0 - 35g l^{-1}) and temperature (3°C - 36°C), and tolerates ammonia levels of 0,1 mg^{-1} and nitrate levels of 4 mg^{-1}.

Freshwater eels have not been successfully reared from the egg as yet. Juvenile eels in either non-pigmented or pigmented form must therefore be caught from the wild for on-growing. Local stocks of juvenile eels are moderate but are not large and would probably not stand intensive long-term exploitation as is practised in Japan and Europe. Preliminary growth trials have shown that growth rates in captivity are slow. Of the four species of freshwater eels in southern Africa *(A mossambica, A marmorata, A bengalensis labiata* and *A bicolor bicolor)*, *A mossambica* normally comprises more than 90% of the juvenile eels caught in eastern Cape, Transkei and southern Natal estuaries. Until techniques can be found for accelerating its growth in a culture environment, the future of this local species for aquaculture in South Africa is unknown.

C.24 SPIRULINA *(Spirulina platensis)*

Blue-green algae of the genus *Spirulina* have been eaten by people in certain parts of the world for centuries. Amongst the new foods found by the Spanish conquistadors in the New World was an alga which the Aztecs knew as tecuilatl. This was harvested from Lake Texcoco, dried and marketed throughout Mexico. Tribes around Lake Chad also eat cakes of dried blue-green algae, most probably a *Spirulina* species. More recently spirulina has been strongly promoted as a health food, with one of the main entrepreneurs claiming some remarkable cures for a variety of health problems.

Potential for aquaculture

Spirulina shows more promise in aquaculture than any other planktonic alga at present. There are two factors responsible for this. The first is that *Spirulina* can be harvested relatively easily, while harvesting planktonic green algae is currently a major component of production expenses. The second and possibly more important factor is that spirulina has a higher protein content (65-70%) than green algae and that the cell wall is not indigestible as is the case with green algae. Thus the product does not require further processing to rupture the cell wall before it can be used.

Potential market

Currently spirulina is distributed through the health food market, where the sun-dried product fetches between R100 and R200 kg^{-1}. This market could expand, as it is limited to the relatively higher socio-economic group. The high protein content of the product would make it a valuable food for human consumption or for stock feed if production costs were sufficiently low, but currently this is not the case.

Culture conditions

Spirulina grows well in Zarouk's Medium, but it is essential to use this medium at full strength to avoid contamination by *Chlorella*. Spirulina thrive between 20° and 40° C, but temperatures in excess of 42 °C or below 5°C are lethal.

Under natural conditions a production of 12 000 to 30 000 kg of dried spirulina per hectare per year can be realized. Under optimal culture conditions this production level can be doubled.

ACKNOWLEDGEMENTS

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The drawings were skilfully executed by Mrs E Tarr, Mr D Voervelt and Prof M Smith.

SUGGESTED GENERAL READING

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GLOSSARY OF SPECIAL TERMS IN AQUACULTURE

ACCLIMATIZATION: the adaptation of organisms to a new environment or habitat or to different climatic conditions.

ACTIVATED SLUDGE PROCESS: a system in which organic waste containing particulate sludge on which a rich biota of aerobic micro-organisms has developed is continually circulated in the presence of oxygen. In an activated sludge plant, organic matter is rapidly oxidized and nitrogenous wastes mineralized to ammonia, nitrite and then to nitrate.

AERATION: the mixing of air and water by wind action, by paddlewheel or by air forced through the water.

AEROBIC: a process (eg respiration) or an organism (eg a bacterium) that requires oxygen.

ALKALINITY: the power of a mineral solution to neutralize hydrogen ions, usually expressed as equivalents of calcium carbonate.

AMMONIA: the gas NH_3, highly soluble in water, which is toxic to fish in the molecular or un-ionized form (NH_3 or NH_4OH), especially at low oxygen tensions. At high pH values the ratio of un-ionized to ionized ammonia (and hence the toxicity) increases dramatically.

AMMONIA NITROGEN: also called total ammonia. The summed weight of nitrogen in both the ionized (ammonium, NH_4+) and molecular (NH_3) forms of dissolved ammonia (NH_4-N plus NH_3-N). Ammonia values are reported as N (the hydrogen being ignored in analyses).

AMMONIUM: the ionized form of ammonia (NH_4+).

ANAEROBIC: a process or organism not requiring oxygen.

ANOXIA: reduction of oxygen in the body to levels that can result in tissue damage.

AQUACULTURE: culture or husbandry of aquatic organisms.

BALANCED DIET: a diet that provides adequate nutrients for normal growth and reproduction.

BRACKISH WATER: a mixture of fresh and sea water, usually with total salt concentrations between 0,5‰ and 30‰.

BROODSTOCK: adult fish retained for spawning.

BUFFER: chemical that, by taking up or giving up hydrogen ions, sustains pH within a narrow range.

CAGE CULTURE: the culture of aquatic organisms in cages either suspended from the water surface or attached to the substratum. There is usually a free exchange of water to wash away toxic metabolites and, in some cases, to carry in food.

CARRYING CAPACITY: the population, number or weight of a species that a given environment can support for a given time.

COLDWATER SPECIES: generally, fish that spawn in water temperatures below 13°C (eg trout and salmon).

DECHLORINATION: removal of the residual hypochlorite or chloramine from water to allow its use in fish culture.

DENITRIFICATION: a biochemical reaction in which nitrate (NO_3-) is reduced to NO_2-, N_2O and nitrogen gas (N_2).

DENSITY INDEX: the relationship of fish size to the water volume of a rearing unit, calculated by the formula:

$$\text{Density index} = \frac{(\text{weight of fish})}{(\text{fish length} \times \text{volume of rearing unit})}$$

DISSOLVED OXYGEN: the concentration of elemental oxygen, O_2, in solution under existing atmospheric pressure and temperature.

ENVIRONMENT: the sum total of the external conditions that affect growth and development of an organism.

EXTENSIVE CULTURE: rearing of fish in ponds with lower water exchange and at low densities; the fish utilize primarily natural foods.

FECUNDITY: the number of eggs in a female spawner.

GONADOTROPIC HORMONES: hormones which act on or stimulate the gonads.

HYBRID: progeny resulting from a cross between parents that are genetically dissimilar.

INTENSIVE CULTURE: rearing of fish in densities greater than can be supported in the natural environment by utilizing high water flow or exchange rates and by supplemental feeding of formulated feeds.

METABOLISM: process whereby nutritive material is built up into living matter or protoplasm is broken down into simpler substances for special functions.

MILT: sperm-bearing fluid.

MONOCULTURE: the culture of one species at a time in a given holding facility.

NITRIFICATION: a process by which nitrifying bacteria oxidize ammonia first to nitrite (NO_2-, toxic to fish), and then to nitrate (NO_3-, non-toxic to fish).

NUTRIENT: a chemical used for the growth and maintenance of an organism.

NUTRITION: the sum of the processes whereby an animal (or plant) takes in and utilizes food.

PATHOGEN: a specific cause of a disease.

PROPHYLAXIS: measures designed to preserve health and prevent the spread of disease.

POLYCULTURE: the culture of more than one species at a time in the same holding facility.

RECIRCULATING SYSTEM: a system in which all or part of the water is passed from rearing units through reconditioning units such as settlement tanks and biological filters, and back again to the rearing units.

RATION: a fixed allowance of food for a day or other unit of time.

RECONDITIONING TREATMENT: treatment of water to allow its re-use for fish rearing.

SEA WATER: water containing from 30 to 35‰ total salts.

SEDIMENTATION POND: a wastewater treatment facility in which settleable solids are removed from effluent derived from a hatchery and rearing unit.

SELECTIVE BREEDING: selection of broodstock in a breeding programme to produce offspring possessing certain desired characteristics.

SINGLE-PASS SYSTEM (THROUGH-FLOW SYSTEM): a system in which water is passed through the fish rearing units without being recycled and then discharged from the hatchery or rearing facility.

SLUDGE: the mixture of predominantly organic solids and water that is drawn off a settling chamber.

STABILIZATION POND: a simple wastewater treatment facility in which organic matter is oxidized and stabilized (converted to inert residue).

STOCK: a group of fish that share a common environment and gene pool.

WARMWATER FISH: fish that normally spawn at temperatures above 16°C (eg tilapia, sharptooth catfish).

WATER TREATMENT: the cleansing of water, which may be carried out in three stages: primary, removal of a substantial amount of suspended matter, but little or no removal of colloidal and dissolved matter; secondary, biological treatment methods (eg by stabilization or aeration); tertiary (advanced), removal of chemicals and dissolved solids.

CLASSIFICATION OF PLANTS AND ANIMALS MENTIONED IN THE TEXT

Phylum	Cyanophyta - blue-green algae
Family	Oscillatoriaceae
	Spirulina platensis - spirulina
Phylum	Angiospermae - flowering plants
Family	Aponogetonaceae
	Aponogeton platensis - waterblommetjies or water hawthorn
Phylum	Mollusca - snails, bivalves and relatives
Class	Bivalvia
	Crassostrea gigas - Pacific oyster
	Choromytilus meridionalis - black mussel
	Perna perna - brown mussel
Class	Gastropoda
	Haliotis midae - abalone or perlemoen
Phylum	Crustacea - crabs, crayfish, prawns and relatives
Order	Decapoda
	Penaeus monodon - marine prawn
	Macrobrachium rosenbergii -freshwater prawn
	Artemia salina - brine shrimp
	Cherax tenuimanus - marron
	Scylla serrata - marine crab
Phylum	Chordata - chordates
Class	Osteichthyes - bony fishes
Family	Chanidae
	Chanos chanos - milkfish
Family	Salmonidae
	Salmo gairdneri - rainbow trout
	Salmo salar - Atlantic salmon
Family	Cyprinidae
	Ctenopharyngodon idella - grass carp
	Hypophthalmichthys molitor - silver carp
	Aristichthys molitor - bighead carp
	Cyprinus carpio -common carp
	Labeo umbratus - moggel
Family	Ariidae
	Galeichthys feliceps - sea catfish
Family	Schilbeidae
	Eutropius depressirostris - butter catfish

Family Clariidae
Clarias gariepinus - sharptooth catfish

Family Ictaluridae
Ictalurus punctatus - American channel catfish

Family Scophthalmidae
Scophthalmus maximus - turbot

Family Soleidae
Solea solea - Dover sole
Austroglossus pectoralis - Aqulhas sole

Family Sciaenidae
Argyrosomus hololepidotus - kob

Family Haemulidae
Pomadasys commersonnii - spotted grunter

Family Sparidae
Acanthopagrus berda - river bream
Diplodus sargus - blacktail
Rhabdosargus holubi - Cape stumpnose

Family Cichlidae
Tilapia rendalli - redbreast tilapia
Oreochromis mossambicus - Mocambique tilapia

Family Mugilidae
Mugil cephalus - flathead mullet

Family Siganidae
Siganus canaliculatus - whitespotted rabbitfish
Siganus sutor - mottled rabbitfish

Class Reptilia
Family Crocodylidae
Crocodylus niloticus - Nile crocodile

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