MICROCOMPUTER BASED FISH FARM PRODUCTION PLANNING

The development of a microcomputerised data recording and production decision support system for individual fish farmers and its implementation on a fresh water trout hatchery.

Ph.D Thesis

by

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To my parents John and Aristea.

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ABSTRACT

In order to develop a system that could provide fish farmers with information to monitor stock performance and plan for timely production, a computerised recording system was designed and tested on a trout hatchery in Scotland.
It facilitated routine data capture on site with a small hand-held computer, programmed in BASIC language, which subsequently downloaded the data to a central desk-top microcomputer for further processing. Both direct and long-distance transmission via the telephone network using modems were possible.
The LOTUS 1-2-3 general purpose software package, running on the microcomputer, was customised using 'macro' commands to accept the transmitted data and create files for storage on 'floppy' or 'hard' magnetic disks. Further information could be calculated and graphs and summary reports for stock control could be generated at will.
Other customised LOTUS worksheets were developed to allow identification and access of specific historical data in order to calibrate regression equations and provide growth predictions for particular fish types.
This information combined with cost and pricing details was further utilised by a linear programming package. Guidelines on optimum policies were formulated and sensitivity analyses could be performed.
This production information system was implemented on the IBM-PC and the OLIVETTI M24 desk-top microcomputers and as field devices the SHARP PC 1500A and the HUSKY HUNTER were used.
Since existing technology and "off-the-shelf" software were utilised, the developed information system can be easily adjusted to suit the individual needs of different fish farms. However, the most important requirement for successful implementation would be the commitment and enthusiasm of the fish farm manager.

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INTRODUCTION

The ultimate aim of this study was to initiate and apply the idea of a **microcomputer based production management information system** in the business environment of a fish farm, operated efficiently by the fish farmer with minimal involvement of outside expert assistance.

Fish farming is not a typical agricultural operation. Production systems and designs are usually adapted to specific circumstances that nobody knows better than the farm manager. It is proposed that if an investment in the necessary equipment and software is made and the fish farm manager is prepared to devote some time to become familiar with the software and microcomputer usage, a computerised information system tailored to the particular farm needs can be developed.

Although sophisticated techniques have been devised for planning and analysis of agricultural businesses (simulations, linear programming, etc.), there is a need to adapt these for fish farm use and establish a system through which the manager would be able to receive rapid and frequent 'images' of the current state of the business.
An up to date picture of the strong influence of biological and environmental elements and of management on fish growth should be available as well as information on the most rewarding production and marketing plan. Thus, likely developments of the production processes in the near future could be pinpointed.

Now that the technology exists at an affordable price, immediate, on site, interactive and low cost computing is a practical recommendation and a management information system based on this technology can be made available, operated in the fish farm office with a relatively small amount of training and contributing positively to the real decision environment of the manager. Essentially, all farm planning and controlling activities must be left to the farmer who should be directly exposed to the challenges of a clearly pictured fish farming system.

Timely, accurate information is the starting point for any successful decision making. The organisation therefore, of a sound data system -or rather subsystem in the context of an integrated management information system- must precede all other efforts.
The data recording system described in this study was designed to minimise most of the burden of physical data capture and to input into a computerised system which further evaluated, analysed and subsequently stored the records in the form of organised electronic files on magnetic 'floppy' or 'hard' disks. Moreover, the assembled data was used, firstly, by a report generating programme which produced reports on stock status, availability and mortality as well as for insurance purposes. Secondly, a programme for forecasting model generation was created. It could automatically process selected data and generate growth models for each precise type and size-range of fish for various seasons and in relation to different stock management policies, such as feeding regimes. The manager could generate growth, food and water need forecasts at will and examine the influence of various factors upon stock performance. Thirdly, a computer-based optimisation technique was implemented. It accepted all the information about the various production alternatives open to the farmer, the expected growth under the different methods and during the various seasons, the existing resources-constraints and their costs as well as pricing information and market opportunities. It provided the economically optimum policy which should minimise costs and maximise revenue, accompanied with a full justification of the reasons why 'the computer' selected that particular course of action.

The outlined management system took advantage of the most recent information technology at an economically feasible scale

for the average fish farm.
Its design was based on easy to use and flexible 'off the shelf' software with only a small additional amount of custom built programme encodement. Clear documentation of assumptions is provided in order to enable any adjustments needed for different fish farms to be carried out.
The hardware selected, apart from being able to cope with specific software needs, should also comply with such basic criteria as long term maintenance support by the supplier, existing wide user base and reasonable costs.
Although the system was built around specific hardware this is by no means restrictive. As far as the system's qualities are satisfied other -possibly better- hardware can be used at own choice.
Nevertheless, because of the number of initially successful microcomputer systems which subsequently have disappeared from the market, the choice made for this project, was of the most popular hardware systems (IBM and its compatible OLIVETTI) using the most popular software system (LOTUS 1-2-3), a "mainstream" philosophy.

A pilot computerised data system which dealt with environmental data, data on production management and stock performance coupled with stock reporting facilities, a forecasting model and an optimisation model, were applied to a fish hatchery and the results evaluated.

FIRST CHAPTER

A microcomputer based data record-keeping system for the individual fish farm.

CONTENTS

SUMMARY

The basis of any effective business planning is good information. Fish farmers in particular need to adapt their production policy according to the performance of their stock and changes in the market conditions.
Accurate knowledge of stock performance requires detailed record keeping but this can be time consuming and frequently is made to take second place to other tasks in the day-to-day running of the farm.

To minimise collection time and errors, a microcomputer based system was tested which recorded environmental and stock data in a standard form presenting the results in a daily, weekly or monthly format as required with all arithmetic calculations completed by the computer.
Data was stored on electromagnetic disks and as hardcopy in files. This is adequate for efficient record keeping and reduces the required man-hours significantly, but more importantly, accurate data are made available easily, at any time, for further analysis and business planning.

The microcomputers chosen as field data collection devices were firstly, the Sharp 1500A pocket computer, which was the lowest-priced, suitable machine, and secondly, the HUSKY HUNTER, an expensive but environmentally rugged machine.
Programmed in BASIC language they held up to one week's data, collected daily, and performed calculations on these.
Data were downloaded, via their interface ports, to a simple printer to give a system adequate for small farm needs. In addition successful downloading of data to an IBM PC or to an OLIVETTI M24 desk-top computer, either by direct connection or over long distances via the telephone network with the use of modems, was used to establish a system where several data collectors, used in remote locations, could feed information to a central management office.
After transmission, LOTUS 1-2-3 software was used to analyse and store the data.

1. BASIC CONCEPTS OF INFORMATION SYSTEMS

1.1. Data and information.

For the purposes of this study **'data'** is regarded as low-level, elemental, relatively unprocessed quantitative representation of facts, observations or occurrences.*
Examples would be:

- readings of water temperature,
- measurements of water pH,
- dissolved oxygen,
- number of feeds per day,
- amount of fish biomass and number of fish in a container (eg. a fish tank).

'Information' results from the processing of these data. If it is of proper quality, it facilitates decision making and planning on the part of management.

By **'data processing'** we mean the assembly, distillation, analysis, comparison, summary, tests and rearrangements applied to data giving to it a meaningful form in order to extract useful information from it.
Examples would be:

- the Summer water temperatures on average were lower this year than during the similar period last year,
- when the dissolved oxygen content of water drops, fewer feeds per day are required by the fish.

Information resulting after a first attempt to process data may be processed further to give even higher level information, which is helpful for more difficult tasks within the decision making responsibilities of a fish farm manager.

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* Data may also be presented in the form of words, or codes composed of numerical and alphabetical characters, or special symbols (eg. fish sex: ♀), or by any type of graphics.

For example, such information may reveal the effect of fish stocking densities on fish food conversion efficiency, or the effect of water temperature on fish growth rates.
These quantified influences of one factor upon another are necessary for management to carry out difficult and complex tasks, such as predicting and planning future farm production. Sometimes, however, they need sophisticated techniques to be used for their estimation, and certain assumptions to hold in order to interpret the results in a certain useful way.

1.2. Management Information System (MIS).

As we move from the very low level data needs towards higher and higher levels of information needs, one requirement becomes apparent: the existence of a system capable of providing the appropriate person (fish farm manager) in the business with the sort of information (strategic-long term, or tactical-operational-short term) and feed-back information required in order to take decisions within a particular area of responsibility. That is, it is necessary to organise a sound **'fish farm management information system'**.

1.3. Decision areas.

Although no one decision should be taken in isolation, within the decision making complex of the manager various related responsibilities may be grouped into **'decision areas/centres'**.
The decision centre which focuses the attention in this study is production planning and control. The manager tries to make optimum use of the on-farm resources and the external opportunities which appear. The best possible mix of production possibilities must be defined, which will allow the business to come closest to the short or long run objectives. The manager attempts to secure that what actually happens is as close to the production plan as possible and modifies the corrective actions that should be taken whenever necessary.

Other decision centres would be: financial planning and control, marketing of fish farm produce, managing the farm personnel, etc. The various decision areas are constituent parts of the complex decision making duties of the manager and may be focussed in even more detail by introducing time as a criterion. Decisions may then be distinguished into short, medium, or long term.

1.4. Developing an information system.

Farm management must not only generate plans for the business according to specified objectives but must also be responsible for implementing the selected plan, evaluating its performance continuously and be able to make adjustments when necessary. These functions of management require a constant flow of information about the effects of its actions. This information must be of the proper value and quality in terms of its brevity, accuracy, timeliness and volatility. It should be adequate to enable effective and immediate action to be taken and presented in a form which is easy to understand and use.

To organise an effective management information system on a fish farm, the data flow must be followed in the opposite order, ie. first, a close look of the fish farm business as a whole must be taken and the decision areas within the responsibility of the fish farm manager have to be defined. Then the information requirement to support such decisions has to be specified and, finally, the data elements which must be gathered and analysed in order to give management this information must be identified.
But a management information system should be planned also in terms of the techniques it will use to carry out such duties. Namely, how are the data elements collected from the field, how are these data processed and how is information manipulated and presented to support management decisions?

When developing an information system for fish farmers the sequence of analyses should thus be as follows:

-- Study of the fish farm environment and operations.
-- Definition of the decision areas / responsibilities.
-- Selection of the techniques to be used for decision support.
-- Listing of the information needs of the above techniques.
-- Decision on how such information should be generated.
-- Definition of the data needs to provide the information.
-- Decision on how this data is to be collected, stored, and accessed. (Recording system - data base...)

The present study was concerned with decisions relevant to rational planning and controlling of the fish farm production operations. For these purposes, in the sector of traditional agriculture there is enough experience and knowledge in applying techniques, such as budgeting, linear programming, annual budgetary appraisal, or system's simulation. Since these techniques could prove suitable in solving fish farming problems, linear programming was applied and evaluated.
Its inclusion in the pilot fish farm information system did affect the decisions on the type of information requirements and subsequently, on the data records to be utilised.
The most important factors which affect fish production should be identified for subsequent recording in order to facilitate prediction of their influences on the optimisation of input use in the process of fish production.

2. IDENTIFYING THE NEED FOR RECORDS

2.1. More attention on farm records needed.

Farm management has been intensified by the rapid increase in the scale of operations, the degree of specialisation and commercialisation according to a pace set by technological change. Following this pace, data demands for more effective decision support have grown considerably.
Although accurate and valid data removes much of the uncertainty which surrounds operations and its use in efficient decision support is widely acknowledged, the attention paid by fish farmers to providing it is usually small.

An important reason for fish farmers not keeping records is that the importance of having past data on the different factors which affect the production system is underestimated. Recording is a difficult task to be practised under the harsh fish farm environment and records that are kept should be profitably used. Recording incurs costs as well as providing returns. The costs consist primarily of the value of the time and effort of the fish farmer and the labour force, which could have been used for other work on the farm or for leisure (opportunity cost).

2.2. The cost of obtaining data.

The law of diminishing returns applies also to the value of time spent in recording. There is a point where the further records, extra details, or additional accuracy are not worth the extra costs incurred to provide them (Barnard, C.S. and J.S. Nix, 1979).
The maximum gain from obtaining more data may be decided by balancing the extra costs of gathering it against the extra benefits stemming from superior problem solving. However, approximating this optimum point in practice is far from easy. The assessment of the likely benefits arising from more relevant, timely or accurate data is related to the importance

and the degree of urgency of the problem to be solved and this is a subjective criterion.
On the other hand, it is difficult to foresee and therefore evaluate the side-benefits of accumulating data other than that related to the specific objective/problem. Thus, in theory, the view that the law of diminishing returns does not apply to the extra data could be supported, since the last bit of it may prove to be the most valuable of all (Barnard, C.S., 1975). However, in practice, there is no point in collecting and producing information that is not utilised when making decisions. Likewise, any information produced should be used properly. After establishing a clear idea of the purpose for which data is needed, priorities must be established in determining what to record, and a sufficient degree of flexibility retained in order to permit new data to be collected if the need arises (Barnard, C.S., 1975).
Serious consideration must be given to data quality in terms of accuracy, relevancy, compatibility to the purpose in hand and comprehensiveness.

2.3. Why record the data ?

Through up-to-date records it is possible to identify the current state of the particular fish business's affairs, its environment and operations. Key success functions, like the fish food conversion rate (FCR), or the fish growth rates, are identified and then subsequently measured, so that the farm's performance and capabilities in these key success areas are assessed.
The historical records, held in a "data bank", can be compared with current figures to assess performance at any point in time. These records reflect the particular conditions of the individual farm and the quality of its environment, labour and management. Sometimes such information may need to be 'normalised' ie. adjusted on the basis of expectations in a 'normal' future year.

Since decision support is the major role of data and information, what needs to be recorded depends on the decision purpose. Three main such purposes suggest what records need to be kept (Barnard, C.S. and J. S. Nix, 1979):

- **to check on performance.** It is only through good records that a check can be made on how performance has compared with past plans.
- **to guide tactical decisions.** Records should reveal the degree of technical efficiency of the various production operations and highlight weaknesses that must be removed as part of short-term management.
- **to provide planning data** for strategic, long-term decisions when making or revising future plans. Planning involves selecting the right planning technique which utilises the data held in the past records.

2.4. The qualities of data records.

Good farm records should:

- serve a definite purpose,
- be easy to complete,
- be up-to-date (Barnard, C.S. and J.S. Nix, 1979).

Successful data recording involves decisions on what data to collect, how to capture it, from whom and by what means, as well as how to process and present it so that any action needed can be taken as early as possible.

Overall the data recording system should comply with the targets of the information system on the farm, ie. to provide the manager with exactly what information is necessary to make the appropriate decisions. Moreover, it should be flexible and be kept under continuous review in order to make changes should the need arise.

The contemporary progress of Information Technology provides an extremely wide area of applications and its use as an aid in establishing a recording system for individual fish farms might prove revolutionary. With a steadily increasing capacity to handle data, the recording costs are progressively overshadowed by the forthcoming benefits.

2.5. The unique nature of the fish farm.

There are many individual variations in design and product mix of different fish farms, giving each farm a uniqueness which creates problems in deriving generalised planning models. Farm designs are major cost and productivity determinants and, in practice, farms operate on a combination of systems the evolution of which under new, improved designs is a continuous process.

Even so, a flexible recording system can be designed for farms in general, which defines what data to collect, how to capture it and by what means, as well as how to process and present it. The system may be adjusted to the unique identity of a farm in order to supply the manager with representative data which suit the particular decision making needs.

3. CATEGORIES OF RECORDED INFORMATION

The recorded information may be classified into two major categories: **internal** and **external** information.

As the terms imply, they are concerned with those factors inherent to the aquaculture facility itself or those which affect it but come from the real world outside in which the fish farm operates. In other words, a fish farm holding is regarded as an open system accepting influences from the environment which surrounds it.

The same information may also be classified into 'historical' (past production cycles, past market situations...) and 'current' (present day information). Both are equally important when decisions are to be taken.

3.1. Information external to the fish farm.

External information, be it historical or current, in direct relation to the fish farm operational environment can be considered as:

- the state of the industry home and abroad.
- Government measures and/or legislation regulating or promoting the industry and its markets.
- Market competition nationally or internationally.
- Supply and demand characteristics of the consumer markets into which the fish farm directs its produce (eg. customer preferences, pricing policies, distribution channels, purchasing patterns through time, etc.).
- Technological innovations and breakthroughs into problematic areas of operations.

Some of the external information will be available in a routine form through industry related or University research publications, Governmental statistics, or international organisations' statistics (FAO).
Others, however, are not provided so effortlessly and demand the continuous awareness of the manager, for example a technological breakthrough made by a competitor.
The manager's general interest and critical view of the industry are needed to predict future trends and harness opportunities yet unforeseen by others in the industry.

3.2. Information internal to the fish farm.

The fish farm's internal information concerns the production status of the holding and also its financial status.
Financial status information can be obtained and analysed using wellknown and tried techniques and forms common in all agricultural businesses, like cash flow analyses, trading profit/loss accounts, balance sheets, flow of funds statements, etc., which describe the present and future capital position of the business.

This is not so simple, however, when the esoteric production affairs of a fish farm must be described. These include physical (environmental, biological) parameters as well as the management of production operations.

3.2.1. Fish farm production data.

In any aquaculture facility the following identifiable major components affect its productivity (Klontz, Brock, McNair, 1978):

- fish (species, age, size),
- water (quality, flow rate, dissolved oxygen, temperature),
- container (cage, tank, earth pond, concrete raceway),
- nutrition (quantity, quality),
- management (eg. feeding schedule, grading policy etc.).

Each has one or more interactions with each of the others and each consists of several unique factors that may not necessarily be present individually at any one particular facility.
The factors associated with each major component can, in most cases, be quantified. Also, each factor must be considered as having either a cause or an effect role in relation to one or more other factors. Altering one of them in an aquaculture facility may have indirect as well as direct effects on one or more major components.

3.2.2. Environmental factors affecting fish productivity.

In intensive aquaculture systems the increase in fish body size depends on the energy and nutrients made available to the fish and the way that these are distributed and utilised within the fish body under the influence of environmental and biotic parameters. Understanding of how the fish react to the environmental effects expressed as food consumption, metabolism and growth is necessary in order to realise economic benefit from fish production.

Fry (1971) classified the nature of environmental effects into: lethal, controlling, limiting, masking and directive.

Lethal factors restrict the range of the environment in which the organism can exist. Beyond this range metabolism is destroyed.

Controlling and limiting factors influence the metabolic rate. The controlling factors, such as temperature, impose minimum and maximum levels of metabolism through their influence on the rates of chemical reactions.
However, what the controlling factors allow may be constrained by the presence of one or more limiting factors which operate by restricting the supply or removal of materials in the metabolic chain: for example, low levels of oxygen, reduced food amount and poor quality of the diet, or inefficient removal of waste products (carbon dioxide, nitrogenous excreta etc.).
Thus, the limiting factors lower the maximum metabolic rate allowed by the status of the controlling factors. (Eg. as a result of decreased dissolved oxygen at high temperatures appetite for many species is decreased.)
Various factors may act indirectly as limiting. Suspended solids and solutes displace oxygen, thus restricting its supply. They may in addition damage the gills and interfere with gas exchange. Generally, limiting factors which are in excess of their limiting levels are neutral unless very high levels of them are reached that may be toxic to the fish (eg. bubble disease from excess oxygen).

Masking factors are exploited by the fish in order to achieve and maintain internal organic regulation. Their effects emphasise the importance of water quality for good production. For example, salinity can be considered as a masking factor since changes in it induce regulatory costs to the fish.

Directive factors trigger physiological responses. For example, the effects of photoperiod on the pituitary gland and the overall influence of environmental periodicity which channels metabolism into the appropriate response/strategy. The complex effects of the multitude of environmental stimuli that act as directive factors are reflected in a fish's activities and behaviour.

The strict categorisation of factors is not always possible. So, water pH may be thought of as a masking factor requiring internal regulatory responses, but also as a limiting factor, since low pH probably affects deleteriously the blood/oxygen saturation kinetics and indirectly deprives oxygen availability.
Controlling and limiting factors may combine in a way to become lethal. This may happen, despite the regulatory mechanisms of the fish, in cases when the limitation is too severe to permit the level of metabolism imposed by the status of the controlling factors.

Clearly, for given site characteristics, environmental manipulation -whenever feasible- could potentially increase productivity if backed with a proper understanding of the fish responses.
Since manipulation of the water conditions is a potentially expensive method of increasing production, increased and/or more efficient production may be dependent on optimum use of the naturally occurring environmental variability (Webb, W. P., 1978). This may be achieved by a combination of experience and production planning techniques.
Usually, there is a chance to manipulate some of the limiting factors in order to enhance the fish growth responses to other favourable conditions. For example, fish can be often graded and fed suitable diets at the right amounts and feeding frequencies and 'comfortable' stocking densities may be used.
Therefore, it might be possible to programme growth by stock management adjustments in order to exploit the uncontrollable natural variation towards the desirable product timing and the economic target.

3.2.3. Biotic factors affecting fish growth.

When considering metabolism and growth of fish the effects of biotic factors need to be examined in addition to the environmental ones. Fish species, genetic composition of the particular strain, the current body size, age, sex, disease and past history are all responsible for variability in the responses to environmental factors.
Fry (1971) stressed that in each locality, with its unique environment, a species is subject to different genetic selection pressures. Additionally, in the short run, the physiological state of the organism is continuously being modified by its day-to-day environmental history -"conditioning of the individual by its experience"- which possibly causes irreversible changes of most physiological responses.

In order to benefit from the interactions among the environmental and biotic factors in a growth process there is the need for proper understanding of their relationships. This requires research in different species under a multitude of different environments.
In experiments, factors which do not participate directly in the relationship under examination are usually restricted to steady state situations, which is untrue for real farming. Fish are acclimated to the experimental conditions but acclimation* might not effectively condition the fish to long-term cyclic changes, such as the annual cycle of day length. Experimental fish species may be selected according to specific life histories but in commercial farming fish origins vary.
As a result of this multiplicity of possible combinations of seasons, locations, fish genetic qualities, etc. there is still a large gap between theoretical suggestions and results in

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* As opposed to "acclimation", which describes the short-term adaptation, the term "acclimatisation" is used for the long-term, genetic adaptation of a species introduced to a new environment.

commercial fish production. The ideal of a reproducible response which can be evoked at any time is impossible to attain in practice and descriptions of metabolism require statements of life history details, such as latitude and time of year, that are not usually provided (Fry, F. E. J., 1971).
However, the information that experimentalists are not in a position to provide may be supplemented by the farm records. Combining scientific knowledge with the actual facts of the commercially cultivated fish may bridge the information gap.

4. IMPORTANT RELATIONSHIPS AFFECTING THE ECONOMICS OF FISH GROWTH AND INPUT UTILISATION

4.1. Food consumption and growth.

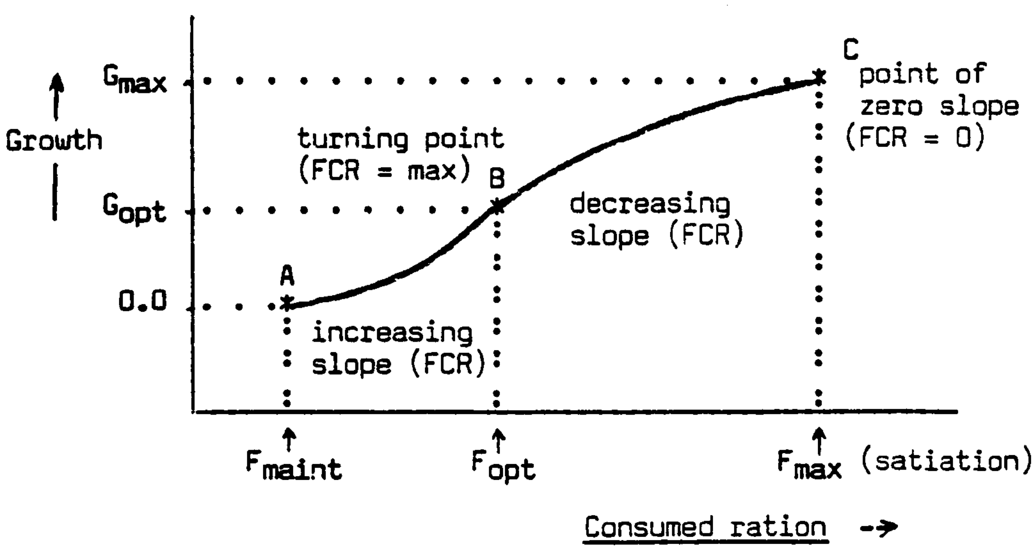
From the fish producer's point of view, all the effects of the major components in the holding should be combined towards materialising the production objective.
Output depends on the quantities of different inputs used in the production process and the rationally thinking fish farmer should seek to optimise the use of them for more, better quality and timely production. Therefore, the major aim would be to maximise the efficiency of converting food -the main, costly input- into fish flesh -the output.

According to agricultural economic theory, if successive units of an input are added to a production process, given constant quantities of the other participating inputs, a point is eventually reached where the addition to the product per each extra unit of that input will decline -the law of diminishing marginal returns (Bishop, C. C. and W. D. Toussaint, 1958).
This concept should also be true in fish production under the specific environmental complex and culture system of a fish farm. A **production function** can be expected to apply between food (input) and fish flesh produced (output) for a period of time which is small enough to preclude wide variations of the

environmental parameters and to avoid technological change (modification of tactics or culture system designs).
During a growth period the farmer should seek to attain maximum production per unit of input/food, ie. maximum growth efficiency in terms of food utilisation. Given that food is by far the dominant cost element, this could substantiate least cost production per unit of output.
The fish should, therefore, be on the food vs. growth curve at the point where the marginal product of food, that is, the addition to total production (fish) resulting from the addition of one extra unit of input (food) assuming constancy of all other inputs, is maximised. Beyond this point and under the law of diminishing marginal returns, the marginal product of food will diminish until zero. Further it becomes negative as the fish cannot eat all their food, which is partly wasted.

The growth vs. food curve is 'S' shaped as shown below:

Fig. 1. The Growth vs. Food consumed curve.



This curve applies between G (growth) and F (food eaten) during each growth period (Rafail, S. Z., 1968, 1969). The shape (slopes) and location of it relative to the axes' scale depends on such factors as:

-- the species, their genetic composition and past history,

-- the current fish average size,

-- the environmental conditions which prevail during the growth period under consideration (especially water temperature and food energy content).

The slope of the above curve represents the food conversion efficiency (FCR = G/F), or, in the terminology of agricultural economics, the marginal growth product of consumed food.
Three points (A, B and C) are noted on this curve which define a segment (AB) of increasing growth with increasing FCR (slope), and a segment (BC) of increasing growth but with decreasing efficiency in food terms, FCR (slope).

Point A corresponds to maintenance ration (F_{maint}) which is needed to maintain the physiological functions of the fish body without any energy allowance for the metabolic process of growth.

Point B is the curve's "turning point". That is, behind it the slope-FCR is increasing, whereas beyond it is decreasing. It represents maximum efficiency of food utilisation for growth and corresponds to a particular ration consumption level, found on the x-axis, F_{opt}, and a particular growth achieved at this feeding level of maximum efficiency, found on the y-axis, G_{opt}.

Point C represents adlibitum food consumption. That is, F_{max} is the maximum amount that the given fish can possibly eat under the circumstances until they are satiated. The FCR -slope of the curve- at this point is zero. Beyond point C no more food can be consumed by the fish. It is also the point where maximum growth is achieved (G_{max}), or in other words, the point of fastest production for the particular set of biotic and environmental factors.

So, in recapitulation, for each kind of fish at a certain size range and for a given set of environmental conditions, there is a representative growth vs. food curve and a point on it of optimum food utilisation/efficiency for fish growth, F_{opt}. Beyond this ration level, although growth continues to rise, growth efficiency declines possibly due to such reasons as increase in specific dynamic action, principally from increased deamination of amino acids, decreased assimilation efficiency and increased activity of the fish (Wurtsbauch, W. A. and G. E. Davis, 1977).

Overall, it has to be recognised that food consumption/supply is a key element of fish growth: hence the success or not of a fish farming operation might lie on the balanced exploitation of all environmental and biotic factors through adjustments to the feeding regime. It is necessary, therefore, that at least the major influential factors are monitored and that their effects are understood.

4.1.1 Effects of water temperature on food consumption and growth.

Since fish are poikilothermic organisms, temperature changes -within the tolerable range- have a strong effect on food consumption and fish growth.

Temperature increases seem to lead to increases of the maintenance ration requirements (F_{maint}), of the ration level for optimum growth efficiency (F_{opt}) and of the satiation food amount for maximum growth (F_{max}) on the growth vs. food curve.

So, it seems that increases in temperature shift the curve towards the greater values along the x-axis (ie. to the right) and vice versa. The extent of the shift depends on the existing levels of all the other biotic and environmental factors when the temperature changes.

The practicality of this concept may be illustrated by the experimental observations of Wurtsbauch and Davis (1977).

They found first, that when feeding low ration levels, that is somewhere between points A and B on the curve, increases in temperature decreased the growth efficiency of fish. This may be explained by a shift of the growth vs. food curve to the right so that the same feeding level appears now closer to maintenance level, point A.

Secondly, as the food consumption increased, at a given temperature, growth efficiency also increased until it reached a maximum level (point B) beyond which it then declined until satiation levels (point C).

Thirdly, at high ration levels close to satiation (point C), temperature variations had little effect on efficiency. In this case, drastic shifts of the curve are needed in order for the particular feeding level to approach the optimum efficiency point (point B) and thus substantially improve efficiency.

Lastly, growth efficiency in terms of ration was highest at intermediate consumption rates between maintenance and satiation, that is, at levels around F_{opt}.

The above observations result from the fact that standard metabolism increases rapidly as temperature rises and, since most of the energy of the maintenance ration is accounted for by energy expended in standard metabolism, the F_{maint} level shifts to a greater value, given a stable energy content per unit of food (Elliot, J. M., 1976, Wurtsbauch, W. A. and G. E. Davis, 1977).

Similarly, temperature regulates the fish metabolic energy needs and so, together with the energy content of the food, decides the volume of food to be consumed by the fish to satiation level (Grove, D. J. et al., 1978, Jobling, M., 1981).

Therefore, if the energy content per unit of food is kept constant, the F_{max} level is expected to shift towards the bigger values when temperature increases.

On the other hand, the rate (speed) of stomach evacuation -used as a measure of the digestion rate- increases with rising temperature, possibly due to increased activity and enhanced secretion of gastric juices. This fact has a direct effect on the return of appetite and hence, if increases of food intake are allowed, concomitant increases in growth may occur (Brett, J. R. and D. A. Higgs, 1970).

4.1.2. Effects of fish body size on food consumption and growth.

With all other biotic and environmental factors considered constant, fish size influences growth through its effects on the food consumption rates.

Considering food consumption as a percentage of body weight, maintenance rations, ie. food consumption at zero growth of fish, decrease as size increases due to the decrease in standard metabolic rates. Maximum rations also decrease with increasing fish size.

In larger fish, as consumption rates approach maximum levels, increasingly portions of the food energy may be lost as faeces. Respiratory losses may increase due to relative increases in specific dynamic action and perhaps increased activity.

Generally, as fish grow, smaller and smaller proportions of the increasing total energy intake of the food consumed are channeled into growth (Paloheimo, J.E. and L.M. Dickie, 1965-6).

Fish of different sizes evacuate a given meal at different rates/speeds, larger fish taking relatively more time than small fish for meals of "equal stimulus" (Jobling, M., D. Gwyther and D.J. Grove, 1977). Thus, a decrease in the daily food intake, expressed as a percentage of body weight, may be expected since, at least for salmonids, there is correlation between gastric emptiness, appetite and food intake.

Additionally, size may regulate protein synthesis and thereby influence growth efficiency as shown in results between RNA/DNA ratios in fish, which seemed to decrease with increases in fish size suggesting a decline in the rate of protein synthesis as the fish grow.

Generally, the role of biochemical and physiological changes in the fish body associated with age and size are important determinants of growth -"physiological age".

If on the discussed growth vs. food curve the quantities on both axes are divided by the fish average weight, the result is a plot of Growth rate (G/w) versus Food consumption rate (F/w), -where w is the fish average weight. The relationship between

food and growth and, therefore, the shape of the curve remains unaltered, but the effects of the various fish body sizes on the curve become obvious.
Considering that all other factors remain stable, as fish size increases the curve is shifted towards the left hand side that is, towards the lower relative ration rate (F/w) values on the x-axis. Therefore, the effect of body size on the position of the curve in relation to the system of the vertical and horizontal axes is opposite to that of temperature and the resulting changes in the relationships between growth or growth efficiency and consumed ration can be given analogous interpretation.

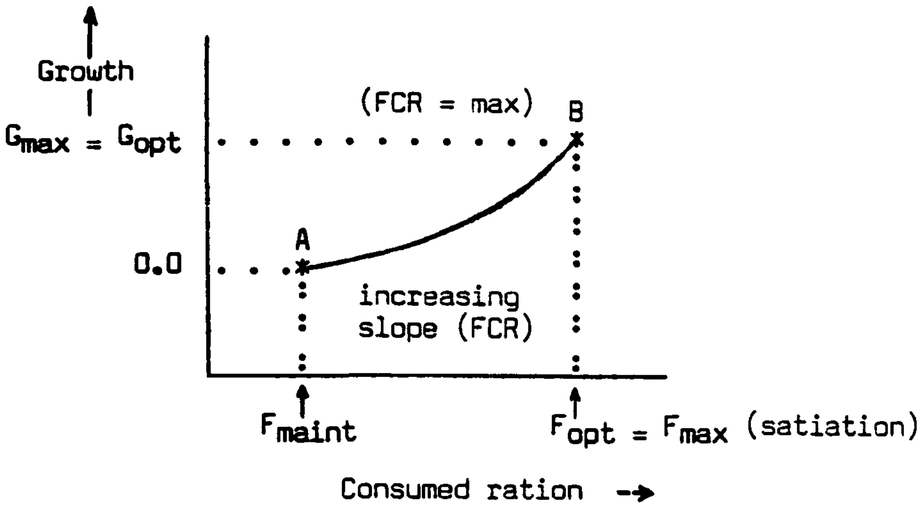
It has been found in fish growth experiments (Paloheimo, J.E. and L.M. Dickie, 1965-6) that under stable, controlled environments food intake and fish body size are highly correlated and either could be used to predict growth efficiency (FCR). In other words size could replace ration along the x-axis.
However, when the environmental factors vary, their effects on growth efficiency cannot be described by fish weight. For example, at higher temperatures the fish may complete faster a part of their growth. Since such changes always influence food consumption, the latter is a better alternative to specify FCR (Paloheimo, J.E. and L.M. Dickie, 1965-6), that is, the average fish size appears to determine the location of the growth vs. food curve relative to the axes but not its slope (FCR) for different feeding levels and varying conditions.

4.1.3 Growth vs. Food relationship in small fish.

It has been observed (Rafail, Z. S., 1968-9, Wurtsbauch, W. A. and G. E. Davis, 1977) that when plotting growth (G) versus Food consumption (F) data for relatively small fish, the slope of the curve which represents growth efficiency of food (FCR) continued to increase with ration increases up to the highest levels that can be consumed, ie. up to the F_{max} point.
Therefore, in hatcheries F_{max} level combines both maximum growth

and optimum efficiency/food utilisation. Adlibitum feeding if practiced in commercial hatcheries would take full advantage of this growing capacity of the young fish which should be given full 'favourable' treatment.

Fig. 2. The Growth vs. Food consumed curve for small/hatchery fish.



However, at a size threshold the turning point of the curve is established and it becomes $F_{opt} < F_{max}$.
This size threshold appears to depend on biotic factors, such as the species and their genetic composition.

4.1.4. Significance and implications of the feeding frequency.

Appetite and feeding are suppressed as the stomach fills during a meal and gradually return as the stomach empties and the food passes into the intestine. Because stomach evacuation is closely related to appetite, the feeding frequency of flesh eating animals with short intestines (eg. salmonids) can be optimally scheduled according to the rate of their gastric emptying (Brett, J.R. and D.A. Higgs, 1979).
Gastric emptying depends on the influences of a multitude of biotic and environmental factors the most important of which, for a given carnivorous species are its body size, the water temperature, the nutritional quality of the food and its energy

content.
It has been found (Ruohonen, K., 1986) that for atlantic salmon fingerlings there is an optimum feeding frequency in regard to fish size. At this frequency the growth rate (speed) of the fish is maximised and further frequency increases have no better effect.

The existence of an optimal feeding frequency reveals that at low frequencies the fish cannot eat all the food quantity fed at once, and also that by increasing the feeding frequency the importance of the social hierarchy and the competition among the fish are diminished. By maximising the feeding possibilities of all fish -especially those on the lower end of 'their society'- it is assured that they get as much food as is planned for them. This is supposed to reduce in practice the unexpected size variation in fish groups, hence optimal feeding frequency is necessary for a particular feeding policy to be effective. It could be predicted based on the understanding of the factors which control gastric emptying rate.

Appetite does not persist above a certain degree of temperature which is near the maximum tolerated by the species and it is depressed at low water temperatures.
Temperature increases lead to increases in the rate of stomach emptying and hence to faster return of appetite, which in turn demands more frequent feeding if the fish are to consume the food amount for which they are scheduled (Elliott, J.M., 1975).
For example, in situations where manual feeding to satiation is exercised and the water temperature is high, labour restrictions may result in a 'pseudomaximum' feeding level. The fish may be fed adlibitum each time but their appetite returns sooner than the next feeding.
This drawback may be partly counterbalanced by an increase of the satiation amount needed which is induced by the relative food deprivation (Grove, D.J., et al., 1978), and especially by the role of food quality.
Artificial food pellets are nutritionally very rich when compared

volume-to-volume with natural food, so, the digestive system of the fish might not process effectively all the food when they are fed to satiation and more than 30% of it might be wasted as a result of incomplete digestion (Goddard S. and P. Scott, 1980).

Food quality must be considered when the frequency of feeding is adjusted.
When food of decreased energy content per unit weight was presented to trout in experiments, the daily food intake was increased by more frequent bursts of feeding associated with increases in gastric emptying rate (Grove, D.J., et al., 1978). Growth may be considered as protein gain analogous to the amount of protein consumed. When the protein intake level is kept constant, growth is determined by the amount of consumed fat. Fat may be used instead of protein for gluconeogenesis resulting in a higher utilisation of the protein in the ration. (Machiels, M.A.M. and A.M. Henken, 1986). However, a decrease in gastric emptying rate occurs when the fat content of the food is particularly high (Brett, J.R. and D.A. Higgs, 1979).

In addition, whether feeding by hand or by the use of automatic feeders, food must be made available to all the fish. So, feeding frequency must comply with the individual farm site characteristics, such as the size and the properties (hydraulics) of the containers. For example, when stocking densities are high and the surface area of the container is small, feeding needs to be carried out more frequently, or over a longer period at each feed, in order to ensure even distribution of food. (Goddard, S. and P. Scott, 1980, Ruohonen, K., 1986).

Other environmental factors, such as natural light, have a big effect on the feeding behaviour of the fish, particularly in the summer, when the early feeding period of the day is the most active. Furthermore, the intensity of feeding should be made bimodalic with greater food amounts given in the morning and evening (Ruohonen, K., 1986).

In all, careful timing of the feeds is required to achieve good assimilation of food consumed at the scheduled amounts. This contributes towards the realisation of the planned length of production cycle up to the target fish size. It necessitates close monitoring of the feeding schedule and of its changes in relation to the other parameters on the farm.

4.2. Economics of feeding.

From the biological point of view assuming balanced diet in terms of the nutritional requirements and the energy content suitable for the fish growth needs under the circumstances, it is apparent that when fish are being fed to satiation (adlibitum) they reach the point of maximum production of flesh (growth). This is the point of zero marginal production of food.
When, on the other hand, feeding is practised at what has been considered as optimum level (F_{opt}) growth efficiency is maximised, that is, the best utilisation of food is made. This is the point of the maximum marginal production of food.

However, optimum food utilisation or maximum growth may not be the only production targets of management. The two points: B and C on the growth vs. food curve simply define the region whithin which the fish farmer ought to feed in order to operate economically.
Below F_{opt} growth efficiency is still increasing and it would be advantageous to increase growth and at the same time improve the food converting efficiency. Beyond F_{max} on the other hand, food is wasted as it is in excess of what the fish can possibly eat. The exact point in the region of economical feeding that the fish farmer would select for each type of fish depends on the marketing plans. Markets demand certain timing of production and average size of product, hence in commercial fish farming the optimum point would be that which best serves the profit maximisation objective. Therefore, there is clear distinction between the maximum profitability per unit of food and the maximum utilisation of food for growth.

It appears that, given a farm's fish stock types and sizes, and its environmental and site design characteristics, feeding regulation is a very effective tool to achieve the economically optimum production targets.
For example, feeding above F_{opt} despite the poorer conversion may speed up growth to meet an inevitable sale deadline.

Although in hatcheries feeding regulation is less of a problem since the F_{opt} and F_{max} points coincide, if feeding regulation is to be applied on a different farm, the growth vs. food relationships of the fish must be identified.
The manager needs to know for each type/batch and size range of fish under every season/environment, the growth vs. food curves that apply. Then the maximum feeding level and the corresponding maximum growth would be recognised in each case. Feeding at a certain percentage of the maximum ration could be experimented with and the corresponding growth and FCR studied.

Consistently kept food, growth and environmental data records, collected from a few units (ponds, tanks) under no stress and at satiation feeding, soon reveal the maximum feeding-maximum growth point (point C on the curve) for the particular stock in the particular season (Bregnbale, F., 1986).
Several reduced feeding levels, being known percentages of the maximum, may then be applied and the data collected in the same fashion. Recording these observations over a few years will reveal the nature of the growth vs. food curves and the points of optimum efficiency under all circumstances applicable to the particular farm site.

The availability of this information facilitates growth predictions for each type of stock under alternative feeding schedules and for different seasons to be made. Thus, it forms the basis of "growth programming" in the attempt to regulate fish growth for better timing of production resulting in more profitable sales.

4.2.1. Temperature regulation.

Although decisions mainly concern the regulation of food supplies, when, in addition, water temperature can be controlled new opportunities for programming fish growth are opened.
Each temperature level, apart from being associated with a particular feed vs. growth curve and a point of optimum efficiency on it, is also associated with a certain speed of growth (growth rate: G/t , where t is time unit) in the form of a growth versus temperature curve (Andrews, J.W. and R.R. Stickney, 1972).
In this context, speedier growth means that the same growth level for the same food amount consumed is achieved quicker, the speed depending on the water temperature level.

There is an optimal water temperature for each fish species which is associated with the fastest growth, that is, there is a point on the growth vs. temperature curve -the shape of which must be species specific- where the slope of the curve is zero, or, in other words, the curve reaches a maximum point beyond which it declines.
Therefore, for every combination of biotic and environmental factors, there exists a particular temperature level that offers the fastest growth, and a particular feeding rate which offers optimum FCR. It appears that temperature and feeding could be adjusted to achieve both the fastest and most food efficient growth (optimum time and feed growth efficiency).
This ideal point, however, should be adjusted further to cater for the market implications on the fish farm economics of production.
The most economically efficient combination of temperature and feeding rate in each case is that which results in such growth speed and in such FCR which satisfy the production targets of the business exploiting optimally the available resources of labour, water, food, etc..

4.2.2. Growth programming.

Growth programming is a relatively new fish culture practice which takes into account the interactions of the biotic and environmental factors in order to obtain economically the desired product within the scheduled time.
It offers the benefits of being capable of reducing production costs, increasing production efficiency and reducing loss-of-production potential (Klontz G.W., et al., 1978).
To achieve its targets, growth programming must predict growth under the particular farm's circumstances (fish stock, seasons, etc.) resulting out of all feasible combinations/adjustments of the variables which can be controlled, mainly feeding policy and perhaps temperature.

It is felt that the biggest concern of fish culturists is how to feed a prepared diet in order to produce fish of the desired size within a prescribed time period with reasonable assurance of meeting the deadlines.
The first step is gathering the data which will facilitate the analysis of production affairs and growth predictions thereafter. Armed with such information the seasonally fluctuating capacity of a fish farm can be effectively exploited.
A rule of thumb is that, although it is impossible to make the fish grow faster than the set of conditions allows, it is always feasible to reduce growth by restricting feed in order to adjust stocks to demand (Bregnbale, F., 1986).
Feed adjustments coupled with the natural variability in growth potential may also spread sales throughout the year.

4.2.3. Accounting for some important limiting factors of growth.

The limiting factors are responsible for setting a constraining ceiling to the growth response that is expected for particular fish growing at a particular site (Fry, F.E.J., 1971). Therefore it is essential to make sure that limiting factors are not constraining the application of the production plans by invalidating the fish growth forecasts.

- Oxygen availability.

Dissolved oxygen concentration may limit growth through its effects on food consumption. Low oxygen concentrations in respect to the requirements suppress appetite (Andrews, J.W. et al., 1973).

The oxygen needs of the fish depend on factors such as fish size, temperature and nutritional status.

Both standard and routine oxygen consumption increase with fish weight (all other factors constant), although respiration per unit of biomass decreases as the average weight of the fish increases. That is, if oxygen demand is plotted against body size, the curve will be increasing but at a decreasing rate (slope) (Beamish, F.W. and P.S. Mookherjii, 1964, Klontz, G.W. et al., 1978, Bo Moller and K.I. Dahl-Madsen, 1986).

At a given fish size it has been found that rising temperature, handling and increased activity, feeding and digestion can all be considered to cause acceleration of the fish metabolic rate and hence increase the demand for oxygen (Andrews, J.W., et al., 1973, Bo Moller and K.I. Dahl-Madsen, 1986).

Warmer water leads to high oxygen requirements by increasing the basic metabolic rate and affects the speed of food passage through the intestine. The latter, together with meal size and food composition, affect the amount and duration of the increased rates of oxygen consumption after feeding. When an organism digests food its oxygen consumption increases as all food have a "specific dynamic action" (Beamish, F.W.H., 1974, Goddard, S. and P. Scott, 1980).

Understanding and measuring these relationships may lead fish farmers to ensure that oxygen does not prove a limiting factor. Severe oxygen shortages in terms of what the fish demand in their condition may prove fatal, but often a less acute situation may suppress growth and degrade the food conversion efficiency. Therefore, measures must be taken either to supply the oxygen concentrations needed (aeration, increased water flow), or to exercise growth programming in order to have always the right amount of fish at suitable sizes. Stock management could comply with the water flow and oxygen concentration that is available on the fish farm at each time of the year (Bregnbale, F., 1986).

- Stocking density.

Stocking density may be considered in relation to oxygen availability since the denser the fish biomass is stocked per unit of water volume, the more oxygen or the faster water flow must be supplied. It has been found for territorial fish that the rate of oxygen consumption of individuals is not affected by stocking density changes unless stocking is so dense that territoriality is broken down. That would induce stress, increased activity and hence increase oxygen consumption (Klontz, G.W., et al., 1978).
Therefore, in addition to oxygen availability, the behaviour and social interactions of the fish must be accounted for when each container is stocked. Moreover, the density of stocking must be related to the way and frequency of feeding in order for food to be available to all -even to the subordinate- fish.

- Fish grading.

Considering stable conditions of the environment and of the farm and fish which have been acclimatised to them, both within- and between-individual variations in fish growing efficiency are to be expected.
Between-individual growth potential differences are mostly related to the social hierarchies among the fish (dominant - subordinate individuals).
Within-individual variation is related to the effectiveness of the fish body in restoring its homeostasis when the conditions of its environment change. Changes in the environment affect the rates of energy turnover of the fish from their food and the pattern of distribution of the components of the total energy in

their system (Paloheimo, J.E. and L.M. Dickie, 1966).
The time lag needed by the body's internal regulatory mechanisms to restore its condition under the new environment along with its position in the social hierarchy characterise the growth potential of each individual fish.
This growth variability soon results in a distribution (normal ?) of fish sizes in a container even when every measure has been taken to ensure stocking of a homogenous population. But different fish sizes have different feeding demands and respond differently to the various components of their environment.
Hence, fish grading becomes a necessity. Sorting fish according to size creates populations of uniform needs and narrows the gap of growth potential among individual fish. Thus, growth can be effectively programmed and controlled and the waste of inputs can be minimised. Moreover, the fish farmer will soon discover the percentages of fast, slow and average growing fish and will be able to identify easily the fish which reached marketable size.

- Pellet size.

Salmonid fish in nature show a high degree of prey selection which implies a mechanism for optimising foraging efficiency, ie. their effort to catch the food they need. For a given type of food, fish of particular weight seem to optimise growth on a particular size of offered food particles for which the energy expenditure during grazing/searching is minimised. The optimum particle size increases with fish body size (Paloheimo, J.E. and L.M. Dickie, 1965 & 1966, Wankowski J.W.J. and J.E. Thorpe, 1979).
So, in intensive fish culture, whatever the circumstances, best utilisation of a feed of particular quality is achieved when the correct pellet size is used which is easily picked up by the fish and quickly satisfies their requirements and which minimises their effort and the amount of food that reaches the bottom.
Obviously, the right pellet size can be easily determined for homogenous fish populations after grading.

In all, successful fish farming requires recording of the data which will then facilitate growth forecasts for the type of cultivated fish under the environment of the particular site during the different seasons. But to ensure smooth application of the production plan the fish stock must be maintained in a 'comfortable' environment where no factor limits the effectiveness of the feeding regime on fish growth. So, monitoring the limiting factors and taking decisive corrective actions (aeration, water flow regulation, density adjustments, fish grading), whenever it is necessary, might be demanded.

5. OBTAINING THE INFORMATION

5.1. Keeping production records.

If records on the important physical-environmental variables and those technically imposed (management) are kept consistently, they may explain the 'behaviour' of the food conversion efficiency of the fish. Mathematical models may be derived from the historical records in order to predict the marginal effect of changes in these variables upon the degree of food utilisation.

The recording tasks range from simple, like water temperature monitoring, to difficult and laborious, such as sampling fish from each tank. There is sophisticated but fairly easy to use equipment for regular monitoring of some physical variables like water pH, dissolved oxygen levels, etc. Keeping a continuous watch on these limiting factors helps to maintain the state of good health and growth efficiency of the fish.
However, in order to monitor the evolution in practice of a growth programme, data must be recorded on growth and food consumption as well as mortalities and fish transfers in and out of the container. Controlling production and input use accurately is unattainable by mere guesses.
The value of FCR calculations depends on frequent data collection using accurate, sometimes repetitive, procedures

which stress the importance of the managerial skill and labour efficiency on the particular farm.

It is significant to emphasise that the less the variability in production management the easier the attempt to monitor a growth programme becomes. Although it is impossible to control totally the physical environment, management practices can be reasonably standardised to methods which proved to be efficient. Fish stock handling may be performed in an effective but simple and consistent way.
Feeding can be standardised if a nutritionally balanced diet according to species, size and age requirements is maintained for all the stock and the food is distributed always with the proper pellet size using the most appropriate schedule for the season. With special equipment the dissolved oxygen may be kept always at non-limiting levels and the fish could be graded at certain stages of their growth in order to restore homogeneity in their populations. Moreover, in order to simplify the stocking density calculations it might be possible to maintain a constant water flow and water level in each container.
Whenever sudden adjustments are required due to environmental changes or disasters, their occurrence should be recorded, even in the form of notes in the case of unquantifiable events. Thus, some reasoning may be available in the accumulated data to explain, to some extent, such disturbances.

5.2. Recording fish growth data.

Data on growth is the central point of every production planning effort, but growth samples are laboriously collected from the field. Unfortunately, there is no instrument to sense the fish biomass and/or the fish numbers which exist in a container, although the important role that such a sensor could play in fish farm automation is widely acknowledged (Zahradnik, J.W., 1986).
Sampling must be performed manually, at clearly defined time

intervals, and requires several fish samples to be patiently drawn from each container. The difficulties relate to the design of the farm site and particularly to the system of culture, sampling of fish in ponds being a lot more difficult than from tanks.

Sampling appears to be mostly responsible for the reluctance of fish farmers to keep production data records. Until any suitable sensing equipment becomes available, manual growth sampling must be integrated with the rest of the routine operations of the farm. It has to become a normal operation among all those others which are not automated.

A proposal, which might be attainable by most tank fish farmers, is to select sample data of fish weights weekly. In order to relieve most of the labour burden when many tanks are in use, samples may be drawn from only a small number of them, but carefully selected to represent the range of growth patterns of the remaining fish.

For those fish culture systems where fish sampling is very time consuming, hard work and may also introduce considerable stress to the fish by netting and perhaps anaesthesia (eg. pond farms), sampling cannot be performed so often. However, even a seasonal weight sample is a much better policy indicator than a guesstimated figure.

When sampling, practical difficulties are also encountered in terms of measurement error. When, for example, samples are taken by a landing net after the fish have been brought together in a 'lump' with a dragnet, sample bias problems are introduced. This was proved in experiments where analyses of variance indicated a significant difference between samples drawn successively from the same pond at time intervals of about ten minutes (Sparre, P., 1976). The problem of determining this bias has still to be resolved and hence, for reasonable accuracy, several samples must be drawn from each unit/tank, especially for small fish.

A margin of error is expected in all measurements of raw facts in the field no matter how difficult to obtain, such as growth samples, or trivial, such as temperature recording. However,

apart from the relevant amount of error, the element of randomness of the error occurrences is of even greater significance. That is, for statistically sound analyses all deviations from the true data value, whenever they happen, must be considered to occur with equal probability, or, in other words, data measurements must be "unbiased".
Techniques which may introduce bias in favour of bigger or smaller values must be avoided. So, sensing instruments need to be regularly calibrated and a formula for fish sampling has to be devised which minimises the possible measurement bias and should be followed thereafter.

5.3. More accuracy is needed when calculating FCR.

The Food Conversion Ratio (FCR) is the slope of the growth vs. food curve (Fig. 1.) expressing the efficiency of food utilisation for growth of a fish batch under the particular circumstances of the farm at a period of time.
Thus, statistically speaking, it is a dependent variable of the production system being determined by the multitude of the independent factors of the environment, of the intensive culture system's design, of the day-to-day stock management tactics, of the genetic composition of the species, their history, etc. (Paloheimo, J.E. and L.M. Dickie, 1966).
However, because of practical difficulties when sampling fish growth from several units (tanks, ponds) at regular time intervals, fish farm managers usually presume a constant FCR figure, based on their experience, which they appoint to a particular fish batch as their performance indicator. This figure is a one-off calculation based on the final growth and food consumption results of a complete production cycle of a previous similar batch. Future decisions on production plans and feeding policy are formulated according to this approximate FCR.

The food conversion ratio demonstrates production efficiency in terms of the most costly input and its status

reveals the implications on food utilisation of the complex interactions of all the factors, controllable or not, which affect fish growth.
Even for uniform fish, FCR values vary with time, seasonally, from month to month, even daily. The more this variation can be identified and predicted the better decisions can be made for optimum economic utilisation of the production inputs, such as food, labour, energy for temperature regulation, etc.
Therefore, more action must be taken for as precise and as frequent recording of growth and feeding as is practically possible in order to minimise forecasting errors and increase the accuracy of future production planning.

5.4. Recording food consumption.

The portion of uneaten food is another unknown quantity which makes the calculations of FCR and the planning of feeding rates uncertain.
The food waste depends on the food quality and its properties, such as particle size, sinking speed etc., the homogeneity of the fish population and the feed distribution management.
In the production unit (tank, pond, cage) there is a 'social' group of fish which compete for the supplied food. Subsequently, food is not shared among them in a way which gives the same feeding level to each fish. Even among fish of similar sizes with no 'size-hierarchy' effect, the feeding level of each fish must still be considered as a stochastic element. It depends on each fish's ability as a food competitor.
Therefore, the calculations of feeding rates or FCR are averages for each population, expressed per biomass unit and since the uneaten amount of food is not observed, their accuracy depends on the severity of the food waste problem.

However, in cases of feeding fish to satiation and provided that growth is closely monitored (sampling), the FCR figure may reveal the feed waste problem. Although an error may always be present due to the unobserved food losses, worsening FCR value leads the manager, having checked on mortalities and environmental extremes, to examine the feeding policy before blaming the fish.

Uncertainty of food consumption may also exist when natural food is found in the water and supplements the nutritional requirements of the fish. In an earth pond the contribution of the ponds' natural ecosystem as a supplement to the fish feed requirements may be substantial, or the river water circulating in the fish tanks may seasonally carry plenty of zooplankton organisms. In fact the higher the pond's biogenic capacity, and the higher the zooplankton load of the river water, the more fish weight gain should be attributed to this 'free', external food source, and therefore, the FCR figure -calculated in terms of the 'technically' provided food- may become misleadingly good.

In any fish culture system, a distinction may be made between **apparent** feed conversion ratio, defined as the gain in fish biomass divided by the supplementary food provided and utilised by the fish, and **true** feed conversion ratio, defined as the gain in biomass reduced by the estimated amount of gain attributed to natural food divided by the supplementary food provided and utilised by the fish (Gerking, S.D., 1978).

However, growth due to natural food is impossible to discover since the amount consumed by the fish is unknown. Given, in addition, that the waste of supplied food is also an unaccounted quantity, in practice only an **"observed apparent FCR"** value may be calculated. Unexpectedly high/good or low/bad values of it may caution the manager about natural food or excess waste respectively.

5.5. Attention when using feeding charts.

Feeding charts are a general guide to fish daily food intake calculated as a percentage of body weight. They point at an intermediate feeding rate level for each average water temperature and FCR combination which is supposed to allow for reasonable growth rate. In terms of the growth (G) vs. food (F) curve they are expected to indicate a feeding level lying somewhere between F_{opt} and F_{max} that is, a compromise point for good growth and food utilisation.

However, the charts do not account for any variation in water quality and are generally calculated on the assumption of maximum dissolved oxygen levels. They presume a good status in all the limiting factors which might impose constraints on growth and efficiency. Also, there is no guarantee that the factors which led to the construction of these charts during experiments still hold under the particular conditions on a given farm site.
In fact, most fish farmers seem to regulate their feeding according to their own judgement and either over- or underfeed their fish in respect to what the tables indicate.

Overall it is clear that there is no general and straightforward formula for feeding fish since the circumstances differ on all farms. It is only through consistent recording of environmental, feeding and growth observations and the subsequent analysis of this data that the physiological and behavioural processes underlying growth in any life-history phase of the fish may find simple and stable mathematical expressions. The latter can be used as the starting point to make growth programming decisions. Additionally, the severity of any limiting condition on the farm may be identified and tackled.

5.6. Accounting for mortalities.

Intensive fish farms hold defined fish populations in containers of certain water volume. These populations can be described by the size distribution and the numbers of the fish. Natural mortalities occur however, and are considered as the losses due to natural deaths, predation, escapes, stress, etc. Excluding any form of intentional introduction or extraction of fish, a change in their number in a population during a specified time period expresses the mortality rate.

Differences exist when calculating the mortality rate under the different farming systems. A fish pond, for example, is a difficult production unit to control in detail. The total number of the fish population cannot be calculated precisely at any point during the production cycle because it is impossible to observe the exact number of the fish dying and sinking to the pond's bottom.
Since accurate, regular recording of deaths is impossible, a total view of the mortalities over a complete production cycle of a pond could be taken instead. The natural mortality rate should be adjusted for the fish which have been transfered out after grading, or have been sold during the cycle. On the other hand, the live population must be increased by the numbers which, possibly, have been transferred in the pond at some point during the cycle. So, recording the initial size of the population stocked in a pond and every movement of fish thereafter, may give a measure of the mortality rate at the end of the cycle. Such compiled data from several ponds over the years may serve as a future indicator of what degree of stock losses to expect during a 'normal' growing cycle in the 'average' pond.

In tank farming systems the routine recording of mortalities and fish transfers may allow precise calculation of the mortality rate during time intervals (eg. weekly) and correlations may be attempted with fluctuations in the environmental parameters or with stock handling activities (eg. vaccinations, grading, etc.).

Tank farmers may calculate:
Mortality rate = observed natural mortalities (Nos) /
/ [opening fish Nos + transfers in - transfers out]

However, this mortality rate calculation may still be slightly inaccurate because the precise number of fish initially stocked

in a tank is not known. Initial stocking is based on biomass stocked and the number of stocked fish is calculated by dividing the total biomass by the average fish weight. Although this is a small additional problem, fish grading reveals the error and backcalculations can be made to adjust the initially incorrect figure. Grading may help also to correlate mortality with average fish size. Natural mortality is usually greatest when the fish are small diminishing as they grow.
Given the ability to record mortalities regularly, more accurate food provision adjustments are possible.
It would be difficult to evaluate accurately the production efficiency (FCR) unless the existing number of fish in the unit were known. Consistent records of fish sample average weight, transfers of fish in/out of each container and of mortalities, ensure a FCR figure that tends to express realistically the conversion efficiency of the healthy fish stock.
For example, the amount of food that was eaten by fish which subsequently died represents unaccountable food waste that may be attributed to the consumption of living fish. The result of ignoring mortalities would be a misleadingly poor efficiency, especially when fish are fed to satiation.

When the recorded mortalities represent only a fraction of the total due to unaccounted reasons, such as seagull or heron predation, escapes, etc., the calculation of the healthy stock shows a higher than real number. So, the biomass figure, even when its calculation is based on sampled average weight, is artificially high.
An example of this effect on feeding policy adjustments would be the overestimation of the planned food provisions resulting in overfeeding when fish should consume only a calculated percentage of their satiation amount.

5.7. The 'transfers' problem.

In fish populations where a distribution of sizes is established due to varying growth rates among the fish, when fish of selected sizes are transferred in or out the average weight figure at the end of the time interval (eg. one week) will be biased. For example, the sampled weight figure shows an artificially bad status of fish growth when the removed fish are of the bigger sizes and when smaller fish are removed it shows misleadingly fast growth.

When fish are transferred into a unit the artificial effect on the average weight samples is opposite. The introduced fish, even when they comply with the existing average size of the fish already in the unit, represent external biomass which cannot be regarded as real production. Inevitably, the new fish take part in the weight samples, although they should not be included in the growth calculations for that period. The distortion of the records is increased when the fish are transferred in the unit near the end of the recording interval.

On the other hand, the transfers out represent real production from a particular unit. Therefore, as total biomass produced in a unit during a time interval must be regarded the sum of the biomass transferred out from it, reduced by the sum of the biomass which has been 'donated' to it during that interval, plus the biomass gains achieved by the 'resident' population.

6. MICROCOMPUTERS SOLVING FISH FARM INFORMATION PROBLEMS ?

6.1. Can micro-computers help ?

Computers perform the most complex of operations in practically no time, store and retrieve data effectively, and have tremendous flexibility of vital analyses (listing, sorting, comparing, etc.) and presentation (graphs, reports, etc.).

The major technological advances in the field of microelectronics have made the applications of microcomputers in relatively small businesses, such as some of the smaller fish farm units, a feasible consideration because:

- powerful 'micros' are now affordable,
- there is a great variety of flexible "off the shelf" software programmes to choose from,
- useful complementary options, such as computer communications, are available at low cost,
- microcomputers and programmes are now very easy to use by non experts ('user friendly').

Computerisation is a very important decision affecting the running of the business, so a considerable amount of time and effort must be spent working out what the needs are -and are likely to be in the future- and what system will meet these requirements.

It should be obvious that computers process whatever figures are entered without much reference to or acknowledgement of their quality. The value of the calculations depends on the validity and accuracy of the data input and this accuracy, ultimately, is down to people not the machines.

Computers can provide management with all it needs in the way of facts and figures. This helps to take decisions in the light of the best possible information. A microcomputer can be widely used to perform all that data and information processing for planning, controlling etc. of the business, using those management techniques the data has been recorded for, and producing high-level information for decision making whenever it is needed and in the form preferred.

Management tools, some of which are not feasible manually such as linear programming, system simulation, or others commonly practised like budgeting, budgetary control, sensitivity analysis, financial accounts etc., are all effectively performed by 'micros' and can be made widely available to every single fish farm.

The microcomputer's role in a fish farm management information system is envisaged to be twofold:

Firstly, create the fish farm's data collection, and secondly, use the accumulated data further to produce information which together with the ability to apply sophisticated techniques will give the background support needed for decision making.

The immediate benefit to the manager is that more time is made available for constructive thinking than when performing series of laborious calculations, and the data are processed error free. Techniques for forward planning are easy to use whenever and for as many times as necessary.
However, the even more important side advantages are that the manager may now think in a more orderly fashion, understand deeper and evaluate correctly the farming situation, have clearly defined objectives, and exercise tight control over the business.

6.2. Why use micros rather than a manual system ?

Sound data records are invaluable for good decisions but very hard to organise. Manual systems attempted on individual fish farms are frequently abandoned because the time and effort required for them is not felt to be balanced out by the perceived benefits. It was found that in several cases data figures were recorded on paper sheets which became unreadable with time and only in the best cases was there a standard form* of records kept. Record sheets were piled up in fish farm offices only to indicate the effort that had been wasted on them. After all not all 'sharp' managers are also neat in their 'homework'.

Personal computers are to be preferred to even good manual record systems because they are efficient at:

- capturing field data on site (hand-held devices, data communications),

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* The same data elements collected at defined time intervals by the same methods.

- consistent standard record keeping,
- storing neatly organised records,
- easy recapitulation of past records,
- very fast calculations and unlimited recalculations,
- making no errors or miscalculations,
- avoiding the paperwork,
- better presentation of results,
- performing techniques otherwise impossible (linear programming, simulations, etc.),
- making time savings.

In summary, it is possible to relieve the burden of field data capture, make exhaustive analyses of the appropriate current or historical data with less effort, present results in the most suitable form, and make substantial time savings.

6.3. Economic considerations.

The total estimated costs of implementing a microcomputer based data system can be divided into one-off costs, associated with acquiring the system, and running costs, that recur throughout the life of the system, such as hardware and software maintenance, upgrading etc.
It is recognised that one of the major cost items is the time devoted to system development by the manager responsible for the farm, and the opportunity costs of the time of managers may be heavy. It is important to envisage how and to what extent other people should be involved and the amount of time the manager can afford for them to train and practise.
Attempts to evaluate the opportunity cost of the manager's time, or of any other member of staff involved, are risky and subjective, because different people think of their time differently.
It is a fundamental necessity for the fish farm manager (or whoever the user may be) to devote some time to familiarise with the operation of the system.

Getting to know the system is not a one off operation but requires continuous commitment and some initiative by the operator. Nevertheless, it is interesting to note that possession of a system often creates a form of addiction such that many evenings are spent in exploring it to the exclusion of other leisure activity.

Normally it is the benefit that is very difficult to quantify. Sometimes it may be relatively straightforward to calculate cost savings in terms of the time of staff involved, but the assessment of benefits becomes more difficult at higher management levels where cost savings become less apparent but improved performance may instead form the justification for the new computerised data system. For example, quicker and more effective implementation of plans, easy access of past records, speedy and accurate analyses and reports.

Some information was traced from some, mostly large, fish farms which had invested in computer systems in order to automate various (mainly secretarial) tasks, such as word processing, invoicing, etc., but, apart from the purchasing costs of computer hardware and programmes, no precise evaluation of these systems was ever attempted by their users nor was it known whether they had realised all of their system's potential.
The encouraging fact, however, was that those fish farmers involved in computers were keen to proceed further to upgrade their systems, which indicated their positive feelings towards the computerisation of at least some specific tasks.
After all, it is up to the individual manager's personal feel of the situation whether to adopt computerised techniques or not and consequently whether to invest in them.

6.4. Fish farmers adopting data computerisation.

A microcomputer based data system requires two fundamental concepts to be understood by its ultimate users. First the vital necessity of organising a comprehensive data record system to be used in decision making. Secondly the need to apply computer technology to derive as much information as possible from the data to form and test decision options.

In order to proceed with the development of a system for a particular farmer, active participation and cooperation is needed. However, unless it is possible to give information on the costs and benefits based on actual experience which has been obtained elsewhere, it is often difficult to secure this initial commitment.

In the early stages of this particular project there was often the feeling that records were generally useless as a result of previous abandonment of past, unsuccessful, manual systems. Relatively capital constrained fish farmers needed clear cost-benefit calculations to appraise their investment and these were impossible since most benefits could be quantified only after some experience at the particular site and with a subjective view of the farmer's own evaluation of time spent. Breaking this 'circle', by securing the wholehearted cooperation of a farmer as a 'gamble' on his part, was the turning point which enabled the first system to be installed and proved.

To illustrate the problem, it is useful to distinguish between two broad categories of fish farms.

First, there are the relatively small holdings with less working capital involved in fish production. The manager on these farms, who may also often be the proprietor of the business, is totally responsible for all decision taking and controlling of all processes on the farm. The decisions are taken out of experience and since the holding is small enough the farmer may be able to maintain sufficient control over the business activities in order to keep it viable. Because of the lower capital resources a greater proportion of them will tend to be allocated to conservative investments in order to ensure a small but secure return as losses are much more painful for the small and vulnerable business compared with a wealthier one. It is also possible that small farmers put more emphasis on intrinsic aspects of work, that is, they are relatively more concerned with personal fulfillment and an independent lifestyle.

Secondly, there is the category of larger holdings with substantial working capital tied up in the business. Under such circumstances even marginal mistakes or forgone opportunities may prove very costly because of the scale of the operations. The manager usually needs to justify all decisions and actions and present the results to the superiors in the management hierarchy who expect to maintain their business profitable and, if possible, expanding. Management needs to be exercised rationally and close control over the business operations is needed. Since the holding is big enough it possibly employs several people to carry out various tasks. Therefore, there is a definite need for information and information feed-back, flowing from the field towards the centre of decision taking, and vice versa, in an organised speedy manner in order to coordinate these various tasks under the different spheres of responsibility.

Obviously, it is this second category which provided the most fertile ground where the idea of pioneering a fish farm information system could be applied. In fact most of these big farms did operate at least manual record keeping systems, while others had gone some way into computerising clerical tasks. The need for a consistent data system was recognised, and the proprietors or higher standing managers of such businesses who decided upon investments, did have the capital resources required. They usually also had the willingness to undertake risks in promising projects because they recognised that to expand or even to keep their present state of business they needed to keep up with technology and modern methods if not to pioneer new ideas.
Managers appointed to such big scale businesses were knowledgeable people with experience and some formal education in a relevant field of aquaculture, management, etc., and there were more possibilities to have a constructive open approach towards innovative ideas.

From the above discussion the features of a fish farm which was most likely to develop, implement, and test a computerised data system may be identified as follows:

- Relatively big business with enough capital to invest in new developments.
- Management committed toward business growth and profitability.
- Managers who are experienced, educated, and open minded to new ideas.
- Managers who are willing to take some risks at least as far as their time spent.

However, unless the manager is determined to take an active part in the development of the business's own information system, the fundamental idea of having a representative system on the specific farm, totally mastered and controlled by the decision maker, cannot materialise.

6.5. Computer programmes that may help.

Buying a microcomputer can be a confusing decision because it is difficult to quantify its real benefits.
Nobody successfully using a computer in business can claim that the business would not have expanded at the same rate without it, but may express the view that life is easier and that operations are faster and more efficient. This is true since 'micros' automate the information already used to run a business. They are not a cheap way of solving management problems, but simply give guidelines of promising policies.

When thinking to apply information technology in management practice, the first decisions to make concern software -the instructions which tell the computer what functions to perform.
There is little to choose technically between different makes of computers in a given price range, but not all of them will accept the software needed. Therefore, it must first be examined, in great detail, what tasks the computer should

perform.

The most directly accessible and relatively cheap is "off-the-shelf", Packaged software. It is bought as a package, comprising a programme (or set of programmes) usually on floppy disk, and documentation explaining how to use them.
There are two broad classes of packaged software:
Firstly Specialist, (or Vertical market), software. This is aimed at a specific set of users in a particular industry or profession, such as estate agents, general practitioners, farmers etc., and, secondly, General purpose, (or Horizontal), software. This aims to solve one general problem for a wide range of users from any industry or profession. This category includes spreadsheets, wordprocessing programmes etc.

Very often either of these types could be suitable and for example, a general spreadsheet programme for, say, financial calculations and a specific dairy farming package could both be very useful on a dairy farm.
Moreover, it is likely that more than one type of general purpose package will be needed to meet all requirements, and this has led to a growth in 'integrated packages', which provide several general purpose functions, for example, spreadsheet, graphics and database, all in one package.

However, it is not to be expected that even the specialist application packages do exactly what is required, so the general purpose and especially the integrated programmes are able to be adapted to any needs. In addition, the integrated packages are relatively cheaper than the specialist ones since they are directed to a much broader market.
Apart from the price, there is also the need for long term support, that is, help and programme improvements provided by the software company. The number of existing users of the package provides some indication of the level of support and experience expected.
The commonality of documentation and appearance of the different functions to the user is also a benefit. The documentation of an

integrated package usually has a common design and presentation for each of its integrated modules with good cross referencing between applications. Far more useful though is the common 'face' which each application of the package presents to the user, because even simple things like the functions of the same keys on the computer keyboard can vary tremendously between different packages. As a consequence there is a much shorter learning curve than if applications, such as spreadsheet, database and wordprocessing, are all obtained from different packages as would be the case if a non-integrated system were in use.

However, more important than these, data interchange, along with the adaptability, is perhaps the main advantage of integrated packages. It is possible to switch instantly and link data automatically between applications. So, a graph of the data stored in a spreadsheet may be created within seconds! Additionally, software producers have made it possible for the most popular packages to interchange data between them and generally to 'give away data', a fact which sets the computer user free from any specific programme.

In summary the advantages that integrated software packages offer are as follows:

- Directly accessible for purchase,
- Cheaper,
- Long term support and advice,
- Detailed, versatile documentation,
- Commonality of documentation,
- Commonality of the presentation of their different applications,
- Data interchange between applications (modules),
- Data interchange with other popular packages,
- Adaptability.

The other big category of computer software is that of "Bespoke" or custom built software. This is where systems analysts and computer programmers from a software company will

create a package especially for a particular firm and it is, consequently, very expensive.
It may be useful in cases of fairly standard applications where existing packaged software is not sufficient, but very careful appraisal of such a costly investment is needed.

Because fish farming has unusual requirements, and is not yet adequately covered by specialised packages, an appraisal was made to see whether the facilities that were required could be put together from a general purpose package. The more wide-ranging and the more powerful the facilities offered by any package, the more likely it would be that it would cover the requirements and also be capable of minor changes by the operator if necessary.
It is in the nature of any business to change and it is good practice to be able to make any changes needed smoothly.
Wherever custom written code must be used, it is usually extremely difficult to adjust the design unless it is clearly obvious through its documentation.
There are many examples where reliance on a custom built software system has been a major factor in delaying a much-needed change in a business due to the added cost and upheaval of modifying or rewriting the software.
Therefore, the 'golden rule' throughout this study was: Buy "off the shelf" and subsequently adapt. Keep bespoke code to the minimum, and keep it as simple and as clearly documented as possible.

6.6. Selecting the hardware.

Firstly, the equipment had to be identified from what was currently available in the marketplace which should conform to the conception of the system's design.
The following equipment was required:

- a desk top microcomputer,
- a printer,
- a hand-held 'pocket' device,
- two modems,
- floppy disks.

Secondly, the performance criteria of these individual items should be specified. This was determined by analysing the scale and type of the fish farm, the amount of data which was likely to be processed, the cost restrictions imposed and, in the case of the computer operating system, its ability to run commonly available software of the sort under consideration.
For example, the minimum needs that were eventually defined in this study for each one of the hardware items, irrespective of prices, were identified as follows:

Desk-top microcomputer:

- Popular operating system suitable for a wide range of software, (MS DOS).
- Communications software availability.
- 250 kbytes of Random Access Memory with provision for expansion.
- Twin floppy disk drives with a 360 kbytes storage capacity each.
- High resolution monitor.
- Standard RS232 serial and parallel I/O ports.
- Manufactured by a reliable company providing long-term support.

The 'pocket' computer:

- Relatively robust, ideally shock and waterproof.
- Small and light for portability.
- Battery powered with data and programme power back-up when not in use.
- Standard RS232 serial I/O port.
- 22 kbytes of Random Access Memory.

- Standard computer programme language availability (such as BASIC) with provision for data transmission operations.
- Display one line of 26 characters.
- Manufactured by a reliable company with good documentation and support.

The printer:

- Provide 80 character printing width.
- Accept continuous paper as well as A4 sheets.
- Capable of drawing graphs.
- 80 cps average printing speed.
- Compatible with a wide variety of makes and models of microcomputers.

The modems:

- Full duplex data transmission.
- 300 bps minimum transmission speed.
- Approved by the country's telecommunication services.

Floppy Disks.

- Double sided, double density, soft sectored floppies.
- Floppies and cables of reliable quality. (Cheap disks are a false economy.)

7. A MICROCOMPUTER BASED PRODUCTION RECORD KEEPING SYSTEM APPLIED TO A TANK TROUT HATCHERY

A computerised system was applied to and is currently in operation on a tank trout hatchery which was producing fingerlings for restocking ongrowing farms. Fish grading was practised, and growth sampling was feasible on a weekly basis. A dry pelletised fully balanced nutritional ration was provided to the fish, and the feeding rates and feeding frequencies varied appropriately. The water flow on the farm was evenly regulated throughout the year by a water dam which acted as a buffer and a constant water flow and level/volume was maintained throughout the year in all tanks.

7.1. Fish farm enterprises and identification of 'data units'.

On the farm the enterprises represented specific production activities which were defined by their final production target, timing, and method of production. For example, rainbow trout fingerlings to be sold at 25g (or 20 Nos/lb) in the following June, produced in circular tanks according to certain feeding, grading, etc. schemes.
With grading fish were separated into groups which showed uniform characteristics and occupied separate units. Groups of the same fish batch, showing similar responses (eg. growth efficiencies and 'speeds') which were grown under uniform management policies and were aimed towards the same final product, represented a unique enterprise.
Obviously, each fish farm enterprise might require not only a single but a group of production units (tanks).

Computer programmes may organise the data records in groups and form electronic 'data files'. Each data file should hold the data of a defined entity, ideally a single production unit stocked with fish of a particular enterprise. Because the

production unit is the source of the data which is recorded in the data file it may be called a '<u>data unit</u>'.
Records should represent the whole 'spectrum' of farm activities and so should be kept on all the distinct enterprises of the fish farm. However, this did not necessarily mean that records should be kept on every single production unit. An enterprise usually consisted of a number of similar fish groups held in different units. Just a few, or even one, of the latter could be selected to represent the performance of the whole enterprise. Thus data collection might be minimised, focused to just a few representative data units.
Names and/or numbers were given to the data units and these same names/numbers should be given also to the corresponding computer data files for quick identification.

7.2. The system software and its functions.

The specific needs perceived for the data collection and record filing system could be satisfied by a powerful spreadsheet, data base and graphics package supported by a small, custom written programme suitable for data capture on site.
Since it was decided that a handheld data collector and a desk top personal computer were required, which, in addition, should be able to communicate as a part of the system, a communications' package was also part of the software requirements.

The custom built programme should be used for direct input of raw data which would then download, via the communication's package, to a specifically adapted worksheet of the powerful integrated package offering a spreadsheet, a data base and graphic facilities.
The spreadsheet would accept the data, analyse it and store it in data files on floppy disks. These files would then be retrieved from the disks at will and the data displayed, "What if" / sensitivity analyses could be performed, with reports for specific purposes being generated automatically via the data

base facility, and the data and reports printed on paper with the desired format.
The graphics application would make available various types of graphs to illustrate trends, which could also be printed. These graphs would be automatically updated as new data were entered into the file.

7.3. The desk-top microcomputer system.

An IBM PC desk top microcomputer was used first, with two disk drives (drive A and drive B) addressing 360k bytes of storage memory each, 256k RAM and IBM communications software. The machine had also to be fitted with an Asynchronous Communications Adaptor providing an RS232 serial data input/output port.
When, however, the system was adopted by the hatchery business the decision on hardware inclined in favour of the IBM--compatible OLIVETTI M24 machine which offered much greater computing speed. The latter was also equipped with 640k RAM and instead of twin drives, a single 360k disk drive (drive A) and a Winchester 'hard' disk (drive C) addressing 20m bytes of memory. Parallel and serial RS232 ports and communications software were also available on the machine.
The OLIVETTI system was overspecified in terms of RAM and storage memory capacity, but this ensured against most of the likely future computing needs. On the other hand, the massive on-line storage space offered by the hard disk allowed both programme and data files to coexist. Different computer programmes and their corresponding electronic data files had to be neatly arranged in "hard disk directories" branching into a related 'tree' of "sub-directories". Hence, the computer could access any programme or data file speedily, eliminating the cumbersome floppy disk swapping from the drives. Floppy disks were needed only for keeping 'safety copies'.

7.4. Field data capture.

Two battery powered machines with the additional ability to transmit data to a desk top microcomputer were tested for this purpose. Moreover, if a printer were available on-farm, both machines could be used, if required, to create quick printouts of the collected data in the desired format.
First, the SHARP pocket computer 1500A was used. It was very small and could be carried around the farm without difficulty. Protected in a suitable transparent plastic case it could be used as a data input terminal on site. Programmed in BASIC language (a 'Sharp' version), it accepted fish-farm data input daily and held it in Random Access Memory for a maximum period of one week during which the memory contents were safe even when the machine was switched off. Some data could be entered once a week according to the farm's data collection schedule, and several different sources of raw data (data units), ie. tanks, were distinguished. Data was entered in response to prompts appearing on the small, one line LCD (liquid crystal display) screen. The fish farmer entered the current day, specified whether it was a daily input or a weekly input, identified the unit, then selected the data item and typed in the figure. Amendments of data figures could be made very simply by repeating the data input procedure (see Appendix A for complete user information).
Secondly, the HUSKY-HUNTER hand-held computer was used. It was a small rugged machine with large Random Access Memory allowing part of it to be used as a "RAM disk" for 'on-line' programme and data storage. The custom software was written in BASIC language (Husky BASIC) and offered all the necessary features of data input, amendment, printing and transmission. Moreover, the programme design utilised the advantages offered by the relatively large LCD screen and the RAM disk. The latter allowed more applications to be developed and made possible data from more units to be captured, whereas on the bigger screen clear explanatory messages could be displayed (see Appendix B for operation instructions).

Below the relative qualities and drawbacks of these two field data capture machines are comparatively criticised.

7.4.1. Discussion on the specific features, relative advantages and disadvantages of the SHARP PC and the HUSKY-HUNTER when used as raw data logging devices on fish farms.

Machines built with a wider purpose in mind may not be absolutely suitable for a specific task. However, both computers mentioned may play a valuable role in organising an electronic data system for the benefit of the fish farm manager.

a. The 'Sharp' solution. After testing the SHARP PC 1500A under the environment of the day-to-day operations on a commercial fish farm it proved not to be the ideal machine for the task of fish farm data recording on site. The most significant features lacking were found to be environmental robustness, a larger memory availability, a bigger display screen and a data communication port incorporated on to the PC unit itself.
Even with its RAM extended to its maximum of 22.5k bytes, the available memory was not sufficient to hold the data, especially for the bigger fish farming businesses operating many production units (tanks, cages). Additional applications, such as that of recording overall stock data,could not be accomplished due to this limitation. On the other hand, frequent downloading and 'reading' of programmes and data to and from magnetic tape was practically impossible, since the operator needed quick on site data logging and access to the farm office was restricted.
The machine was not considered to be sufficiently rugged or waterproof for efficient use in the open under the wet, sometimes rough fish-farm conditions unless certain precautions for its safety were taken, such as wrapping in a plastic case and taking extreme care while handling it.
The single line LCD display, although not a major drawback, was not suitable for quick menu reading.
The fact that the interface was an extra add-on 'box' and not an

integral part of the machine, increased the time needed to set-up the hardware for data transmission or printing, but offered the advantage of housing both a serial and a parallel data ports.

In summary, most important of these limitations were the lack of ruggedness and water resistance as well as the restricted RAM.

The BASIC interpreter, however, was 'sharp' enough and supported powerful features that were very useful for data capture purposes. Especially among them, the provision of two-dimensional array variables was particularly suited to data collection from different sources at discrete time intervals. It offered easily programmable data communication options/protocols, which facilitated the downloading of the data to the microcomputer.
The RAM contents were protected by a battery back-up feature when the computer was switched off and the machine was very light and so small that it could fit into an overall pocket.
It was the cheapest suitable machine on the market (June 86).
For the price of £450 (excluding V.A.T. charges), the SHARP PC 1500A (£189), the 16k RAM expansion module (£110) and the RS232 and parallel interface (£150) could be purchased.

So, in conclusion, the Sharp may represent a viable solution for a capital-tight, small, or very cautious fish farmer.

b. The HUSKY alternative. This type of microcomputer was still small enough to be carried around the farm, was environmentally sealed and was manufactured to function under harsh conditions. It had a sufficient memory (RAM) capacity which retained its contents even when the computer was switched off, and could be programmed in BASIC language. Programmes and data from several sources could be stored safely on a large segment of the RAM which acted as a storage area, or 'RAM disk'. The BASIC programmes for growth and stock data capture, printing or transmission could be loaded and run on a 'working area' for programme execution which was a smaller, 54k, segment of RAM.

Additional advantages were the larger, eight line screen which could display commands, options and explanatory messages, and the inbuilt communications serial port -a standard RS232 interface- which simplified the hardware connections for printing or data transmission.

However, at the substantial price of £1,500 (December 1986) a 352k RAM HUSKY-HUNTER came with some undesirable features too, which related to its specific use as suggested in the present study.
Every fish farm data element had both a source dimension in relation to the number of monitored data units and a time dimension -which was 7 for data logged daily during weekly recording intervals. Unfortunately, the HUSKY-BASIC interpreter did not support two dimensional array variables, so separate data files were necessary to store a complete set of variables each in respect to every single source. The resulting multiplicity of small data files was worsened by inefficient memory management which allocated a minimum of 2k bytes for each file stored on the 'RAM disk'. Therefore, data storage space was wasted and indeed, the recording system's RAM needs were much less in real terms than appeared on the HUSKY's memory map. Since the user paid more for extra memory capacity, the return in value for money paid was lessened.
In addition, rearranging the 'memory map' was not simple and could not be done repeatedly, so, although the 'working' memory area appeared sufficient for the present system's demands, it might be problematic in cases of applications bigger than the permissible 54k.
A further small drawback might be the lack of a parallel interface port. Therefore, the printer to be connected with the HUSKY should either have a serial port or a serial to parallel adaptor device was necessary. Moreover, since such an expensive machine would be used next to water containers or sometimes on a loch or sea cage, the ability to float was a desirable if not necessary property.

In conclusion, the HUSKY-HUNTER, although it did not offer very good value for money and was not the ideal machine, was suited for fish farm use and can be suggested as an option for relatively larger businesses.

7.4.2. Arrangement of the BASIC programmes and of the data in the hand-held device's RAM.

a. <u>In the SHARP PC 1500A</u>.

The RAM was extended by an add-on memory module to its maximum of 22.5k bytes. No segmentation was possible to define separate storage or programme execution memory areas, so both the BASIC code and the data which was kept on dimensioned, two array variables coexisted occupying all available RAM space. Thus, the computer could not be used for any other purpose unless programmes and data were stored on tape. The single programme ran immediately after switch-on and executed its different functions, such as menu messages, warnings, data input, printing, transmitting, etc., via BASIC subroutines.

b. <u>In the HUSKY-HUNTER</u>.

The machine was marketed with a wide option of built-in RAM capacities, but the actual needs for the described system depended on the number of different sources of data (data units), such as the number of ponds, tanks or cages.
The memory was divided into a 54k 'working area' for programme execution, which provided more than enough space for the use of the present system, the rest being allocated to a 'RAM disk' for on-line storage of both programme and data files.
Each different function of the data collection system was developed into a separate BASIC programme-file which could access the data-files and read or write data to them. So, instead of a big single programme several interacting modules, each devoted to a particular task, had been established. The latter and the data files were stored on the 'RAM disk' area and were loaded onto the 'working' area for programme execution.
The modules interacted with a common programme which

'supervised' them and offered selection of the different options (menus) to the operator. It could be invoked -brought onto the working area- whenever the operator wanted a different option and it could access any module/task it was instructed to.
The above arrangement increased speed of execution since only a small code was present to be interpreted each time and offered great flexibility for programme maintenance since adjustments were carried out easier than in a single lengthy programme.

A list of the separate modules and of their demands in HUSKY 'RAM disk' space now follows:

BASIC programme-file for:

- the menu ('supervisor')	= 2k
- data input	= 8k
- data display	= 4k
- printing	= 6k
- data transmission	= 4k
- stock control	= 6k

ASCII data-files containing data from each source = 2k each.

7.4.3. The data types.

Efficient production planning and control requires well organised data on all phases of the production processes as well as up-to-date information of the stock status on the farm. The SHARP PC 1500A and the HUSKY-HUNTER facilitated regular recording of the following production variables from identified data units.

Production data from individual units:

The Weekly data items accepted include:

- Fish sample weight (Nos/lb)
- Weekly food amount (kgr)

- Daily feed rate used (% on opening biomass)
- Feeding method / frequency (text input)
- Food type and size (text input)
- Food quality (energy %)

The Daily data items accepted include:

- Dead weight (lbs), or number of dead fish
- Transfers IN (Nos)
- Transfers OUT (Nos)
- Size of fish transferred IN -weighted average- (Nos/lb)
- Size of fish transferred OUT -weighted average- (Nos/lb)
- Water temperature (degrees Centigrade)
- Water pH
- Dissolved Oxygen (%sat)
- Water flow (gal/min)
- Diseases / handling (text input)
- Other conditions (text input)

The limiting factors (dissolved oxygen, water flow, etc.) have a neutral effect on growth whenever they are at 'comfortable' levels, so, data on them could be omitted from input when there was no worry of them being scarce. However, in certain cases they should be monitored at least during some seasons (eg. low oxygen in the Summer months).

The measurement units shown were those used in the particular application by the hatchery fish farmer. The data system was flexible and could comply with any preferences.

The large Random Access Memory of the HUSKY has allowed, in addition, a stock control programme to be developed that showed the current status of all fish on farm. This programme imitated the break-down of the farm in sectors, such as 'main shed', 'outlet channel', etc., and the particular identification of each production unit in each sector.
Every time a new unit was stocked, fish were treated or grading took place resulting in fish redistribution, the action was

recorded/input in the stock control programme. First the sector and the unit were identified, for example, 'tank 37 of main hatchery building' and the following data was input:

Stock data:

- Identification of egg batch,
- Current number of fish,
- Stocking date,
- Size at present (Nos/lb),
- Vaccination status.

The stock data could be cleared, displayed and printed on-farm by sector or for the complete farm at will. So, an up-to-date picture of the stock status was always available. Moreover, it could be transmitted to the desk-top computer for stock report generation (see Appendix B for user instructions).

The essential difference between 'individual production data' and 'stock data' was that the first followed the continuous, dynamic evolution of the process of production, the values of the variables being recorded at regular daily or weekly intervals; the latter was logged in irregularly as the changes happened. In terms of their utilisation, data on production was the starting point for fish growth forecasts and growth programming, whereas hatchery stock data, combined with egg purchases and stock valuation, was essential for total mortality, insurance or stock-in-hand reports on each growing batch.

7.5. Data transmission.

Transmitting the data to the desk top microcomputer at a selected location, used as a 'base', formed the second function of the SHARP PC or HUSKY hand-held computers and was made available through their RS232 serial Input/Output data port. Such a data port was an integral part of the HUSKY, but with the SHARP

PC it was a separate accessory 'box', slotting into the computer with its own rechargeable batteries. However, the SHARP interface provided both RS232 serial and parallel ports.

The data transmission can either be direct, eg. to a printer or to the microcomputer, when the latter is on the farm office's desk, or long distance / indirect, over the telephone network, to a microcomputer located at a central office. So, data needs to be typed into the system once!

The production data from the individual units on the farm was filed at weekly intervals, so, when each week's recording was completed, the software installed was instructed to perform calculations, such as averaging daily temperatures or computing the weighted average of fish sizes transferred in or out of the tank during the week, in order to prepare weekly data for transmission. The communications hardware and software was then activated and data transmission could take place. (Details can be found in the appendices.)

When data transmission by direct connection took place, the SHARP pocket computer was connected to its interface. The RS232 serial port on the interface, or in the case of HUSKY its integral serial port unit, was then linked to the RS232 serial port of the OLIVETTI or the Asynchronous Communications Adaptor on an IBM PC via a **gender changer.**

When both cable and equipment have connectors with the same gender a Gender Changer/Line Switching device is necessary to give the cables the mating pairs needed to mate the equipment.

The communications software was then run, "Olitalk" on the OLIVETTI, or "Asynchronous Communications Support" software on the IBM PC. On a twin disk drive system the communications software diskette occupied the disk drive A and a target diskette was placed in the other drive B to receive the data. When a hard disk was available, however, it held the communication software in a particular directory (address) and could store the incoming data on a defined related sub-directory.

The microcomputer system was then ready waiting for the SHARP or HUSKY to transmit the data.

For data transmission by long distance/indirect connection, the RS232 serial port of the hand-held field computer was directly connected to a modem. The type used in this application was a V21 300 bps modem (INMAC Micro Modem). The modem's plug replaced that of the telephone's in the wall socket and the telephone was plugged directly into the modem's equivalent socket.
At the other end -at the microcomputer base- another modem of the same type was also in operation. It interfaced with the telephone in the same manner and was connected also to the RS232 serial port of the desk-top micro. The communications' software was set-up normally on the OLIVETTI or IBM PC and the target disk was put in drive B if no hard disk (drive C) was available.
The final step was for the operator at the 'Husky' or 'Sharp' end to dial the operator at base. When the telephone link was established, both operators depressed the 'data' buttons on their modems and replaced the telephone receiver. As soon as the field machine was instructed the data travelled via the telephone network to the microcomputer at the distant base and on to the target storage medium (a diskette or a hard disk address).
However, this procedure presupposes a good telephone network and problems of data corruption may occur in cases of very long distances. Obviously, for a long distance data transmission two operators must be available at the same time, one at each end when cheap modems, such as those mentioned, are used. This is not necessary where more sophisticated modems (auto-dial, auto-answer) are in use which may replace the operator at the base and undertake all the functions needed to 'wake' the microcomputer.

7.6. Immediate on-farm data printing.

If a small printer were available on site, the data could be printed directly from the SHARP or from the HUSKY and stored away as hard copies, or used as reminders.
Whenever long distance, automatic transmission is impossible, the hard copies may form the intermediate medium for manual data

input into the desk-top micro.
To obtain a printout the Input/Output port of the hand-held computer should be connected to a printer (any common dot matrix printer of the EPSON range would do). If the SHARP PC was in use, it had to be slotted first into its interface which provided both a parallel and a RS232 serial type of I/O port for connection with the equivalent port on the printer. However, the HUSKY provided only a RS232 serial port and the printer in use should comply with it.

Printers often have both types of data ports but they are not simultaneously active. A tiny, sensitive and usually well concealed 'DIP' switch activates one or the other. Thus, any printer accepts electronic messages only of a single type at any time. This may create problems in connection with HUSKY, when the same printer is also used by the larger microcomputer and the latter transmits parallel signals to the printer. The problem can be solved either by a parallel to serial (or vice versa) signal converter device, or, as in the case of the hatchery application, by installing an extra external switch on the printer for input signal selection.
(See appendices A or B for user instructions on how to use the SHARP or the HUSKY respectively for printing.)

7.7. Data processing on the desk-top micro. with LOTUS 1-2-3.

7.7.1. Data import into a Lotus 1-2-3 worksheet.

The information system applied on the hatchery used the LOTUS 1-2-3 software package (spreadsheet, graphics, data base) on the OLIVETTI M24 (IBM PC compatible) machine to process and store data. Data from the HUSKY (or SHARP PC) was received and stored on the specific address on the hard disk and the first step was to introduce this transmitted data into a LOTUS worksheet. The procedure was similar if the data were stored on a 'target' floppy disk.

The data were stored as a 'print' file with the ASCII format. This file appeared in the file directory list with the extension '.PRN' to its name.
ASCII 'print' files can easily be imported into 1-2-3 worksheets, and in this case a standard worksheet was customised to undertake the data processing (Appendix C contains user documentation).

7.7.2. The customised LOTUS worksheet for the production data.

In this standard worksheet layout, the columns were occupied by the data items, which were therefore displayed across the worksheet from left to right. Data 'time' increments increased from top to bottom by weekly intervals. The number of rows/weekly intervals depended on the duration of the production cycle.
One data unit, ie. a tank, was represented in each worksheet file. The worksheet was designed to perform calculations on the imported data automatically and to produce additional data and production information (output) as well as to provide instantly generated graphics. This was achieved by the use of LOTUS 'macro' commands which consisted of a series of keystrokes that the worksheet executed automatically as well as by the creation, in advance, of graph formats connected to the data held by the worksheet. (Appendix C shows sample printouts of the information layout and of graphs).

The worksheet calculations:

The formulae which were built into the customised LOTUS 1-2-3 worksheet were designed to avoid most of the distortion introduced by the stock management operations and to give accurate information on the growth situation of the fish. Some of these calculations may not be immediately obvious and the interested reader may need to cross reference them carefully, or even work out a simple numerical example, in order to obtain the right impression.

In some cases mixing of metric with imperial units was necessary in order to follow the measures used on the farm.
A list of the worksheet output and its calculation follows:

Opening fish No
= Previous week's closing fish No.

Apparent Mortality rate %
= (Opening Nos - Transfers OUT + Transfers IN - Closing Nos) / / (Opening Nos - Transfers OUT + Transfers IN) * 100 %

Weekly total Mortality No
= ((Opening average fish size (Nos/lb) + closing average fish size ie. sample weight (Nos/lb)) / 2) * Total dead weight (lbs)

Closing fish No
= Opening fish No + Transfers IN - Mortalities - Transfers OUT.

Opening Average fish size (Nos/lb):
= Previous week's closing average fish size (Nos/lb).

Average Conversion Ratio [apparent] in decimal form, representing the weight units of food used per weight unit of growth:
= (Total food provided (kgr) * 2.205) / True biomass gain (lb).

The above FCR figure avoided most of the distortion introduced by the fish transfers in and out of the production unit, and it did not consider the dead weight (mortalities) as true product. Thus, the picture of the healthy stock was worsened since the fish which died in the week consumed an unknown amount of food which was attributed to those alive.

Actual average daily feed rate used, as opposed to the standard daily feed rate which was recommended by the food manufacturer's tables. (percentage on average biomass)
= (((Total food provided (kgr) * 2.205) / (Opening + Closing total biomass (lb) / 2)) / 7) * 100.

Average weight gain (lbs/fish):
This figure was not distorted by the fish transfers or the mortalities because it attributed the true (live) growth in the tank to the live fish of it which achieved it.
= True biomass gain (lbs) / (Opening fish Nos - Mortalities).

Opening total biomass (lb):
= Previous week's Closing total biomass (lb).

Biomass increase due to fish transferred IN (lb):
= Nos of fish transferred IN / Their weighted av. size (Nos/lb).

Biomass decrease due to fish transferred OUT (lb):
= Nos of fish transferred OUT / Their weighted av. size (Nos/lb).
If the weighted average size of the fish removed was not measured simply because a random group of fish is taken out, then the opening average weight was used instead.

Closing total biomass (lb):
= Closing fish Nos / Closing average fish size (Nos/lb).

True biomass gain (lbs): This allowed for the biomass transfers in and out of the tank/cage/.. unit in order to reflect the actual fish growth. It did not account for dead weight since it represented practically a wasted product.
= Closing biomass - Opening biomass - Biomass transferred IN +
+ Biomass transferred OUT.

Stocking density (Nos / ft^3):
= Opening fish Nos / Tank water volume (ft^3).

Stocking density (opening Biomass lb / ft^3):
= Opening total biomass / Tank water volume (ft^3).

Note that the closing average fish size in the formula which calculated the closing total biomass was produced by fish samples at the end of the week, and therefore incorporated the

effects of the fish transfers in and out of the tank/cage etc. This effect was largely eliminated in the subsequent calculation of the true biomass gain since the 'donated'/transferred in biomass was subtracted and that which was transferred out was included in the true production calculation.
The average weight gain per fish attributed the above 'true' biomass production to the actual number of fish which produced it, that is, those fish which started the week reduced by the number of those which died.
The above calculations were closer to reality the earlier the mortalities occurred and the later the transfers took place during the weekly recording time interval.

The last part of the worksheet (last column) gave the cumulative results of the production cycle up to the latest recording week. It was printed with the main body of the data, or on its own, and incorporated the items shown below with their calculation:

Average apparent F.C.R:
= (Total food given (kgr) * 2.204) / Total growth (lbs).

Total growth (lbs):
= SUM(true biomass gain).

Gain per fish (lbs):
= SUM(average gain per fish).

Total food given (kgr):
= SUM(weekly food).

Observed mortalities (Nos):
= SUM(mortality Nos).

Observed dead weight (lbs):
= SUM(weekly dead weights).

Apparent mortality rate:

= Observed mortalities (Nos) /

/ ((initial fish Nos stocked + SUM(Transfers in))

Graphs built in the customised worksheet:

The procedure to create a graph with 1-2-3 may seem complicated to the novice or in fact be a nuisance to the very busy user. In the customised worksheet graphs were inbuilt for 'instant' easy use (detailed user instructions on these can be found in Appendix C). Their formats were present even when the worksheet contained no data and they started to take shape as the figures accumulated.

The data elements graphed were:

- Total Week's Food	(XY and bar graph).
- Actual Average Daily Feed Rate	(XY graph).
- Average Week Weight Gain	(XY and bar graph).
- Closing Average Fish Size	(XY graph).
- Week Closing Total Biomass	(XY and bar graph)
- Average Week Temperature -Morning-	(XY graph).
- Stocking Density (Biomass / ft^3)	(XY and bar graph).
- Dissolved Oxygen	(XY graph).
- Water pH	(XY graph).
- Actual & Standard Av. Daily Feed Rate	(XY graph).
- Mortality rate %	(XY graph).

(See graph illustrations in Appendix C.)

Manual data input in the production data worksheet:

The worksheet could be used simultaneously for both manual and automatic data input. By 'automatic' is meant data coming in directly from a field portable device via a clearly defined communications procedure involving specific hardware and software. So, even in cases where a field data capture device was not used but data could be recorded on paper sheets, the customised LOTUS 1-2-3 worksheet could still be exploited for data storage and analysis if manual data entry from the paper sheets was performed.

Moreover, each time a new worksheet file was initiated to represent a 'fresh' data unit (eg. a different tank), the general worksheet had to accept the initial 'set-up' information about the new fish stock manually. The set-up information included:

- Identification number/name of the data unit (tank),
- Stocking date,
- Identification of the fish stock (species reared, origin, sex),
- Opening number of fish stocked initially,
- Starting average fish size (Nos/lb),
- Water volume in the unit/tank (ft^3).

The initiated file could then be stored on disk under a specific name that revealed the data unit it represented (Appendix C).

7.7.3. The customised stock control LOTUS worksheet.

As with the production data, here a LOTUS worksheet was customised using specially designed 'macro' commands to accept the stock data, which the HUSKY computer could capture on site, and generate reports on these. Each report was specifically designed for a particular purpose and could be printed with the suitable format. Although the worksheet was tailored to a hatchery situation, its capabilities are directly relevant to any other type of fish farm.
The fish batches on the hatchery were distinguished by 'code names' of just a few characters. The egg origin, the stocking year or other qualities of the growing fingerlings could be recognised immediately by such a codename. For example, 'Daf86' corresponded to 'all female Danish fry, stocked during 1986'.
The report types that could be created and a brief description of their context follow below. Appendix C offers operation details.

a. Overall stock and total mortality report. This reported on the stock status of a specified batch, or on a specified species that incorporated several batches, or even on all species and batches that were currently stocked on the farm.
The printout showed the fish separated by species and batches indicating their present size, number and vaccination status. Cumulative population figures of every fish type were provided as well as a mortality rate figure which accounted for any sales to-date.

b. Insurance report. After the insurance values of the fish were specified, this reported the available populations of whichever batches or species were required classified into distinct size ranges. The insurance value of each different class was shown and a population total was given.

c. Sales and/or orders report. A report could be generated and printed on any combination of as many of the following criteria: customer, fish size, batch, sale or order.
Therefore, a few reporting options might be total sales or just total orders, the orders placed by a particular customer for all batches or for a specific batch, the total sales or orders that related to a specific fingerling size or batch or size and batch. The information included in the printout was typed in ascending time scale.
However, an auxiliary custom worksheet had to be built in order to facilitate this reporting option. This complementary worksheet's 'macro' commands allowed for input, deletion or amendment of entries in an electronic sales and forthcoming orders 'notebook'. The latter was used as a reference by the report generating programme.

d. Free stock report. This provided a stock availability estimate against a possible order for a particular fingerling batch. The manager needed to specify the egg total that was initially introduced onto the farm for the particular fish under question. If mortalities additional to those indicated by the mortality

report were assumed to occur before the time of sale, a different estimate might be input.
The reporting programme would then cross-reference the current stock data and the data on sales and forthcoming orders that had already been placed for the specific batch and print the following information:

- Fish Nos sold to-date from that batch,
- Fish Nos held at present,
- Estimated percent of losses,
- Estimated fish production (Nos),
- Remaining orders (fish Nos),
- Free stock available (Nos).

8. POSSIBLE EXTENSIONS

The significant factors which affect fish production were identified and the automated recording system was designed to collect measurements of them on a routine basis.
These records formed the basis for monitoring the continuous progress of fish growth but could be utilised in more advanced analyses.
A report generation programme was created to summarise the stock status and offer a clear picture for stock control. However, since the farm data started to accumulate on the computer and a base of historical records was formed, trends in growth responses during various seasons and the differences among fish batches could be revealed. Such information offered the necessary background to form expectations! Predictions could be generated for future performance in order to allow better planning of input requirements and of marketing of produce.

SECOND CHAPTER

A fish growth prediction system for intensive aquaculture, implemented on a microcomputer for use by individual farmers.

CONTENTS

SUMMARY

Fish farmers need information on future production in order to plan the use of inputs -mainly food-, calculate the water space demands by their growing stock and above all arrange sales of produce and deliveries of new young fish or eggs in advance.
To cope with these demands the computerised data recording system that was implemented on a fish hatchery (chapter 1) was extended to include regression and prediction generation routines. The new system could estimate future growth, food and water demands of a growing fish batch during a particular season, given that historical data on these existed in the farm records. 'What if ?' analyses and graphs could also be produced.

The problem of fish farm individuality was overcome since the regression process implemented could be activated by the farmer and utilise data selected freely. The equations could be calibrated with data on any fish batch that grew on the farm during a particular season; hence a similar growth process could be accurately simulated.

The software consisted of customised LOTUS 1-2-3 worksheets utilising 'macro' commands and the hardware that was used was the IBM PC and the IBM-compatible OLIVETTI M24. The system was implemented on the same hatchery farm on which the data records had been computerised. The fact that the farm records were also compiled using LOTUS 1-2-3 worksheet files made data access very flexible.

Linear regression by least squares was thought to be the most appropriate method to fit the predictive equations to real farm data. Estimates on several data sets were obtained and tested statistically for accuracy. Overall it was found that predictions matched closely the actual data.

1. BIOLOGICAL MODELS AND PRODUCTION FUNCTIONS

A biological model describes mathematically some response of an organism to its environment. When the response of a biological system results in the production of output then a model may show quantitatively the effects on output of the application of more or less quantity of one or several production factors/inputs. Such a model may be called a "production function" and shows also the production response to the different states of the environmental variables which influence the utilisation of the inputs.

Combined with economic principles the production functions may lead to practical management recommendations and decision support of farmers. Mathematical representations of the production phenomena express relationships among physical and biological variables which have direct economic significance because they can be used in assessing resource productivities. They complement planning techniques which estimate optimum resource use (Heady, E.O. and J.L. Dillon, 1961).
Schematically, the role of a production function in a farm decision support system could be presented as follows:

```
Production data      -->  Production function
                                 |
                                 v
Costs-prices and
market information   -->  Planning technique
                          (resource optimisation)
                                 |
                                 v
                          Recommendations
```

2. MODELING COMMERCIAL PRODUCTION OPERATIONS

2.1. Functional form design.

For the consistent mathematical representation of a biological production process three major requirements must be satisfied (Heady, E.O. and J.L. Dillon, 1961):

- the production mechanism must be fully known,
- the correct mathematical form should be used,
- accurate data has to be available to fit the parameters using the most appropriate statistical technique.

Such an equation could be used to provide production estimates extending beyond the boundaries of the data on which parameter fitting was based.

In reality, however, the nature of most biological processes is obscure, making a **mechanistic approach** to modeling impossible. Hence, the **empirical approach**, which utilises practical farming experience and the information provided by experimental observations, especially those closely related to practical situations, appears more promising to commercial operations.

A different problem is that the model, empirical or otherwise, has to be computationally feasible. Adjustments are needed to the functional form and to the number and type of the variables considered in the model. For estimation and testing, the polynomial models are much simpler than the asymptotic models and are preferred unless there are strong theoretical reasons to the contrary. The use of transformed variables, using square roots or logarithms, which enables the use of simple linear regression for parameter fitting is a step in this direction (Hildreth, C., 1957).

When the empirical approach to modeling has been adopted, the simplest equation which gives a reasonably good fit to the data should be used. The excellent goodness-of-fit to the data used in calibrating a particular equation may not hold for different data sets and it seems that complicated equations suffer more 'shrinkage' than simple ones (Anderson, R.L., 1957).

The scope, detail, simplicity and structure of an empirical model relates to its ultimate use, since due to the incomplete understanding of the mechanisms involved various algebraic equation forms can be used to describe a production process. Aspects which are not directly relevant to the issues of interest may be aggregated or omitted. No single form is suitable under all environmental conditions and for all types of inputs and methods (Heady, E.O. and J.L. Dillon, 1961). Therefore, the model focuses on what is important for its precise purpose and limits are set confining its applicability (Fridley, R.B., 1986).

The important decisions which must be made while designing an empirical biological model are as follows:

-- What is the eventual use of the model ?

-- Which variables are to be included ?

-- Which factors will be assumed constant ?

-- What functional form will be used ?

-- Which statistical technique will be used to fit the parameters ?

-- Which are the limits of the model's applicability ?

2.2. Model calibration.

As Heady and Dillon (1961) realised, the extent to which an empirical production response function for a given technology in a particular environment can be used with reference to the same technology in a different environment is perhaps the major problem in planning and using production functions for farm management information.

The estimated parameter values do not represent the true mechanistic process but approximate the effects of the variables in the model only within the range of the data they fit. Thus, any empirical function may be used to predict within the range of the observed data to which it has been fitted.

Because of the differences in productivity between farms, hypotheses which are true for one will be false for another and each farm should use a model fitted to data representing its own production activities. Deliberate interventions in the production process unaccounted for by the data will also weaken the prediction accuracy.

The simplifications which are necessarily made when defining the algebraic form of a production function result in the inclusion in the equation of only a limited number of the variables which participate in the production process. The unaccounted variable factors are merely assumed to remain stable during the production period to which the equation relates. This assumption is necessary in order to consider that the effects of the omitted variables on output also remain stable throughout the production period, and hence they do not introduce any unaccountable distortion -'noise'- to the estimates of output. Although in experiments care is taken to control the most important of the unaccounted variables, in reality, especially under practical farming conditions, it is not possible to exercise sufficiently rigid control of them. After all, all farm production systems are "open systems" and some factors may remain unobserved and unrecorded. Therefore the variation of output cannot be fully explained by the independent variables which have been included in the equation. Variation which is due to influences that were not present in the original data used to fit the parameters will remain unexplained.

Thus a particular, unique, production function may never be specified for any production process. In fact there may be as many different calibrations of the same function as there are possible sets of values of all the omitted factors/variables from it. So any proposed function fitted to real life farm data is not the true but a "hybrid" function, fitted on data which incorporates points from more than one of the possible alternative functions.
The validity of a fitted hybrid function depends initially on a good design of the functional form. If it incorporates the most significant variables of production then it might be considered

capable of providing satisfactory estimates. This is particularly true when the parameters are fitted to data which comes from a unique (individual farm) production system. Less tendency for variation in the unrecorded variables is expected for the same site, at least in the short run, and indeed an individual farm's production is far more likely to behave according to its own hybrid function than to a general, theoretically correct one fitted on experimental data (Heady, E.O. and J.L. Dillon, 1961).

Equations fitted on experimental data are not as representative of individual farms as the hybrid equation however much scientific care is taken. This is due to the rigid control that is imposed on the generation of the data.

Researchers decide which variables are to be held constant and which allowed to vary and the level of their variation and interactions. Hence the generated data values have much lower variances than in the real world, thereby reducing the usefulness of the fitted function for extension purposes. It cannot be known how much reliance may be placed on such a model's results for practical advice (Johnson, G.L., 1957), and farm management advisors make adjustments to the experimental results, based on informal observation of the practices used by farmers and their own empirical judgement (Swanson, E.R., 1957).

How well experimental results also apply to other circumstances is either a matter of judgement for the person making practical recommendations or is a matter of further experimentations under other conditions (Hildreth, C., 1957).

A feasible approach would be to design the experiment in order to approximate the unaccounted conditions of real farms in a region and let the recorded factors vary accordingly. Thus, experimental farm management units or "pilot farms" might appear to be an appealing compromise within regions (Swanson, E.R., 1957, Johnson, G.L., 1957).

In terms of policy implications, therefore, the most common hybrid function of the region fitted on real farm data may be of use insofar as it depicts the growth path over time of the 'average' farm's input-output relationships.

However, the farmer's own technical and managerial skill is a variable which cannot be paralleled. Each farmer has a different degree of ability which determines the quality of production inputs and of handling the stock, factors which cannot be measured directly in physical terms. Moreover, some factors, such as available capital to buy and organise resources and labour to carry out management decisions, may prove to be in limited supply under commercial conditions, and markets may impose new policy directions. So, while the small scale of an experimental situation has all resources unconstrained, in real life production is limited to the levels that the constraints permit and therefore it is impossible sometimes for yields to reach their full potential. It is quite possible that the onset of "diminishing returns" occurs at a lower level of output on commercial than on experimental farms. For livestock in particular, there is an important bearing of their past 'welfare' history associated with stock management on their production responses (Antill, A.G. and C. Clark, 1958, Davidson, B.R. and B.R. Martin, 1965).

It appears, therefore, that only if the hybrid production function is used, calibrated using data coming directly from an individual farm's production operations, can valid recommendations be made. This practically acceptable solution presumes of course the existence of an organised data recording system on the individual farm's production systems.

However, in the ideal case the model itself should be a part of a feedback loop in the management information system. Data on the variables of the production system, gathered over time, would be used to 'tune' the parameters of the equation, thus presenting always an updated model absolutely fitted to the specific situation.

The interactions between the biological part (fish species, size ranges, age, etc.) and physical and technical environment of the particular site (seasonal conditions, stocking, feeding, grading, etc.) are inherent in the fish-farm records. If such real historical data, carefully selected, is extracted from an existing 'data bank' it may be utilised in a computerised feedback loop to recalibrate a predictive model of production which could help in developing management strategies. The intuition and experience of the fish farmer could be coupled with the data handling and computing capacity of a microcomputer (Fridley, R.B., 1986, Arnason, A.N. and D.H. Scuse, 1986, Tyssø, A., 1986).

2.3. Statistical estimation of the parameters.

2.3.1. Estimating the linear regression relationship between variables when their measurements are subject to error.

In a linear regression if, for any fixed set of true values of the independent variables (X_i's), there is one and only one corresponding value of the dependent variable, that is, each value of Y would be uniquely determined by each particular set of X_i values, then the linear regression could constitute the "**functional** (or **structural**) relationship" between the X_i's and Y (Lindley, D.V., 1947).
However, even in experiments, there is never complete success in eliminating the disturbing influence of a great number of other, unaccounted variables from the data. These disturbances and the recorded data are subject to all sorts of fluctuations (Wald, A., 1940).

The presence of 'noise' only in the observed values of Y, provided that they are unbiased, does not affect the descriptive ability of the linear regression in so far as the estimates of its constants will continue to be efficient; only their standard errors (variance) will be increased. The effect of the incorporated error in the values of the dependent variable may be reduced by increasing the number of the sampled values. Although the mathematical relationship will not be "functional", since Y is no more uniquely determined, it will be a "true" estimate of it.

When similar errors are found also in the data of the X_i's, whether unbiased or not, the regression's estimates of the corresponding Y values will cease to be valid (efficient) and in fact they will be biased (Lindley, D.V., 1947, Berkson, J., 1950). The suggested constants in the equation will not reveal efficiently the true relationships, since the regression tries to determine the simultaneous probability distributions of the observed -not true- values of Y and X_i.
In this case linear regressions provide simply "observed" estimates of the relationships involved.

2.3.2. Regression relationships in biology.

The physical sciences view the irregular fluctuations in the observed data as being apart from the phenomena under observation, arising solely from inaccuracies of measurement or inefficiencies in experimental control (Eisenhart, C., 1939). However, the biological and social sciences attribute a large portion of the apparent irregularity of observations to a real variability which is an essential constituent part of the phenomenon under study.
In biology variation may be caused by measurement errors due to faults in experimental designs or human error. Usually, such errors may be considered unbiased, random and normally distributed. There is also biological variation inherent in the genetic composition of the species and natural variation of environmental quantities, due to seasonal and microclimatic changes. The precise probability distributions and statistical properties of the latter two categories appear interrelated and generally difficult to define.
Therefore, a structural relationship, as defined by Lindley, is impossible since the inherent variability of the material is the rule. On the other hand, estimation of a true relationship is possible when the independent variables are controlled, as is usually encountered during experimentation, while the dependent variable is freely observed and may be subject to inherent variability as well as to significant observational error.

The true relationship will be somewhere within a zone -not on a single line- and the probability that the estimate of the dependent variable will lie on different parts of that zone must be calculated.
For example, the regression of the data of a fish's oxygen consumption (Y) on the data of controlled water temperatures (X). In such cases, according to Lindley (1953) and Ricker (1973), the true regression* can be estimated irrespective of the existence or not of measurement and/or inherent variability in the values of X_i's. Moreover, Berkson, (1950) was the first to prove that it can be estimated using the ordinary least squares regression of Y on the X_i's.

In the case of commercial records kept on farms, the X_i's are subject to observational error and randomly variable as in nature. A true regression is unfeasible, since the observed distribution of the X_i values results from sampling more than one probability distribution: that caused by measurement error and that caused by the natural fluctuation of the environmental conditions (Eisenhart, C., 1939).
The true regression would be possible only in practice if there was additional information on the degree of measurement error and natural variability, expressed as the ratios of the "point variances" ** (Winsor, C.P., 1946, Lindley, D.V., 1947).

As opposed to the true regression, the observed regression reveals the linear relation of the mean value of the dependent variable (Y) with the means of the observed values of the independent variables (X_i's). The latter should be random observations possibly involving all types of errors due to

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* As defined by these authors, what Lindley accepts as 'true' regression Ricker considers as 'functional'.

** The variance of Y at a true X_i value (all other variables constant) over the variance of that X_i.

uncontrolled measurement, inherent and natural variability.
The practical significance of the observed regression is for prediction purposes where there is no extreme need for precision, especially with increasing sample sizes (Lindley, D.V., 1947).
The practical problem of prediction can be formulated as follows: If n sets of values of the dependent and the independent variables have been observed and a new (n+1) set of observations of only the independent variables is given, the task is to estimate the corresponding (n+1) value of the dependent variable by means of all the previous complete n data sets. (Definition based on Wald, A., 1940.)
The observed regression would estimate (predict) the expected (n+1) value of the dependent variable from the new observed set of independent variable values (n+1) using the relationship it would have established between the mean of the n values of the dependent variable and the means of the n values of the independent ones.

2.3.3. Observed regressions used for prediction in commercial fish farming.

True regressions may be feasible in research where measurement errors can be minimised and, even when the variables which participate in the relationships under study are not themselves controlled, most of the others which are external to the experimentations are kept at desired values. So the external influences on the experimental results can be minimised and usually the directly involved variables are closely controlled. Hence, Ricker's (1973) claim that the true regression can and should be regularly used both for description and for prediction of a biological relationship may be valid for scientific purposes.

In commercial fish farming, data comes from records routinely collected from the field. Measurement errors can be large and the influences of some factors, which are external to a specific relationship, may sometimes dominate. These external (indirect) factors may vary naturally and relate to the particular time of the year and to the specific characteristics of the fish farm site, such as its water quality, design of fish containers (tanks, ponds) and stock management tactics (grading, feeding etc.). They may also interact among themselves and amplify or reduce their effects on the relationship under examination.

Such random 'externally induced variation' is compounded in the recorded data and it cannot be accurately explained and quantified. It is unusual that variables other than some limiting factors of fish growth, such as dissolved oxygen, are controlled, and water temperature regulation is an expensive option applicable only rarely.

Commercially the interest is focused on the behaviour of the fish stock production responses, commonly expressed as somatic growth. Regression analyses should try to estimate growth (Y) and account for the effects of the major independent variables (X_i's) which are expected to influence it critically. Despite the significant contribution of regularity in stock and feeding management strategies, fish growth relationships cannot be 'purified' from indirect influences, and the accounted as independent variables in a regression equation are in reality uncontrolled and observed always with some degree of measurement error.

Therefore, estimation of the observed linear regression appears to be the best solution of representing mathematically a fish growth relationship in commercial farming. The observed regression equation may provide indications which are very useful in practice for prediction purposes.

Estimating a true relationship in the laboratory and extending it in practice is doubtful because the experimental conditions under which the true data is produced cannot be followed in farming.

2.3.4. Observed (predictive) regression estimation by least squares.

The usual standard method of predictive/observed linear regression estimation is that of least squares, which gives the observed regression line or surface when all random variables are subject to error (unexplained variability). It does not require any assumptions about the probability distributions of the variables as it appears to apply to any set of ordered observations (time series or cross section).

Wald, (1940) has proved that for the purposes of prediction, when unbiased observed values of the independent variables are used, the unbiased estimate of the value of the dependent variable obtained by least squares has the smallest variance among all other unbiased estimates, that is, the least squares technique provides the most efficient estimate.

Since all observed facts are measured with some margin of error and, moreover, the dependent variable (Y) has an inherent biological variability in its responses, it is obvious that for any observed set of values of the independent variables (X_i's) there are many possible Y values. There is in fact a distribution of Y values for any given set of X_i values. Least squares attempts to estimate the mean of this distribution ($\bar{Y}$) as well as obtain knowledge of the possible prediction error of this mean estimate (just as when estimating the mean of any population confidence intervals are given). In fact least squares tries to minimise the weighted sum of squares of such deviations about the mean estimate. The deviations are due to measurement errors, natural and biological variability or both. The estimate of prediction error is provided as the minimum sum of the squares of the deviations of the estimated mean ($\bar{Y}$) from the observed value of the dependent variable (Y), both corresponding to each particular set of observed X_i values, divided by the degrees of freedom. So, the practical advantage of the least squares method for prediction purposes is that the true values of the variables are redundant.

Least squares, and indeed any other regression technique, estimate Y values within a zone of equal width. Thus, it is valid under the assumption that the deviations about the predicted line or surface are symmetrically distributed about zero mean with the same variance for all sets of observations, namely, "homogeneity of variance" or "homoscedasticity". This implies that the degree of deviation of the estimates about the true values of Y does not depend on the values taken by the independent variables (X_i's). If no such assumption about the distribution of the prediction errors holds (heteroscedasticity), the process of minimising their squares is only a matter of convenience in so far as it is attempted to pass the line or surface as closely as possible to the observed set of points. Related to the above important property of the data are sampling bias and the transformations of the variables.

Sampling bias: The manner, controlled or random, in which the data observations are obtained is of importance because measurement errors should be unbiased. That is, although it is not essential that the errors are normally distributed, it is necessary for the deviations about the true value of an observed variable to have equal probability (Nair, K.R. and M.P. Shrivastava, 1942, Berkson, J., 1950, Ricker, W.E., 1973).

Variable transformations: Sometimes homoscedasticity may be restored by transforming one or more variables in the functional relationship. In biology logarithmic transformations are very common, and indeed, in many cases -particularly of allometric correlation- it has been found that the distribution of the variables is heteroscedastic and skew. Often, however, the distribution of their logarithms is homoscedastic and more nearly normal,making it suitable for linear regression estimation (Kermack, K.A., and J.B.S. Haldane, 1950, Jolicoeur, P. and Heusner, A.A., 1971).
Nevertheless, it must be remembered that any transformation may change the nature of the relationship between the variables (Zar, J.H., 1968, Glass, N.R., 1969), but if the data is

recorded on commercial farm sites and an observed relationship is only feasible, the consideration is focused on the utility of the linearly transformed equation for prediction. Ideally, a transformation should both stabilise variance and introduce (or retain) linearity (Kermack, K.A., and J.B.S. Haldane, 1950, Ricker, W.E., 1973).

3. MODELING FISH GROWTH

Growth is the measurable increase of an organic system produced by the assimilation of materials obtained from its environment (Bertalanffy, L. von, 1938).
When modelling fish growth processes, growth may be expressed as body gains in weight (dry or wet), length, or energy (calories). This measurable increase is a result of extremely heterogeneous, complex and as yet obscure biochemical phenomena which take place at the cellular and organic systems and characterise the physiology of growth. Furthermore, these multiple processes are triggered, controlled and limited by external factors which characterise the surrounding environment of the fish and they too change, resulting in climatic and microclimatic, periodic or non-periodic fluctuations through time.
The investigation of the specific growth mechanisms is slow and costly. Thus, in the meantime, there is a need for comprehensible descriptive models applicable to commercial environments. Since it is possible to state statistical laws for the overall outcomes of complex phenomena the single events of which are inaccessible to investigation, empirical/descriptive models of growth may be developed. These may simply describe mathematically what is observed, that is, the pattern of growth under measurable changes of influential factors in the environment.
Bertalanffy, von L. (1938, 1957) stressed that the actual complexity is not overlooked or neglected by descriptive models if they give, for an abstract aspect of happenings, an abstract formulation, the mathematical analysis of which is based upon

and is always related to physiological experience.
Moreover, as for any other production function, in fish growth the effects of the multitude of variables are expected to be confounded, so models are not useful when applied in environments different from those which supplied the data that calibrated them.

3.1. Empirical fish growth models based on the metabolic energy balance.

These models are based on the physiological aspect that growth is the net result of building up and breaking down of cellular material. This view was first formalised by Pütter, (1920) and advanced by the work of Bertalanffy, (1938, 1957). Raw 'building' materials -inputs- enter the organism through a boundary of a surface and the breaking down of material occurs in a metabolically active mass of some weight and volume contained within the surface. Removal of metabolic products and heat energy occurs also across surfaces.
Therefore, fish growth seems to depend on the utilisation of inputs -mainly food- according to the internal ratio of metabolically active surfaces and masses. Moreover, the rates of the metabolic functions are controlled or limited by the state of the factors of the ecological environment which are external to the organic system. For example, the efficiency of digestion and the energy conversion of the food intake depend on its quality. The catabolic processes are influenced by the dissolved oxygen concentration in the water via its role in the oxygen absorption through the gills. Temperature appears to regulate the intensity of all metabolic reactions by activating the enzymes.
So, the average gains and losses of fish biomass under an environment of known conditions and after consumption of known inputs could be estimated in terms of a metabolic -energy balance- function which would account for the metabolic relationship between surfaces and masses.

3.1.1. Problems of metabolic model design for fish growth predictions in commercial farming.

Since no true mechanistic view of the metabolic growth phenomena is yet available, even when the living environment is closely controlled, certain unproved assumptions are made in order to derive a mathematically computable energy balance equation. Simple mathematical relationships (linear, parabolic, etc.) must be used between quantities in order to simplify expressions which are difficult to handle (Ursin, E. 1967). Certain variables may be replaced by constants if they are kept at stable desirable levels during the experiments which produce the data to fit the parameters of the equation. Obviously, these pose limitations on the model's applicability.

Ursin, E. (1967) felt that although an account of growth processes should deal with the energy transfer at the molecular level, he practically had to deal with overall body mass changes under several simplistic assumptions both for mathematical convenience and due to limitations in quantitative understanding of metabolism.

Ursin's work has been the starting point for several other researchers in fish growth phenomena especially in the area of intensive aquaculture, such as Sparre, P., From, J., and Rasmussen, G., (1975 - 1986), who had, however, to abide with similar simplistic assumptions, namely:

- The food has the same chemical constitution as the fish body for inputs (food) and output (body gain) to be directly comparable.
- The energy necessary for synthetic processes is supplied by oxidations requiring free oxygen, so, oxygen uptake can be a direct measure of the rate of metabolic processes.
- The fish mass has equal density and specific gravity equal to one.
- Body growth is isometric, that is, the relative growth of a linear dimension is $^1/_3$ of that of weight (or volume). The area of surfaces is assumed proportional to a linear dimension

squared and weight is proportional to a linear dimension cubed.

- The past history, nutritional or otherwise, of the fish has no effect on their future growth potential. Two fish of equal weight at a given time are assumed to have equal growth possibilities irrespective of how they obtained their present weight (the "Markovian assumption").

Obviously, any model that incorporates such approximate assumptions merely describes empirical observation.
For example, it is unlikely that the common assumption of isometry between surfaces and masses (Bertalanffy, L. von, 1938, Ursin, E., 1967), also called "surface rule" or "two thirds' rule", holds in nature. In reality, certain areas may increase enormously with respect to body volume by such devices as gill and lung or intestine structures. On the other hand, there are impossible practical difficulties in physically measuring the internal surfaces due to rapid post mortem changes.
Also, for convenience body mass is considered homogenous and equally metabolically active, having similar material constitution as the food intake. In fact, the total weight of a fish does not coincide with the "metabolically active" weight that should participate in an energy balance equation and occupies different proportions of the fish body according to species, age, etc.

Therefore, the mathematical approximation of the metabolic processes of an observed growth pattern relies on <u>any</u> empirical assumption which conveniently satisfies the description of the pattern encountered in the data. So, possibly several model designs may be devised but none of them would be physiologically correct and hence justify its deep metabolic reasoning.
If such models are to be used for commercial production advice, data must be produced from experiments designed to match as closely as possible the real farming conditions. Since data from aquaria may not represent commercial phenomena, the set-up of "pilot farms" remains as the only feasible solution for data production for a particular farming system of a given species at a specific geographical location (Sparre, P., 1976).

However, this is excessive in its demands for resources in order to produce the desirable qualities of the data and cannot be easily repeated (Sparre, P., 1976).

Metabolic growth models were initially established for the study of fish population dynamics but soon the value of modeling growth was realised by the expanding fish farming industry. So, models have been designed to describe growth of the most commercially significant fish species in the intensive farming environments.
Commercial fish farmers need to estimate the 'fresh' weight that a fish would obtain in a period of time, starting from an initial weight and under a certain degree of water temperature and other levels of environmental variables, when it is offered a known quantity and quality of food. The main emphasis for practical purposes is the numerical prediction of growth rather than the physiological explanation of it.
Until, at some future time, growth curves may have a generally accepted physiological basis, the immediate need is for growth curves/models that are a good summary of the data in hand and use parameters/constants which are easily interpreted (Knight, W., 1969). Energy balance models, although they may provide a scientific challenge and an opportunity to advance physiological theory, do not relate to the directly observable facts and the straightforward variables of commercial practice. So, they should be expected to offer more to research than to practical fish farm management (Fridley, R.B., 1986).
The types of data needed to calibrate metabolic models cannot be collected routinely from the field by the farm personnel because the data elements are not always directly observable and require precision that exceeds the ordinary capacity of fish farm labour. For example, precise knowledge of food consumed is impossible even in pilot experiments since the precise stomach content of a live fish cannot be determined. Using a constant coefficient to account for food waste is yet another rough approximation adding to the pool of assumptions.

In all, metabolic fish growth models can be designed and experimentally calibrated -although with difficulty- to approximate the fish growth pattern of specific fish farming situations, but they suffer from inflexibility when extrapolations are required to different situations. The assumptions, which are inherent in their mathematical design, despite their non-evident physiological significance, may be empirically sound, but in practice, their data demands cannot be satisfied. Very tight control of variables and enough time to spend on complicated routine recording tasks are impossible.

3.2. Empirical fish growth models based on observed fish size (wet weight): The Parker and Larkin equation.

Admittedly, fish growth is a result of very complicated metabolic functions, but to the eyes of the fish culturist it appears as a purely additive process. Fish farmers supply their fish with quantities of a certain food type and observe them adding to their size. They also realise from experience that the fish behave, eat and grow differently according to their size range and are affected by variations in water quality and supply and those of the climate, especially of temperature. Therefore, the practical needs to describe fish growth might be fulfilled by a mathematical expression which, despite the complexity of the mechanisms involved, would adequately depict the observed end result.

Parker, R.P. and P.A. Larkin, (1959), realised that fish growth could be visualised as a series of growth stanzas each defined by ecological and physiological thresholds. Within each stanza fish size alone could be considered to 'summarise' in itself the physiological determinants of growth which would respond to the opportunities offered by the ecological environment and also, in the case of fish farming, the growth opportunities offered technically by management.

Therefore, growth might be appropriately described mathematically by a model with a minimum number of variables and constants. The constants/parameters would reflect the combined/compounded effect of the complex ecological and physiological factors in each particular stage of the fish growth history. Thus, the common hybrid growth equation could be achieved for each different life phase (stanza) of every fish batch.

The growth (G) achieved in a growth period (t) would be adequately described by the final fish 'fresh' weight (W) that is observed at the end of period t.
Parker, R.P. and P.A. Larkin, (1959), related the above variables in the following form:

$$G = k \cdot W^x$$

where: G is the change in fish size achieved in time period t, that is, $G = {}^{dW}/_{dt}$ and $dW = W - W'$(final minus initial weight).
k and x are the constant parameters of the equation.

The parameters (k,x) need to be fitted using only the data of average fish weight observations (W) at the end of each growth period t. This data should be related to a particular stanza. Therefore, data on fish growth must be distinguished according to fish batches and these according to life history groups. So, the growth of the average individual in each sub-group of the fish population on a farm could be described separately by a unique equation.
If an overall picture of the growth of the entire population is required, then a "weighted average" could be calculated according to the relevant abundance of the members of each group in the population.

Any growth stanza is delimited by ecological as well as physiological thresholds which explain the two components of the observed natural growth variation. The latter depends on the

inherent variation in the ability to grow (genotypic) as well as on what is dictated by the surroundings in terms of natural environment and the management of the stock (phenotypic). So, to some degree, fast-growing and slow-growing individuals will maintain their relative status throughout life.
The parameters of the Parker and Larkin type of growth equation can be interpreted in each stanza in terms of these two components, the physiological responses and the ecological opportunity. The exponent of weight (x) may be considered to be primarily established by the biotic properties of the fish's organic systems which determine the growth responses to any changes in the ecological offerings. The latter are in turn given an overall measure in terms of the value of the constant k. The weight exponent, x, being an overall measure of the physiological characteristics, remains stable for similar fish at similar growing phases. It is also less than unity reflecting the observed diminishing growth efficiency as the average size increases. On the other hand, the constant k, which is expected to reflect the ecological opportunity, differs, even for similar fish when data comes from variable environments (Elliott, J.M., 1975, Iwama, G.K. and A.F. Tautz, 1981).

Since x is less than unity, the proposed exponential equation expresses allometry between growth and the final weight achieved at the end of the growing period.
This expression parallels remarkably empirical descriptions of the relationship between fish weight and various other physiological processes in fish. For example, it can describe the fish oxygen uptake, or indeed the directly related metabolic rate, under standard resting conditions or under active conditions (Fry, F.E.J., 1957). The adequacy of such a functional form to describe mathematically the observations of many different body functions and physiological rates of not only fish but also mammals, or even respiration rates of individual organs, underlines the coordinated aspect of a living system, and although it may not be scientifically proved, it establishes empirical confidence on the proposed growth equation.

In addition, the phenomenon of stanzas is characteristic for physiological rates. 'Breaks' in the growth curve of several fish species are related to the drastic physiological changes associated with ossification and maturity. For example, salmon experiences two very distinct physiological transformations, one at the parr-smolt stage and the other at maturity.

3.2.1. Suitability of the Parker and Larkin type equations for fish growth predictions on farms.

In fish farming the ecological part of a stanza is expected to have the most profound effects on growth variability. Usually, commercial operations concentrate on certain fish species at particular phases of their growth. Salmon hatcheries grow young salmon to smolt level, trout hatcheries produce trout fingerlings up to a certain fingerling size, and ongrowing facilities aim at marketable table sizes which are often met before or up-to any physiological threshold is encountered.
Therefore, it is the **ecological** thresholds, which are usually introduced by management, that more often confine the growth stanzas and the related growth data in practice. However, management interferes with the biotic properties as well, since a history of good or bad management may induce permanent changes to growth responses.

The Parker and Larkin type growth equation is based on straightforward description of apparent phenomena. Non-evident assumptions are unnecessary since the equation is computationally simple and minimises data demands. It is a hybrid function which measures indirectly the significance of the complicated effects of all unaccounted variables in the values taken by the constants. Obviously, the quality of the fitted parameter values determines the efficiency of the equation to describe growth, so the data for calibration should be carefully selected in respect to clearly defined stanzas.

Since initial and final fish weight are the basic variables, the equation can be rearranged and integrated in order to derive an explicit solution for the fish weight finally achieved in the defined time period.
Using the same notation of the variables, the algebraic formulation is as follows (Iwama, G.K. and A.F. Tautz, 1981):

$$dW/_{dt} = k \cdot W^{x}$$

$$dW = k \cdot W^{x} \cdot dt$$

$$dW \cdot W^{-x} = k \cdot dt$$

$$\int_{W'}^{W} W^{-x} \cdot dW = k \cdot \int_{0}^{t} dt$$

$$\frac{1}{(1-x)} \cdot W^{(1-x)} - \frac{1}{(1-x)} \cdot W'^{(1-x)} = (k \cdot t) - (k \cdot 0)$$

$$W^{(1-x)} = W'^{(1-x)} + (k \cdot (1-x) \cdot t) \qquad (1)$$

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where: t is the number of growth periods,
W' is the initial weight,
W is the final weight achieved,
$(1-x)$ is the genetically specific weight exponent,
k is the 'ecological constant'

Since $(1-x)$ is less than unity, equation (1) indicates that weight gain $(W - W')$ per growth period increases as initial size (W') increases but at a decreasing rate, that is, the percentage increase declines with increasing W'.
The value of the exponent $(1-x)$ was observed, in experiments with several species, to vary usually between 0.17 and 0.5 (Iwama, G.K. and A.F. Tautz, 1981). Moreover, as expected, fish weight predictions were relatively insensitive to the value of this parameter within a particular species.
On the other hand, k is the representative of the various ecological factors which define the opportunities for growth.

So, if data on some of the environmental variables or management actions that control growth was available for the particular stanza, k could be analysed, at least partly, to some of its major constituent parts. Thus factors such as water temperature, stocking density etc., could be introduced to the growth equation as extra independent variables and, if required, predictions of growth could be achieved relating directly to them too. The remaining part of the 'ecological opportunity' would form the new parameter k.

Elliott, J.M., (1975) in his attempt to estimate maximum growth of different size ranges of trout, held at different constant temperatures, when fed to satiation, derived an equation where the final weight achieved by the end of a growth period is described by the initial weight and the average water temperature during the period of growth as follows:

$$W^{b_1} = W'^{b_1} + b_1 \cdot (c + b_2 \cdot T) \cdot t$$

where: W, W', t are final weight, initial weight and the number of growth periods respectively,
T is the average water temperature,
c, b_1, b_2 are constant parameters.

The exponent b_1 is equivalent to $(1-x)$ and estimated by Elliott as being less than unity. The part $(c + b_2 \cdot T)$ is indeed the constant k of equation (1) analysed to give direct account of water temperature T, which forms here an independent variable with b_2 as its coefficient. The new constant c now represents the remaining part of k.

It is interesting to mention that while Elliott developed his equation from analyses of data from his feeding experiments, Parker and Larkin developed theirs chiefly from theoretical arguments. This remarkable coincidence in the mathematical representation of growth by two distinct approaches, provides strong evidence that equation (1) offers realistic descriptions of fish growth, and shows that the total influence of the multivariate environment, natural or technical, finds an adequate measure in the different values that parameter k may take according to the circumstances.

Hence, the most important property is that those variables on commercial sites which are difficult or impossible to observe and record routinely may be omitted altogether from the equation without invalidating the growth predictions, since their effects will be effectively depicted by the constant k after model calibration.

So, food consumption, for example, need not be included in the model at all. The good or bad results of each feeding policy will be shown in terms of the predicted final weight that is calculated by the equation using the calibrated k value which depicts the degree of the suitability of the particular feeding policy in promoting growth.

Clearly, for different model calibrations to be possible describing growth patterns under different farming conditions, data on these must be available. Management should maintain growth records in relation to the policies that should be compared. Equally, comparisons may be made of the seasonal effects on growth under stable management and for genetically similar livestock.

Extending this aspect further, in cases of reasonably similar fish farms, if the same stanzas in terms of fish properties, environment and culture designs could be recognised on them and data was available, comparisons of growth results, and specifically of their k values, could depict the differences in stock management efficiency.

Overall, it appears that such an empirical equation as equation (1) may describe fish growth in commercial situations efficiently for two basic reasons.

First, its data requirements can be handled by the fish farm workers because they concern directly observable and measurable raw facts; basically regular recording of average fish size.

Second, the proposed model is in agreement with fish farming practice where different fish batches are usually kept separate and the fish are graded in order to achieve uniformity in growth potential. Thus, stock management 'automatically' defines the various life-history groups and often maintains a distinct treatment for each one. Due to this 'subconcious' definition of stanzas by farmers, groups of homogenous data could be established and used to fit the equation.

Assuming that a computerised data recording system is in operation on a fish farm, it could be extended to accommodate the growth model as part in a feed-back loop. Selection of the appropriate data from the data-base would precede the automatic recalibration of the model's parameters to suit exactly the growth pattern of each stanza. A unique, accurate equation would be generated to describe and compare growth and environmental and/or managerial quality of every group of fish. Sets of growth predictions for several combinations of policies and seasons could be generated to give useful management information for improvements of production methods and effective growth programming decisions to be made.

4. A COMPUTERISED SYSTEM FOR DYNAMIC FISH GROWTH PREDICTION IMPLEMENTED ON A COMMERCIAL FISH FARM

4.1. Formalising the practical growth equation.

Fish farm management needs information on expected growth in order to plan production targets and improve day-to-day operations. The ultimate benefit would be better profitability through tighter fish control and more efficient utilisation of inputs and effort.
A Parker and Larkin type of fish growth equation, linearly transformed and fitted by ordinary least squares regression with observed farm data on each specific life-history stanza of a fish batch, may satisfy the purpose of predicting growth.

Farmers often record their stock's average size consistently at intervals, so, opening (W') and closing (W) weight observations of each group of fish every week or fortnight may be available. Equation (1) can be fitted by least squares on observed data after it has been linearly transformed logarithmically and predict the final average weight of a group of fish at the end of a growth interval given the opening size. Taking logarithms from both sides of equation (1) we have:

$$(1-x)\cdot \log W = (1-x)\cdot \log W' + \log(k\cdot(1-x)\cdot t)$$

dividing by (1-x),

$$\log W = \log W' + \frac{\log(k\cdot(1-x)\cdot t)}{(1-x)}$$

for t=1, i.e, for a single growth period,

$$\log W = C + \log W' \qquad (2)$$

where: C is a constant parameter which seems to incorporate all properties of the stanza, that is, both the ecological opportunity and the biotic capabilities of the fish, but in relation to the logarithmically transformed growth data.

Equation (2) could be analysed further to account directly for the effects of at least one major influential factor that controls fish growth, namely, the water temperature.
The constant parameter C in equation (2) is affected by both the ecological and the biotic qualities of the given stanza, and can be broken down into some of its constituent types of influence.
Equation (2) may be rewritten as:

$$\log W = A + b \cdot T + \log W' \qquad (3)$$

where: W is the predicted final fish weight at the end of the growth interval,
W' is the initial weight,
T is the average water temperature during the growth interval expressed in degrees centigrade,
A is the new intercept, that is, the parameter which includes the influences of the unaccounted ecological and biotic variables,
b is the coefficient of water temperature (T) and depicts the significance that temperature has on achieving the logarithm of final weight (logW).

From equation (3) prediction of final weight is achieved in terms of its logarithm and the 'pure' W value may be computed as:

$$W = \text{antilog}(A + b \cdot T + \log W')$$

ie. $$W = 10^{(A + b.T + \log W')}$$

The value of the parameter A might be further exploited for comparative investigations (Jobling, M., 1983). Using data on the same species and growth stanzas, the constant A, estimated by least squares on various similar farm sites, could indicate better or worse site and/or management characteristics across farms.
In addition, on the same fish farm, if data is available for

equal life-history stanzas of similar fish batches but for different seasons, the computed A values could measure the significance of seasonal environmental change on fish growth. Technological change or the implication of altering feeding or any stock management method could also find an approximate numerical expression in terms of a higher or lower constant A estimate.

4.2. The quality of the estimated constant and coefficients.

Although the aggregate effect of the variables that are excluded from a simplified equation may be depicted by the equation's constant intercept, if they are correlated to one or more of the included independent variables, then the parameter estimates of the latter may be systematically distorted away from their true value. The direction of this bias depends on the type of the correlation between the omitted and the included variables.
Nevertheless, despite the possible introduction of bias when simplifying a predictive equation, its overall suitability is found in the combination of unbiasedness and minimum variance of the estimated coefficients. Thus, although by dropping independent variables from an equation its estimates may become biased, the confidence limits of these estimates will usually be shortened, outweighing the drawback (Anderson, R.L., 1957).

Associated with possible interelationships between the independent variables in a regression equation is the phenomenon of "multicolinearity", which denotes substantial correlation between them. If an independent variable is highly colinear with another then its estimated coefficient may have a very large variance and hence be much less precise. Such an unusually large variance can be detected by the high standard error which is attached to the coefficient estimate. The estimated coefficient is unstable and by adding a few more observations to the data and re-calibrating drastic changes can happen to its

estimated value.
However, multicolinearity does not create problems for the predicted outcome as long as it is also accepted to hold in the future. This is true if fish farm records are used to provide predictions for similar future stanzas to those that they represent.

4.3. The types of fish growth data used for prediction.

In the implemented record keeping system (first chapter), the farm data is stored by the computer on magnetic disks (hard or floppies) in the form of electronic files, each containing the data from an individual source/unit during a unique stanza. In each file the data is listed in the form of successive records at equidistant intervals (series of growth periods), preferably weekly, and comprises "time series data".
On the other hand, several files may be created by the recording system for the same stanza and fish batch which correspond to different sources/units (tanks, ponds). Such a collection of 'similar' data across units comprises "cross section data".

Both time series and cross section data, relating to similar batches during identical life history stanzas may be pooled together in order to fit a prediction equation by least squares. Pooling of cross sectional and time series data can be done in cases where the production units have similar characteristics (quality properties) and operate under similar environments (Wu, C.C. and A. Mirakhor 1975, Jabara, C.L. 1982). There should not be any specific trend of any particular factor through the period of observations. The production units should be operated under the same management style and technology, since differences in managerial efficiency affect the computed value of the intercept in the predictive equation.

In general, most livestock production functions are based on data observations being made relative to each of a group of animals at a number of points in time. With animals the observations are usually made at short intervals over a short run period: hence the effects of variations in unmeasurable factors may be comparable (Heady, E.O. and J.L. Dillon 1961).

4.4. Some additional opportunities..

Since least squares regression may fit a predictive linear or linearly transformed equation to observed farm data, on farms with an organised recording system such knowledge could be utilised beyond growth predictions to facilitate the estimation of other important variables.

4.4.1. Predicting food consumption.

Elliott, J.M. (1975), formulated experimentally the following equation in order to calculate the maximum food that could possibly be consumed on average by a fish at a given size:

$$F_{max} = a \cdot W^{b_1} \cdot e^{b_2 \cdot T}$$

where: F_{max} is the maximum food amount consumed per growth period by the average fish,
T is the average water temperature in degrees centigrade,
W is the fish weight,
a, b_1, b_2 are constants (parameters).

'b_1' and 'b_2' depict the degree of influence of weight (W) and temperature (T) on the consumed food respectively. The intercept 'a' may be regarded as an overall indicator of the 'gross' influences of the unaccounted factors on F_{max} for the specific stanza.

This formulation is in agreement with similar work on other species by Wooton, R.J., J.R.M. Allen and S.J. Cole (1980), who also concluded that two of the most important factors related to the rate of food consumption are the size that the fish has already reached and the temperature of the water.

Elliott's equation was transformed logarithmically, as shown below, in order to be fitted by least squares on data from the farm records.

$$\log F = c + b_1 \cdot \log W + b_2 \cdot T \qquad (4)$$

In equation (4) W and T are fish weight and water temperature respectively. F is taken as the feeding rate (amount of food per unit of fish biomass) in order to avoid the dependence on the number of fish being fed.
The interpretation of the intercept and coefficients is not changed; however, they now relate to logarithmic data.

If the feeding regime during a particular life-history stanza is stable, either at the maximum level or at a constant percentage of the corresponding maximum, and data is available, Elliott's transformed equation in its linear logarithmic form should predict the feed rate (F) at that level!
It should be noted that as far as the food quality is concerned, food is considered to be nutritionally balanced, with the right energy content, and to have the appropriate pellet size for every fish type.

4.4.2. Prediction of the water needs.

On commercial farms stocking density, usually expressed as the amount of fish biomass stocked per unit of water volume, is judged by the farmer, who ensures that the fish are 'happy' in their containers. Experiments and experience indicate the appropriate density according to water quality (oxygen, suspended solids etc.), the nature of the container (earth pond, plastic tank), the feeding regime and the habits of the fish.

Assuming a farm where food is amply distributed and oxygen is always plentiful -possibly safeguarded by an automatic system for water aeration or by water flow regulation-, the space that the fish have available to themselves may only limit their growth when it is so scarce that it constrains their social behaviour and physiological activities. Therefore, when stock management and environment are stable, only the biotic properties of the fish are expected to formulate their water needs. Hence, density may be associated with the size-range of the fish, which depicts the physiological demands in each stanza. When a density limit is reached fish must be relocated (transfers, grading). However, until then and given that mortality is insignificant, the density of a growing population confined to the same container will be proportional to average fish weight.

In view of the above discussion, the following linear equation, estimated by least squares, could predict the stocking density for each stanza in relation to average size:

$$D = a + b \cdot W \qquad (5)$$

where: D is stocking density expressed as biomass per unit of water volume,
W is fish average weight,
a, b are constants.

No transformation of the variables was found necessary to improve linear correlation.

On those fish farms where sufficiency of dissolved oxygen to all fish is not guaranteed by artificial aeration or by regulating the water flow, fish density must be often adjusted in order to avoid mortalities. Given that there are no other types of environmental degradation and that correct feeding and stock management stability are ensured, stocking density should in theory be related also to the degree of oxygen shortage. This is because oxygen is a limiting factor influencing growth only below a certain threshold, which relates to the prevailing conditions overall and hence is not clearly identified. Thus in practice such data cannot be recorded.

4.5. Structure and results of the implemented computerised prediction system.

4.5.1. 'Tuning' the equations' parameters and generating a "prediction table".

Since a recording system that could isolate and extract data for each stanza was already in operation (first chapter), equations (3), (4), and (5) were utilised in a computerised system to perform predictions. The general purpose software LOTUS 1-2-3 was used as in the case of data recording. Customised LOTUS worksheets using special 'macro' commands were constructed to interact with the data files stored on the computer disks. Data files containing data on any particular stanza could be selected at will for subsequent calibration of the equations by least squares regression. The equations fine-tuned to the specifically desired circumstances (stanza) were then used to generate a 'prediction table' showing fish growth, conversion efficiency, food and water needs.
The customised worksheets interacted in the following schematical way:

Farm data files (actual records on a stanza)
↓
'Regression' worksheet
↓
'Prediction' worksheet
↓
Prediction files and graphs

The 'regression' worksheet is responsible for calibrating the equations according to the data that the computer operator specifies. Then the linked 'prediction' worksheet generates a prediction table. This is possible because spreadsheets can

present a sequence of linear equations in a table consisting of rows and columns. Rows in the table represent time intervals, such as weeks. They are linked with each other in a time series system where the predicted values of each row-week form the input -opening values- for the next.
In a sense the table forms a recursive system of independent, successive equations linked by their predictions. Columns too are interlinked to give and take values among their equations. For example, 'What if ?' analyses may be performed on the prediction table by changing the water temperature values or the inital opening fish size. After the anticipated average water temperature is input in a row, the predicted fish weight (closing), the food and water demands and the converting efficiency of the fish are calculated. Then the row passes on this information to the next row as opening values for the next time interval.
The depth of the table in terms of the number of growth periods can be extended at will in order to conform with the forecasted growth cycle. However, care should be taken not to exceed the range limits of the original data figures.
In summary, the criteria that should apply to the data when it is selected from the pool of farm records in order to calibrate the equations are listed below:
- The data must relate to the same fish (species, sex, origin, etc.) which, in addition, show equal growth efficiency.
- Data must come from similar containers (data sources).
- The environmental conditions and stock handling should be relatively stable throughout the data records.
- A stable feeding rate either maximum (ad-libitum) or at a constant percentage of the maximum should be represented in the data.

The measurement units of the physical quantities that are used in the prediction system can be tailored according to the demands of the particular fish farmer.
The customised worksheet which is responsible for estimating the regressions expresses weight in grams and water volume in cubic

meters (metric system). However, when the prediction table is being built the initial units may be converted to suit any needs. Changing the measurement units of the variables may affect the estimated parameter values and their standard errors but leaves their statistical significance untouched. The coefficient of determination (R^2), the correlation coefficients, the F- and t-tests for significance of the regression estimates of the coefficients remain unaffected by such manipulations (Zar, J.H., 1967). So, the absolute parameter values may change but not the relationships.

The customised 'prediction' worksheet that generates the prediction table contains also in-built graphics which are automatically updated as soon as the table is complete. These graphs can be viewed on screen, printed on paper or stored on disk and provide illustrations for predicted weight, density and water needs, anticipated temperature and predicted food needs.

The prediction tables with their graphs may be stored on floppy disks or on a specific sub-directory on a hard disk for future further analyses.

Complete user instructions can be found in Appendix C.

4.5.2. An example demonstrating the use of the system and its results.

The hatchery farm on which the computerised recording system was implemented (chapter 1) was also used to test the outlined prediction system.

Here, a data file representing a fish tank from that hatchery was selected at random and this computerised prediction system was activated for demonstration.

The prediction programme initially allows the operator to specify the computer files that hold the fish farm data. Then it accesses them automatically from the storage disk, extracts their data and uses it to calibrate the equations (customised 'regression' worksheet). After this task is completed, the operator may print the regression analysis details on paper for scrutiny.

The regression process was activated on the realistic hatchery data which was randomly selected from the farm's data files and the regression output was printed. The printout is shown below and its results are discussed.

Fig. 1. The regression printout:

REGRESSION ANALYSIS OF THE DATA

\#

WEEKS	Wo (gr)	T (C)	log Wo	D kg/m3	Wt (gr)	log Wt	FR %bicm	log FR
13-Oct-86	2.8375	9.7	0.4529	13.02	3.2899	0.5172	1.0599	0.0253
20-Oct-86	3.2899	7.4	0.5172	15.08	3.4923	0.5431	0.8854	-0.0529
27-Oct-86	3.4923	5.8	0.5431	16.00	3.8475	0.5852	0.6831	-0.1655
03-Nov-86	3.8475	6.0	0.5852	17.56	4.3654	0.6400	0.6119	-0.2133
10-Nov-86	4.3654	6.0	0.6400	19.90	4.4510	0.6485	0.5141	-0.2889
17-Nov-86	4.4510	4.0	0.6485	20.27	4.5400	0.6571	0.3949	-0.4035
24-Nov-86	4.5400	5.0	0.6571	20.65	4.7789	0.6793	0.4332	-0.3633
01-Dec-86	4.7789	5.2	0.6793	21.74	5.0444	0.7028	0.3597	-0.4441
08-Dec-86	5.0444	4.4	0.7028	22.93	5.5366	0.7432	0.3341	-0.4761
15-Dec-86	5.5366	2.8	0.7432	25.16	5.7468	0.7594	0.2238	-0.6501
22-Dec-86	5.7468	3.4	0.7594	26.11	6.0533	0.7820	0.1712	-0.7664
29-Dec-86	6.0533	2.5	0.7820	27.50	6.2192	0.7937	0.1232	-0.9094

Range of the data (Min-Max values)

	SEASON	TEMP.	SIZE gr.	& Nos/lb	DENSITY kg/m3	lb/f3
From:	13-Oct-86	2.5	2.84	160	13.02	0.81
To:	05-Jan-87	9.7	6.05	75	27.50	1.72

Wo: the fish weight (gr) at the start of the growth period (week).
Wt: the fish weight (gr) at the end of the growth period (week).
T : average water temperature (Centigrade) for the growth period (week).
D : Stocking Density (opening biomass kg/m3).
FR: the feeding rate, ie. kgrs of dry food per kgr of biomass, and is either maximum (adlib.) or a certain percentage of the maximum.

Assuming normal stocking practices under sufficient water flow and dissolved oxygen,
then : D = f(Wo)

Regression Output:

Constant	0.282304
Std Err of Y Est	0.018146
R Squared	0.999985
No. of Observations	12
Degrees of Freedom	10

X Coefficient(s)	4.493002
Std Err of Coef.	0.005444

(continued..)

Fig. 1. The regression printout:

Assuming stable feeding, no stress or any environmental extremes, then the degree of feeding rate is given as : log FR = f(T, log Wo)

Regression Output:

Constant	1.102022	
Std Err of Y Est	0.078962	
R Squared	0.935369	
No. of Observations	12	
Degrees of Freedom	9	
X Coefficient(s)	0.013049	-2.43092
Std Err of Coef.	0.034131	0.681144

Assuming a constant degree of feeding rate and constant stocking density, use of dry food, no stress or environmental extremes, and the given technical efficiency of the fish farmer.. then : log Wt = f(T, log Wo)

Regression Output:

Constant	0.032776	
Std Err of Y Est	0.014927	
R Squared	0.977852	
No. of Observations	12	
Degrees of Freedom	9	
X Coefficient(s)	0.004094	0.960160
Std Err of Coef.	0.006452	0.128764

The computer-files which hold the data are:

---

demo60

SUMMARY:
****

1) D = 0.282304 4.493002 * Wo

2) log FR = 1.102022 0.013049 * T -2.43092 * log Wo

3) log Wt = 0.032776 0.004094 * T 0.960160 * log Wo

Note that the equations are assumed to be fitted on growth data representing a unique stanza and a constant feeding rate, ie. maximum, or a constant % of the maximum rate.

The functions hold for data within the ranges shown, and particularly for the defined season shown by the minimum and maximum dates.
They are based on the past performance and management actions of the specific farm, and assuming that conditions are stable, they may be used for prediction.

In the printout of the regression details the original data and its logarithmic transformations are listed first and the notation of the variables is explained. The ranges of the data values are indicated since the subsequent predictions will be safe only within these ranges.
The equations follow with the regression estimates of their coefficients, the standard errors of the coefficients, degrees of freedom and their coefficient of determination (R^2). Finally, a summary is given as well as a list of the computer data files which hold the original data that was used to 'tune' the equations.

As soon as the regression procedure is complete the user is prompted to generate the prediction table. This task is performed by the customised 'prediction' worksheet which imports the statistical results and constructs the table. The worksheet provides customised menu commands based on LOTUS macros, which facilitate 'what if?' analyses, can extend the table in order to accommodate more rows-weekly intervals, make graphical illustrations of the predicted outcomes on screen or print them, print the results and store the predicted information on disk for future reference.
The necessary inputs to the table are the starting date of the growing cycle and the initial opening fish weight, which must be input on the first row, as well as the average expected water temperature values, which are needed in all rows.
A prediction table was built for demonstration using the regression results that have been shown. On this table (Fig. 2.) the past performance was imitated -'prediction of the past'. This was done for the same period as the original data and using similar temperature values and initial opening fish weight. This was done in order to illustrate the close relevance of the simulated figures to those in the real data and hence show, practically, the validity of the prediction.
In general, confidence in the predicted results depends on how similar the future stanzas are expected to be with the past stanzas: that is, whether or not strong changes of the climatic

factors, management or the type of future fish batches are expected.

Fig. 2. Printout of the 'prediction table'.

Prediction model PV v.(May-87)

confidential
############

TROUT HATCHERIES Ltd.

Growth, food and water needs of:

fish batch DEMO-60 (fast growing fingerlings)

Ranges of the original data

	SEASON	TEMP.	SIZE gr.	& Nos/lb	DENSITY kg/m3	lb/ft3
From:	13-Oct-86	2.5	2.84	160	13.02	0.81
To:	05-Jan-87	9.7	6.05	75	27.50	1.72

The computer-files which hold the data are:

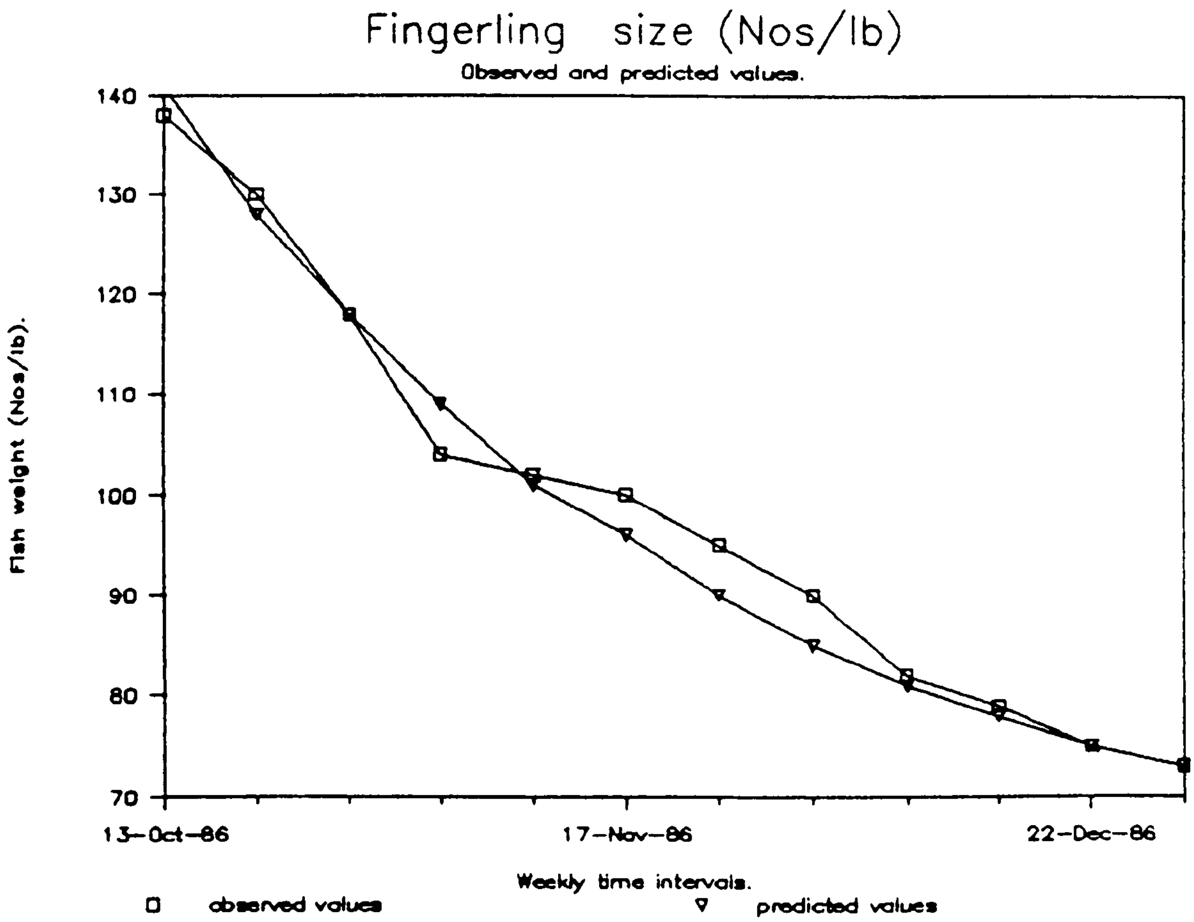
demo60

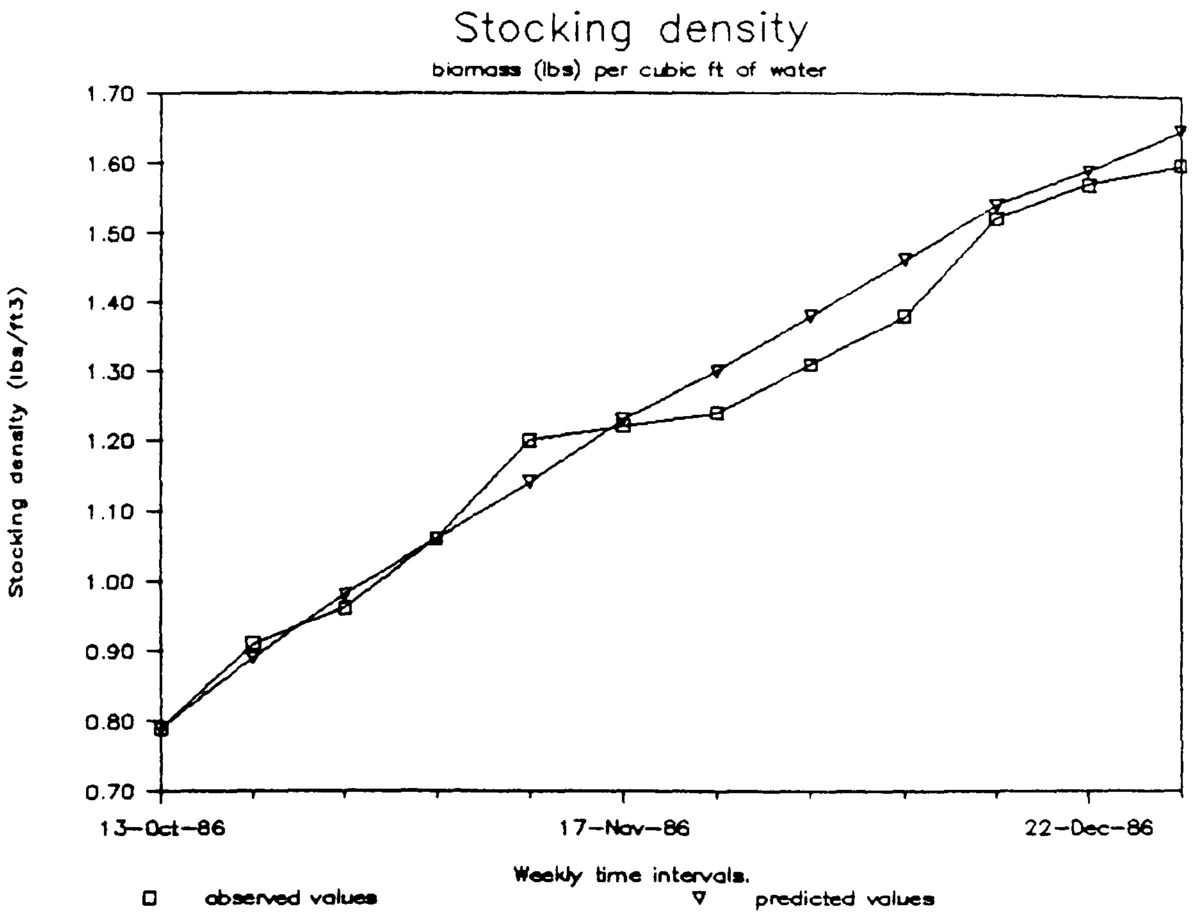
WEEKLY PREDICTION TABLE

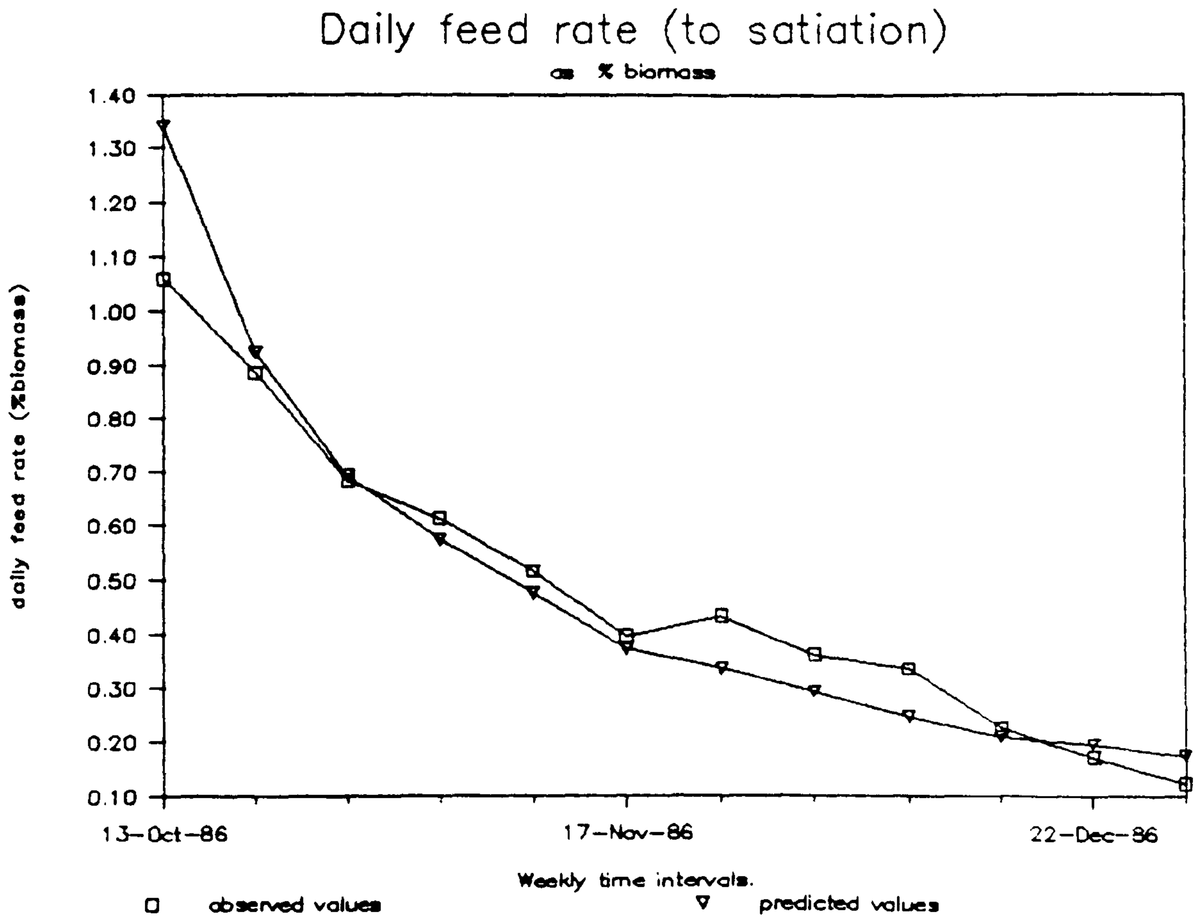
Week COUNTER	Week starts on the:	average Temperature Centigrade	opening mean size nos/lb	closing mean size nos/lb	Stocking Density lbs/ft3	daily Ration (% biomass)	Food needs /'000 fish kgr	Water needs /'000 fish ft3	projected Apparent FCR (food/gain)
1	13-Oct-86	9.7	160	141	0.81	1.3414	0.283	8.71	0.7470
2	20-Oct-86	7.4	141	128	0.92	0.9230	0.218	8.50	0.6536
3	27-Oct-86	5.8	128	118	1.01	0.6920	0.179	8.35	0.6073
4	03-Nov-86	6.0	118	109	1.10	0.5736	0.160	8.35	0.5117
5	10-Nov-86	6.0	109	101	1.18	0.4741	0.143	8.34	0.4405
6	17-Nov-86	4.0	101	96	1.28	0.3718	0.120	8.17	0.4870
7	24-Nov-86	5.0	96	90	1.34	0.3365	0.115	8.23	0.3877
8	01-Dec-86	5.2	90	85	1.43	0.2921	0.106	8.23	0.3395
9	08-Dec-86	4.4	85	81	1.51	0.2463	0.094	8.16	0.3431
10	15-Dec-86	2.8	81	78	1.59	0.2078	0.083	8.03	0.4386
11	22-Dec-86	3.4	78	75	1.65	0.1952	0.081	8.06	0.3644
12	29-Dec-86	2.4	75	73	1.71	0.1729	0.074	7.98	0.4555

The predictive accuracy may best be demonstrated by the following graphs (Fig. 3.) where actual and predicted values are plotted.

Fig. 3. Comparative graphs showing the actual versus the predicted values.




Stocking density
biomass (lbs) per cubic ft of water
Stocking density (lbs/ft3)
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
13-Oct-86
17-Nov-86
22-Dec-86
Weekly time intervals.
observed values
predicted values


Daily feed rate (to satiation)
as % biomass
daily feed rate (%biomass)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
13-Oct-86
17-Nov-86
22-Dec-86
Weekly time intervals.
observed values
predicted values

4.5.3. System testing and validation.

It has been proved on the hatchery farm for a number of production cycles that the system provides accurate expectations of growth for various batches of fish.
Practically, the fish farmer needed only to compare actual with predicted outcomes and test the consistency of the predicted figures with experience in order to be convinced that the system worked sufficiently accurately.
For instance, in the prediction table printout (Fig. 2.), stocking density increases steadily as the growing population remains in the container. Hence, the water needs per thousand fingerlings decrease, since bigger fish with less oxygen demands per biomass unit may be stocked more densely until a threshold is reached. Conforming to experience the feeding rate decreases per biomass unit as the fish grow and as the water becomes colder. Lower temperatures are also mainly responsible for the decreasing growth rate. The projected FCR values (food consumed over weight gains) appear less than unity since highly concentrated dry pelletised food is used. Perhaps they also reveal the existence of suspended natural food in the river water that recirculates in the tanks. FCR values decrease, therefore improve, at lower water temperatures.

Apart from these straightforward comparisons during implementation statistical tests were performed to check the significance of the coefficient estimates, such as the "F-test" for all coefficients in the equation or the "t-test" for individual coefficients. The results varied since the estimates differed among calibrations with different data, but overall were very satisfactory.
Since new coefficient estimates are generated with every new set of data, it was thought that a more detailed picture of the regression results could be of interest, especially to the farm advisor. For this purpose the optional regression printout (Fig. 1.) contains information, such as the "coefficient of determination - R^2 ", the standard errors of the coefficient

estimates and the degrees of freedom.
The 'R^2' value is an overall measure of the descriptive ability of the estimated equation in association with the observed behaviour of the variables. On the other hand, a "t-test" may prove the statistical significance of the estimated coefficients. For the t-tests the standard errors of the estimates are needed and hence given by the computer below each estimate.

However, even where there is adequate information about the real system's historical performance, a considerable degree of subjective judgement is still necessary for validation (Wright, A., 1971). Statistical tests for estimating the 'goodness of fit' of a model are judged subjectively since the stage at which an equation should be rejected on the grounds of such tests still has to be decided.
Therefore, acceptance or rejection of a model presupposes that the objectives of the study are subjectively balanced against the model's representativeness and complexity.
Accurate predictions can be achieved by models which are gross simplifications of reality, where it is appreciated that the relationships built in the model and the statistical techniques used to estimate them may not be entirely accurate but they may be good enough for the purposes for which the model is to be used.
So, in practice, model validation implies some sort of comparison between model and reality (eg. a test of 'predicting the past'). The analytical -mechanistic- correctness (verification) is of less importance than the model's effectiveness in its specific descriptive purpose (validation).

4.5.4. The utility of the implemented prediction system.

Modeling efforts which try to mimic a real system's behaviour under clearly defined circumstances may be characterised as simulations. So, the described fish growth

prediction system may be characterised as a "feedback computer simulation system" at the level of the individual fish production activity.
It is a feedback system because it contains relationships where the current rate at which some quantity changes depends upon its existing state (Charlton, P.J., and S.C. Thompson, 1970).
In fact, this behaviour over time is found on the prediction table as a set of solutions of interrelated equations.
Moreover, the computer operator may redefine the boundaries of the system (fish growth and food usage) by selecting new original data for calibration.

The general properties of the developed system that led to its application on a commercial environment can be summarised as follows:

- The mathematical form of the growth equation may be given physiological interpretation.
- The data demands are satisfied by recording directly observable facts in the field.
- The equations are linear or linearly transformed estimated by least squares regression, which suits the properties of observed farm data.
- The prediction system is implemented on a microcomputer in a non-complicated form using customised LOTUS 1-2-3 worksheets which may easily be modified when required.
- The system can easily extract any data from the farm's data bank (free selection of computer data-files) in order to calibrate the equations for particular stanzas.

Since the system is part of a user-controlled loop which can be activated to fit new parameters to the equations in respect of different data sets, knowledge may also be gained of how the parameters of the model themselves behave under changing environments or for different fish. Therefore, it may initiate improvements to existing production processes in terms of both efficiency in input utilisation and technical design. Moreover, the need of organised methods for data collection is emphasised.

All farming systems are characterised by the fact that man is attempting to control biological processes under an uncertain climatic and socio-economic environment in order to achieve some goals which are predominantly economic in nature. Thus, growth processes are subsystems of the "bio-economic" system of the farm.

On a farm there may be a number of different end products, such as fish of different species or at different final sizes, variable time schedules and several methods of culture. The ultimate purpose of management is to improve the operation of the whole farm-system since its components -subsystems- do not exist in isolation but each influences and is influenced by the others. The consequences of change in one component cannot be limited to it alone but a measure of its impact on the fish farming system as a whole is required. Moreover, important economic links between processes are also involved.

Computerised modeling of a fish production subsystem may lead to the acquisition of better knowledge of the physical input-output (or factor-product) relationships under specific conditions but not of their implications on the pool of available inputs at the firm level which is predominantly of economic importance. It has to be examined how producing more or less of a product by a certain method affects and is affected by the rest of the production activities on the farm.

In addition, the economic effects across activities are related to the scale of each type of output. For profitable production how much to produce must be considered, since the same input rates are not equally economical for each level of output. Even at a constant price and cost ratio the rates of inputs should be judged according to the scale of output of each particular product, its timing and the duration of the process which achieves it.

In reality, the fish farmer is in a weak bargaining position against the competitive markets with little or no control over prices or costs. Markets are unstable and as product demands or prices shift the only real control available to the farmer is the selection of the best possible types of products (what ?), their timely production (when ?) and the manipulation of the quantities of inputs and outputs (how ? and how much ?).

Therefore, the behavioural information that can be produced by the predictive growth model for individual processes should be integrated in a more formal 'holistic' framework. A normative programming model is needed, which would serve the economic objectives of the farm manager whilst simultaneously offering deeper insights into more problems of his production economics.
As such "linear programming" is considered next and tested.

THIRD CHAPTER

Application of linear programming to production planning and control of individual fish farm systems.

"Until electronic computers become more abundant and cheaper it is unlikely that programming will be applied to problems of individual farms."

TYLER, E. J. 1960.
Journal of Agricultural Economics, XII, 4, 473.

CONTENTS

SUMMARY

Decision making in a fish farm business presupposes a deep knowledge of the farming system itself and the market environment within which it operates.
Assuming that the fish farm manager has all the data needed to control the business and to plan future production through a well established data recording system, further techniques may then be used which will produce high level information and guidelines for future policies.

Linear programming is a sophisticated, computer based technique which has recently become available to smaller businesses with the advent of affordable, but powerful microcomputers with simplified, 'friendly' software.
Linear programming produces planning models which provide a decision making tool to indicate the way a farm should operate in order to achieve certain specific objectives.
It is essential, for its use, that comprehensive and accurate records of the business should be available.

In this study the skills needed to use this technique, its data requirements, its strengths and usefulness under a fish farming environment were analysed.
For this purpose 'LPWYE' linear programming package running on IBM PC microcomputers and compatible machines was applied to a fish farming business which operated the circular tank system to produce trout fingerlings for restocking.
The farming system was analysed and its data presented in the LP matrix form, which is the basic input for the technique.
The production process and the marketing environment were faithfully reflected in the matrix and a solution was sought which aimed at a maximum profitability production plan, given the particular resource limits and market constraints of the farm.

From the study conclusions were drawn as to the usefulness and overall suitability of linear programming in a fish farming environment, and a case study is given as an example which states the basic requirements for LP, explains how the matrix can be constructed and how the results can be interpreted.

INTRODUCTION

Planning future production is one of the essentials of (fish) farm management and decisions must be made as to which products, when and how much of them, are to be produced.
Apart from these questions the technical processes which must be followed in order to achieve the end product, must be clearly defined.
Therefore, production planning decisions must answer the following four basic questions:

- What to produce?
- When to sell?
- What quantity of each kind of product?
- How should a particular output be produced?

Possible feasible answers must comply with the existing resource/inputs on the farm and those which the farm is in a position to develop or acquire (buy) from outside. Moreover, these decisions must have an end result, a target.

Management has to make decisions because resources are limited and therefore must be optimally combined to provide the desired outcome each time. The guides to a manager's decisions are data/information and the techniques which process this information. The manager's personal judgement of risk and of uncertainties is then introduced and a decision is made.

The implementation of both a data system, to collect and store data and information, and of processing techniques has been made possible for small firms with the use of electronic micrccomputers. These machines are now affordable by small businessmen, like the average fish farmer, and provide sufficient computing power and ease of use. Highly sophisticated programmes for data and information processing are now accessible and 'friendly' and it is up to the individual manager to enhance management effectiveness using these tools.

The developments which have taken place in the field of farm planning techniques basically stem from the introduction of the linear programming model. LP and its derivatives are generally applied to strategic decision making. Given the existing farm resources and outside market opportunities the optimum combination of production activities is derived in the way that best satisfies the wants of the individual manager.

Management efforts will be directed towards selecting the best strategic plan (What ? When ? How much ?), but also towards continually improving and adjusting the technical efficiency of the various production operations (How ?).

The technical efficiency develops alongside the experience and competence of the farmer and is the ability of the fish farm production system as a whole to produce a specific product. This 'ability' can be quantified in terms of each resource/input which is used in the production process, and the less input needed per unit of production the more economically efficient the production system is.

The degree of technical efficiency is thus dependent on the quality of management and on the availability of certain resources. For example, the fish food conversion can be very efficient on a fish farm where management has adopted the correct feeding schedule and provides the fish with the appropriate balanced ration. But when an automatic feeding mechanism is made available, then the fish producing efficiency may increase since the feeding schedule is now followed more precisely and the labour is reduced.

Linear programming will help to define a production strategy and incorporates among other data the information on production efficiency. Efficiency must be already acceptable before undertaking any effort for planning, since it would seem illogical to strive to allocate resources in a better way while ignoring the fact that they are being used inefficiently.

LP can be placed on the top of a planning pyramid with the techniques which manipulate data to produce the information needed by the LP model at lower levels.

For example, fish growth simulation models may be used to produce information about potential fish growth under the various anticipated environmental conditions. This operation involves 'data production' rather than 'data consumption' and the data so produced will then be used by the LP model which will evaluate critically the various forecast alternatives.

Although LP provides the optimum planning solution for every differently defined planning environment, it should not be presumed that the entrepreneur aims always at maximising profits since maximum profits need not in all cases maximise satisfaction.
As far as no assumption is made about the individual's psychology or behaviour, it is difficult to decide whether a maximum profit plan as such is the fish farmer's objective. Since material demands are satiable and also because leisure is an essential ingredient of a good life, not everyone will be willing to put every resource at hand -and entrepreneurial time is one of the most important- into the service of obtaining maximum profit.
However, it would be sensible to accept that after allowing for personal pursuits, the individual will optimise whatever resources and effort is put in the business.
Thus, LP gives solutions to strategic problems defined according to a planning environment which perfectly suits the fish farmer's style and business objectives. The solution is formed by the amount of resources that the farmer defines as appropriate for a particular purpose, and by certain quantified conditions which must hold before any plan is put forward, such as a minimum amount of personal expenditure for leisure.

1. THE NATURE OF LINEAR PROGRAMMING

1.1. What is LP ?

Linear programming is a mathematical planning technique based on matrix algebra, which is best suited to a computer. It accepts suitably formulated data and is capable of producing optimal (maximum or minimum) mathematical solutions to some stated objective.
Therefore, it can be useful in fish farm planning because it determines the combination of production options (enterprises) and their production techniques which will maximise revenue and also it minimises production costs through the most efficient allocation of resources among the activities in a plan.

The simplex method is widely applied for solving linear programming problems, and in addition to the optimal arrangement, gives certain other information particularly useful to complete the picture of the LP output.

LP produces planning models which provide a decision making tool to indicate the way a farm should operate in order to achieve certain specified objectives in the period ahead.

In summary, the key characteristics of the technique are that:

- it is predictive or forward looking in character,
- because of the uncertainties inherent in any predictive activity, the optimum results generated can never claim perfect precision and must be interpreted as guidelines rather than absolute recommendations.
- planning is conditioned by and dependent on the objectives the entrepreneur is seeking to achieve.

1.2. The LP matrix - the computation.

The computer input must be arranged in the LP matrix which is simply a tabulated form of the farm's data. In other words the real life situation is expressed in a way that the LP programme can 'understand' in order to identify the planning problem and work out the optimum solution.

Linear programming introduces no new economic principles. It is simply a mathematical means of handling all the relevant data and producing from them an optimum solution in terms of maximum net revenue. The basis lies in the relative net revenues of the various products per unit of the various scarce resources which are needed to produce them.

Using the language of economic theory, the marginal rates of product substitution are compared with the ratios of the net revenues in terms of each of the resource restrictions. This means that comparisons are made for each production option between the additional value to the plan (ie. net revenue) of an extra included unit of that product, and the forgone value of the production options already in the plan that need to be sacrificed in order to release enough resources to enable it to be introduced (ie. opportunity cost).

The first option to be introduced in the plan is that with the largest net revenue and is brought in up to the maximum possible level until one limited resource is entirely used up. The number of product possibilities being introduced in the plan gradually increases in the process, until no further substitution is possible without losing more than is gained.
The computer then prints out the solution in terms of types and levels of activities to be pursued, together with the total net revenue.
In order to calculate profits the fixed costs are subtracted (ie. regular labour, machinery and buildings depreciation, rent, general overheads etc.) from the total optimum net revenue figure.

Some good computer programmes will print out additional useful information such as sensitivity analyses of the solution, the marginal value products of the hinding resources etc.

Although, typically, the aim is to maximise profit there are certain types of agricultural problems which demand to direct the optimisation procedure towards achieving minimum cost rather than maximum profit.
Such minimisation models are structured in the same way but incorporate costs instead of revenues and are used when the objective is to achieve the most economic combination of inputs for the production of a certain output, or, in cases of product transportation, among several locations in the cheapest possible combination of routes.

1.3. Data requirements for the matrix construction.

When trying to obtain a maximum profit fish farm production plan, four types of information are typically required:

1. The resources available. Limitations on production inputs, "resource restrictions" or **constraints** within which the farm has to operate, must be known. They can be internal to the business (eg. working capital available, water input) or external (eg. market restrictions).

2. The production possibilities are all the alternative enterprises and all the alternative methods of producing them that the farmer is able and is prepared to pursue. They have to be decided together with any possibiliities of buying in useful materials (eg. eggs/fry or food) or casual labour, or selling by-products (or excess products).
Each of all these types of possibile alternative actions is called an **'activity'**.

3. The gross margin (or net revenue) for each 'activity'

must be calculated. This equals revenue less the variable costs *
allocated to the activity per unit of it. This figure may conveniently be replaced in the matrix by the farm gate price of the fish produce, if the variable costs are accounted for in the model separately.

The gross margin does not account for fixed overhead costs, that is costs which are not easy to allocate to each specific production activity since they are unevenly spread over all the business (eg. labour costs).

The net revenue will be a negative figure for those activities which represent the purchase of goods, eg. food provisions, egg/fry supplies etc. because in such cases it will essentially represent cost instead of revenue.

4. The resource requirements, ie. the quantity of each 'constraint' needed in the production process of one unit of each activity has to be known.

These form the "**input-output coefficients**" which are built in the body of the matrix, which is the area defined by the horizontal list of all the activities and the vertical list of all the constraints.

A negative coefficient value signifies that the activity is supplying, or adding to, a resource constraint instead of using it (eg. an egg purchasing activity has a negative coefficient as regards the egg constraint of the fish farm).

1.4. Data accuracy.

A major requirement of any planning model is accuracy. If decisions are to be based on the results generated by the LP

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* The variable/allocable costs, as opposed to fixed costs (overheads), are those specific to a particular activity and change proportionally to the changes of the level of that activity.

model, it should be capable of predicting the outcomes of alternative courses of action as closely as possible. The achievement of this reliability is dependent, as always, on the availability and accuracy of the data on which the model is constructed.

Accurate data is equally significant for all planning methods, such as budgeting, programme planning etc. However, LP is able to handle problems of choice in far more detail and with mathematical precision, which may lead to the erroneous conclusion that it is far more data demanding.
The fact that the availability of the computer may encourage the planner to use more data and avoid the simplifications necessary with the manual techniques, and also that the first step is usually to assemble the data and construct the matrix, give the impression that LP needs more data than other simpler techniques. Nevertheless, a well developed data recording system on the farm must precede the adoption of LP or any other planning technique.

A hidden danger is the illusion of absolute competence and accuracy on the part of LP as a formal planning model, which may be created by its apparent computational precision.
This danger is particularly true when a fish farm manager uses LP without correct, balanced appreciation of the technique and without experience in interpreting its results, which may be acquired only through personal effort in self-training.

2. USING LINEAR PROGRAMMING

2.1. Why recommend the use of LP on fish farms?

Linear programming should not be considered merely as a powerful optimisation technique, especially in fish farms which operate under a multivariate complex environment. It gives a lot more information besides the optimum production plan.

The LP technique will make the manager realise clearly the trading situation and the quantified effect of all external and internal factors on the farm operations and certainly on profitability.
The manager will realise how important having information about production factors is and may be guided towards organising or updating an efficient data recording system.
Quantified information will be obtained with LP about how much good or how much bad an imposed decision is for the overall profitability and this may enforce rational thinking and make clear why less or more profit is made out of the various production plans given the set of the farm's resources. LP may suggest product combinations which have never been tried before. It may show that when resources are valued properly one production option (enterprise) is much more profitable than had previously been imagined. It will indicate which resources are scarce, how much worth to the farm additional quantities of them may be and how these additional resources should be best used.

A well organised data system is necessary to record the appropriate information and keep it up to date ready for use by the linear programming system, which will then provide high level information and guidelines for 'ideal' decision making towards the aim of the business.

The LP system is divided into the hardware, ie. the microcomputer system that the LP programme will be run on, and the software, ie. the LP package which is to be employed for the solution.

With the arrival on the market of affordable microcomputers and computer programmes, it is now possible to identify and collect the data, understand the concepts and implications of LP and translate farm data into LP models. The system is planned for use by the fish farm manager with a minimum of interference from anyone external to the business environment, such as farm consultants or public advisory services. Realistic models can be set-up and the results can be best interpreted in terms of the particular farm's needs, since the fish farmer can 'feel' and balance correctly what the computer suggests for the farm and formulate the computer input according to experience.

On the other hand, crossfertilisation of ideas and methods to tackle matrix construction problems in order to reflect as realistically as possible the farming environment is always very useful when based on cooperation between LP users.

The reasons behind the recommendation of LP as a production planning tool on the individual fish farm are:

- The availability of powerful personal computers with an easy operating environment at affordable prices.

- The availability of affordable LP software packages suitable for microcomputers and simple enough to use easily.

- The belief that direct management involvement in both production planning and in the organisation of a sound data system is necessary for the further expansion of the fish farming business.

2.2. Changes in the problem.

Linear programming is a mathematical technique which solves problems resulting from many different practical situations presented in the form of the LP matrix which is a tabulated form of a set of quantified factors. These factors may, for example,

be the price of selling fish, the cost of food, the amount of water which is available, etc. They are all measured and their values are properly arranged in the LP matrix.
Therefore, the coefficients which occur in the mathematical problem have a physical significance in the practical problem, like the revenues of the various activities and the constraints which represent the limits on the availability of resources.

In real life it is appreciated that these values can change and this in turn will change the mathematical problem.
The way to cope with new situations is to change the LP matrix in order to take account of the physical changes and solve the new problem 'from scratch'.
For example, certain constraints and/or activities may be included or excluded, which require somewhat drastic changes to the matrix. Or the values of net revenues, of constraint limits or the input/output coefficients may alter, which require, simply, change of the relevant figures in a constructed matrix.
This approach to the planning process provides further insight into a variety of relationships and can be even referred to as simulation.

The availability of microcomputers and LP packages suited to them have made matrix construction, amendment and the computation of new optimal solutions fast and easy even when a new 'from scratch' matrix has to be developed.

2.3. Sensitivity analysis.

Linear programming transforms a real life problem into a mathematical problem where each coefficient represents the value of a factor in the real life situation.
However, each of the factors has a different significance, a different 'weight', in the practical problem. The influence of each factor in the formulation of the optimum plan may be assessed and a check made on the plan's response when certain assumptions about the values of specific factors are altered.

In other words the linear programming model can be used for **sensitivity analysis.**

Firstly, given the considerable uncertainty about the validity of one or more of the key assumptions, their influence on the plan needs examination.
The key assumptions concerning the activities in the plan are those regarding prices per unit and the possible yield level (fish growth in this case).
Similarly, the key assumptions made for the resources consider costs per unit and the resource quantities necessary to produce a unit of each activity.
In summary, the key assumptions concern:

- the price per unit of product,
- the growth efficiency of fish,
- the cost per resource unit,
- the activity-resource relationships (technical efficiency).

Sensitivity analyses are more likely to be required for growth rates or prices than for costs. An example could be the case of a new entrant to fish farming with little spare capital. In this case a separate estimate of the lowest likely level of profit (or maximum likely loss) in the event of a bad year may be of interest. In fact it is possible to reveal the effect on profit or return on capital of a complete range of price and/or yield levels. (This is described as parametric budgeting.)

To perform this type of sensitivity analysis, using LP, the existing matrix must be amended. The constraints or activities remain unaffected, but the net revenue figures and any other coefficients in the body of the matrix are adjusted accordingly. After a new 'run' of the LP programme a completely new plan may result providing a new 'activity mix', with new requirements in resources and, possibly, different scarce resources may now prove to be the true decision constraints.
In some instances it may be discovered that a plan differing

fairly radically from the optimum yields only a slightly smaller profit. The original plan may have advantages which more than compensate for a small loss in profit, such as reduced risk or smaller investments in equipment.
G.J. Tyler (1966) offers advice in an attempt to identify those sub-optimal plans which may offer more in terms of overall utility to the farmer. Modern LP packages which facilitate rapid modifications to the LP matrix may be used to isolate the most desirable plan. The planner is guided towards the most suitable amendments to the matrix by analysing the LP output information of the optimum plan.

LP may also be forced to adopt a specific plan (eg. the initial optimum plan) in order to see the results of the changes on its profitability.
For this purpose 'equality' constraints must be imposed on the activities which were accepted in the initial plan forcing them to remain at the initially accepted levels.
This latter analysis is useful under certain circumstances when a farmer is unable or unwilling to undertake major shifts in the production plan from year to year or within the same year, although the initial assumptions no longer hold. Thus, the shifts in income that can be expected to occur under a stable farming plan are focused and the analysis serves as a guideline on how to remedy unexpected difficulties when conditions worsen, or take advantage in favourable environments.

A second type of sensitivity analysis is performed with the key assumptions of yield, price, unit factor cost etc. held constant.
Changes are imposed on the plan itself altering the level of resources, forcing in some activities and/or including additional or excluding existing activities or constraints, but holding the key assumptions constant.
For example, it is possible that market situations dictate the production and sale of certain quantities of various products (activities) other than those perceived when planning was

attempted. The impact of such restrictions on the farm's profitability must be analysed.

2.4. Simulation of past performance.

This procedure attempts to reflect in an LP model the existing organisation of the farm and concentrates on what has happened in the business in the previous year or even during the current year in cases where the production processes are sufficiently advanced. The model describes the relationships that have prevailed among activities, coefficients and constraints. Specifically, defined in the model are the range of activities under production, the resources needed per unit of them achieved (efficiency), the prices that were actually received (past and not expected prices) and so on.

Each activity is then bound to the level at which it was conducted during the past period under simulation. Therefore, eventually, the model represents the farm's past status and also reflects the farm's past decisions taken for the 'product mix' now currently produced.

The solution of such a simulation model can be then checked in detail to ascertain how well its outcome conforms to what has actually happened.

The scope of this procedure is to establish confidence in the technique since reasonable correspondance of the simulated outcome to what actually occurred provides a very good basis on which to structure the future planning LP models. On the other hand, simulating the current plan will demonstrate relative strengths, weaknesses or existing opportunities through the LP programme's versatile solution.

2.5. LP budgeting.

Budgeting and linear programming are two distinct techniques which are both used in farm planning and both equally

depend on the existence of sufficient, reliable farm data.
LP is a very flexible tool but it is feasible to restrict its flexibility to decide upon the optimum product mix by fixing the level of one or a set of activities (using equality constraints). Taking this to the extreme, the LP model could be used as a convenient framework for computerising the arithmetic involved in budgeting.
In such a case, the level of income that the plan can generate, the quantities of each resource required for its implementation and information about the stability of the plan and its effectiveness in exploiting the resources could be computed.
Thus, LP can be used as both a computerised budgeting tool and/or as a planning optimisation tool with the objective to develop a feasible farm plan that achieves the targets of the business.
As an optimisation technique LP attempts to find the combination of the alternative production activities that will make most efficient use of the scarce resources and as a consequence maximise income.
As a computerised budgeting method LP estimates the expected income and the resource needs of one or more formulated production plans.

Although the concept of farm plan optimisation appears more appealing, 'LP budgeting' might be considered more easily acceptable by an inexperienced planner because it approximates the trial and error approach to decision making. For example, a fish farmer may be sceptical and prepared to accept only marginal changes to existing operations.

2.6. Brief practical guidelines for LP matrix construction.

Linear programming can be employed only through a computer 'running' a special LP programme. The input to such a programme (the information about the fish farm system), must be arranged in a specific form called a 'matrix'.

A linear programming matrix is a rectangular area with rows

and columns. Each column (after the first three columns) represents one 'activity' and each row (after the first three rows) represents one 'constraint'.
The activities are all those production options which are open to the fish farmer, and the constraints are the resources which must be utilised during the production process but which seem to be limited and/or costly, thus imposing restrictions on the plans.

The first three rows and the first three columns of a matrix may be imagined as its horizontal and vertical boundaries respectively.
So, a linear programming matrix, schematically, comprises the following discrete major sections:

```
-------------------------------- section 1 -------------------
                                 (horizontal boundary)

                          (1)   .. Activity names...
                          (2)   ..    ..    units...
                          (3)   ..    ..    Net Revenues per unit..

      section 2           !------------- section 3 -------------
   (vertical boundary)    !     (the enclosed rectangular area)
                          !
  (1)  !  (2)  !  (3)     !
Constraint..   !          !    This area is..
       !       !          !               the 'body'
 names ! units ! limits   !                        of the matrix
       !       !          !
---------------------------------------------------------------
```

The first three rows in a matrix, ie. section 1, contain information, such as which are the production options, how are they measured and how much revenue is earned if one unit of their product (eg. 1kg of fish, 1,000 of fingerlings, etc.) is sold. To fill this section of the matrix, the manager must define all feasible and desirable production possibilities, then give names to these activities and define units to measure their output. Expectations of the market prices will form the Net Revenues per unit of each activity.

Producing output always requires resources/inputs to be used in the process of production and situations may arise where the available amount of a resource is restricted and, therefore, limits the production of more output of a particular kind. Such scarce resources form the planning constraints and information about them must be built in the LP matrix.

The 2nd section of a matrix accepts the information about the constraints. Column 1 is simply a vertical list of all the names given to them, the second column is a list of their respective measurement units (eg. water is a finite resource which may be measured in ft^3 or m^3 etc.), whereas the third column shows the amount that can be made available for these resources.

However, informing the computer about the quantities of the resources that are available on the farm is not sufficient. It is often possible that some resources must be utilised up to some minimum level or that some products must definitely be produced irrespective of their profitability, either because the markets dictate it or, simply, because it is the farmer's wish!

The LP matrix offers the flexibility to impose maximum or minimum resource amounts to be utilised by the plan or even set them equal to some desired level. During matrix construction the computer LP programme accepts **'signs'** for all constraints. These are the algebraic signs denoting equality or inequality and are used to specify whether a constraint level that is input in the matrix is the maximum available, or if the plan must use at least that amount, or even whether an amount exactly equal to that should be used.

Therefore, three constraint types can be distinguished according to their signs:

- **maximum** constraints (>) when the specified constraint level in the plan must <u>not be exceeded</u>,
- **minimum** constraints (<) when the plan must utilise <u>at least</u> the specified level, and
- **equality** constraints (=) when the plan is forced to utilise <u>the exact amount</u> of the particular resource.

When the basic information about the activities and the

constraints is built in sections 1 and 2, a 'border' is created which defines section 3 of the matrix. This area, enclosed by the border, is usually called the 'body' of the matrix and it is constituted by a number of locations, each one of which corresponds to a particular column (activity) and row (constraint), like a cell in a spreadsheet.
In these locations, the matrix coefficients, the figures which indicate the relationships between the activities and the constraints, are input. Their values represent the number of units of a particular constraint that are required to produce one unit of a related activity.
The coefficients are also called 'input-output coefficients' since they express the relationships between the resources -inputs and the activities-output. They may have positive, negative or even zero values. In the last case they indicate that the constraint is irrelevant to the production process of the activity.

2.7. Fish-farm planning environments.

Because of the different management objectives which prevail in individual farms, it is necessary to define the following two broad categories of fish farm planning environments:

- Fish farms which produce variable products, for example, farms producing fingerlings which may be sold at various sizes to on-growers, or farms which produce more than one aquatic species.
- Farms which produce a predetermined level and kind of product (or ideally due to market demand should standardise their output), for example, farms producing table-fish, smolt producers etc.

Within both of these two categories the fish farms may be distinguished according to their culture systems into:

- Farms where fish grading and their subsequent grouping according to size and growth potential is possible. Fish growth can be monitored realistically, such as on farms operating tank or cage culture systems.

- Fish farms, operating mainly pond culture systems, where fish grading is difficult and therefore not practised frequently. The fish remain in the same production unit/pond from their very early stages of growth until harvest, and their growth is forecast according to the farm's past performance records.

Linear programming may be employed in all of the above cases since it is able to produce an ideal solution in every planning situation according to a specified objective, providing that the production environment is realistically represented in the LP matrix.

2.8. Selection of the LP software.

The microcomputer LP package which was used and is currently recommended through this study is 'LPWYE' developed at Wye College (University of London).

It was developed for purely scientific and teaching purposes in an agricultural college by scientists with experience in farming. Therefore, it is suited to agriculture and uses agricultural terminology. It is easy to operate and very cheap since the prime purpose was not commercial but educational. It provides very useful additional output apart from the standard optimal solution, and is fast in operation. The maximum matrix size offered is appropriate for solving reasonable agricultural problems in practice. The package is well documented and available for most popular microcomputers (CP/M and MS DOS operating systems).

3. APPLICATION OF LP FOR PRODUCTION PLANNING OF A FISH FARM PRODUCING TROUT FINGERLINGS

"LP-WYE" software was used to plan production on a trout hatchery in order to test the value of LP as a fish farm management tool. The acquired experience may be demonstrated by the following example of a fictitious business.

3.1. Farm description and matrix construction.

'Trout fisheries Ltd.' is an imaginary fish farm which operates on circular tanks and produces trout fingerlings for restocking other farms which produce table fish.

3.1.1. Tank capacities.

The tanks on the farm are separated into groups by diameter; there are five tanks of 30ft diameter and twenty tanks of 12ft diameter. The water depth in these tanks is maintained constant throughout the year providing a total capacity of about 17,690 ft^3 of water all year round (a minimum water supply is guaranteed by the local water authority, a fairly common situation).

Analytically, the tank water volume capacities are shown below:

30 ft. diam. tanks	:	13,550 ft^3
12 ft.	:	4,140 ft^3
Total	:	17,690 ft^3

3.1.2. Fish egg supplies and egg costs.

The farm is able to produce a maximum of 1m eggs a year from its own brood stock, but can also import eggs from abroad, mainly from Denmark and the U.S.

The anticipated egg input costs are as follows:

Own produced eggs	£ 1.0 per '000,
Danish imported eggs	£ 3.0 per '000,
US imported eggs	£11.0 per '000.

3.1.3. Definition of the production options (activities).

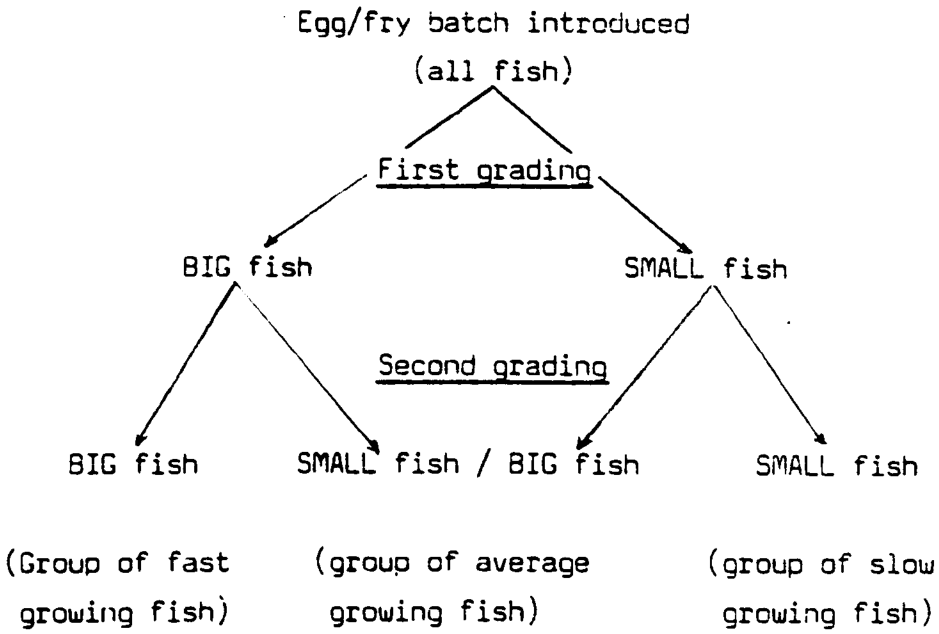
The identification of all the possible final fingerling sizes which may be produced on the farm should account for the different growth potential among the fish of a given population. The fingerlings come from either of three batches of eggs (own eggs, eggs imported from Denmark or from the US) hatched on the farm at certain periods in the year.

However, not all of the fish which start together continue to grow equally efficiently throughout, and as a result of this growth variation fish grading and putting fish of similar size together is practised. As fish of similar growth potential tend eventually to be gathered together, they show similar growth thereafter, thus several different fish sizes might be produced at the same time.

Three distinct categories of fish -fast, average and slow growing- are considered according to their growth potential. These come from the same initial batch/origin and are eventually isolated through grading.

Therefore, although a continuous fish-size distribution in the total population might be expected, consistent grading, apart from the well accepted benefit of improving the food conversion, groups the fish by their growing efficiency and narrows down the size deviation within each category. Thus it is necessary to recognise at least three different fish sizes from each egg batch. This was taken into account in the possibilities under consideration for the production planning process.

Schematically the fish grading during the life of a batch of fish may be represented as follows:



Obviously, the relevant percentages of fast, average, and slow growing fish within the same batch should be revealed from the fish farm's historical records.

However, market supply and demand forces make quite clear to an alert fish farm manager the marketable sizes at which the fingerlings should be sold.
In this imaginary case, the market situation dictates that fingerlings could be expected to sell in combination of the following sizes:

- small size 100/lb fish,
- average size 60/lb fish, and
- large size 16/lb fish.

The information about the fish growth together with the information about what the customers want, will form the production options which are open to the farm manager.
These are available for planning, are called 'activities' in the linear programming terminology, and for the 'Trout Fisheries Ltd' farm look as follows:

Own produced		Danish origin		USA origin	
sizes	month	sizes	month	sizes	month
		FAST GROWING FISH			
100/lb	JUNE	100/lb	AUGUST	100/lb	NOVEMBER
60/lb	JULY	60/lb	SEPT	60/lb	MARCH
16/lb	SEPT	16/lb	APRIL	16/lb	JULY
		AVERAGE GROWING FISH			
100/lb	JULY	100/lb	SEPT	100/lb	MARCH
60/lb	AUGUST	60/lb	NOVEMBER	60/lb	MAY
16/lb	OCTOBER	16/lb	JUNE	16/lb	AUGUST
		SLOW GROWING FISH			
100/lb	AUGUST	100/lb	OCTOBER	100/lb	MAY
60/lb	OCTOBER	60/lb	FEBRUARY	60/lb	JULY
16/lb	JULY	16/lb	JULY	16/lb	SEPT

The production cycle for some of the above activities, especially the "slow" ones, may extend to the next year.

3.1.4. Estimation of food costs.

For reasons of insufficient data rather than for simplicity, the fish food conversion is assumed equal for all fingerlings irrespective of the egg origin or timing of production cycle and even irrespective of the naturally occurring variability in growth potential among the fish of a certain batch which causes some fish to reach a specific size earlier than others.

The food cost for each size of fish sold is calculated assuming a baseline FCR of 1.3 throughout the production cycle. Obviously, the food cost coefficient is influenced by the assumptions made about the FCR value.

The food costs in pounds(£) per production unit (= 1,000 fish) for the various activities are as follows:

activities	producing	100/lb	fingerlings	:	£ 5.304
..	..	60/lb	..	:	£ 7.278
..	..	15/lb	..	:	£22.208

3.1.5. Allowance for mortalities.

The mortalities are assumed to be independent of the duration of production, the time it started, and of the final fish size produced, that is, as if all deaths occur at the very initial stages and are not affected seasonally.
In reality, mortalities differ according to production timing, fish strain and duration of production cycle, but limited data records prevented this detail being included in the matrix.
The plan assumes that for a given end number of live fingerlings to be produced, a larger amount of eggs has to be introduced at the start of the production cycle in order to offset the mortality losses throughout the process of rearing the fish.

In the LP matrix the cost of mortalities is taken into account by adjusting the egg cost value to allow sufficient eggs to guarantee a target number of fish after mortality occurs.
The fish farm records suggest that a **40.0%** mortality rate for all origins of fish can be expected, so, the egg costs for all three fingerling origins, allowing for the above mortality rate, are:

Own produced eggs	1.67	per '000 fingerlings,
Danish imported eggs	5.0	per '000 fingerlings,
US imported eggs	18.33	per '000 fingerlings.

3.1.6. Prices of the fish farm produce.

No seasonal variation is assumed for the farm gate prices for the same size of fish of the same batch origin.
The production plan assumes the following prices (excluding transport costs):

Fingerling size sold. Nos/lb	Farm gate price. (£) Danish/USA	Own
100/lb	27.4	31.5
60/lb	30.8	35.4
16/lb	61.4	70.6

Transport costs are excluded from the model because no stable pattern could be assumed for them. In any case, the cost of deliveries will be charged to the customers, so there is no reason to allow for it in the LP matrix.

3.1.7. Stocking densities.

The stocking densities vary according to the size of fish and those in use are as follows:

Fish sizes Nos/lb	Stocking Density lbs/ft^3
2000	0.890
1000	1.060
500	0.820
400	0.970
200	1.700
100	1.257
80	1.257
60	1.344
40	1.504
20	1.791
16	1.730

According to the figures in the fish farm records, the stocking densities differ even for the same fish sizes depending on the tank type that the fish are held in. Densities are higher in the small - 12ft diameter tanks - than in the big - 30ft diameter tanks. Since the fish transfer schedule in and out of the tanks, as the fish grow or as new fish are introduced, is not known at the time of planning production, the LP matrix is built using a "probability weighted average" of the density values for each tank category, assuming a steady water flow and dissolved oxygen level (ie. the most likely densities to be used for fish at various sizes are calculated).

A probability value is calculated to indicate the chances that fish at a given size range have to be stocked in a "big" or in a "small" tank under their relevant densities.
For this farm these probabilities are 0.766 (ie. 13,550 / 17,690) and 0.234 (ie. 4,140 / 17,690) for a fish to be stocked in a big or in a small tank respectively. Multiplying those probabilities by the relative densities for the tank category and summing the results, the "probability weighted average" figure for stocking densities is reached, which, in other words, is the average expected stocking density for fish at specific sizes.

3.1.8. Fish farm labour restrictions.

The workforce on the farm imposes also some restrictions on the production plan since available labour is a relatively scarce resource.

With the current labour force situation on the farm, accepted at least as far as the next production period is concerned, there is a limit on the biomass which can be sold/handled in any one month's overall activities.
Moreover, there is a maximum level of fish sales from any one size group in each month, which is jointly determined by the market demands, the availability of transport, and the existing workforce capacity. So, some additional constraints to the plan are defined as follows:

- Maximum biomass limit of 15,000 lbs. to be sold/handled in any one month overall activities.
- Maximum level of sales in any one size group within each month set at:

  200,000 fish at 16/lb,
  380,000 fish at 60/lb,
  480,000 fish at 100/lb.

At this point, with the assumptions, constraints and activities defined above, the LP matrix can be constructed; that is, these parameters can be presented to the computer in a form which it is capable of processing.
The matrix includes twenty nine (29) alternative production options (activities) and thirty six (36) constraints. It appears as a rectangular area with rows and columns. Each column represents one 'activity' and each row represents one 'constraint'. The relationship between a constraint and an activity is expressed by the coefficient which has these as coordinates.
A printout of the constructed matrix follows in Figure 1.

3.1.9. Revealing the matrix logic..

An explanation of how the fish farm environment is represented in the matrix and some problems which may occur from time to time are described below. An elementary introduction to a few useful concepts of matrix structure is also included.
Imperial measurement units (used throughout this analysis) or metric could be used.
The farm gate prices form the net revenue figures since the major variable costs are accounted for separately in the matrix.
Two major variable cost items are included:

- Egg purchasing or producing costs (OVACOST row and column)
- Food costs (FOODCOST row and column).

The farm is supposed to borrow from an unlimited capital source, say a friendly bank manager, which charges 13.5% per annum on the amount borrowed. This flexible assumption is built using the first two activities (Ovacost, Foodcost) which are combined with the first two constraint rows and bearing the same names to indicate clearly that they are dependent on each other. These constraints are used in the form of "tie lines", since they do not impose any particular maximum amount for any of those costs.
They are supplied with capital by the first two relevant

Fig. 1. The LP matrix.

The title of the problem is: 'TROUT FISHERIES LTD' PRODUCTION PLAN OPTIMISATION

					1	2	3	4	5
					OVACOST	FOODCOST	OJUN100	OJUL60	OJUL100
					£1	£1	'000	'000	'000
			Net Revenues		-1.135	-1.135	31.500	35.400	31.500
1	OVACOST	£1	0.000	}	-1.000	.	1.670	1.670	1.670
2	FOODCOST	£1	0.000	}	.	-1.000	5.304	7.278	5.304
3	JANWVOL	ft3	17690.000	}	.	.	.	.	.
4	FEBWVOL	ft3	17690.000	}	.	.	.	.	.
5	MARWVOL	ft3	17690.000	}	.	.	0.562	0.562	0.562
6	APRWVOL	ft3	17690.000	}	.	.	2.439	2.439	0.943
7	MAYWVOL	ft3	17690.000	}	.	.	2.941	2.941	2.577
8	JUNWVOL	ft3	17690.000	}	.	.	7.955	7.955	2.941
9	JULWVOL	ft3	17690.000	}	.	.	.	16.622	7.955
10	AUGWVOL	ft3	17690.000	}	.	.	.	.	.
11	SEPWVOL	ft3	17690.000	}	.	.	.	.	.
12	OCTWVOL	ft3	17690.000	}	.	.	.	.	.
13	NOVWVOL	ft3	17690.000	}	.	.	.	.	.
14	DECWVOL	ft3	17690.000	}	.	.	.	.	.
15	OEGGFAST	'000	200.000	}	.	.	1.670	1.670	.
16	OEGGAVER	'000	500.000	}	.	.	.	.	1.670
17	OEGGSLOW	'000	300.000	}	.	.	.	.	.
18	DEGGFAST	'000	300.000	}	.	.	.	.	.
19	DEGGAVER	'000	750.000	}	.	.	.	.	.
20	DEGGSLOW	'000	450.000	}	.	.	.	.	.
21	UEGGFAST	'000	200.000	}	.	.	.	.	.
22	UEGGAVER	'000	500.000	}	.	.	.	.	.
23	UEGGSLOW	'000	300.000	}	.	.	.	.	.
24	JANBIOM	1LB	15000.000	}	.	.	.	.	.
25	FEBBIOM	1LB	15000.000	}	.	.	.	.	.
26	MARBIOM	1LB	15000.000	}	.	.	.	.	.
27	APRBIOM	1LB	15000.000	}	.	.	.	.	.
28	MAYBIOM	1LB	15000.000	}	.	.	.	.	.
29	JUNBIOM	1LB	15000.000	}	.	.	10.000	.	.
30	JULBIOM	1LB	15000.000	}	.	.	.	16.667	10.000
31	AUGBIOM	1LB	15000.000	}	.	.	.	.	.
32	SEPBIOM	1LB	15000.000	}	.	.	.	.	.
33	OCTBIOM	1LB	15000.000	}	.	.	.	.	.
34	NOVBIOM	1LB	15000.000	}	.	.	.	.	.
35	DECBIOM	1LB	15000.000	}	.	.	.	.	.
36	OOCT16	'000	200.000	}	.	.	.	.	.

(continued..)

Fig. 1. The LP matrix.

			6	7	8	9	10	11
			0JUL16	0AUG60	0AUG100	0SEP16	0OCT16	0OCT60
			'000	'000	'000	'000	'000	'000
			70.600	35.400	31.500	70.600	70.600	35.400
1	OVACOST	£1	1.670	1.670	1.670	1.670	1.670	1.670
2	FOODCOST	£1	22.208	7.278	5.304	22.208	22.208	7.278
3	JANWVOL	ft3	16.622	.	.	.	.	.
4	FEBWVOL	ft3	16.622	.	.	.	.	.
5	MARWVOL	ft3	16.622	0.562	.	0.562	0.562	.
6	APRWVOL	ft3	17.184	0.943	0.562	2.439	0.943	0.562
7	MAYWVOL	ft3	17.566	2.577	0.943	2.941	2.577	0.943
8	JUNWVOL	ft3	30.495	2.941	2.577	7.955	2.941	2.577
9	JULWVOL	ft3	39.068	7.955	2.941	16.622	7.955	2.941
10	AUGWVOL	ft3	7.955	16.622	7.955	27.917	16.622	7.955
11	SEPWVOL	ft3	9.944	.	.	36.127	27.917	9.944
12	OCTWVOL	ft3	12.401	.	.	.	36.127	12.401
13	NOVWVOL	ft3	16.622	.	.	.	.	.
14	DECWVOL	ft3	16.622	.	.	.	.	.
15	OEGGFAST	'000	.	.	.	1.670	.	.
16	OEGGAVER	'000	.	1.670	.	.	1.670	.
17	OEGGSLOW	'000	1.670	.	1.670	.	.	1.670
18	DEGGFAST	'000	.	.	.	.	.	.
19	DEGGAVER	'000	.	.	.	.	.	.
20	DEGGSLOW	'000	.	.	.	.	.	.
21	UEGGFAST	'000	.	.	.	.	.	.
22	UEGGAVER	'000	.	.	.	.	.	.
23	UEGGSLOW	'000	.	.	.	.	.	.
24	JANBIOM	1LB	.	.	.	.	.	.
25	FEBBIOM	1LB	.	.	.	.	.	.
26	MARBIOM	1LB	.	.	.	.	.	.
27	APRBIOM	1LB	.	.	.	.	.	.
28	MAYBIOM	1LB	.	.	.	.	.	.
29	JUNBIOM	1LB	.	.	.	.	.	.
30	JULBIOM	1LB	62.500	.	.	.	.	.
31	AUGBIOM	1LB	.	16.667	10.000	.	.	.
32	SEPBIOM	1LB	.	.	.	62.500	.	.
33	OCTBIOM	1LB	.	.	.	.	62.500	16.667
34	NOVBIOM	1LB	.	.	.	.	.	.
35	DECBIOM	1LB	.	.	.	.	.	.
36	0OCT16	'000	.	.	.	.	1.000	.

(continued..)

Fig. 1. The LP matrix.

			12	13	14	15	16	17
			DAUG100	DSEP60	DSEP100	DOCT100	DNOV60	DFEB60
			'000	'000	'000	'000	'000	'000
			27.400	30.800	27.400	27.400	30.800	30.800
1	OVACOST	£1	5.000	5.000	5.000	5.000	5.000	5.000
2	FOODCOST	£1	5.304	7.278	5.304	5.304	7.278	7.278
3	JANWVOL	ft3	.	.	.	.	.	9.944
4	FEBWVOL	ft3	.	.	.	.	.	12.401
5	MARWVOL	ft3	.	.	.	.	.	.
6	APRWVOL	ft3	.	.	.	.	.	.
7	MAYWVOL	ft3	.	.	.	.	.	.
8	JUNWVOL	ft3	0.562	0.562	0.562	.	0.562	.
9	JULWVOL	ft3	2.577	2.577	2.439	0.562	2.439	0.562
10	AUGWVOL	ft3	7.955	7.955	2.941	2.439	2.941	2.439
11	SEPWVOL	ft3	.	12.401	7.955	2.941	7.955	2.941
12	OCTWVOL	ft3	.	.	.	7.955	9.944	7.955
13	NOVWVOL	ft3	.	.	.	.	12.401	9.944
14	DECWVOL	ft3	.	.	.	.	.	9.944
15	OEGGFAST	'000	.	.	.	.	.	.
16	OEGGAVER	'000	.	.	.	.	.	.
17	OEGGSLOW	'000	.	.	.	.	.	.
18	DEGGFAST	'000	1.670	1.670	.	.	.	.
19	DEGGAVER	'000	.	.	1.670	.	1.670	.
20	DEGGSLOW	'000	.	.	.	1.670	.	1.670
21	UEGGFAST	'000	.	.	.	.	.	.
22	UEGGAVER	'000	.	.	.	.	.	.
23	UEGGSLOW	'000	.	.	.	.	.	.
24	JANBIOM	1LB	.	.	.	.	.	.
25	FEBBIOM	1LB	.	.	.	.	.	16.667
26	MARBIOM	1LB	.	.	.	.	.	.
27	APRBIOM	1LB	.	.	.	.	.	.
28	MAYBIOM	1LB	.	.	.	.	.	.
29	JUNBIOM	1LB	.	.	.	.	.	.
30	JULBIOM	1LB	.	.	.	.	.	.
31	AUGBIOM	1LB	10.000	.	.	.	.	.
32	SEPBIOM	1LB	.	16.667	10.000	.	.	.
33	OCTBIOM	1LB	.	.	.	10.000	.	.
34	NOVBIOM	1LB	.	.	.	.	16.667	.
35	DECBIOM	1LB	.	.	.	.	.	.
36	OOCT16	'000	.	.	.	.	.	.

(continued..)

<u>Fig. 1.</u> The LP matrix.

			18	19	20	21	22	23
			DAPR16	DJUN16	DJUL16	UNOV100	UMAR60	UMAR100
			'000	'000	'000	'000	'000	'000
			61.400	61.400	61.400	27.400	30.800	27.400
1	OVACOST	£1	5.000	5.000	5.000	18.330	18.330	18.330
2	FOODCOST	£1	22.208	22.208	22.208	5.304	7.278	5.304
3	JANWVOL	ft3	27.917	12.401	9.944	.	7.955	2.941
4	FEBWVOL	ft3	27.917	16.622	12.401	.	9.944	2.941
5	MARWVOL	ft3	27.917	16.622	12.401	.	12.401	7.955
6	APRWVOL	ft3	36.127	16.622	12.401	.	.	.
7	MAYWVOL	ft3	.	27.917	16.622	.	.	.
8	JUNWVOL	ft3	0.562	36.689	27.917	.	.	.
9	JULWVOL	ft3	2.577	2.439	36.689	.	.	.
10	AUGWVOL	ft3	7.955	2.941	2.439	0.562	0.562	.
11	SEPWVOL	ft3	12.401	7.955	2.941	2.439	2.439	0.562
12	OCTWVOL	ft3	16.622	9.944	7.955	2.941	2.941	0.943
13	NOVWVOL	ft3	16.622	12.401	9.944	7.955	7.955	2.439
14	DECWVOL	ft3	27.917	12.401	9.944	.	7.955	2.439
15	OEGGFAST	'000	.	.	.	.	.	.
16	OEGGAVER	'000	.	.	.	.	.	.
17	OEGGSLOW	'000	.	.	.	.	.	.
18	DEGGFAST	'000	1.670	.	.	.	.	.
19	DEGGAVER	'000	.	1.670	.	.	.	.
20	DEGGSLOW	'000	.	.	1.670	.	.	.
21	UEGGFAST	'000	.	.	.	1.670	1.670	.
22	UEGGAVER	'000	.	.	.	.	.	1.670
23	UEGGSLOW	'000	.	.	.	.	.	.
24	JANBIOM	1LB	.	.	.	.	.	.
25	FEBBIOM	1LB	.	.	.	.	.	.
26	MARBIOM	1LB	.	.	.	.	16.667	10.000
27	APRBIOM	1LB	62.500	.	.	.	.	.
28	MAYBIOM	1LB	.	.	.	.	.	.
29	JUNBIOM	1LB	.	62.500	.	.	.	.
30	JULBIOM	1LB	.	.	62.500	.	.	.
31	AUGBIOM	1LB	.	.	.	.	.	.
32	SEPBIOM	1LB	.	.	.	.	.	.
33	OCTBIOM	1LB	.	.	.	.	.	.
34	NOVBIOM	1LB	.	.	.	10.000	.	.
35	DECBIOM	1LB	.	.	.	.	.	.
36	OOCT16	'000	.	.	.	.	.	.

(continued..)

Fig. 1. The LP matrix.

			24	25	26	27	28	29
			UMAY60	UMAY100	UJUL16	UJUL60	UAUG16	USEP16
			'000	'000	'000	'000	'000	'000
			30.800	27.400	61.400	30.800	61.400	61.400
1	OVACOST	£1	18.330	18.330	18.330	18.330	18.330	18.330
2	FOODCOST	£1	7.278	5.304	22.208	7.278	22.208	22.208
3	JANWVOL	ft3	2.941	2.439	7.955	2.439	2.941	2.439
4	FEBWVOL	ft3	2.941	2.439	9.944	2.439	2.941	2.439
5	MARWVOL	ft3	7.955	2.941	12.401	2.941	7.955	2.941
6	APRWVOL	ft3	9.944	2.941	12.401	2.941	9.944	2.941
7	MAYWVOL	ft3	12.401	7.955	16.622	7.955	12.401	7.955
8	JUNWVOL	ft3	.	.	27.917	9.944	16.622	9.944
9	JULWVOL	ft3	.	.	36.127	16.622	27.917	16.622
10	AUGWVOL	ft3	.	.	0.562	.	36.127	27.917
11	SEPWVOL	ft3	0.562	0.562	2.439	0.562	0.562	36.689
12	OCTWVOL	ft3	0.943	0.562	2.941	0.562	0.943	0.562
13	NOVWVOL	ft3	2.439	0.943	7.955	0.943	2.439	0.943
14	DECWVOL	ft3	2.439	0.943	7.955	0.943	2.439	0.943
15	OEGGFAST	'000	.	.	.	.	.	.
16	OEGGAVER	'000	.	.	.	.	.	.
17	OEGGSLOW	'000	.	.	.	.	.	.
18	DEGGFAST	'000	.	.	.	.	.	.
19	DEGGAVER	'000	.	.	.	.	.	.
20	DEGGSLOW	'000	.	.	.	.	.	.
21	UEGGFAST	'000	.	.	1.670	.	.	.
22	UEGGAVER	'000	1.670	.	.	.	1.670	.
23	UEGGSLOW	'000	.	1.670	.	1.670	.	1.670
24	JANBIOM	1LB	.	.	.	.	.	.
25	FEBBIOM	1LB	.	.	.	.	.	.
26	MARBIOM	1LB	.	.	.	.	.	.
27	APRBIOM	1LB	.	.	.	.	.	.
28	MAYBIOM	1LB	16.667	10.000	.	.	.	.
29	JUNBIOM	1LB	.	.	.	.	.	.
30	JULBIOM	1LB	.	.	62.500	16.667	.	.
31	AUGBIOM	1LB	.	.	.	.	62.500	.
32	SEPBIOM	1LB	.	.	.	.	.	62.500
33	OCTBIOM	1LB	.	.	.	.	.	.
34	NOVBIOM	1LB	.	.	.	.	.	.
35	DECBIOM	1LB	.	.	.	.	.	.
36	OOCT16	'000	.	.	.	.	.	.

activities. The 'supply' element is shown by the - 1 (negative) value of the corresponding coefficients built in the body of the matrix, that is, for each unit (£1) of capital needed for a particular purpose, one unit of capital (£1) is supplied for this purpose.
Moreover, these resource rows are charged 13.5%, ie. 0.135 for each £1 of capital supplied. This is shown by a negative (-1.135) Net Revenue value of these supplying activities which in fact represents cost of capital.

So, activities may be included in the matrix which buy in (supply) resources to the farm instead of producing output. Such activities incur costs which are represented by a negative figure of net revenue.

The coefficients (positive) built in the body of the matrix represent how many units of a resource/constraint are needed for the production of one unit of an activity.
For example, the calculation of the coefficients across the 'OVACOST' row embrace the assumed fish mortalities during the production of each activity. The cost of eggs required for the production of one unit ('000 fish) of an activity producing fish from a Danish egg batch is £5.0 in spite of the normal cost of £3.0/'000 eggs, because more than a unit ('000) of eggs is required for the production of one unit ('000) of fish. Specifically, in this model, with 40% mortalities, 1,670 eggs are needed to produce 1,000 fingerlings.

The calculation of the coefficients for the 'FOODCOST' row needs to take into consideration the food conversion efficiency of the fish.
For example, for 1,000 fish of the 'UMAR100' activity (Nº 23) to be produced, 5.304 for food is needed, which equals (weight of 1,000 fish ie. 10lb.) * (FCR ie. 1.3) * (cost of a unit of food weight ie. £0.408/lb.).
Therefore, the 'FOODCOST' row coefficient for the above activity is 5.304.

The names given to the activities in the matrix may seem very strange, but these are created by the model user and must be informative and unambiguous whilst being no more than eight characters in length.
For example, the name of activity No 4 (OJUL60) was derived from three pieces of information. The egg origin, the month of fish sale, and the size of the fish sold. So, O-JUL-60 is: -from Own eggs - sold in JULY - at 60/lb.

The monthly 'WVOL' which stands for the Water Volume constraint restricts the plan to avoid exceeding the water amount available each month. The coefficients along each of these twelve rows express for every activity the monthly water requirements in water units (1 ft^3) of one unit ('000) of fish at their current stage of growth each time.
For example, one unit of the activity No 3 ie. 'OJUN100' needs 2.439 units (ft^3) of 'APRWVOL'. So, 1,000 fingerlings, which come from own produced eggs and which are intended to be sold in June at 100/lb., occupy 2.439 ft^3 of water during April.

These coefficients are calculated for each month based on data of the fish average size in that particular month and on the fish farmer's policy on stocking densities practised for fish of that average size range. It is essential, therefore, that the growth pattern expected should be clear from the farm's data records. In essence, built into the LP matrix is the monthly growth pattern of the fish and the policy on fish densities, which depends on the different fish sizes.
So, the monthly 'WVOL' coefficients express how much water space is needed by 1,000 fish of the given average size at the density stocked.
Since the production cycle of some activities extends to more than a year, some monthly coefficients are the compound of water needs in the same month but for the successive years into which the production cycle extends.

The constraint rows numbered 15 to 23 deal with the fish

egg resources of the farm. For each egg supply source (own produced, Danish and US imported) there are three constraint rows each representing a growth intensity group of fish expected from each batch of eggs, namely 'FAST' for very good growing fish, 'AVER' for moderately growing fish and 'SLOW' for bad growing fish. The proportions of these fish-growth groups are indicated by the relative maximum limits set for them.
These expected proportions, as the farm records show, are 20% for 'Fast' fish, 50% for 'Average' fish and 30% for 'Slow' fish. Given that the farm is able to produce 1m 'Own' eggs, to import 1.5m 'Danish' eggs and 1m 'U.S.' eggs, the upper limits for all of these nine egg availability restraints are those shown in the LP matrix.
The coefficients across these rows tie up only with the relevant activities, (eg. 'DEGGFAST' coefficients are derived from only the 'Fast' Danish fish origin activities). These coefficients also depict the assumed 40% mortality rate and for every unit ('000) of fish they reveal a need for 1.67 units ('000) of eggs ie. 1,670 eggs.

However, a very interesting point must be stressed here. Although it is possible to group the egg resources according to the future growth performance of the fish which will come from them, the computer is unable to 'understand' that these three growth categories of fish should be produced jointly, that is, 20 'fast' fish may be produced only if another 50 'average' and 30 'slow' are also produced. So, if the other resources on farm are suitable, the programme may very well produce an artificial optimal solution where there might be say only fast growing fish and the accepted proportions (in this case 20% fast, 50% average, and 30% slow fish) will be ignored.

Similar problems are also encountered in arable farming where crop rotations, that is, the proportions and sequences of various crops through the years, must be planned. But in arable farming, the end product of each cropping activity is standard (wheat grain, potato, etc.) and the production cycle is well

established.
However, in fish farming, and in this model in particular, a set of different activities ('fast', 'average', 'slow') is defined, but these activities also have variable end products (different final fish sizes). So, even if the matrix is restricted in order to accept 50 'average' and 30 'slow' fish for every 20 'fast' ones produced, it would still not be possible in practice to instruct **which** of the several 'average' or 'slow' activities to combine with any spacific 'fast' activity.

Therefore, the techniques used when planning traditional farm production such as the use of "proportional constraints", i.e. constraint rows which give and receive 'permissions' for activities to be produced (Barnard and Nix, 1979), do not solve this particular problem. Another way would be to compound several activities of each category together but since it is possible in practice to include only a few of such combinations in the matrix, the planning flexibility, which is needed for a true optimum solution, is lost.

The above problem stems from a basic theoretical property of linear programming, that of **additivity** (or **independence** of the various activities in the matrix). The problem arises in cases where if one activity is introduced into the plan, then another must be brought in as well because the activities are not independent.

The solution devised in this particular case, which did not allow the computer to 'corrupt' the optimum strategy, is the adjustment of the amount of eggs of the different groups in the matrix until the computer accepts all offered eggs in the desired proportions between 'fast', 'average' and 'slow' fish. This may often necessitate some preliminary runs of the programme and subsequent amendments of the egg resource maximum limits.

A more 'formalised' way of approaching this problem is by the inclusion in the matrix of "**transfer activities**". These are 'dummy' activities which in combination with an equal number of extra rows eliminate the additivity problem. There is one transfer activity corresponding to each different egg source, so, the resulting matrix is expanded by as many rows and as many columns as the existing different egg sources in the plan (three sources in this case).

The amendmends in the matrix for this particular case are shown in Figure 2.

The only other difference in the matrix is that the constraint rows numbered 15 to 23 are now used in the form of tie lines, ie. they do not define the total availability of own produced, Danish or US imported eggs. This role is now taken over by the three added rows numbered 37 to 39.

These latter rows provide the transfer activities (numbered 30, 31 and 32) with eggs. The transfer activities in turn pass on these eggs to the relevant 'fast', 'average' and 'slow' constraint rows of each origin (row numbers 15 to 23) in the appropriate proportions defined as 20% of 'fast', 50% of 'average' and 30% of 'slow' fish to be hatched from them. This is done by the means of negative (supply) coefficients.

Therefore, the role of the transfer activities is clear, just as their name indicates. They pass on -transfer- resources from one constraint row to another.

For example, in this matrix, transfer activity No 30 receives a total amount of 1.5m eggs from constraint row No 37 and passes on 20% of them (0.2 * 1.5m) to the constraint row No 18 (ie. the fast growing danish origin fish), 50% to row 19 (ie. 0.5 * 1.5m eggs are passed on to the moderately growing danish origin fish) and 30% to constraint row No 20 (ie. 0.3 * 1.5m eggs are allowed to provide slow growing danish origin fish).

Thus, the defined analogies which characterise the growth potential shown by a fish batch are strictly obeyed by the programme by the means of transfer activities.

The transfer activities are useful tools for matrix construction and are not treated as true planning alternatives by LP. Hence they usually have a net revenue value of zero.

Fig. 2. Matrix formulation to cope with the 'additivity problem':

The title of the problem is: 'TROUT FISHERIES LTD' PRODUCTION PLAN OPTIMISATION

				1	2	3	4	. . .	30	31	32
				OVACOST	FOODCOST	OJUN100	OJUL60		DANOVA	USAOVA	OWNOVA
				£1	£1	'000	'000		'000	'000	'000
	Net Revenues			-1.135	-1.135	31.500	35.400		0.000	0.000	0.000
1 OVACOST	£1	0.000	}	-1.000	.	1.670	1.670		.	.	.
2 FOODCOST	£1	0.000	}	.	-1.000	5.304	7.278		.	.	.
3 JANWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
4 FEBWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
5 MARWVOL	ft3	17690.000	}	.	.	0.562	0.562		.	.	.
6 APRWVOL	ft3	17690.000	}	.	.	2.439	2.439		.	.	.
7 MAYWVOL	ft3	17690.000	}	.	.	2.941	2.941		.	.	.
8 JUNWVOL	ft3	17690.000	}	.	.	7.955	7.955		.	.	.
9 JULWVOL	ft3	17690.000	}	.	.	.	16.622		.	.	.
10 AUGWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
11 SEPWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
12 OCTWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
13 NOVWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
14 DECWVOL	ft3	17690.000	}	.	.	.	.		.	.	.
15 OEGGFAST	'000	0.000	}	.	.	1.670	1.670		.	.	-0.200
16 OEGGAVER	'000	0.000	}	.	.	.	.		.	.	-0.500
17 OEGGSLOW	'000	0.000	}	.	.	.	.		.	.	-0.300
18 DEGGFAST	'000	0.000	}	.	.	.	.		-0.200	.	.
19 DEGGAVER	'000	0.000	}	.	.	.	.		-0.500	.	.
20 DEGGSLOW	'000	0.000	}	.	.	.	.		-0.300	.	.
21 UEGGFAST	'000	0.000	}	.	.	.	.		.	-0.200	.
22 UEGGAVER	'000	0.000	}	.	.	.	.		.	-0.500	.
23 UEGGSLOW	'000	0.000	}	.	.	.	.		.	-0.300	.
24 JANBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
25 FEBBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
26 MARBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
27 APRBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
28 MAYBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
29 JUNBIOM	1LB	15000.000	}	.	.	10.000	.		.	.	.
30 JULBIOM	1LB	15000.000	}	.	.	.	16.667		.	.	.
31 AUGBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
32 SEPBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
33 OCTBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
34 NOVBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
35 DECBIOM	1LB	15000.000	}	.	.	.	.		.	.	.
36 OOCT16	'000	200.000	}	.	.	.	.		.	.	.
37 DANOVA	'000	1500.000	}	.	.	.	.		1.000	.	.
38 USAOVA	'000	1000.000	}	.	.	.	.		.	1.000	.
39 OWNOVA	'000	1000.000	}	.	.	.	.		.	.	1.000

Regarding the finite capacity of the fish farm's workforce, constraints have been imposed on the maximum quantity of biomass to be sold or handled for sale each month. These monthly 'BIOM' constraint rows are related to the activities by coefficients which are calculated as the amount of biomass of one unit ('000) of fish at the assumed final average size.
Since each activity will produce fish ready for sale on one particular month only, it is obvious that it needs only to be related to the particular biomass maximum constraint row which represents that particular month.
For example, activity No 5 produces 100/lb fish in July and therefore demands 10 lbs out of the total handling capacity in that month ('JULBIOM' coefficient for activity 5 is 10.0).

Finally, as described in the introduction to the farm's planning environment, there are constraints on the total monthly amount of fish sold from each particular activity.
Since to allow for this would necessitate roughly the additional inclusion of as many more constraint rows as the number of activities in the matrix, and since most of them would eventually prove 'slack' -or non-participating in the plan-, it is better to obtain a first provisional solution and check it. If some activities are included at an excess level then constraints should be introduced for these only. Then the solution is checked again until there are no 'abuses' of the assumptions in it.
In fact only one -the 36^{th}- such constraint is required in the example case.

A complication may arise when planning a fish farm's production, especially on farms where grading of fish is possible and fish of similar sizes are brought together. There are defined production units -circular tanks- of certain water capacities. When a number of fish of a specific size is transferred to a tank, then no more fish may be added to this tank unless they are of similar size. Therefore, it is obvious that in such cases the space within a tank may be only partly utilised and the stocking densities of the fish lower than normal.

However, the LP programme assumes continuity of the water resource. Therefore, it may divide the water supply into arbitrary units which hold just the appropriate number of fish at the precise densities each time.

Although the computer logic favours a very efficient water utilisation, this is sometimes infeasible in practice especially for farms with a few large tanks. In such cases the computer produces an artefactual situation where different groups of fish may be allocated different portions of water within the same tank.

One answer to this problem is to include a monthly constraint regarding the total fish biomass that the farm as a whole is able to hold at any one time.

Such a total monthly "MAXBIOM" constraint is related to all, fish producing, activities and for all months. It is inevitable that when this constraint is introduced plenty of water seems to remain unused, which is actually correct since the ideal stocking densities cannot be followed consistently.

Another effective solution to the same problem would be to estimate the water which remains unused every month on farm due to the unavoidable inefficiencies of the stock management schedule and then subtract it from the monthly water available. This would cause the computer to calculate in terms of less water available and its optimum allocation among the fish groups would not create any further problems.

With this latter approach a smaller LP matrix could be produced since the twelve extra constraint rows necessary to restrict the monthly maximum biomass would be avoided.

3.1.10. General notes on matrix construction.

Building relations between activities. It is possible to build in the body of the matrix negative coefficients which correspond to activities which supply rather than demand a particular input. Such activities are usually those which represent buying in materials, like fish eggs, in order to supply others with the particular resources they need, and have negative figures -costs-

in place of net revenues.
So, in general, negative input-output coefficients represent supply to a constraint through a particular activity. Activities demanding that particular resource will have positive coefficients in the constraint row, thus integrating the supply-demand model in the LP matrix between related activities.

For example, in a hatchery, the activity 'buy eggs', the activity 'sell fingerlings' and the constraint 'eggs available' illustrate this concept. Assuming for simplicity, no mortalities the matrix looks as follows:

		name:	buy eggs	sell fing/s
		unit:	1,000	1,000
		N.R :	-X	Y
name	unit	level		
eggs available	1,000	0 >	-1	1

In this matrix the buying in activity supplies 1,000 eggs at a cost of £X to the constraint row which in turn offers them to the producing activity which has a NR of £Y per 1,000 fingerlings sold.
Given that both activities and the constraint use the same measurement units (ie. 1,000 of fish or eggs) and assuming no mortalities, one unit of the supplying activity (1,000 eggs) is provided for the production of one unit of the producing activity (1,000 fingerlings). Thus, the coefficients across the constraint row 'eggs available' are: -1 egg unit supplied against +1 egg unit demanded.
Through, the constraint row a 'link' between the activities has been established.

A special case of relating activities with resources -tie lines.
In the previous simple matrix example the level of the 'eggs available' constraint is zero (0).
This type of activity-resource relationship where there is a zero constraint level but the resource is supplied by an activity (or

more activities), is common in linear programming and sometimes is designated a '**tie line**'.
The constraint level -and therefore the units of the supply activity necessary- is undefined and is determined by the computer during the procedure of optimisation which requires the maximisation of total revenue and the minimisation of purchasing costs.

Relating resources by the means of transfer activities. (Passing resources from one constraint row to another.)
When the Net Revenue figure of an activity is zero (0), the activity is a "dummy" providing neither revenue nor costs. This is sometimes useful when constructing a linear programming matrix. Such unrealistic activities are called "**transfer activities**" because they are devices passing resource units from one constraint row to another, thus adding flexibility to the LP model and not participating in the production plan.
They are distinguished by having a zero as NR value, so they neither add nor subtract from the value of the total NR of the plan. The computer is using them simply as short-cuts when dealing with relationships between resources.
A transfer activity may be used also to pass on the supply of a resource in terms different from those in which it has been received, ie. connecting constraint rows expressed in different measurement units.

When dealing with input-output coefficients, supply is expressed by a negative coefficient and demand by a positive, therefore, within the same transfer activity column the location(s) which corresponds to the demanding row(s) will have a positive coefficient (ie. the transfer activity offers that commodity to this row), and the location(s) corresponding to the supplying row(s) will have a negative coefficient (ie. the transfer activity demands the commodity from it).

Example:

			Smolt	Trout	Transfer
		name:	Smolt	Trout	Transfer
		unit:	1 fish	1 fish	1ft^3
		N.R.:	X	Y	0.0
name	unit	level			
Water for Smolts	1ft^3	30,000 >	a	.	-1
Water for Trout	1ft^3	40,000 >	.	b	1

In this matrix formulation it is assumed that a fish farm produces smolts and trout in circular tanks and utilises 30,000 ft^3 of water into its smolt production operations and 40,000 ft^3 for trout production.
However, it is felt that producing smolts is more profitable so flexibility is built into the matrix so that LP may consider the possibility of taking away some water from the trout enterprise (positive coefficient down the transfer activity column) and offering it to the smolt enterprise (negative coefficient down the transfer activity column).

So, a one way short-cut link (ie. from Trout towards Smolts) between the two water constraints is established and since water for both smolt and trout activities is measured in the same unit (1ft^3), the coefficient values down the transfer activity column are equal in absolute terms.

3.2. Interpretation of the results.

3.2.1. The optimum plan.

The selection of the best possible activities by the computer in terms of what, how much and when to produce is based on the relative demands of the activities for the available resources (such as water, biomass handling capacity, maximum sales in any one month for each activity, etc.), their costs in terms of egg production or purchase, their relative mortality rates, their foodcosts, the farm gate prices they are sold at,

and the resources' relative scarcity.
When the model described is 'run' the optimum plan, found in the 'LPWYE' output, is as shown in Figure 3. below:

Fig. 3. The optimum plan.

- - Maximum value of Net Revenue = 46803.803 - -

The Plan : N.R. range for which each activity level stays constant
********** (with the incoming variable)

		Level	Lower limit	Present N.R.	Upper limit
FOODCOST	£1	29590.560	-1.191(UEGGSLOW)	-1.135	-1.077(OJUL60)
OJUL16	'000	171.701	70.340(OJUL60)	70.600	71.653(OAUG60)
UMAY60	'000	106.898	29.640(UMAR100)	30.800	31.732(OAUG60)
OAUG100	'000	7.940	30.447(OAUG60)	31.500	31.760(OJUL60)
OSEP100	'000	200.683	27.192(OJUL60)	27.400	28.245(OAUG60)
ONOV60	'000	53.353	29.741(OAUG60)	30.800	31.425(OOCT16)
OSEP16	'000	89.824	66.773(OAUG60)	70.600	71.544(OJUL60)
OVACOST	£1	16467.066	-1.150(UEGGSLOW)	-1.135	0.000(OVACOST)
DAPR16	'000	179.641	53.586(DAUG100)	61.400	OPEN
OJUN100	'000	29.936	31.397(OJUL60)	31.500	35.327(OAUG60)
DFEB60	'000	269.461	30.046(DJUL16)	30.800	OPEN
UMAR60	'000	119.760	30.472(UEGGFAST)	30.800	OPEN
UAUG16	'000	192.503	60.468(OAUG60)	61.400	80.161(OOCT60)
UMAY100	'000	179.641	27.120(UEGGSLOW)	27.400	OPEN
DJUN16	'000	195.066	57.232(OAUG60)	61.400	61.699(OJUL60)
OJUL100	'000	99.401	31.139(OAUG60)	31.500	33.786(OOCT16)
OOCT16	'000	200.000	68.314(OOCT16)	70.600	OPEN

Some rounding of the results has to be made, since LP does not 'think' in terms of integer activity levels.
This happens because **divisibility** (or **continuity**) is a conceptual property of LP which assumes that resources and activities are divisible into infinitesimally small units.

In the above plan the suggested optimum is that 600,000 fingerlings must be produced from 1,000,000 eggs using own facilities allowing for 40% mortalities. From 1,500,000 eggs imported from Denmark 900,000 "Danish" fingerlings must be produced, and 1,000,000 imported eggs from the US will give 600,000 fingerlings both with a 40% mortality rate.

Of all the above produced fish, 20% are expected to grow fast, 50% to grow at an average pace, and 30% to grow slowly. If the fish origins are ignored and the sizes sold overall concentrated on, then the farm is supposed to sell in total about 2,100,000 fingerlings.

Analytically:

	49.0% at the size of	16/lb	(1,030,000)
	26.3%	60/lb	(550,000)
	24.7%	100/lb	(518,000)
Total :	100.0%		2,098,000

The total cost of produced and imported eggs is £16,467.
The total food cost assuming an overall FCR of 1 / 1.3 is £29,590.
The above figures bear a capital charge of 13.5%, that is, £6,218 total capital cost.

The total Net Revenue to be achieved at farm gate prices is £46,804 and if the 13.5% capital cost charges are ignored the figure becomes £53,022 which allows for food and egg costs but not for the transport of fish.

3.2.2. Slack constraints.

The monthly breakdown of the resources, which prove to be more than enough for the optimum plan, and the amount of their surplus, is given in the output under the heading of "slack constraints" and is shown in Figure 4.

The water surpluses are based on the initial assumption that a constant 17,690 ft^3 water level is maintained on the farm throughout the year and a part of the surplus is certainly due to the imposed maximum biomass carrying-capacity in order to account for the inevitable inefficiencies of the stocking schedule.

Another resource in surplus, in all months, is the monthly

Fig. 4. The slack constraints.

Slack constraints
****

		Lower limit	Surplus	[Upper limit	Surplus	
JANWVOL	ft3			[17690.000	2451.048	[
FEBWVOL	ft3			[17690.000	727.406	[
MARWVOL	ft3			[17690.000	1947.795	[
MAYWVOL	ft3			[17690.000	2955.074	[
APRWVOL	ft3			[17690.000	922.765	[
JULBIOM	1LB			[15000.000	3274.682	[
NOVWVOL	ft3			[17690.000	4237.501	[
DECWVOL	ft3			[17690.000	2870.090	[
JUNBIOM	1LB			[15000.000	2509.022	[
JANBIOM	1LB			[15000.000	15000.000	[
FEBBIOM	1LB			[15000.000	10508.892	[
MARBIOM	1LB			[15000.000	13003.952	[
APRBIOM	1LB			[15000.000	3772.455	[
MAYBIOM	1LB			[15000.000	11421.926	[
AUGBIOM	1LB			[15000.000	2889.143	[
SEPBIOM	1LB			[15000.000	7379.166	[
OCTBIOM	1LB			[15000.000	2500.000	[
NOVBIOM	1LB			[15000.000	14110.765	[
DECBIOM	1LB			[15000.000	15000.000	[

biomass handling and selling capacity, which was given a maximum limit of 15,000 lbs. Thus, it seems that labour is not at all restricted as far as handling fish for sale is concerned and may be shifted elsewhere.

3.2.3. Activities not in the optimal plan.

The section titled "Activities not in optimal plan" in the 'LPWYE' output (Fig. 5.) lists all those production possibilities which are not included in the optimum plan, and states the net revenue needed (in this case the farm gate prices) before these activities can be considered for inclusion, all other assumptions being equal.

When assessing the pricing system for the different products their relative prices and their demands on inputs must

Fig. 5. Activities excluded from the plan.

Activities not in optimal plan
****

		Present N.R.	N.R. needed before entry
OJUL60	'000	35.400	35.515
OAUG60	'000	35.400	35.761
OOCT60	'000	35.400	39.245
OAUG100	'000	27.400	35.214
OSEP60	'000	30.800	42.516
USEP16	'000	61.400	70.258
OOCT100	'000	27.400	28.560
OJUL16	'000	61.400	62.154
UNOV100	'000	27.400	28.560
UMAR100	'000	27.400	28.560
UJUL16	'000	61.400	62.154
UJUL60	'000	30.800	35.174

be considered. Since the pricing system used assumes equal prices for the same sizes of fish (even though they are produced during different periods of the year) the assessment of activities dealing with fish of the same size is based only on their relative resource requirements.
For example, if it is necessary, for a particular product, to use a price which is dictated by market circumstances or personal intuition, then the model's information will show whether this price is acceptable given the demands which the product makes on the pool of resources compared with the return obtained from other product possibilities which compete for the same resources. This element of "opportunity cost" is clearly built into the logic of planning production using the linear programming technique.

3.2.4. Sensitivity analysis for the activities in the optimal plan.

In "the plan" section of the output (Fig. 3.) along with the activities in the optimal plan, there is additional sensitivity analysis, that is, information which states the range of net revenues (farm gate prices) within which the included activities will remain constant in the plan at the chosen levels. It would be worth changing the production plan only if the revenues are likely to go beyond these limits. This information on permissible net revenue changes is used to assess the stability of the optimum plan and large ranges indicate a much more 'confident' plan.

Thus, the analysis of the activities included in the plan reveals the degree of their advisibility when prices change, and, if the difference between the present net revenue figure and the lower limit of it is large, then it means that the activity is relatively overpriced. On the other hand, in the "Activities not in the optimal plan" section of the output, the prices needed by the rejected activities in order to be considered for inclusion reveal by how much their current price needs to increase for them to be competitive with the others in the plan, ie. that they are relatively underpriced.

The word "relatively" in the above analysis means that activities are over or underpriced relative to the others in the LP matrix in terms of their demands on scarce resources (cost-based pricing).

This analysis presumes that there is no correlation between any of the activities, i.e. if a price of one activity changes this does not cause changes in the price of other activities. In general the stability of one activity is assessed assuming that no other factor in the plan alters due to the change in the NR of the activity under examination.

In the printout of the plan beside the lower net revenue limit figure of an activity the name of the new incoming activity which will replace it or the name of the resource which will come into surplus when some units of the former activity are dropped out is given in brackets.

Moreover, in this same sensitivity analysis of the 'resistance' of an activity in the plan, the upper limit of the net revenue that each unit of the activity would need to earn for

the plan before any more of this activity is included at the expense of some others, is also stated.
In cases where the word 'OPEN' is stated instead of a figure, it means that the plan used up the maximum amount allowed of that activity by the most constraining resource and the computer would have accepted more of it if it could.
Beside the upper limit figure of an activity, the first candidate among the other activities some units of which have to be sacrificed in order to allow the inclusion in the plan of more units of the former, is mentioned in brackets.

When interpreting this sensitivity analysis, it should be remembered that the hypothesised change in the net revenue of the activity is assumed to be the only change and no information can be drawn for the effect of two or more simultaneous changes in activities' N Revenues.

3.2.5. Binding constraints.

Information is provided under the output section of "Binding constraints" concerning all those resources which are completely utilised in the plan and which moreover prove to be scarce, thus dictating the computer's 'decision' on the final form of the plan (Fig. 6.).
An important attribute of a binding constraint is the concept of its **Marginal Value Product**, or **M.V.P.**, which is defined as the amount of extra net revenue which would be added to the final (optimum) solution for an extra unit of this binding constraint made available.

According to the definition of MVP, those constraints with a positive value reveal that the programme will preferentially accept more than the level imposed if more are available. It will then produce a final net revenue figure, increased on the margin by the amount of MVP.
Constraints with negative MVP values will reduce the total NR figure on the margin by the MVP amount if their imposed level is increased.

Fig. 6. The binding constraints.

Binding constraints ******************		Resource supply range over which the M.V.P. is constant (with the outgoing variable)			
		M.V.P. $/unit	Lower limit	Present Level	Upper limit
OEGGSLOW	'000	12.772	285.500(OAUG100)	300.000	1323.122(JULBIOM)
OVACOST	£1	1.135	OPEN	0.000	16467.066(OVACOST)
OEGGAVER	'000	12.948	437.512(OAUG100)	500.000	1213.282(JUNBIOM)
OOCT16	'000	2.286	164.317(OJUN100)	200.000	214.575(DNOV60)
FOODCOST	£1	1.135	OPEN	0.000	29590.561(FOODCOST)
JUNWVOL	ft3	0.378	10642.857(OJUN16)	17690.000	19140.295(JUNBIOM)
OEGGFAST	'000	12.322	150.006(OJUN100)	200.000	1679.413(OJUN16)
DEGGAVER	'000	5.963	513.029(OJUN100)	750.000	1461.030(OSEP16)
OCTWVOL	ft3	0.117	17159.457(DNOV60)	17690.000	19685.592(OSEP100)
OEGGSLOW	'000	8.611	46.495(OSEP100)	450.000	547.267(FEBWVOL)
OEGGFAST	'000	13.212	159.960(OJUN100)	300.000	343.249(APRWVOL)
AUGWVOL	ft3	0.122	17304.801(OAUG100)	17690.000	19428.231(AUGBIOM)
UEGGFAST	'000	0.197	0.000(UMAR60)	200.000	325.626(FEBWVOL)
JULWVOL	ft3	0.107	15869.281(JUNBIOM)	17690.000	17987.662(OAUG100)
UEGGSLOW	'000	0.168	0.000(UMAY100)	300.000	818.545(FEBWVOL)
UEGGAVER	'000	0.836	319.388(UMAY60)	500.000	656.486(APRWVOL)
SEPWVOL	ft3	0.408	15509.214(AUGBIOM)	17690.000	18812.307(OJUN100)

Therefore, when imposing on the plan more of a factor with a negative MVP, LP warns that the solution shifts away from the optimum. The opposite applies when the computer is free to select greater levels of those factors which bear a positive MVP, and the bigger the positive MVP value the better the total net revenue result.

3.2.6. Sensitivity analysis for the binding constraints.

The "Binding constraints" section offers the MVP values for each exhausted resource and a sensitivity analysis which states the lower and upper limits for the supply range of the resource that the MVP is constant.

Beside the figures of the lower or upper limits, in parentheses, are the names of those resources which go out of surplus or those activities which would be first reduced when these limits are exceeded. However, it must be born in mind that all other factors in the plan are assumed to be independent and remain constant.

3.3. The market environment.

Although a plan produced by Linear programming may look totally feasible in terms of resources available and of management attitudes, the question of its applicability lies mostly in the influences from the marketing environment. These factors are external to the fish farm itself, but contribute drastically towards the formation of the production plan.

For the present example study it is assumed that there are no such market influences and the plan is formed assuming equal opportunities for all the products (activities).
However, if any market trends exist which favour one or the other fingerling size and/or timing, or if customers' preferences concentrate on one particular product, then this must be accounted for by the farm's management. The LP matrix must depict such external impositions and allow for them in the form of constraint limits (minimum, maximum or even equality constraints), which will contribute towards the formation of an optimum plan suitable for the anticipated market situation.

In this discussion the fish farming business that is modelled is insufficiently large to be able to influence or regulate the market. If this assumption does not hold then it is economically beneficial to impose its plan on the customers rather than to conform to their preferences.
For example, a hatchery supplying the market with fingerlings at times when there is virtually no competition in a specific locality could preferably sell those fish sizes which are shown, by linear programming, to be most profitable to the business. However, competition is, more usually, a major factor and in these cases the computer's freedom of choice must be limited by imposing decisions in the LP matrix by defining certain

production constraints (equalities) or giving them minimum acceptable values.

The essential difference between an equality and a minimum (or a maximum) constraint is that 'equalities' do not allow any sort of flexibility to the programme. They impose exactly the level of the resource entered. Minimum constraints, however, allow the programme to exceed the specified resource level if it 'thinks' it is of benefit, but forbid any reductions of it. In fact the matrix may be reformed in order to accept as facts whatever product restrictions the marketing environment dictates. What the computer will then do is to find the optimum strategy under these restrictions. LP will also give the best possible (least costly) resource distribution for optimum results and a clear indication of the implications that the imposed strategies have upon profitability (MVP values).

Such a planning model, where part of the activity levels are fixed and others are optimised, is referred to as a partial optimisation model. In no case will a partially optimised plan have a higher value in the solution than one, virtually the same, but without some of the production constraints, that has been fully optimised. This is made clear by the MVP values of the various constraints, which show the direction of the adjustments needed in the plan in order to move towards a 'full' optimum.

4. SUITABILITY OF LP FOR PLANNING FISH FARM PRODUCTION

4.1. General contribution to the planning problem.

When fish farm production is planned, in the short run, the main concern is with the existing production operations rather than the design of new production systems or the analysis of the technical efficiency of production operations. LP is not supposed to show the way in which certain tasks, such as determining the correct feeding levels the fish farmer should use, should be carried out. It accepts the current production operations and their level of efficiency given in the form of the input-output coefficients which are built into the body of the LP matrix.

However, if the data exists, LP may be used to check the impact of alternative production techniques and pinpoint possible technical inefficiencies of operations. The LP solution will reveal the relative economic efficiency of different production methods by selecting, in the optimal plan, the most profitable of them. The requirement is that information on the alternative production methods for the same output should be built into the model and form distinct activities in the matrix.

LP assists in the decision of the best "product mix" according to some clear idea of the business's primary objectives which in turn determine the objectives for production. The clear definition of the business's targets reflects the internal characteristics of the firm and its expected response to the conditions of its environment. Hence it influences the construction of the model and the interpretation of its results. The actual times within a year that a production plan should be generated depends on how stable the operating environment is in terms of internal processes and external influences that might affect the optimum plan.

Forecasts or predictions of future events, like the overall growth in the market, monthly demand of each product etc., are vital when planning future production.

LP provides a solution which is subject to subsequent revisions according to the changing circumstances. Any solutions must be interpreted in the broad sense of providing guidance towards making the best possible decisions.

The way LP is used in this study is orientated towards improving the resource allocation and planning of existing fish production activities rather than radically restructuring future production plans. To leave the latter possibility open to the model, data about new activities never previously attempted on the farm must be found. If such data is generated by simulation models, the reliability of which is questionable, the LP results will be equally doubtful. Data of this kind is thought to be better obtained either from other farms which already operate these activities and are willing to disclose information, or from experimental agricultural stations and consulting bodies.

In the example case study a complete production cycle is reflected in the matrix by a monthly breakdown of resource requirements and production scheduling.

It is a further task for the manager to consider the detail of day-to-day running of the fish farm in pursuit of the optimal plan. Such an attempt frequently highlights the inadequacy of record-keeping and it is this identification of data problems that helps to improve the existing recording system.

The demands for detailed and accurate data appear to be but are definitely not excessive. In fact the same information is needed -although in a much more informal way- for any other less sophisticated farm planning technique, or even when the whole business management and decision making is based solely on the farmer's experience and inspiration.

The only serious demand of LP is the accurate statement of the problem. If a manager is so uninformed and unable to specify the scarce resources or the likely input-output relationships, the planning efforts, no matter which method is used, cannot be surrounded by much confidence.

Linear programming can also stand criticisms regarding some basic theoretical and structural concepts around which it has

been developed.
It can be criticised on the grounds of its theoretical inadequacy in representing realistically a 'real world' situation.
In fact LP provides relatively short-term static solutions which assume perfect knowledge of all the values which take part in the matrix, although in actual life managing a fish farming system is a dynamic process surrounded by uncertainty.
There are also the structural criticisms relating to LP's assumptions of linearity and continuity. Linear programming cannot handle adequately situations where integer quantities only are acceptable and, as a matter of fact, linear relationships are rare in the real world.
But although it deals with straight line factor-product functions, taking successive discrete linear segments on these functions may approximate continuous curves. For example a matrix may reflect the monthly fish growth in the form of successive 'steps'.
Fractional quantities in the final plan, wherever inappropriate, may be rounded up to the closest integer amount without much loss of accuracy.

4.2. Handling uncertainty. *

LP itself was employed formally, in many cases, to solve the problems of uncertainty that a farmer was confronted with when planning production.

J.P. McInerney (1967) accepts that 'Nature' may represent a spectrum of uncertainties in the biological, institutional (ie. legislation) and market complex within which the farmer operates. Thus, the farmer may be considered as being involved in a 'game' with the different states of Nature that may prevail, in the

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* Uncertainty prevails when a course of action may be followed by a set of possible outcomes with unknown probabilities.

attempt to achieve the best combination of farm activities -given finite resources- in order to derive at least some guaranteed minimum level of income.

McInerney suggested an "optimal scheme of diversified production in the face of uncertainty" and proposed a method for the standard LP technique to solve such 'games' with Nature. He recommended a normal farm LP model extended by an additional system of a few extra constraints combined with fictitious -'dummy'- activities useful for this purpose. This formulation ensured that a "maximin", that is, a maximum level of the minimum acceptable revenue for the farmer would be achieved, regardless of the states of Nature.

Although such a "maximin plan" is not necessarily the one which provides maximum revenue, it is useful to the farmer who cannot afford to ignore the consequences of a year of unexpected low return.

The additional information required, however, relates to the possible states of Nature and their quantified effects on the enterprises (activities) in the optimum farm plans. Reliable historical data records should supply such information. The planner should also specify the desired security minimum level of return. This extra information can be then integrated in the LP model for the farm, according to McInerney's suggestions, and run normally on the computer.

J.P. McInerney (1969) demonstrated also that several other criteria, apart from the "maximin" (or Wald criterion), apply when selecting among alternative production plans under uncertainty. These are all considered in the so called "theory of games" and include the "minimax regret" (or Savage criterion), the "Principal of insufficient reason" (Laplace criterion) and the "Optimism/Pessimism Index" (Hurwicz) decision criteria.

Any one of these criteria may 'accompany' an LP model and generate a solution which satisfies the requirements of both the programming constraints (scarce farm resources) and the decision criterion constraint. Thus, optimum plans with totally different resource allocation patterns among activities may be generated according to the criterion.

Which decision criterion, from the the game theory, is to be used with LP depends on the psychology of the planner who sets the objectives for decision making under the uncertain farming business.

A variation of the previous method was used by M.E. Tadros and G.L. Casler (1969), who also attempted to help farmers' decisions under uncertainty. They produced with LP an optimum strategy for every state of Nature and then tabulated these plans against them. Thus, a "pay-off matrix" was produced in which each state of Nature was represented by only one optimal strategy. A farmer could then select that plan (or a linear combination of two or more farm plans) according to the subjective decision criteria which corresponded best to the business objectives, work attitudes or financial obligations.

Thus, two distinct ways of applying a decision criterion, when planning under uncertainty, may be utilised in LP.
Firstly, the decision criterion can be incorporated into the LP model itself by extending the LP matrix. So, a single optimum solution according to the criterion is generated.
Secondly, a series of optimum farm plans for the different states of nature can be generated with LP and then, at a later stage, selection of the most desirable plan among them can be made using the decision criteria.

J.M. Boussard and M. Petit (1967) offered a more informal -rule of thumb- approach for taking uncertainty into account. Their main assumption was that farmers maximise their profit provided that the possibility of a result which is below that which they define as minimum acceptable loss is negligible. The minimum acceptable loss, or "focus loss", criterion was first introduced by G.L.S. Shackle (1949). This concept is defined as the level of possible loss that a decision maker would not normally accept. Farmers were supposed to maximise the "normal" or mean value of their revenues under the constraint that the focus of loss, for the optimal production plan, is at least equal

to a permissible loss (ie. equal to the difference between the mean expected revenue and a minimum revenue).
The idea was integrated into an LP model by expanding the matrix to include the focus of loss constraint. The optimum plans that resulted maximised the farm's net revenue under the constraint that the possibility is very small, in any given year, to have a total net revenue below a fixed minimum.
The additional data required for this method may be obtained by interviewing farmers or advisers and is related to their subjective judgements.

However, when planning production under uncertainty, a true representation of the future production factors and output in the LP model can never be achieved since the future variations which need to be incorporated into the planning model are mostly unknown.
Thus, the analysis offered by McInerney incorporated the effects of the states of Nature upon yields and prices of products which mostly determine revenue, but did not handle the uncertainty in respect to the availability of resources and physical productivity which constrain the final plan, due to the lack of information upon these. For the same reason the model proposed by Boussard and Petit also took into account only yield and price uncertainty.

4.3. Handling risk. *

For a formal evaluation of risk Risk Evaluation Models (R.E.Ms) can be used (M.C. Murphy, 1971), but this presupposes a sound data base which enables the production of statistical information about the probability distribution of the planning parameters such as growth rates, mortalities, prices, costs, etc. With such information available, a LP plan may be obtained first using mean expected values and then the solution tested for

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* Risk prevails when probabilities can be calculated for all possible outcomes of a course of action.

variation by means of a REM. If the degree of variation is unacceptable the solution can be modified to give lower variation/risk by altering the planning constraints and coefficients generally at the cost of providing a lower total net revenue.

A more practical approach to accounting risk involves **sensitivity analyses,** which may be used extensively to show how possible changes could affect profitability. It is possible to formulate a set of standard LP solutions for different states of nature, thus, 'good', 'medium' and 'bad' plans may be generated and then some subjective probabilities attached to them. Then it is up to the personal appreciation of risk to act along the lines of the one or the other alternative plan. This type of planning, where the manager has the appropriate plan ready for a future possible situation, is called "contingency planning".
For highly risky activities a set of 'security constraints' might be included in the matrix, which impose a certain conservative idea on the final plan in order to provide for the worse case. Alternatively, the same conservative effect on the plan can be achieved by restricting the resources in the model to an excessively low level.

4.4. The fish farm production planning system.

In summary, fish farm production can be planned via a system which incorporates the following parts:

Firstly, the data system supplies the necessary data for the construction of the LP matrix. A well organised data system which gathers, analyses, stores and retrieves information must precede all serious planning efforts.
As far as LP is concerned, the data system will provide the manager with the following sets of data according to the special needs they cover for matrix construction:

- the production process,
- resource availability,
- pricing and costing,
- alternative production possibilities,
- sales and marketing.

Secondly, it comprises the linear programming system. This is divided into the hardware, ie. the microcomputer system that the LP problem will be run on, and the software, ie. the LP package which is to be employed for the solution.

A third factor needed may be named "the human interface" and incorporates the three basic functions that the human operator should perform, namely, to maintain comprehensive, accurate records, to construct the linear programming matrix and to interpret the results.

According to our research observations, these functions demand the manager's commitment to master the technique and are continuously sharpened through experience and personal involvement. Business orientated persons with entrepreneurial skills will have the patience and be determined to devote personal effort and the time needed for such self-training now that suitable microcomputer software has come to the market.

4.5. Likely problems for the beginner.

Problems may be encountered by the inexperienced user but will diminish with time depending on the determination to master the technique and adapt it to the specific business environment. A lot of personal effort and trial and error repetitions of the work required for the production of a correct matrix will, no doubt, precede a reliable LP solution. Presuming a well organised data system and a clear idea of the key assumptions which hold in the farm, the sheer volume of data and the usual quite complex planning situations will demand the manager's patience and consistent thinking.

However, no-one should demand expertise without going through a self-training, first phase. LP matrices will be small initially growing bigger with time along with the experience gained by the operator, since they may easily be extended to cater for more factors or amended as better data is obtained from an evolving data system. This latter factor of better data organisation will evolve in parallel with the competence of the manager, who will be subconciously motivated to scrutinise the data figures and the overall trading situation of the farm.

In cases where the fish farm's operations are well established and no radical changes -such as new products or new constraints- are expected but only in the long run, once the production and marketing environment of the farm is successfully represented in the matrix form, it is readily available to be consulted at anytime. Amendments to the data or the assumptions may be made at will in order to reflect changes in the production factors or in the market.

Problems associated with interpreting the LP output are directly linked with the competence of the operator in creating the LP matrices. Experience and understanding in these functions evolves in parallel. For example, by interpreting the output correctly, mistakes, hidden in an erroneous matrix, may be isolated.

Experience forms performance expectations of the farming system, so, when examining a LP solution, the manager will recognise an unacceptable plan. One or more restrictions may be forgotten from the original formulation of the problem which must be identified and the matrix which is responsible for the inappropriate result has to be amended.

4.6. Conclusion.

LP does not provide solutions to be followed as such. What it does is to provide guidelines for the best policy according to the current operational environment which is reflected in the matrix. It should be considered as a valuable decision making tool which in addition motivates a better organisation of data and deeper understanding of the fish farm system as a whole. Its utility increases under variable marketing environments and in cases where considerable flexibility to adjust production schedules and capacity exists.

"LP-WYE" software was applied on a fish farm business for a period of two years before the views that are described in this chapter were developed.

The theoretical concepts of LP as a planning technique were tested rigorously by the farm manager, who helped to clarify the potential benefits that LP may offer to fish farmers. Only a few weeks of training with "LP-WYE" were enough to create the necessary confidence in matrix construction and generation of optimal plans.

It is hoped that it will become more familiar to other fish farm managers as a result of the continuing upward trend in the use of microcomputers.

In conclusion LP when used in fish farm production planning:

- stresses the paramount importance of the existence of a sound data recording system on the farm,

- points out any weaknesses of the existing data recording system because of its demands in consistent and verified data to be built in the matrix,

- shows the status of the various resources on the farm, the relative scarcity of each particular one and their value to the system,

- points out all relative advantages and disadvantages of the various production alternatives given the farm's resource status and can adjust the solution to the market reality and/or to a hypothetical complete marketing freedom,

- will give incentives to modify production processes, adjust output prices, introduce new production possibilities, or supply extra units of necessary inputs when this contributes to the overall financial benefit,

- provides sensitivity analyses of the stability of the proposed plan since the assumptions made about quantities, costs and prices may change,

- challenges the fish farmer to obtain a better understanding of the farming system and to explore it further in order to reveal all of its potential by the identification of inefficiently utilised inputs and by exploiting new market opportunities,

- may identify the most profitable targets for expansion.

FOURTH CHAPTER

A review and economic evaluation of the information system.

<u>CONTENTS</u>

1. A SCHEMATIC REVIEW

Decision making is a personal affair of the fish farm manager whose decisions in an uncertain world relate to his own perceptions of reality and preferences.
In essence, perceptions represent conceptual models of the farming system in the manager's mind. They depend on past experience -historical information, but are in continuous revision under the flow of new information.
Therefore, the objective of the developed computerised system was to clarify these 'images', leaving the selection of the desired immediate action or strategy to the manager on the basis of the analyses presented. In addition, the manager had complete freedom to intervene and 'drive' the computer programmes intuitively.

A schematic representation of the proposed system is as follows:

The computerised information system for fish production management:

Farm site

PRODUCTION DATA COLLECTION
& TEMPORARY STORAGE
- Growth,
- Environment,
- Stock management.
(portable device programmed in BASIC)

↓

DATA TRANSMISSION
(electronic communications, analog to digital conversion -modems)

↓

CALCULATION AND FILING
(creation or updating of electronic data files)

↓

PERMANENT DATA STORAGE
(on microcomputer floppy disks or hard disk)

↓

DATA RETRIEVAL

INSPECTION
PRINTING
GRAPHING

Additional information on:
- Alternative production options,
- Status of farm resources,
- Markets (prices - costs).

↓

PROCESSING
(on the desk-top microcomputer by the customised 'LOTUS' worksheets (reporting, growth modeling) & by 'LPWYE' (optimisation)

↓

PRODUCTION INFORMATION

Stock and Mortality control

Growth control (short term)

Production planning (strategic)

↓

PROFITABLE DECISIONS

For:
- optimum product mix
- improved growth efficiency (input utilisation)
- timeliness
- minimum stock losses

2. SYSTEM IMPLEMENTATION

Educating the user-manager gradually to appreciate the value of the information output and understand the operation of the computer programmes was necessary and it is believed that failure to do this might restrict any extensive applications of such information systems in the future if not tackled successfully from the very beginning of system design.

Fish farmers in general are frequently interested in the possibility of installing a computerised record keeping and processing system on their farm but usually find difficulties in visualising the precise nature of the contribution that computers can make. They have different beliefs of their ability to handle them and their enthusiasm varies. On the other hand, the succesful implementation of any computerised system depends on conforming to the disciplined structure of the computer programmes and on the willingness to undertake routine data collection work which very often is a new experience.

Attitudes towards innovation in relation to the size of the business and the character of its manager have already been discussed in the first chapter of this study, where the criteria had been established in order to select the appropriate entrepreneur who would most likely pioneer the implementation of such a project and undertake the investment risks.

The present computerised system was designed step-by-step with the close cooperation of a hatchery manager whose practical information needs were being gradually defined and accommodated in the computer environment. The farmer refined his views and made suggestions which contributed directly to the system's development. Thus he could foresee the utility of information and build confidence and enthusiasm that absorbed the initial operational errors ('teething problems') of the newly constructed system. He helped to improve any shortcomings and encouraged its adoption among his personnel.

Since most of the computerised procedures were new to the farm

there was no possibility of "parallel operation" or "parallel running" of the computerised system alongside old procedures, although it is recognised that this is the safest solution in project testing.
The developed software -custom written code or customised worksheets- often still contained errors that were discovered by the business user. Errors often resulted from unusual combinations of inputs or operator errors that were not conceived during programming. Sometimes it was difficult to decide whether a problem was a programme error or was due to programme misuse. Generally, introducing a computer system to a business which has not previously used such equipment is likely to involve operator errors arising from inexperience which may initially appear to be programme errors. On the other hand, a computer programme becomes longer and less manageable as more error checking is built into it to provide more safeguards. Inevitably the designer is faced with a compromise between length and fallibility.
The cooperating manager was the essential link in the effective programme 'debugging'. He carefully documented the circumstances under which something was going wrong so that the error situation could be recreated and the 'bug' identified.

Needless to say all programmes were also recorded on back-up disks and printed as hard-copies in case an irreparable 'corruption' of a programme occurred.

3. MACRO POTENTIAL

The objectives of any research that relates to farm production and its economics were expressed by E.O. Heady, (1948) as follows:

- Provide guidance to individual farmers in the efficient use of their resources.
- Analyse the impact of public policies or government programmes on the use of farm resources.
- Improve central administration and design of adjustment programmes for farming areas (agricultural policy).

Hence, the objectives of research in aquacultural production are twofold. Guiding the individual fish farmer (micro-level) and acquiring a broader understanding of the industry in order to implement beneficial policies (macro-level).
Both levels aim to better resource utilisation. The more efficient combinations of resources on individual farms inevitably benefits the society's welfare (Heady, E.O., and J.L. Dillon, 1961).

Micro-recommendations should relate to the particular targets of the individual business and flexibility in the use of resources must be maintained by farmers' decisions based on information recorded and analysed on site.
The information system that was developed here attempted to direct the farmer's own decision making by the produced analyses and plans towards the most satisfactory solution.

However, the same data which was used to guide the particular farmer could be extremely useful for wider economic development. If such information systems were adopted by more members in the industry, precise data could be made available for readjustments of the industry in regions or nationwide.
With production data on individual farms readily available, aggregate models of regions and farm types or simulation studies of the industry's sensitivity to certain policies would be facilitated. Accurate fish-farm management surveys would open new possibilities for effective strategic central and regional policy.

4. ECONOMIC FEASIBILITY STUDY OF THE IMPLEMENTED PROJECT

In order to apply any innovative idea in the area of information technology the following 'tests of feasibility' should be satisfied:

- Technical: The hardware must be adequate and the software should be readily available or able to be customised.
- Economic: The economic benefits should outweigh the costs of the new system, ie., the value of the added information must be worth its costs.
- Operational: Management and work force must be able to implement the system successfully.

Although the technology may exist or can be developed and a genuine effort towards implementation can be guaranteed, it is frequently the case that only a partial estimate of economic benefit can be given due to originality of the project. Unexpected benefits or disadvantages become apparent only after a degree of implementation.

The initial "one-off costs" for establishing an information system must be positively outweighed by the final account of running costs and benefits when the system is fully operational for a defined period of time. That is:

Development costs < projected benefits less running costs over X? years.

4.1. Problem layout.

In this study the **benefits** could not easily be quantified. They might be accounted in terms of the extent to which the manager's own decision-making processes were aided and speeded by the computer-produced information and by the increased possibility of success that the plans had due to the improved control over the production operations.

In a risky world the 'best' decision may give rise to a 'bad' outcome. However, the result and not the decision should be judged to be poor. This adds to the problems when calculating the benefits (Dillon, J.L., 1971).

For example, a list of anticipated benefits might be:

- Increased discipline in data recording and storage.
- Extra management control available to the owner if non-manager.
- Accurate information being available early to give warning of problems.
- Freedom from errors.
- Availability of advanced techniques (eg. LP) which are not possible manually.
- More time available for problem solving since retrieval and processing time is minimised.
- Instant response to customer enquiries.
- Interface with other systems for data exchange (printouts or data can be transmitted to colleagues, accountants, vets, etc.)
- Possible expansion of the system to incorporate new advances.

Time was yet another illdefined element to consider in the evaluation. Time was spent operating the computer to update the data files, generate reports or plans and print them, examine graphic illustrations etc, but, overall, time savings were realised by rapid decisions and quick answers to problems in the light of well presented, previously unavailable information.

Inevitably, the manager should judge subjectively the value of time saved and whether extra information was worthwhile and should decide the limits of information needs.

The **one-off costs** of developing and implementing the system on the hatchery were the following:

- Purchase of hardware.
- Purchase of packaged software.
- Time of writing new or customising existing software.
- Time to train the manager and the involved personnel.

Since the described system was a Ph.D research project the last two items in the above list, the costs of time spent and the development effort, were not considered; however, they are expected to form a serious source of expenditure for possible future investors in similar systems.

In the particular information system, apart from the development costs, **running costs** concerned maintenance contracts, insurance against damage as well as consumable items such as floppy disks, printer ribbons, paper and electricity.

In all, the balance of costs and benefits of an operational system over a period of X years could be estimated as follows:

Costs	Benefits (over X years)
- Development costs, (one-off costs)	- Better decisions (efficiency),
	- Quicker decisions (time savings),
- Running costs. (over X years)	- Safer outcomes (control).

4.2. Cost and return on investment calculations.

A total one-off cost figure of £5,500 was calculated (Spring 1986), which represented an inflated figure capable of accommodating possible requirements of supplementary software or computer accessories.
During the recent years, despite the continuous technological advances, there is a clear trend for powerful computer hardware to be offered at progressively cheaper prices. However, this may be offset by inflation and possible increases in the price of new, better software.

Since computer technology improves rapidly, depreciation mostly due to obsolescence is high and the equipment should be written-off over a short, 3-5 year, period.
Considering also £5,500 as the approximate future replacement cost and estimating £2,000 as the terminal value of hardware and software packages, the "straight line" method calculated a steady depreciation of £700 over five year period (3500 / 5), which was taken into account as a sinking fund.

An estimation of the running costs of the system for the five year investment period was added to the above figure in order to form the total investment cost.
Yearly maintenance and insurance (£650) was about 12% of the value of the equipment. Consumables and electricity were approximated at £300 per annum. For simplicity both these figures might be considered constant (£950) over the five years.
The manager, who would be the major computer user, did not wish to estimate any cost figure for operation time.

Therefore,

Total investment cost = (one-off costs + sinking fund + total running costs)

The computerised system should be capable of offering a return which would at least 'break even' with the initial investment and running costs and facilitate its replacement at the end of the investment period.

A tabulated picture of the marginally expected capital inflows compared with the outflows, calculated by the manager, was as follows:

	Establishment cost	Running cost	Annual sinking fund	Terminal value	Break even return
year 1	-5,500	-950	-700		+2,350
year 2		-950	-700		+2,350
year 3		-950	-700		+2,350
year 4		-950	-700		+2,350
year 5		-950	-700	+2,000	+2,350
Totals	-5,500	-4,750	-3,500	+2,000	+11,750
Break even totals			-13,750	+13,750	

The table accounts simultaneously for the establishment cost and for a sinking fund for future replacement. Thus, this was a concervative calculation which would facilitate free of charge replacement of the system at the end of the first five-year period.

According to this calculation, in order to be profitable, the particular investment should generate at least an annual break even return of £ 2,350.

For example, in the case of a fish farm with a turnover of £150,000 per annum the above annual break even return figure would represent 1.56%. If profit is 20% of turnover, ie., £30,000 then such a farm should achieve, on average, at least 7.83% pre-tax profit increase to justify the investment.

Clearly, the scale of the business operations would define the relative portion of turnover needed to cover the system's costs. If a successive, constant 10% increase in turnover is considered -steady growth of the business-, the relative portions that the annual investment costs would represent are tabulated as follows:

10% steady, progressive increase in business scale Turnover in £	Break even return as a percentage of turnover
150,000	1.56%
165,000	1.42%
181,500	1.29%
199,650	1.17%
219,615	1.07%

In addition, larger businesses have disproportionately bigger demands for information and administration and a more complicated decision process, which enhance the chances for economic success of investments in computerised information systems.

4.3. An interview with the hatchery manager.

The manager of the pilot hatchery farm in this project confirmed that deep insights to the farming system were facilitated by the exhaustive analyses of fish growth efficiency and of the production alternatives. In addition, improved control over the operations and timely reporting saved him considerable management time. Replies to customers or insurance institutions concerning fish-stock status and availability could be given instantly by computer printouts in any desired form. The monthly time saving that was realised due to stock and mortality control alone was estimated as 4 working days. Considering a 25-working day month this was a significant (16%) reduction in workload which would involve journeys to the farm site, consultation with the workforce and inspection of stock. Generally, there was no need to visit the farm site as often as in the past in order to supervise field personnel and check results.

The mutual trust between management and farm personnel guaranteed the quality of the field data collected which the computer analysed. Searching questions could be asked in the case of losses in order to identify and eliminate their reasons, whereas the losses themselves -fish mortalities- were expected to diminish considerably in the long term due to the tighter control over the stock status.

It was calculated by the manager that at current prices (1986) and for a total yearly input of 9 million fish eggs for hatching, a subsequent average decrease in fingerling mortalities by 2.2% per annum could effectively cover all the investment costs.

Moreover, the manager stressed the non-financial benefits of the present project and expressed them by his intrinsic satisfaction to manage more confidently.

However, he added, a fish farm manager should be already competent before computerisation. Computers enhance but do not introduce management efficiency.

5. A POSSIBLE NEXT STEP FORWARD

For a relatively small firm, growth in the short term, when the market itself may not be increased, could be realised by increasing the firm's share of it. This could materialise by producing more products of better quality and more cheaply and by tackling new marketing opportunities. Areas of inefficiency must be identified, all alternative actions examined and a complete financial analysis of their consequences presented.

Therefore, a study of the policies that could encourage data computerisation among the smaller fish farms and the implications that this would have for the aquaculture industry as a whole might be of interest.

However, a more immediate step forward would be the expansion of the system to incorporate the financial side of the fish farm business, perhaps by introducing standard measures of financial

performance equivalent to those currently used in traditional agriculture. Customised packaged software, perhaps LOTUS 1-2-3, could also be used for this purpose in order to be interfaced easily with any existing system.
In addition, attempts to adjust and apply an information system, based mostly on "off-the shelf" software, on other fish farms of different design and cultivating different species could extend the point made in this thesis, namely, that with existing technology the information needs of the individual fish farmer can be fulfilled at a reasonable cost.

It is recognised that a very important technological breakthrough would be the development of cost effective sensors that could be interfaced to a wide variety of microcomputers using standard output ports. If such units were cheaply available, they would eliminate the effort of measuring and logging the data for further processing. This must be emphasised in the case of total biomass or average fish size detection in fish containers which constitutes the most labour intensive recording activity on any fish farm.
Research in this area has started and continues in some countries (Denmark, Norway) in order to bridge the gap between data capture and processing.

Allen, K. R. (1966). A method of fitting growth curves of the von Bertalanffy type to observed data. Journal of the Fisheries Resources Board of Canada, 23, 2, 163-179.

Anderson, R. L. (1957). Some statistical problems in the analysis of fertiliser response data. In E. L. Baum et. al. (Ed.) Economic and Technical Analysis of Fertiliser Innovations and Resourse Use. Chapter 17. The Iowa State College Press, Ames, Iowa, U.S.A.

Anderson, J. R., and J. B. Dent (1971). Agricultural systems analysis: Retrospect and prospect. In J. B. Dent and J. R. Anderson (Ed.) Systems Analysis in Agricultural Management. Chapter 17. John Wiley and sons, Australasia pty ltd.

Andrews, J. W., and R. R. Stickney (1972). Interactions of feeding rates and environmental temperature on growth, food conversion, and body composition of channel catfish. Transactions of the American Fisheries Society, 1, 94-99.

Andrews, J. W., T. Murai, and G. Gibbons (1973). The influence of dissolved oxygen on the growth of channel catfish. Transactions of the American Fisheries Society, 4, 835-838.

Anglesea, J. D. (1984). Electronic spreadsheets. Fish Farmer, 7, 3, 20-21.

Anglesea, J. D. (1985). Electronic record-keeping. Fish Farmer, 8, 3, 33-34.

Antill, A. G., and C. Clark (1958). The overfeeding of dairy cows. Westminster Bank Review, February 1958, 13-15.

Antill, L. (1985). Desk-top computing: A comprehensive guide to successful business and professional microcomputing. In D. Tebbutt (Ed.), Business Computing: The Survival Guide. Personal Computer World, special issue.

Arnason, A. N., R. Day, and D. H. Scuse (1984). Computer implementation of Markovian growth models for predicting mean size and size variability. Congressus Numerantium, 42, 101-120. Department of Computer Science, University of Manitoba, Winnipeg, Manitoba, Canada.

Arnason, A. N., and D. H. Scuse (1986). Design and implementation of a computerised decision support system for hatchery management. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Arnold, G. W., and D. Bennett (1975). The problem of finding an optimum solution. In G. E. Dalton (Ed.), Study of Agricultural Systems. Applied Science Publishers ltd. Chap. 4.

Bagshaw, E. (1985). Applications put on the rack. FINANCIAL TIMES SURVEY. 1st May 1985, Nº: 29,613.

Balchen, J. G. (1986). Bridging the gap between aquaculture and the information sciences. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Banfield, S. J., and H. P. Cory (1981). A study on the use of on-farm computers in the United Kingdom. Dissertation submitted in part fulfilment of the requirements for the Royal Agricultural College Diploma in Agricultural Farm Management, Royal Agricultural College Cirencester.

Banks, M. (1986). Information gap. Personal Computer World, 9, 8, 94-

Barnard, C. S. (1963). Farm models, management objectives and the bounded planning environment. Journal of Agricultural Economics, XV, 4, 525-549.

Barnard, C. S. (1965). Computers at the farmer's service. Agriculture, 72, 2, 72-75.

Barnard, C. S. (1966). Computers and farm planning. Fatis Review, 4, 106-108.

Barnard, C. S. (1975). Data in agriculture: A review with special reference to farm management research, policy and advice in Britain. Journal of Agricultural Economics, XXVI, 3, 289-331.

Barnard, C. S., and J. S. Nix (1979). Farm planning and control. Cambridge University Press, Second edition.

Bartlett, M. S. (1949). Fitting a straight line when both variables are subject to error. Biometrics, 5, 207-212.

Barwood, W. (1983). Trout profit needs plans - part I. Fish Farmer, 6, 3.

Barwood, W. (1983). Trout profit needs plans - part II. Fish Farmer, 6, 4.

Bauer, L. (1972a). CANFARM's computerised farm records. Canadian Farm Economics, 7, 3, 10-21.

Beamish, F. W. H., and P. S. Mookherjii (1964). Respiration of fishes with special emphasis on standard oxygen consumption. I. Influence of weight and temperature on respiration of goldfish, Carassius auratus L. Canadian Journal of Zoology, 42, 2, 161-175.

Beamish, F. W. H. (1964). Respiration of fishes with special emphasis on standard oxygen consumption. II. Influence of weight and temperature on respiration of several species. Canadian Journal of Zoology, 42, 2, 177-188.

Beneke, R. R., and R. Winterboer (1973). Linear programming applications to agriculture. The Iowa State University Press. AMES Iowa.

Berkson, J. (1950). Are there two regressions? Journal of the American Statistical Association, 45, 164-180.

Bertalanffy, L. von (1938). A quantitative theory of organic growth (inquiries on growth laws II). Human Biology a Record of Research, 10, 2, 181-213.

Bertalanffy, L. von (1957). Quantitative laws in metabolism and growth. The Quarterly Review of Biology, 32, 3, 217-231.

Bishop, C. C., and W. D. Toussaint (1958). Introduction to agricultural economic analysis. John Wiley & sons, Inc.

Black, J., and J. F. Bradley (1980). Essential mathematics for economists. John Wiley & Sons Ltd. 2nd edition.

Blackie, M. J., and J. B. Dent (1974). The concept and application of skeleton models in farm business analysis and planning. Journal of Agricultural Economics, XXV, 2, 165-174.

Blackie, M. J. (1976). Management information systems for the individual farm firm. Agricultural Systems, 1, 23-36.

Boles, J. N. (1955). Linear programming and farm management analysis. Journal of Farm Economics, XXXVII, 1, 1-24.

Bond, R., P. G. Carter and J. F. Crozier (1970). Computerised farm planning - MASCOT. Farm management, 1, 9, 17-23.

Boussard, J. M., and M. Petit (1967). Representation of farmers' behaviour under uncertainty with a focus-loss constraint. Journal of Farm Economics, 49, 869-880.

Brabb, G. J. (1980). Computers and information systems in business. Houghton Mifflin Company -Boston.

Bradbeer, R., B. Miles, J. Allanson, and R. Webb (1982). Choosing and using a business microcomputer. Gower Publishing Company Ltd

Bregnballe, F. (lecture) (1986). Forward planning in the production of trout. Scottish Fish Farming Conference, 20-22 February 1986, Inverness, Scotland.

Bregnballe, F. (1986). Trout timing. Ways to phase supply. Fish Farmer, 9, 3, 8-11.

Brett, J. R. (1965). The relation of size to rate of oxygen consumption and sustained swimming speed of sockeye salmon Oncorhynchus nerka. Journal of the Fisheries Resources Board of Canada, 22, 6, 1491-1501.

Brett, J. R., and D. A. Higgs (1970). Effect of temperature on the rate of gastric digestion in fingerling sockeye salmon, Oncorhynchus nerca. Journal of the Fisheries Resources Board of Canada, 27, 1767-1779.

Bright, P. (1985). Switch on to communications. In D. Tebbutt (Ed.) Special Business Computing: The Survival Guide. 108-121. Personal Computer World, Special issue.

Brockington, N. R. (1979). Computer modelling in agriculture. Clarendon Press. Oxford University Press.

Bunday, B. D. (1984). Basic linear programming. Edward Arnold ltd.

Bywater, M. (1985). Enslaved in the tyranny of data. THE OBSERVER (Business), 8th September 1985, No: 10,118.

Camamile, G. H., and T. W. D. Theophilus (1964). Records for profitable farming. Hutchinson of London.

Candler, W. (1956). A modified simplex solution for linear programming with variable capital restrictions. Journal of Farm Economics, 38, 940-955.

Candler, W., and W. F. Musgrave (1960). A practical approach to the profit maximisation problems in farm management. Journal of Agricultural Economics, XIV, 2, 208-222.

Candler, W., and R. Slade (1981). Collection of reliable farm level data in LDC's. Journal of Agricultural Economics, XXXII, 1, 66-70.

Cane, A. (Ed.) (1984). Why companies buy microcomputers. FINANCIAL TIMES (Technology), 6th November 1984, N°: 29,467.

Cane, A. (Ed.) (1984). Hand held terminals in a networking system. FINANCIAL TIMES (Technology), 28th November 1984, N°: 29,486.

Cane, A. (1985). Minicomputing at a micro price. FINANCIAL TIMES (Technology), 30th April 1985, N°: 29,612.

Cane, A. (1985). Computers help fatten sheep. FINANCIAL TIMES (Technology), 2nd August 1985, N°: 29,691.

Cane, A. (Ed.) (1985). Computer dating for cows. FINANCIAL TIMES (Technology), 8th August 1985, N°: 29,696.

Carline, R. F., and J. D. Hall (1973). Evaluation of a method for estimating food consumption rates of fish. Journal of the Fisheries Resources Board of Canada, 30, 623-629.

Chan, C. K. (1984). A study of the introduction of a microcomputer-based data handling system to the fresh water fish farm at Howietoun. M.Sc. Thesis, University of Stirling, Department of Management Science.

Charlish, G. (1985). How industry is setting standards. FINANCIAL TIMES (Technology), 21st March 1985, Nº: 29,580.

Charlton, P. J., and S. C. Thompson (1970). Simulation of agricultural systems. Journal of Agricultural Economics, 21, 373-389.

Charlton, P. J., and P. R. Street (1975). The practical application of bio-economic models. In G. E. Dalton (Ed.) Study of Agricultural Systems. Chapter 7. Applied Science Publishers ltd.

Charnes, A., and W. W. Cooper (1960). Chance-constrained programming. Management Science, 6, 1, 73-79.

Clarke, G. B., and I. G. Simpson (1959). A theoretical approach to the profit maximisation problems in farm management. Journal of Agricultural Economics, XIII, 3, 250-274.

Clifton, H. D. (1983). Business data systems, a practical guide to systems analysis and data processing. Prentice-Hall International, Inc.

Coleman, J. S. (1956). Computers as tools in management. Management Science, 2, 2, 107-113.

Cowe, R., A. Brown, and D. Keeling (1984). Maintenance: Avoiding the PC scrap-heap. PC User, 30, 110-120.

Dalton, G. E. (Ed.) (1975). Study of agricultural systems. Applied Science Publishers ltd.

Dantzig, G. B. (1955). Linear programming under uncertainty. Management Science, 1, 3 & 4, 197-206.

Dantzig, G. B. (1956). Recent advances in linear programming. Management Science, 2, 2, 131-144.

Dan Manh Dao (1979). On the formation of risk constraints for linear programming: A comment. Journal of Agricultural Economics, XXX, 3, 195-196.

Davidson, B. R., and B. R. Martin (1965). The relationship between yields on farms and in experiments. Australian Journal of Agricultural Economics, 9, 129-140.

Dawkins, W. (1985). Microcomputers: The dangers of an abundance of options. FINANCIAL TIMES, 19th March 1985, N°: 29,578.

Dawkins, W. (1985). Microcomputers: The dangers of an abundance of options. FINANCIAL TIMES SURVEY, 30th April 1985, N°: 29,612.

Deasington, R. (1982). A practical guide to computer communications and networking. Ellis Harwood Publishers.

Dent, J. B., and J. R. Anderson (1971). Systems, management and agriculture. In J. B. Dent and J. R. Anderson (Ed.) Systems Analysis in Agricultural Management. Chapter 1. John Wiley and sons, Australasia pty ltd.

Dent, J. B. (1975). The application of systems theory in agriculture. In G. E. Dalton (Ed.), Study of Agricultural Systems, Chapter 3. Applied Science Publishers Ltd.

Digital Equipment Corporation, (1982). Guide to personal computing.

Dillon, J. L. (1971). Interpreting systems simulation output for managerial decision-making. In J. B. Dent and J. R. Anderson (Ed.) Systems Analysis in Agricultural Management. Chapter 6. John Wiley and sons, Australasia pty ltd.

Dixon, J. (1967). Uncertainty and information in agriculture. Farm Economist, 11, 4, 147-161.

Donaldson, G. F., and J. P. G. Webster (1967). A simulation approach to the selection and combination of farm enterprises. The Farm Economist, 11. 6, 219-229.

Duguay, C., M. Todd and H. M. Wagner (1973). Linear programming with relative bounded variables. Management Science, 19, 7, 751-759.

Eary, J. (1983). When are microcomputers good value for money. Surveyor, 9, 10-11.

Edwards, C. (1982). Developing microcomputer-based business systems. Prentice-Hall International Inc., London.

Eisenhart, C. (1939). The interpretation of certain regression methods and their use in biological and industrial research. Annals of Mathematics and Statistics, 10, 162-186.

Eisgruber, L. M. (1967). Micro- and macro- analytic potential of agricultural information systems. Journal of Farm Economics, 49, 5, 1541-1552.

Elliot, J. M. (1975). The growth rate of brown trout (Salmo trutta L.) fed on maximum rations. Journal of Animal Ecology, 44, 805-821.

Elliot, J. M. (1976). The energetics of feeding metabolism and growth of brown trout (Salmo trutta L.) in relation to body weight, water temperature and ration size. Journal of Animal Ecology, 45, 3, 923-248.

Evans, M., A. N. Arnason, and D. H. Scuse (1986). A dynamic data-driven entry system. Congressus Numerantium, 51, 137-161. Department of Computer Science, University of Manitoba, Winnipeg, Manitoba, Canada.

Fisher, T. (1985). Exploiting the power of D.O.S. LOTUS, 1, 2, 85-

Folley, R. W. (1967). Records and management. Farm Economist, 11, 5, 215-217.

Foster, A., and J. Theobald (1984). Computers. What's New in Farming, November 1984, 46-52.

Fouche', L., W. Killcreas, P. Webb, J. E. Waldrop, K. Chin, N. Kennedy and R. Paschal (1983). A records system for catfish production management decision-making for... microcomputers. Agricultural Economics Technical Publication N^{o} 43, Department of Agricultural Economics, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State, Mississippi 39762.

Freund, R. J. (1956). The introduction of risk into a programming model. Econometrica, 24, 253-263.

Fridley, R. B. (1986). Modeling, identification, and control of aquacultural processes and facilities. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

From, J., and G. Rasmussen (1986). A model of fish growth in aquaculture. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Fry, F. E. J. (1971). The effect of environmental factors on the physiology of fish. In W. S. Hoar, and D. J. Randall (Ed.) Fish Physiology. Volume VI. Environmental Relations and Behavior. Chapter 1. Academic Press.

Gerking, S. D. (Ed.) (1978). Ecology of freshwater fish production. Blackwell Scientific Publications.

Glass, N. R. (1967). A technique for fitting nonlinear models to biological data. Ecology, 48, 1010-1013.

Glass, N. R. (1969). Discussion of calculation of power function with special reference to respiratory metabolism in fish. Journal of the Fisheries Resources Board of Canada, 26, 10, 2643-2650.

Goddard, S., and P. Scott (1980). Understanding fish appetite - part I. Fish Farmer, 3, 6.

Goddard, S., and P. Scott (1980). Understanding fish appetite - part II. Fish Farmer, 4, 1.

Gooding, C. (1985). Into the era of specialisation. FINANCIAL TIMES SURVEY, 4th October 1985, Nº: 29,744.

Goodwin, S. (1985). Operating systems explained. Personal Computer World, 8, 7, 219-

Greene, L., and T. Harris (1983). Farm business analysis with computers. NACTA Journal, September 1983, 27-28.

Grove, D. J., L. G. Loizides, and J. Nott (1978). Satiation amount, frequency of feeding and gastric emptying rate in Salmo gairdneri. Journal of Fish Biology, 12, 5, 507-516.

Grushcow, J. (1984). Business worksheets for 1-2-3. Reston Publishing Company, Inc. Prentice-Hall.

Guild, A. (1985). Rival paths to fulfilling a computer user's dream. FINANCIAL TIMES (Technology), 20th August 1985, Nº: 29,706.

Hall, S. (1982). An appraisal of commercial oyster culture in the United Kingdom. Ph.D Thesis, Department of Management Science, University of Stirling, Scotland.

Hambrey, J. B. (1980). Technical and economic consequences of increasing fish growth through the use of waste heat in aquaculture. Ph.D Thesis. Department of Management Science, University of Stirling, Scotland.

Hammond, D. E., and R. T. Lackey (1976). Analysis of catchable trout fisheries management by computer simulation. Transactions of the American Fisheries Society, 105, 48-56.

Hansen, E. (1986). Computer aided control and monitoring of aquaculture plants (the NCS-100 system). Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Hanson, J. S., W. L. Griffin, J. W. Richardson, and C. S. Nixon (1985). Economic feasibility of shrimp farming in Texas: An investment analysis. Natural Resources Working Paper Series, Department of Agricultural Economics, Texas A & M University, College Station.

Hardaker, J. B. (1967). The use of simulation techniques in farm management research. Farm Economist, XI, 4, 162-171.

Harle, J. T. (1974). Further towards a more dynamic approach to farm planning - a technically based model of the farm firm. Journal of Agricultural Economics, XXV, 2, 153-.

Harle, J. T. (1975). Further towards a more dynamic approach to farm planning - a technically based model of the farm firm: A reply. Journal of Agricultural Economics, XXVI, 3, 399-.

Harper, I. (1985). Foolproof communications for doctors. FINANCIAL TIMES, 12th August 1985, Nº: 29,699.

Harper, W. M. (1982). Statistics. Macdonald & Evans Ltd. Fourth Edition.

Heady, E. O. (1948). Elementary models in farm production economics research. Journal of Farm Economics, XXX, 2, 201-225.

Heady, E. O. (1954). Simplified presentation and logical aspects of linear programming technique. Journal of Farm Economics, XXXVI, 5, 1035-1048.

Heady, E. O., and E. L. Baum (1957). Methodological problems in programming farms. In E. L. Baum, E. O. Heady, J. T. Pesek, and C. G. Hildreth (Ed.), Economic and Technical Analysis of Fertiliser Innovations and Resource Use. The Iowa State College Press - Ames, Iowa, USA. Chapter 23.

Heady, E. O. (1957). Organisation activities and criteria in obtaining and fitting technical production functions. Journal of Farm Economics, 39, 360-369.

Heady, E. O., and J. L. Dillon (1961). Agricultural production functions. Iowa State University Press, Ames, Iowa.

Hendricks, W. A. (1953). Some specific problems in collecting agricultural data. Estadistica, 11, 48-55.

Higgins, J. C. (1978). Information systems for planning and control: Concepts and cases. Edward Arnold ltd.

Higgins, J. C. (1985). Computer-based planning systems. Edward Arnold ltd.

Hildreth, C. G. (1957). Some problems and possibilities of farm programming. In E. L. Baum, E. O. Heady, J. T. Pesek, and C. G. Hildreth (Ed.), Economic and Technical Analysis of Fertiliser Innovations and Resource Use. The Iowa State College Press - Ames, Iowa, USA. Chapter 21.

Hildreth, C. (1957). Possible models for agronomic-economic research. In E. L. Baum et. al. (Ed.) Economic and Technical Analysis of Fertiliser Innovations and Resourse Use. The Iowa State College Press, Ames, Iowa, U.S.A.

Hodge, E. (1985). Horses for courses. In D. Tebbutt (Ed.) Special Business Computing: The Survival Guide 1985, 84-86. Personal Computer World, Special issue.

Houvenaghel, G. T., and T. Huet (1986). Computer-aided production modelling in fish-farming. Application to the eel. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Howe, K. S., and C. M. Palmer (1975). Further towards a more dynamic approach to farm planning - a technically based model of the farm firm: A comment. Journal of Agricultural Economics, XXVI, 3, 395-.

Huffman, D. C., and L. A. Stanton (1969). Application of linear programming to individual farm planning. American Journal of Agricultural Economics. 51, 5, 1168-1171.

Iwama, G. K., and A. F. Tautz (1981). A simple growth model for salmonids in hatcheries. Canadian Journal of Fisheries and Aquatic Sciences, 38, 649-656.

Jabara, C. L. (1982). Cross-sectional analysis of wheat import demand among middle-income developing countries. Agricultural Economics Research Review, 34, 3, 34-37.

Jackson, M. (1985). Creative modelling with LOTUS 1.2.3. John Wiley & sons ltd.

James, M. (1986). Data representation. Personal Computer World, 9, 8, 134-140.

James, P. J. (1972). Computerised farm planning. Farm Management, 2, 2, 78-84.

Jobling, M., D. Gwyther, and D. J. Grove (1977). Some effects of temperature, meal size and body weight on gastric evacuation time in the dab Limanda limanda (L). Journal of Fish Biology, 10, 3, 291-298.

Jobling, M. (1981). Mathematical models of gastric emptying and the estimation of daily rates of food consumption for fish. Journal of Fish Biology, 19, 3, 245-257.

Jobling, M. (1982). A study of some factors affecting rates of oxygen consumption of plaice, Pleuronectes platessa L. Journal of Fish Biology, 20, 5, 501-516.

Jobling, M. (1983). Growth studies with fish -overcoming the problems of size variation. Journal of Fish Biology, 22, 2, 153-157.

Jobling, M. (1983). Influence of body weight and temperature on growth rates of Arctic charr, Salvelinus alpinus (L.). Journal of Fish Biology, 22, 4, 471-475.

Johnson, G. L. (1957). Planning agronomic-economic research in view of results to date. In E. L. Baum et. al. (Ed.) Economic and Technical Analysis of Fertiliser Innovations and Resourse Use. Chapter 19. The Iowa State College Press, Ames, Iowa, U.S.A.

Jolicoeur, P., and A. A. Heusner (1971). The allometry equation in the analysis of the standard oxygen consumption and body weight of the white rat. Biometrics, 27, 841-855.

Kakizawa, S. (1985). Analysing disks. Personal Computer World, 8, 4, 113-

Kelly, M. G. (1983). Data collection with a microcomputer. Using a TRS-80 Model I for environmental research saves time and money. Byte, 8, 3, 295-302.

Kennedy, C. M. (1985). Microcomputer modelling of aquaculture processes. M.Sc Thesis, Institute of Aquaculture, University of Stirling, Stirling, Scotland.

Kennedy, J. O. S., and E. M. Francisco (1974). On the formulation of risk constraints for linear programming. Journal of Agricultural Economics, XXV, 2, 129-.

Kennedy, J. O. S., and E. M. Francisco (1979). On the formulation of risk constraints for linear programming: A reply. Journal of Agricultural Economics, XXX, 3, 197.

Kermack, K. A., and J. B. S. Haldane (1950). Organic correlation and allometry. Biometrica, 37, 30-41.

Kerr, S. R. (1971). Analysis of laboratory experiments on growth efficiency of fishes. Journal of the Fisheries Resources Board of Canada, 28, 6, 801-808.

Kewney, G. (1986). A cure for a mess DOS. Personal Computer World, 9, 8, 77-83.

Kidwell, J. F., and H. B. Chase (1967). Fitting the allometric equation -a comparison of ten methods by computer simulation. Growth, 31, 165-179.

King, R. (1985). MS-DOS and PC-DOS. PC User, 32, 128-129.

Klontz, G. W., I. R. Brock, and J. A. McNair (1978). Aquaculture techniques: Water use and discharge quality. Research Technical Completion Report. Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Knight, W. (1969). A formulation of the von Bertalanffy growth curve when the growth rate is roughly constant. Journal of the Fisheries Resources Board of Canada, 26, 3069-3072.

Koutsoyiannis, A. (1977). Theory of econometrics. The Macmillan Press Ltd. Second edition.

Landless, P. (1980). Fish and (silicone) Chips. Fish Farmer, 3, 6, 35-.

Lang, T. (1985). Common ground: Operating systems. In D. Tebbutt (Ed.) Special Business Computing: The Survival Guide 1985. Personal Computer World, Special issue.

Lang, K., and T. Lang (1985). Just add data. In D. Tebbutt (Ed.) Special Business Computing: The Survival Guide 1985, 46-48. Personal Computer World, Special issue.

LeCren, E. D. (1978). Some density relationships for fish population parameters. In S. D. Gerking (Ed.) Ecology of Freshwater Fish Production. Chapter 11. Blackwell Scientific Publications.

Lewis, M. R. (1979). Fish farming in Great Britain: an economic survey with special reference to rainbow trout. University of Reading, Department of Agricultural Economics and Management, Miscellaneous study N° 67.

Lewis, M. R. (1984). Fish farming in the United Kingdom. University of Reading, Dept. of Agricultural Economics and Management, Miscellaneous study N° 71.

Liardet, M. (1984). Creating a programme. Personal Computer World, 7, 7, 194-197.

Liardet, M. (1984). Spoilt for choice. Personal Computer World, 7, 12, 128-132.

Lillestol, J. (1986). On the problem of optimal timing of slaughtering in fish farming. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Lindley, D. V. (1947). Regression lines and the linear functional relationship. Journal of the Royal Statistical Society Supplement, IX, 2, 218-244.

Lindley, D. V. (1953). Estimation of a functional relationship. Biometrica, 40, 47-49.

Locke, J. (1985). Down to BASICs. Personal Computer World, 8, 3, 148-150.

Loomis, M. E. S. (1983). Data communications. Prentice-Hall, Inc.

Lorenz, C. (1985). IT changes the rules of the game. FINANCIAL TIMES (Management), 26th July 1985, Nº: 29,685.

Low, A. R. C. (1974). Decision taking under uncertainty: A linear programming model of peasant farmer behaviour. Journal of Agricultural Economics, XXV, 3, 311-.

Machiels, M. A. M., and A. M. Henken (1986). A dynamic simulation model for growth of the African catfish, Clarias gariepinus Burchell 1822. II. Effect of food composition on growth and energy metabolism. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Manne, A. S. (1960). Linear programming and sequential decisions. Management Science, 6, 1, 259-267.

Marquardt, D. W. (1963). An algorithm for least squares estimation of nonlinear parameters. J. Soc. Indust. Appl. Math., 11, 2, 431-441.

McCartney, J. (1985). Data dictionaries. Personal Computer World, 8, 9, 152-155.

McElroy, J. K. (1983). Provisional world list of computer programmes for fish production (including aquaculture) and fisheries management. Discussion paper Nº 37, Technological Economics Research Unit (TERU), University of Stirling, Stirling FK9 4LA, Scotland.

McFarquar, A. M. M. (1961). Practical use of linear programming in farm planning. The Farm Economist, 9, 10, 472-496.

McInerney, J. P. (1967). MAXIMIN - Programming. An approach to farm planning under uncertainty. Journal of Agricultural Economics, XVIII, 2, 279-289.

McInerney, J. P. (1969). Linear programming and game theory models - some extensions. Journal of Agricultural Economics, XX, 269-278.

McInerney, J. P. Developments in planning techniques with a practical potential in the 1970's - other developments. First International Congress on Farm Business Management/Methodology.

McMullan, R. (1986). First encounters with DOS. PC user, 49, 221-224.

McNamara, J. E. (1977). Technical aspects of data communication. Digital Equipment Corporation.

McNichols, C. W., and T. D. Clark (1983). Microcomputer-based information and decision support systems for small businesses: A guide to design and implementation. Reston Publishing Company Inc. (A Prentice-Hall Company) Reston, Virginia.

McPherson, W. W. (1952). Sources and use of technical data in farm management analysis. Journal of Farm Economics, 34, 5, 799-806.

Moller, Bo, and K. I. Dahl-Madsen (1986). Continuous monitoring of respiration in production scale trout culture. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Monro, D. M. (1985). basic BASIC. Edward Arnold, Second edition.

Muetzelfeldt, R. I. (1979). Simulation modelling for fisheries management. Fisheries Management, 10, 1, 33-42.

Murphy, M. C. (1971). Risk evaluation in farm planning, a statistical approach. Journal of Agricultural Economics, XXII, 1, 61-74.

Nair, K. R., and M. P. Shrivastava (1942). On a simple method of curve fitting. Sankhya, 6, 2, 121-132.

Needham, M. (1986). A micro in the hand. Personal Computer World, 9, 2, 154-155.

Nix, J. S. (1963). Linear programming. N.A.A.S. Quarterly Review, Winter 1963.

Nix, J. S. (1979). Farm management: The state of the art (or science). Journal of agricultural economics, XXX, 3, 277-291.

Noakes, D. L. G. (1978). Social behaviour as it influences fish production. In S. D. Gerking (Ed.) Ecology of Freshwater Fish Production. Chapter 14. Blackwell Scientific Publications.

Nuthal, P. L. (1971). On the analysis of a simplex linear programming solution tableau with reference to net revenue stability limits. Journal of Agricultural Economics, XXII, 1, 49-60.

O'Brien, J. (1978). Computers in business management: An introduction. Richard D. Irvin Inc, revised edition.

Ostrom, C. W. Jr. (1978). Time series analysis: Regression techniques. Sage Publications, Beverly Hills, London.

Paloheimo, J. E., and L. M. Dickie (1965). Food and growth of fishes. I. A growth curve derived from experimental data. Journal of the Fisheries Resources Board of Canada, 22, 2, 521-542.

Paloheimo, J. E., and L. M. Dickie (1966). Food and growth of fishes. III. Relations among food, body size, and growth efficiency. Journal of the Fisheries Resources Board of Canada, 23, 8, 1209-1248.

Pannell, B. K., D. C. Jackson, and J. B. Lucas (1983). Make a success of microcomputing in your business. Enterprise Books, revised edition.

Parker, D. (Reprt) (1983). Pilwood conference: Computers and costs under scrutiny. Fish Farmer, 6, 5, 5-.

Parker, N. (1984). Technological innovations in aquaculture. Fisheries, 9, 4.

Parker, R. R., and P. A. Larkin (1959). A concept of growth in fishes. Journal of the Fisheries Resources Board of Canada, 16, 5, 721-745.

Petit, M. (1976). The role of models in the decision process in agriculture. Proceedings of the 16th International Conference of Agricultural Economists, 1976, 62-76.

Penning de Vries, F. W. T. (1977). Evaluation of simulation models in agriculture and biology: Conclusions of a workshop. Agricultural Systems, 2, 99-108.

Piedrahita, R. H., J. M. Ebeling, and T. M. Losord (1986). Use of data acquisition systems in aquaculture. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Piercy, N. (1984). The management implications of new information technology. Croom Helm.

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fouler, and J. R. Leonard (1983). Fish Hatchery Management. United States Department of the Interior, Fish and Wildlife Service, Washington D.C.

Plaunt, D. H. (1963). Use of high-speed computers for farm record keeping and farm business analysis. Journal of Farm Economics, 45, 5, 1192-1199.

Poynor, R. (1984). Don't judge a book.. (programme documentation). PC User, 30, 85-93.

Pugh, C. L. (1977). Farm management information systems - a practical approach. Farm Management, 3, 5, 247-255.

Puterbaugh, H. L., E. W. Kehrberg and J. O. Dunbar (1957). Analysing the solution tableau of a simplex linear programming problem in farm organisation. Journal of Farm Economics, XXXIX, 2, 478-489.

Rafail, S. Z. (1968). A statistical analysis of ration and growth relationship of plaice (Pleuronectes platessa). Journal of the Fisheries Resources Board of Canada, 25, 4, 717-732.

Rafail, S. Z. (1969). Further analysis of ration and growth relationship of plaice (Pleuronectes platessa). Journal of the Fisheries Resources Board of Canada, 26, 3237-3241.

Ricker, W. E. (1973). Linear regressions in fishery research. Journal of the Fisheries Resources Board of Canada, 30, 3, 409-434.

Robson, D. S., and G. R. Spangler (1978). Estimation of population abudance and survival. In S. D. Gerking (Ed.) Ecology of Freshwater Fish Production. Chapter 2. Blackwell Scientific Publications.

Rogers, G. L., T. L. Richard, S. L. Klementson, and A. W. Fast (1986). Application of spreadsheets in aquaculture. Aquaculture Magazine, 12, 2, 51-54.

Rowlands, G. J. (1983). Data standards for computer systems in livestock recording for dairy herd management. Livestock Production, 10, 5, 419-429.

Ruohonen, K. (1986). Biological models related to automatic control in aquaculture. A case study: Automatic feeding control. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Russell, A. M., and G. J. Rowlands (1983). COSREEL: Computerised recording system for herd health information management. The Veterinary Record, 112, 9, 189-193.

Schware, R., and A. Trembour (1983). All about 1-2-3 (Lotus). Dilithium Press.

Scitovszky, T. De (1943). A note on profit maximisation and its implications. Review of Economic Studies, 11-12, 57-60.

Scott, P. W. (1983). Fish farm checklist. The Veterinary Record, 112, 9, 198-200.

Shaffer, D. N. (1984). Lotus 1-2-3 revealed. Reston Publishing Company, Inc. Prentice-Hall.

Shapiro, L. (1984). Data design. Byte - The Small Systems Journal, 11, 4, 129-134.

Simpson, I. G. (1960). Linear programming for increasing farm profits. A Yorkshire example. Farm Economist, 9, 7, 291-309.

Smith, V. E., and C. S. Barnard (1960). Cost allocation and the detection of unprofitable ventures. Journal of Farm Economics, XLII, 3, 666-675.

Sparre Per (1976). A Markovian decision process applied to optimisation of production planning in fish farming. Meddelelser fra Danmarks Fiskeri -og Havundersøgelser, 7, 111-197. The Danish Institute for Fishery and Marine research, Copenhagen.

Spedding, C. R. W. (1975). The study of agricultural systems. In G. E. Dalton (Ed.), Study of Agricultural Systems, Chapter 1. Applied Science Publishers Ltd.

Sperber, O., J. From, and P. Sparre (1976). A method to estimate the growth rate of fishes as a function of temperature and feeding level, applied to Rainbow trout. Meddelelser fra Danmarks Fiskeri -og Havundersøgelser, 7, 275-317.

Spivey, W. A. (1973). Optimisation in complex management systems. Transactions of the American Fisheries Society, 102, 2, 492-499.

Staples, D. J., and M. Nomura (1976). Influence of body size and food ration on the energy budget of rainbow trout, Salmo gairdneri Richardson. Journal of Fish Biology, 9, 1, 29-43.

Stephens, A. J., and R. J. Esslemont (Ed.) (1978). A feasibility study of the use of small computers by dairy farmers and practicing veterinary surgeons. Veterinary Epidemiology and Economics Research Unit (VEERU), Department of Agriculture and Horticulture, Univ. of Reading, Earley Gate, Reading RG6 2AT, Berks, England.

Stewart, J. D. (1961). Farm operating capital as a constraint. A problem in the application of linear programming. Farm Economist, XXX, 10, 463-471.

Surya, (1986). Phone home. Personal Computer World, 9, 4, 150-155.

Swanson, E. R. (1957). Problems of applying experimental results to commercial practice. Journal of Farm Economics, 39, 382-389.

Swanson, E. R. (1957). Programming of fertilizer mixing operation. In E. L. Baum, E. O. Heady, J. T. Pesek, and C. G. Hildreth (Ed.), Economic and Technical Analysis of Fertiliser Innovations and Resource Use. The Iowa State College Press - Ames, Iowa, USA. Chapter 8, 72-76.

Tadros, M. E., and G. L. Casler (1969). A game theoretic model for farm planning under Uncertainty. American Journal of Agricultural Economics, 51, 5, 1164-1167.

Taylor, C. C. (1962). Growth equations with metabolic parameters. Journal Du Conseil, 27, 270-286.

Tebbutt, D. (Ed.) (1985). Business computing: The survival guide. Personal Computer World, Special issue.

Thompson, S. C. (1975). Economic analysis of farms. In G. E. Dalton (Ed.) Study of Agricultural Systems. Chapter 9. Applied Science Publishers ltd.

Titlow, F. B., and R. T. Lackey (1974). DAM: A computer-implemented water resource teaching game. Transactions of the American Fisheries Society, 103, 601-609.

Tootill, P. (1985). Intelligent modems. Personal Computer World, 8, 10, 162-165.

Tootill, P. (1986). Intelligent modems. Personal Computer World, 9, 8, 130-133.

Tyler, G. J. (1966). Analysis of the solution tableau of a standard linear programming problem. Journal of Agricultural Economics, XVII, 2, 159-170.

Tysso, A. (1986). Computer-aided modelling of aquaculture plants. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Upton, M., and G. Dalton. Linear production response. Journal of Agricultural Economics, XXVII, 2, 253-257.

Upton, M., and H. Casey (1974). Risk and some pitfalls in the use of averages in farm planning. Journal of Agricultural Economics, XXV, 2, 147-152.

Upton, M. (1979). The unproductive production function. Journal of Agricultural Economics, XXX, 3, 179-190.

Ursin, E. (1967). A mathematical model of some aspects of fish growth, respiration and mortality. Journal of the Fisheries Resources Board of Canada, 24, 11, 2355-2453.

Varvarigos, P. (1984). Economic importance and development of intensive aquaculture - special reference to Britain and Greece. M.Sc. Thesis, Wye College, University of London.

Varvarigos, P., and M. T. Horne (1986). An inexpensive microcomputer based data record-keeping system for the individual fish farm. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Varvarigos, P., and M. T. Horne (1986). Application of linear programming to individual fish farm production planning. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Vine, J. (1985). Pocket micro survey. Popular Computing Weekly, 4, 12, 21-27.

Wald, A. (1940). The fitting of straight lines if both variables are subject to error. Annals of Mathematics and Statistics, 11, 284-300.

Walker, N. (1985). Benchtest: Sharp PC 1350. Personal Computer World, 8, 3, 136-142.

Wankowski, J. W. J., and J. E. Thorpe (1979). The role of food particle size in the growth of juvenile atlantic salmon (Salmo salar L.). Journal of Fish Biology, 14, 4, 351-370.

Weatherley, A. H., and S. C. Rogers (1978). Some aspects of age and growth. In S. D. Gerking (Ed.) Ecology of Freshwater Fish Production. Chapter 3. Blackwell Scientific Publications.

Webb, P. W. (1978). Partitioning of energy into metabolism and growth. In S. D. Gerking (Ed.) Ecology of Freshwater Fish Production. Chapter 8. Blackwell Scientific Publications.

Whitehead, C. (1979). The control of reproduction in rainbow trout - commercial and technical aspects. Ph.D. Thesis, University of Aston, Birmingham. June 1979.

Winsor, C. P. (1946). Which regression ? Biometrics Bulletin, 2, 6, 101-109.

Woodworth, R. (1957). An application of linear programming techniques to the planning of commercial farms in North Georgia. In E. L. Baum, E. O. Heady, J. T. Pesek, and C. G. Hildreth (Ed.), Economic and Technical Analysis of Fertiliser Innovations and Resource Use. The Iowa State College Press - Ames, Iowa, USA. Chapter 25.

Wooton, R. J., J. R. M. Allen, and S. J. Cole (1980). Effect of body weight and temperature on the maximum daily food consumption of Gasterosteus aculeatus L. and Phoximus phoximus L.: Selecting an appropriate model. Journal of Fish Biology, 17, 6, 695-705.

Wright, A. (1971). Farming systems, models and simulation. In J. B. Dent and J. R. Anderson (Ed.) Systems Analysis in Agricultural Management. Chapter 2. John Wiley and sons, Australasia pty ltd.

Wu, C. C., and A. Mirakhor (1975). A recursive model of consumption: The case of Taiwan's farm families, 1964-66. American Journal of Agricultural Economics, November 1975, 710-713.

Wurtsbaugh, W. A., and G. E. Davis (1977). Effects of temperature and ration level on the growth and food conversion efficiency of Salmo gairdneri, Richardson. Journal of Fish Biology, 11, 2, 87-98.

Wurtsbaugh, W. A., and G. E. Davis (1977). Effects of fish size and ration level on the growth and food conversion efficiency of rainbow trout, Salmo gairdneri, Richardson. Journal of Fish Biology, 11, 2, 99-104.

Zahradnik, J. W. (1986). Status and perspectives in the instrumentation of aquacultural facilities. Paper presented in the symposium "AQUACULTURE'86". The 1st International Conference on Automation and Data Processing in Aquaculture. August 1986, Trondheim-Norway.

Zar, J. H. (1967). The effect of changes in units of measurement on least squares regression lines. Bioscience, 17, 818-819.

Zar, J. H. (1968). Calculation and miscalculation of the allometric equation as a model in biological data. Bioscience, 18, 1118-1120.

APPENDIX A

OPERATIONS WITH THE SHARP PC 1500A USED AS A FISH-FARM DATA CAPTURE DEVICE

CONTENTS

General description of the SHARP PC 1500A

The SHARP pocket computer 1500A is very small and can be used as a data input terminal on site protected in a suitable transparent plastic case. It has the additional ability to transmit this data to a desk top microcomputer.
It is programmed in BASIC language and accepts fish-farm data input daily storing it in memory (RAM) for a maximum period of one week during which the memory contents are safe even when the machine is switched off. Some data may be entered only once a week, such as weight samples, and several different sources of raw data (data units) may be distinguished, ie. tanks, cages, etc. Data is entered in response to prompts appearing on the small screen. The fish farmer enters first the current day of the week, specifies the tank number, whether it is a daily or weekly input, then selects the item and types in the data.
Amendments of data figures can be made very simply by repeating the data input procedure.

Start.

The programme starts by pressing the "!" key near the top left corner of the SHARP's keyboard.
The computer must be switched on at the time using the "ON" key at the top right corner of the keyboard.
After the programme starts execution, the current day of the week must be input using the two initial letters only, eg. 'MO' for Monday.

Menus.

The operation of the data capture programme is orderly based on a clear menu structure.
The initial menu appears after the day of the week is input and provides the following options:

1. INPUT/AMEND DATA
2. SEND DATA TO BASE OR PRINT
3. SPECIFY NEW WEEK-DAY
4. STOP THIS PROGRAMME

Because of the display limitations on the single line screen of the SHARP the options are displayed sequentially one at a time. Therefore, an option to "REPEAT THE MENU ?" appears anytime the programme goes through a menu list.
The answer is with a "Y" (yes) or a "N" (no).

Input.

Data is input by selecting option 1 from the initial menu.
The identification number of the unit/tank is then requested by the programme.
This procedure of day and tank number specification is necessary in order to relate the data input to the correct source (tank).

The input is grouped for versatility into weekly and daily data items.
A choice "INPUT WEEKLY/DAILY (W/D)?" is requested by the programme. The response is with a "W" or a "D" accordingly.

One of the following menus then follows:

INPUT WEEKLY DATA:

1. Fish population.
2. Feeding.
3. Save & Return.

INPUT DAILY DATA:

1. Fish mortalities.
2. Fish transfers.
3. Farm environment.
4. Notes & observations.
5. Save & Return.

The program traps spelling errors while selecting a menu option or when typing the day or the tank number. In such cases it prompts for reentry.

Under the weekly or daily input options the data items are grouped as follows:

Weekly data:

- option 1. Fish size
  - Sample weight (Nos/lb)
- option 2. Feeding
  - Weekly food amount (kgr)
  - Daily feed rate used (% biomass)
  - Feeding method / freq. (*)
  - Food type and size (*)
  - Food quality (energy %)
- option 3. Save & Return (**)

Daily data:

- option 1. Fish mortalities
  - Total dead weight (lbs)
- option 2. Fish transfers
  - Transfers IN (Nos)
  - Transfers OUT (Nos)
  - Size of fish transferred IN (Nos/lb)
  - Size of fish transferred OUT (Nos/lb)
- option 3. Farm environment (***)
  - Water temperature (C)
  - Water pH
  - Dissolved Oxygen pm.Inlet
  - Water flow (gal/sec)
- option 4. Notes and observations
  - Diseases / handling (*)
  - Other conditions (*)
- option 5. Save and Return (**)

Items marked with (*) do not accept figures but text, so the user may type in comments, facts or observations up to a maximum length of 16 characters (by abbreviations if necessary).

Options marked by (**) return to the initial menu. The programme is designed to ensure that the data entries are saved in memory.

The data on the environmental factors (***) needs to be input only once because it is common to all tanks on the farm. There is no need to specify a certain tank No as any legitimate number

equally suffices.
Note that environmental daily data must not be omitted in any one day of the week since when the weekly averages are calculated all 7 daily inputs are assumed present.

Amend.

Existing data is amended by following the menu procedure for data input and re-entering the new/correct data.
The new entries will replace/overwrite the old (wrong) ones.
Care is needed though not to replace useful data by mistake!

Erase.

There are times when an erroneus data entry or command is typed in and this is realised as soon as it happens. Such a false entry may immediately be erased and retyped by pressing the red coloured "CL" key (clear) on the SHARP's keyboard.

Interrupted input.

If the menu structure of the programme is followed, the user is allowed to interrupt input for one tank, type figures for another, then resume input to the previous one, a.s.o.
The user should leave a tank's input through the "SAVE & RETURN" menu option, then select "INPUT/AMEND DATA" and specify the new tank No. The same procedure must be followed in order to return to the previous tank to complete its interrupted input.

The data input is safe only when the "SAVE AND RETURN" option is activated and the programme is stopped using option 4 of the main menu.
In cases when input must be suspended due to an emergency, the computer may be switched off. It remembers the most recent data input for the specified day and tank No until the programme is restarted, so, input may continue from the point it was left off.

Stop.

The programme is stopped by the 4th option of the initial menu, **"STOP THE PROGRAMME"**, or by issuing a 'break'.
A break of programme execution may be activated by pressing the **"ON/BREAK"** key (the same key that is used to switch on the SHARP). The hidden danger of this action, in the middle of data input, is the possible loss of the most recent information.
So, the daily or weekly data for the current tank No when the break was issued must be reentered.

Clear.

Every time the operator begins input on a new week, all previous data which is still stored in the SHARP's memory must be cleared. The computer must be switched on (ON key) and the word "CLEAR" typed followed by a depression of the ENTER key. The memory is then cleared ready for fresh input!

The SHARP PC as a calculator.

The data are stored in the SHARP's current memory (RAM) in the form of array or simple variables.
Turning the computer off does <u>not</u> affect the values stored in these variables, but using the SHARP as a programmable calculator might corrupt them when the algebraic expressions contain the same variables with the programme.
Therefore, although using the SHARP as a simple calculator is harmless and is recommended, it should never be used to solve equations.
Example:
Consider a variable 'T' in the programme which stores the value: 4. If the SHARP is used as a programmable calculator and is typed: "T = (36/4)*3.14", the value of 'T' will change corrupting the fish farm data.

Display the farm data.

For memory economy the programme does not provide a 'formal' menu option to display the data which is stored in the appropriate variables.
However, a simple alternative is to switch the computer on without starting the programme and to type the name of the variable which contains the data. By pressing ENTER the value is displayed on the right end of the screen. Text variables are displayed on the left side.
The variable names must be typed as follows:
In order to display a variable named 'Y' the user must type: "Y(X,N-1)" where 'X' is a number from 0 to 6 representing the day of the week:

X = 0 for Monday
X = 1 for Tuesday
X = 2 for Wednesday
X = 3 for Thursday
X = 4 for Friday
X = 5 for Saturday
X = 6 for Sunday

'N' is the tank No. However, (N-1) should be typed, ie. for tank No 6 type 5, etc.
This formulation is useful for the daily variables, but for the variables which are input for each tank only once a week, the general format "Y(N-1)" must be followed to display the variable 'Y' for tank 'N'.
The environmental variables are input daily but are common to all tanks. So, "Y(X)" must be typed, where 'Y' is the variable and 'X' is the day.

A list of variable names (Y's) now follows:

	data item.	variable name.
Daily data:		
	Total dead weight	Y(X,N-1)
	Transfers IN	U(X,N-1)
	Transfers OUT	V(X,N-1)
	Av. size transferred IN	K(X,N-1)
	Av. size transferred OUT	L(X,N-1)

	data item.	variable name.
Daily data (continued..)		
	Diseases / Handling	T$(X,N-1)
	Other conditions	H$(X,N-1)
Environmental daily data:		
	Water Temperature	T(X)
	Water pH	P(X)
	Dissolved Oxygen pm.Inlet	G(X)
	Overall flow	O(X)
Weekly data:		
	Sample weight	W(N-1)
	Weekly food amount	F(N-1)
	Daily feed rate	R(N-1)
	Feeding method / freq.	Z$(N-1)
	Food type and size	E$(N-1)
	Food quality	Q(N-1)

Note that ERROR 1 or ERROR 6 are displayed when the variable name is mistyped. ERROR 9 appears when the variable name is typed in the correct form, but with wrong 'X' or 'N' values.

Send the data to a microcomputer or to a printer.

Sending data to a microcomputer or to a printer is the second option of the initial (top level) menu and is the ultimate task after all data input is complete.

Option 2 "SEND DATA TO BASE or PRINT" instructs the computer, initially, to calculate weekly sums and averages in order to prepare weekly figures from the daily data.

For example, it calculates the weighted average of fish sizes transferred in or out of the tank, the average water temperature, the total food, etc.

Then the user is provided with two options. The first is to transmit the data to a desk top microcomputer for subsequent analysis and storage, the second is to print the data and obtain a 'hard copy' of it, possibly for further manual input into a computer.

The choice is made by typing "B" for base, ie. for transmission to a microcomputer in the main office, or "P" for the printer.

An additional choice is whether to send weekly or daily data by typing "W" or "D" accordingly.

Print.

Preparing the hardware involves connecting the SHARP with the interface by slotting the one into the other and on to the appropriate metal base provided. Both must be switched off at this stage.
The next step is to connect the parallel port of the interface (upper) to the printer's own parallel port with a suitable cable. Then the printer, the interface, and the computer must be switched on in this order and the programme started. ("!" key)
The tanks and the type of data to print are specified with the menus as described.
ERROR 27 or ERROR 69 are indicated whenever the computer is instructed to print but the printer is not connected properly, or is switched off.

Sample printouts of the weekly and daily data:

```
TANK No:  XX
**********  WEEKLY DATA **********

SAMPLE WEIGHT Nos/lb:  xx
WEEKLY FOOD kgr:  xx
DAILY FEED RATE % :  xx
FEEDING METHOD /FREQ:  ttt
FOOD TYPE/SIZE:  ttt
FOOD QUALITY %Energy:  xx
TOTAL DEAD WEIGHT (lbs):  xx
TRANSFERS IN Nos:  xx
TRANSFERS OUT Nos:  xx
AV. SIZE IN Nos/lb:  xx
AV. SIZE OUT Nos/lb:  xx
WATER TEMPERATURE (C):  xx
WATER pH :  xx
AV. DIS/D OXYGEN pm.I. (%sat):  xx
AV. OVERALL FLOW RATE (gal/min):  xx
DISEASES/TREATMENT/HANDLING:  tt/tt/tt
OTHER CONDITIONS:  ttt
```

*** ENVIRONMENTAL DATA FOR ALL TANKS ***

	MON	TUE	WED	THU	FRI	SAT	SUN
TEMP (C)	x	x	x	x	x	x	x
pH	x	x	x	x	x	x	x
OXYGEN pm.In	x	x	x	x	x	x	x
FLOW gal/min	x	x	x	x	x	x	x

****

TANK No: XX
********** DAILY DATA **********

	MON	TUE	WED	THU	FRI	SAT	SUN
DEAD WEIGHT Lb	x	x	x	x	x	x	x
TRANSF. IN Nos	x	x	x	x	x	x	x
TRANS. OUT Nos	x	x	x	x	x	x	x
W.AV. SIZE IN	x	x	x	x	x	x	x
W.AV. SIZE OUT	x	x	x	x	x	x	x
NOTES: DIS/HAN	tt	tt	tt	tt	tt	tt	tt
NOTES: OTHERS	tt	tt	tt	tt	tt	tt	tt

****

Transmit data to a microcomputer.

The SHARP holds the data for one week at the end of which it can be transmitted to a desk top computer.
The communications hardware can be prepared and data transmission may take place as follows:

Direct connection to the microcomputer.

Hardware and software requirements:

a) Transmitting end:

- SHARP PC
- RS232 interface
- Line switching box (gender changer)
- Programme capable of asynchronous communications.

b) Receiving end:

- Desk-top PC with RS232 interface
- Communications software

Hardware preparation:

- Connect the SHARP with the interface and on their metal base by slotting into each other. Both should be switched off at this phase.
- Connect the gender changer to the RS232 port of the interface (lower). (The "male" port of the changer must be slotted into the "female" RS232 port.)
- Connect the other port of the gender changer to the microcomputer's cable leading to its RS232 port.

Software preparation and data transmission:

a) Desk-top microcomputer:

- Switch on the microcomputer and load the asynchronous communications software.
- Define the communication protocols to match those specified on the SHARP's programme.
- Specify on the comm's menu the intention to receive data.
- Define the medium that the incoming data is to be recorded on, eg. a floppy disk in drive B or a hard disk, and name the file which will accept the data (ASCII file).
- The microcomputer then waits to receive data (hunting).

b) 'SHARP' end:

- Switch on the interface.
- Switch on the SHARP PC.
- Start the program ("!" key).
- Input any day of the week and proceed to the initial menu.
- Select option 2.
- Specify to send data to base ("B").
- Press ENTER.
- The SHARP then transmits the data which also appears on the microcomputer's screen.

c) When transmission is completed ..

- Type "Y" on the SHARP to end the programme.
- Exit from the communications programme on the microcomputer.
- Switch off the SHARP, the interface, and the micro removing the disks.

Indirect -long distance- connection over the telephone network.

Hardware and software requirements for transmission:

a) Transmitting end:

- SHARP PC
- RS232 interface
- Modem

A modem is used to convert computer digital signals into acoustic signals, compatible with the telephone systems, and vice versa. Obviously, modems are used in pairs one at either end.

- Connecting SHARP-Modem cable
- Telephone apparatus
- Programme providing communications

b) Receiving end:

- Desk-top PC fitted with..
- RS232 port and
  Asynchronous communications software
- PC to modem connecting cable
- Modem
- Telephone apparatus.

Hardware preparation:

a) Transmitting end:

- Connect the SHARP with the interface as for the direct connection.
- Connect the RS232 serial port of the interface (lower) to the modem using the appropriate cable and sockets.
- Connect the telephone's plug to the modem and the respective modem's plug to the wall telephone socket.
- Plug the modem to the wall mains socket.
- Set the modem switches/buttons to 'Voice' and to 'Originate'. (The INMAC V21 300 bps Micro-modem is referred to here)

b) Receiving end:

- Connect the microcomputer's RS232 port to the modem.
- Connect the telephone's plug to the modem and the modem's plug to the wall telephone socket.
- Plug the modem to the wall mains socket.
- Set the modem switches/buttons to 'Voice' and to 'Answer'. (The INMAC V21 300 bps Micro-modem is referred to here)

Software preparation and data transmission:

- The SHARP user with the modem switched to 'Voice' and 'Originate' dials the telephone number of the office where the computer is based.

With cheap modems a computer operator must be available at the receiving end to answer the phone.

- To answer the call from the SHARP user and receive the data sent over the telephone network, the microcomputer user at the office should set up the communications' software as for the direct connection. Then,
- Answer the ringing telephone, and when a low pitched whistle (data carrier signal) is heard,

- Depress the 'Data' button on the modem.
- Replace the receiver handset. The modem will hold the line.
- The SHARP will transmit the data via the telephone network to the base microcomputer and the office operator can see the data appearing on the computer screen.

During data transmission the modem of the SHARP user has the 'ON', the 'DCD' carrier detect, and the 'TXD' transmit data lights on. At the microcomputer end the modem has the 'ON', 'DCD' and the 'RXD' receive data lights on. (The abbreviations are those used on the INMAC Micro-modem.)

After the transmission is complete

When communications are finished, the message "TRANSMISSION END" appears on the SHARP's screen and the 'TXD' light on the modem goes off.
At the office, when comm's are over new data does not appear on screen and the 'RXD' light on the modem is off.

- Both users should then lift their telephone handsets and then reset the Voice/Data switch on their modems to the 'Voice' position.

The telephone can be used independently for speech after data transfer if the handset is lifted before switching the modem back to "voice".

The SHARP user may ask the colleague at the computer office whether the data was received satisfactorily. Then,

- Type "Y" on the SHARP to confirm the end of transmission.
- Switch off the SHARP and the interface.
- Disconnect all hardware and store it safely.

The office microcomputer user should then,

- Exit from the communications' programme.
- Switch off the micro, removing the disks. (The modem, switched to 'Voice', may be left connected with the telephone.)

Communication protocols.

The set of parameters which characterise the format of the content of the electronic messages which are transmitted between devices constitute the communication protocol.
Computers (CPU's) communicate with other devices using different transmission speeds, different word lengths and different controls for acceptance and checking of the transmitted data.

When using the SHARP PC to send data to a desk-top microcomputer these parameters are specified in the programme code. The protocol specified in the communications' software on the micro should agree with them for the transmitted data to be well received.

The protocol used on the SHARP for data transmission is:

- Speed (Baud rate) : 300 bps.
- Word length : 7 bits.
- Parity : Even.
- Stop bit : 1

The storage of data on the SHARP.

The recorded data values must be retained by the pocket computer until the end of the week when the calculations take place and the data is printed or transmitted to the office microcomputer.
Therefore, the data must be retained either on memory (RAM) for the entire week or the values must be recorded on magnetic tape, immediately after input.
The programme on the SHARP PC uses the first option. No data storage devices, such as a tape recorder, are in use and the machine is operated as a dedicated data collection terminal. Other programmes are not supposed to be loaded on its memory which is occupied entirely by the data collection software.

Data variables.

The data input is stored on appropriate variables. There are six variables corresponding to data collected weekly and eleven daily.
Daily variables are two dimensional array variables allowing seven daily figures to be recorded on them for each individual tank. However, the environmental variables which are common to all tanks allow only a single dimension of seven days.
The weekly variables are arrays of one dimension, that of tank number.
The daily variables take part in the calculations when the week's records are complete in order to produce weekly sums or averages. So, seventeen weekly variables are ultimately formed in order to be transmitted to the desk-top microcomputer.

About the SHARP PC.

The SHARP PC 1500A is a small pocket computer weighing approximately 375g (0.88 lbs) with the batteries installed.
Its dimensions are: width = 195mm, depth = 86mm, height = 25.5mm.
It has a 26 character liquid crystal display with 7 x 156 dot graphics and a keyboard consisting of 65 keys which include: alphabetic, numeric and user-definable function keys.
It is equipped with an 8 bit CMOS CPU and a BASIC interpreter which provides many useful features such as two-dimensional arrays, variable length character strings etc.
(CMOS -Complementary Metal-Oxide Semiconductor- is a type of electronic memory units which use very little power.)
The standard RAM capacity provides 6.6k bytes of usable memory area but it can be expanded by a maximum of additional 16k bytes. For this purpose the CE-161 programmable RAM module must be connected/slotted to the machine. This optional memory expansion module weighs just 12g.
The memory contents are protected by a CMOS battery back-up, which ensures that both the software and the data are protected when the computer is switched off.

Moreover, the RAM module itself has its own lithium cell battery (1 DC 3V lithium cell CR2032), with a life of about five years (at normal temperature 25 °C) when the module is connected to the computer, and about one year when disconnected from it.
The SHARP can be powered either by a 6V DC via a mains adaptor supplied by the manufacturer, or by four (4) dry batteries (type AA, R6 or SUM-3, 1.5 V).

Battery change on the SHARP PC 1500A.

Turning the computer off does not affect values stored in the programme's variables, but removing of the batteries does. So, although the programme remains unaffected, all variable values are cleared from memory, just like when a CLEAR command is issued.
When the batteries in the SHARP are weak they must be changed only after the data has been transmitted to the microcomputer or printed.
Weak batteries can be detected by watching the small black dot on the right corner of the SHARP's screen (battery indicator). When the battery indicator disappears, the batteries need to be changed. All four (4) batteries must be replaced at the same time.
Battery replacement procedure:

- Turn the computer off by pressing the OFF key.
- Remove the screw from the battery cover with a coin or a small screw driver, but do not impose excess force.
- Replace all four batteries.
- Push the battery cover in slightly while replacing the screw.
- To proceed press the ON key.

The SHARP interface.

In order to print the data or transmit it to a desk-top microcomputer, the SHARP PC must be connected to its asynchronous communications interface, model CE-158, which provides both an RS232C serial and a parallel input/output (I/O) port.

The RS232 serial interface is a device used in information exchanges between data processing equipment and data terminal equipment. Data transmission is serial, ie. each bit is sent sequentially along a single channel.
It complies with the specific standards set by the Electronic Industries Association (EIA) in the U.S.A. which specify the interfaces for use in data transmission.
The Parallel interface is a similar device where all bits in a byte are sent at the same time along multiple channels.
Usually, for data transmission to a computer the serial port is used, whereas the parallel port is often needed to send the data to the printer.

The SHARP interface is a separate, detached device which weighs 435g and has the shape of a small box with width = 86mm, depth = 115mm and height = 50mm.
The PC and the interface are slotted into each other and onto a special metal base which holds them firmly attached.

Power supply on the RS232 / parallel interface:

The unit is powered by a rechargeable Ni-Cad battery which provides 4.8 V DC. It can also be operated on AC power through the use of an AC adaptor (model EA-21A) which is provided by the manufacturer.
The battery needs recharging when the interface is not used for three months or more.
A slightly longer than a 15-hour recharge is needed to fully charge the interface.

When the battery is low, the following error messages appear on the SHARP's screen after the interface is connected:

- When the computer is turned on with the interface power switched on :

  error message : CHECK 8

- During program operation (data transmission):

  error message : ERROR 50

Battery recharging procedure:

- Switch off or disconnect the computer.
- Turn the interface switch OFF.
- Connect the AC adaptor to the interface.
- Plug the AC adaptor into a wall outlet.

It takes more than 15 hours before the battery is fully charged.

Make sure to turn off the power switch on the interface before connecting or disconnecting the adaptor.
When the unit is not in use, make sure to remove the adaptor from the interface and the wall outlet.

The interface can be operated for about 3 hours when the battery is fully recharged.

Quick reference cards of the SHARP programme.

The following six pages may be used as a quick reference instruction booklet for the fish farmer.

INSTRUCTION CARD: 1.

START THE PROGRAMME

- press the ON key,
- press the ! key,

CLEAR OLD DATA

- start the programme,
- type 'CLEAR',
- press the ENTER key.

THE INITIAL MENU

1. Input/Amend data
2. Send data to base or print
3. Specify new week-day
4. Stop the programme

INSTRUCTION CARD: 2.

INPUT

1. Input / Amend data:
   - Input Weekly data.
   - Input Daily data.

   (type W or D)

-- Input Weekly data:

- 1. Fish size
  - Sample weight (Nos/lb)
- 2. Feeding
  - Weekly food amount (kgr)
  - Daily feed rate used (%biomass)
  - Feeding method / freq.
  - Food type and size
  - Food quality (energy %)
- 3. Save & Return

-- Input Daily data:

- 1. Fish mortalities
  - Total dead weight (lbs)
- 2. Fish transfers
  - Transfers IN (Nos)
  - Transfers OUT (Nos)
  - Size of fish transferred IN (Nos/lb)
  - Size of fish transferred OUT (Nos/lb)
- 3. Farm environment
  - Water temperature (C)
  - Water pH
  - Dissolved Oxygen pm.Inlet
  - Water flow (gal/sec)
- 4. Notes and observations
  - Diseases / handling
  - Other conditions
- 5. Save and Return

INSTRUCTION CARD: 3.

SEND DATA TO THE PRINTER

- slot the SHARP into the interface and onto the metal base,
- connect the parallel port to the printer via the cable,
- switch on the printer,
- ... . interface,
- ... . computer,
- start the programme (! key),
- specify any Day,
- select option 2 from the initial menu,
- respond by typing 'P' when asked:
  "DATA TO PRINTER OR BASE ?"
- specify Weekly (W) or Daily (D),
- specify first tank No to print,
- specify last tank No to print,
- press 'ENTER'

INSTRUCTION CARD: 4.

SEND THE DATA TO BASE (DESK-TOP MICRO.) (LONG DISTANCE TRANSMISSION)

- slot the SHARP into the interface and onto the metal base,
- connect the RS232 serial port to the modem via the cable,
- plug the telephone to the modem,
- plug the modem to the wall telephone socket,
- plug the modem to the wall mains socket,
- set the modem to 'VOICE' and 'ORIGINATE',
- switch on the interface,

(the interface should be either charged or connected to the mains via its mains adaptor)

- switch on the SHARP,
- start the program (!),
- specify any legitimate day,
- select option 2 from the initial menu,
- command to send the data to base (B),
- when the message: "GO!!..." is displayed ring the base,
- when the computer at the base is ready to receive, set the modem to 'DATA',
- replace the receiver handset.

When the data is transmitted to the base microcomputer the modem must have the 'ON' light, the 'DCD' carrier detect light, and the 'TXD' transmitted data light on.

WHEN TRANSMISSION IS COMPLETE

The SHARP displays "TRANSMISSION END" and the 'TXD' light on the modem is off.

- lift the telephone receiver handset,
- set the modem to 'VOICE' position,
- confirm whether the data was received satisfactorily at the base,
- press ENTER on the SHARP,
- the SHARP now displays the message: "SATISFIED ?? (Y/N)",
- if data was transmitted error free, type "Y", (if not type "N" to repeat the data transmission),
- ring off,
- switch off the SHARP,
- switch off the interface,
- disconnect all equipment and store them safely.

INSTRUCTION CARD: 5.

DISPLAY THE DATA

- switch on the SHARP (ON key),
- type the name of the variable,
- press ENTER.

HOW TO TYPE A VARIABLE NAME ?

The list of variable names now follows:

data item.	variable name.
Daily data:	
Total dead weight	Y(X,N-1)
Transfers IN	U(X,N-1)
Transfers OUT	V(X,N-1)
Av. size transferred IN	K(X,N-1)
Av. size transferred OUT	L(X,N-1)
Diseases / Handling	T$(X,N-1)
Other conditions	H$(X,N-1)
Environmental daily data:	
Water Temperature	T(X)
Water pH	P(X)
Dissolved Oxygen pm.Inlet	G(X)
Overall flow	O(X)
Weekly data:	
Sample weight	W(N-1)
Weekly food amount	F(N-1)
Daily feed rate	R(N-1)
Feeding method / freq.	Z$(N-1)
Food type and size	E$(N-1)
Food quality	Q(N-1)

where : X is a number from 0 to 6 corresponding to the day of the week ie. X = 0 for Monday,
X = 1 for Tuesday,
X = 2 for Wednesday,
X = 3 for Thursday,
X = 4 for Friday,
X = 5 for Saturday,
X = 6 for Sunday,

and N is the tank N°. Type (N-1),
ie. for tank 6 type 5, etc.

INSTRUCTION CARD: 6.

USUAL ERROR MESSAGES

- ERROR 1 : The name of a variable is typed wrongly, while trying to display its value, or..
Instructions are given that the computer cannot understand.

- ERROR 9 : Wrong 'X' or 'N' numbers are used to display a variable, (ie. the dimensions of an array variable are exceeded).

- ERRORS 27 and 69 : The printer is not properly connected.

- ERROR 50 : The interface needs recharging. (Meanwhile, it may be connected to the mains via its adaptor in order to proceed with the transmission.)

- CHECK 8 : The SHARP is switched on while connected to the interface which is either switched off or needs recharging.

APPENDIX 8

OPERATIONS WITH THE HUSKY HUNTER USED AS A FISH-FARM DATA CAPTURE DEVICE

CONTENTS

USING THE HUSKY HUNTER FOR FISH FARM DATA CAPTURE

The HUSKY HUNTER is a small microcomputer which can be easily carried around the farm and hence used as a portable field data logger.
It can contain software and data in its memory which is protected even when the device is switched off and moreover, it is a rugged machine able to be used without many precautions.
It is programmed in BASIC language to accept fish-farm raw data for a period of one week and has the ability to transmit this data to a desk-top microcomputer or send it to a printer. Several different sources of data (data-units) may be distinguished due to its ample memory (RAM).
The developed software is operated by a versatile menu system which provides options and prompts for the appropriate input. The fish farmer defines the unit (eg. a fish tank) and the input item and types in the data.
Amendments of the input figures can be made very simply by repeating the data entry procedure.

The HUSKY is switched on by depressing the red coloured "PWR" key at the top right corner of its keyboard.
The software in the HUSKY's memory always resumes operation at the point where it was suspended. So, the screen display at switch-on depends on what was done when the machine was turned off. This automatic resumption of programme execution is useful whenever the user is forced to suspend operation while working with the computer. After the emergency the work may be completed.

There are several programmes resident in the HUSKY's memory which are linked by a menu.
A menu is a list of the alternative options that are available to the computer user for selection. Each option activates specific software routines. Menus often branch further into more detailed secondary menus ('sub-menus') forming a hierarchy of choices. If their structure is clear and simple it allows quick use of the programmes.

In order to move from a 'deep' menu to a more general -higher level- menu the option "RETURN TO PREVIOUS MENU" can be selected, whenever it is provided, or the break key "ESC/BRK" must be depressed. This key lies next to the power key at the top right corner of the HUSKY keyboard. Thus, with a few depressions of the "BRK" key the 'top level' menu can be reached.
However, the "BRK" key should not be depressed during a routine execution, such as storing data in memory, or generally, when the computer displays a 'WAIT' message.

THE PURPOSES OF THE SOFTWARE

The HUNTER's software has two purposes. Firstly, the detailed record keeping of individual production units (tanks, cages) and secondly, the stock control of the whole fish farm.
A 'top menu' allows selection of either of these two functions.
The 'top menu' display is as follows:

```
FISH-TANK RECORDS
Individual units  :  1
Fish-stocks       :  2
-----------------------
Your choice please:  ?
```

1. Records on individual units.

Option 1 leads into a data recording programme which handles detailed raw data of each individual fish unit. However, the exact task to be performed with individual data must be clarified. Thus, a fresh menu list is displayed:

```
          INDIVIDUAL UNIT DATA
Input/amend physical data      :  1
Transmit to desk-top or print  :  2
Display the data               :  3
----------------------------------
         Your choice please:  ?
```

This is a secondary list of options and might be called 'the second level menu'.

1.1. Input/Amend physical data.

This option displays the following messages on the HUNTER's screen:

```
    This computer is programmed to hold 40
individual fish unit (tank) data files in
its memory, numbered: 1,2,..,40.
However, for more clarity, you may give
them more descriptive names.
----------------------------
             [ press  ENTER ]


Type 'NEW' to give a new name to a file.
Type 'CHECK' to examine which names are
given to any of the 40 data files.

If, however, you remember the name-No
relation, press ENTER to continue..

                      --- --- >  ?
```

By pressing the ENTER key the computer requests:

WHICH UNIT (TANK) ?
(Type the respective tank name.)

--- ---> ?

The programme requires the specification of the data unit in order to distinguish the data input among several sources and subsequently store it on the proper electronic file.
If a non-existing file-name is specified, the computer beeps and shows the message:

There is NO file for this name !!
(press ENTER to continue..)

The user may try again or check the existing file names.

If 'CHECK' is typed the following message appears:

The computer file Nos with their
respective tank names will be displayed
by pressing ENTER..
(press 'BREAK' to finish)

--- --- > file 1 is: 'XXXXX'

[press ENTER]

With each depression of the ENTER key the next file number and the corresponding unit name appear.

'NEW' should be typed in order to give a name to a fresh data file. The computer responds by the following message:

Type the new name below:
--- --- > ?

then,

Since in the computer's memory
the data files are numbered 1--> 40,
type below the respective file No.
--- --- > ?

The name that is attributed to the particular file number is remembered by the HUNTER until the user decides to erase it or change it. It is automatically stored on a specifically created electronic file which acts as a 'file-name bank'.
Error checking is built in the programme to avoid replacing existing names by mistake unless this is clearly dictated by the user. So, if a number of an already named file is specified, the computer warns that:

```
The specified computer file No: xx
has already been assigned the name:
              'XXXXX'
------------------------------------
Type 'DO' below to rename it,
..else  press ENTER        --- -->  ?
```

The computer confirms the naming or renaming of a file by displaying the message:

```
The file has been SUCCESSFULLY renamed !
             press ENTER
```

As soon as the unit/tank number is defined the programme proceeds to a further breakdown of options forming the 'third level' menu.

```
DATA INPUT OPTIONS:
Weekly data records        1
Daily   ..    ...          2
Specify new unit           3
Return to previous menu     4
ERASE last week's data     999

 --- -->  Your choice ? --- ->
```

The data input is grouped in weekly and daily data which represent figures collected on either a weekly or a daily basis.

Both daily and weekly input options branch deeper into 'fourth level' menus. These provide further categorisation of the data figures into groups.
Thus, the 'fourth level' options for weekly input are as follows:

```
INPUT WEEKLY DATA FOR:

1   Fish size
2   Feeding
 3  Save data and Return to menu
--------------------------------
Your choice:  ?
```

The 'fourth level' menu for the daily data appears after the day of the week is specified.
The programme asks:

```
WHICH DAY OF THE WEEK: ?
```

Entry of the day is in the form of a two or three letter abbreviation, or the complete name can be typed.
For example, for Monday acceptable entries are: 'MO', 'MON', or 'MONDAY'.
If the day is input incorrectly, a 'DAY SPELLING ERROR' occurs, the computer beeps and requests the day to be re-entered.

The 'fourth level' daily input menu is as follows:

```
INPUT DAILY DATA FOR:

1   Mortalities
2   Fish transfers
3   Environment
4   Notes & observations
 5  Save data and return to menu
--------------------------------
Your choice:  ?
```

The last option of both these 'fourth level' menus stores the data on the appropriate file in the computer's memory and then branches to the 'third level' menu.

Option 3 on the 'third level menu' allows the user to identify the name of a subsequent unit (tank, cage etc.), for data entry. The programme asks again:

WHICH UNIT (TANK) ?
(Type the respective tank name.)

--- ---> ?

The daily or weekly data groups as shown on the 'fourth level' menus contain the following data items:

Weekly data:

- option 1. Fish size
  - Sample weight (Nos/lb)
- option 2. Feeding
  - Weekly food amount (kgr)
  - Daily feed rate used (% biomass)
  - Feeding method / freq. (*)
  - Food type and size (*)
  - Food quality (energy %)

Daily data:

- option 1. Fish mortalities (**)
  - Total dead weight (lbs)
- option 2. Fish transfers
  - Transfers IN (Nos)
  - Transfers OUT (Nos)
  - Size of fish transferred IN (Nos/lb)
  - Size of fish transferred OUT (Nos/lb)
- option 3. Farm environment (***)
  - Water temperature (C)
  - Water pH
  - Dissolved Oxygen pm.Inlet (% sat)
  - Water flow (gal/sec)
- option 4. Notes and observations
  - Diseases / handling (*)
  - Other conditions (*)

Input items marked by (*) are not figures but text. The user may type in the computer brief comments, facts or observations. The length of text entries is limited to sixteen characters maximum, so, abbreviations may be necessary.

Daily fish mortalities, marked by (**), can be input either as dead weight (lbs) or as dead fish numbers. In the latter case an estimate of the average size of the dead fish will be requested, in addition, in order to calculate the daily total dead weight. Environmental daily data, marked by (***), must not be omitted in any day because the computer calculates the weekly averages assuming that all 7 daily inputs are present.

The screen display during input is as follows:

```
File No: x  for tank XXXXX  on MONDAY
****************************************

(existing value :  10 C)
WATER TEMPERATURE (C): ?
```

In this example, the user is reminded that data is input on water temperature for tank XXXXX on Monday. The existing value is the previous entry which will be replaced by the new entry. If no new entry is input the existing value will be cleared.

When text is entered in cases where only pure numerical input is expected, a "? REDO FROM START" message appears asking for the correct entry format.

When the "PWR" key is depressed during input the computer is switched off. Also, when the computer is left unattended (no key depressions) it switches itself off automatically to conserve battery power. The programme 'freezes' at that point and resumes operation as soon as the machine is switched on again.

Depressing the "ESC/BRK" key returns to an upper level menu and may be used as a shortcut. However, the most recent data entries are lost and the user should always save the input before deciding to 'break'.

When the fish farm operator starts data collection on a 'fresh' week, the previous week's data are still on the HUNTER's

memory and must be cleared to avoid confusion.
This task is provided by the 'third level' input/amend menu that includes the option to erase the previous week's data by typing '999'. The process must be repeated for each tank. The programme safeguards against accidental data clearance by asking for confirmation:

```
*************************************
     ARE YOU SURE ? (Y/N)  --- --->
```

1.2. Transmit to desk-top or print.

This option from the 'second level' menu introduces either the programme module which transmits the data to a desk-top microcomputer or the programme which directs the data to the printer in order to obtain a 'hard copy'.
The option branches to a 'third level' menu which offers selection of either of the following two possibilities:

```
SEND DATA TO:
... the printer         : 1
... the microcomputer   : 2
---------------------------
     Your choice please  ?
```

Whenever HUSKY prints or transmits the data to a desk-top microcomputer, it calculates the raw figures first in order to get weekly totals and averages. For example, it calculates the weighted average of the fish sizes which have been transfered in or out of a particular unit (tank) within the week, the average water temperature, the total food, etc.
When the data is transmitted to a desk-top computer or printed, it may be cleared from the memory to allow storage for next week's input.

1.2.1. Data printing.

When the user decides to print (option 1), the computer suggests:

```
    Type 'CHECK' to examine the names
given to the 40 data files in memory.
..else
press ENTER to continue..
-------------------------
             Your choice: --- -->
```

It then asks for the first and the last units (tanks) of the printout:

```
START FROM FILE No. :?

STOP AT FILE No. :?
```

For example, if the start No. is 10 and the stop No. is 12, data on units 10, 11, and 12 will be printed.
Illegal entries, such as a start No. which is greater than a stop No. or non-existing numbers, are trapped and the computer prompts for re-entry.
The printing options ('fourth level menu') are as follows:

```
 PRINTING OPTIONS:

1   Weekly data
2   Daily data
3   Specify new data
 4  Quit printing
----------------------
Your choice  ?
```

Options 1 and 2 decide whether weekly or daily input will be printed, option 3 redefines the start and stop file numbers and option 4 branches to the 'top level menu'.

If the printer's serial port is connected to the HUSKY via a gender changer, printing may start.

However, apart from the correct connection, the printer hardware must be set-up in the appropriate way.

Setting-up the printer.

The printer receives electronic signals from the microcomputer and draws the corresponding figure or character images on paper. So, the parameters which characterise the format of the contents of the electronic signals, such as data transmission speed, word length, parity check, serial or parallel transmission, etc. must be set for the different equipment (computer-printer) to communicate.
Moreover, the desired control modes for printing must be selectable, such as condensed print mode, page length and width, automatic line feed, character set and fonts etc.
These can be achieved either via specific software programmes -printer drivers- which instruct the computer how to send its signals to the printer or by arranging special small switches -the 'Dual In-Line Package' or simply DIP switches- on the printer.
Usually, printers have two or three sets of DIP switches which must be set according to the technical specifications of the computer hardware and the user's specific needs.

As an appropriate example, the set-up of the printer model BROTHER M-1509 is described.

The BROTHER M-1509 printer is equipped with both serial and parallel input ports and has three sets of DIP switches: DIP SW1, DIP SW2 and DIP SW3, which can be set for use with the IBM PC and the IBM-compatible OLIVETTI M24 microcomputers and the HUSKY-HUNTER.
The microcomputers run LOTUS 123 and LPWYE (linear programming) software packages, whereas the HUNTER runs programmes in interpreted Basic language.

BROTHER M-1509 DIP SWITCH SETTINGS

DIP SW1	SELECTED FUNCTION	SETTING
1	300 bps BAUD RATE	OFF
2	... .	ON
3	... .	OFF
4	7 bit WORD LENGTH	ON
5	PARITY CHECK (Yes)	OFF
6	EVEN PARITY	OFF
7	X-ON/OFF (Disabled)	OFF
8	I/F Parallel-Serial	OFF/ON (*)

DIP SW2		
1		OFF
2	These switches (1 to 6)	OFF
3	are set to	ON
4	immitate the IBM	OFF
5	GRAPHIC PRINTER	ON
6		OFF
7	Near L Q (Prestige)	OFF
8	.. ..	OFF

DIP SW3		
1	CHR SET (UK II)	ON
2	CANCEL (Valid)	OFF
3	BUFFER FULL LF (Valid)	ON
4	CHR SET (Normal)	OFF
5	FORM LENGTH (12")	ON
6	PITCH (1/6")	OFF
7	SELECT IN (FIX)	ON
8	AUTO FEED (Invalid)	OFF

Other information, such as connecting printer accessories, mounting ribbons and paper, maintenance etc. are found in the printer manufacturer's manual.

The setting of switch 8 in the first group is marked with a (*) since both serial and parallel printing is needed in the fish farm recording system. The microcomputer sends parallel signals to the printer, whereas the HUNTER sends serial signals.
The solution is an external, custom built, switch that was fitted on the printer in order to facilitate easy resetting of SW2-8
The OLIVETTI needs the SW2-8 switched to OFF (parallel), whereas the HUNTER to ON (serial).

The 'Weekly' and 'Daily' printouts look as follows:

```
Printed on dd-mm-yy at  hh:mm:ss

File No: Z  for tank XYZ
*************** WEEKLY DATA ***************

SAMPLE WEIGHT     (Nos/lb)                     :  xx
WEEKLY FOOD       (kgr)                        :  xx
DAILY FEED RATE   (%biomass)                   :  xx
FEEDING METHOD & FREQUENCY                     :  tt
FOOD TYPE & SIZE                               :  tt
FOOD QUALITY      (%Energy)                    :  xx
TOTAL DEAD WEIGHT (lbs)                        :  xx
TRANSFERS IN  (Nos)                            :  xx
TRANSFERS OUT (Nos)                            :  xx
AVERAGE SIZE IN   (Nos/lb)                     :  xx
AVERAGE SIZE OUT  (Nos/lb)                     :  xx

DISEASES-TREATMENT & FISH HANDLING             :  tt
OTHER CONDITIONS                               :  tt

WATER TEMPERATURE (c)                          :  xx
WATER pH                                       :  xx
AVERAGE DISSOLVED OXYGEN pm.Inlet (%sat)       :  xx
AVERAGE WATER FLOW     (gallons/min)           :  xx
```

```
Printed on dd-mm-yy at  hh:mm:ss

File No: Z  for tank XYZ
*************** DAILY DATA ***************

                  MONDAY TUESDAY WEDNESDAY THURSDAY FRIDAY SATURDAY SUNDAY
DEAD WEIGHT lbs     xx     xx       xx        xx      xx      xx      xx
TRANSF  IN (Nos)    xx     xx       xx        xx      xx      xx      xx
TRANSF OUT (Nos)    xx     xx       xx        xx      xx      xx      xx
WGHTD AV.SIZE IN    xx     xx       xx        xx      xx      xx      xx
WGHTD AV.SIZE OUT   xx     xx       xx        xx      xx      xx      xx

DISEASES            tt     tt       tt        tt      tt      tt      tt
OTHER NOTES         tt     tt       tt        tt      tt      tt      tt

TEMPERATURE         xx     xx       xx        xx      xx      xx      xx
pH                  xx     xx       xx        xx      xx      xx      xx
OXYGEN pm. Inlet    xx     xx       xx        xx      xx      xx      xx
FLOW gal/min        xx     xx       xx        xx      xx      xx      xx
```

1.2.2. Transmit data to a desk-top micro.

After the microcomputer hardware and communications software are activated, the option to send the data to a microcomputer may be selected on the HUNTER. All data from all units is sent to the desk-top.

The communications protocol.

The HUSKY is equipped with a serial RS232 interface port and with communications software which may receive or send data to external devices.
However, electronic CPU's (Central Processing Units) communicate with other devices using different transmission speeds, different word lengths, and different controls for acceptance and checking of the transmitted data.
This set of parameters which characterise the format of the content of the electronic messages which are transmitted between devices constitute the communication protocol.
The protocol can be specified at will given the characteristics of the equipment. However, the user of the system is not expected to have expertise in computing so, the protocol is specified on the HUNTER as follows:

Transmission parameters on the HUSKY-HUNTER

Rate - 300 Prtcl - none Pty - even
CTS - y DTR - n LF - y Echo - n T/O - no Null - 0

This protocol agrees with the specifications programmed on the devices which accept the electronic signals -data. Thus, the printer is set-up as described and the protocols of the communications software on the microcomputers (IBM and OLIVETTI) are defined as follows:

Microcomputer: IBM PC

Comm's software: 'Asynchronous Communications Support'

Protocol:

1 Line Bit Rate [300]
2 Type of Parity Checking [Even]
3 Number of Stop Bits [One Bit]
4 XON/XOFF Support [Absent]
5 Line Turnaround Char Sent to Host [EOT]
6 Local or Host Character Echoing [Local]
7 First Character to be Deleted [None]
8 Second Character to be Deleted [None]
9 Third Character to be Deleted [None]
10 Fourth Character to be Deleted [None]
11 Line End Character Sent by Host [EOT]
12 Communications Adapter Address [1]

The IBM offers an option to save the specification for further immediate use. The file name given to it here is 'spec1'. Note also that the HUNTER must have its LF parameter set to 'n' in order to avoid double spacing of the data received on the IBM PC (LF - n).

Microcomputer: OLIVETTI M24

Comm's software: 'Olitalk'

Protocol:

A (CR) is treated as a (CR) (LF) on data reception.
The network is half duplex.
A backspace should not be transmitted as a (DEL) character.
For transmission, end of line handling is: (CR) (LF) sent as (CR).
CTRL_Z is not disk input end of file indicator.
The baud rate is 300.
The parity is even.
The number of stop bits is 1.
The number of data bits is 7.
The protocol is (CR) await (LF).
The port is COM1.
The terminal is Basic TTY.
The screen will scroll.
The cleaning mode is: accept anything.
The detection mode is: no detection.

The most recent definitions of the communication parameters (protocol) can be remembered by the programme (Olitalk), so, there is no need to create any file to store them.

Direct connection to the microcomputer.

Requirements for transmission:

a). Transmitting end:

- HUSKY-HUNTER fitted with
- RS232 serial interface,
- Software for asynchronous communications.
- Line switching box (Gender Changer).

b). Receiving end:

- Desk-top PC fitted with
- RS232 interface,
- Asynchronous communications software

Hardware set-up:

- Connect the gender changer to the RS232 port of the HUSKY.
- Connect the other port of the gender changer to the microcomputer's cable leading to its RS232 port.

Software set-up and data transmission procedure:

a) Desk-top microcomputer:

General instructions:

- Switch on the micro and load the asynchronous communications software.
- Define the communication protocols to match those specified on the HUSKY.
- Specify that the intension is to receive data.
- Define the medium the incoming data is to be recorded on, eg. a floppy disk in drive B or a hard disk, and name the data file which will accept the incoming data (ASCII file).
- The microcomputer waits to receive data (hunting).

Instructions for the IBM PC, twin drive system:
(as used in this study)

-- Place the IBM asynchronous communications support disk in drive A.
-- Switch on the IBM PC.
-- Type current date and time as prompted.
-- Select option 6 from the appearing menu in order to access a predetermined communications protocol held on disk as a computer file.
-- Type: **spec1**, press ENTER.
("spec1" is a computer file created and stored on the comm's programme disk and contains the communications protocol. It is recommended to create such a file(s) in order to be readily available each time the comm's programme is to be used.
The file name is, of course, a matter of choice.)
-- Place a 'target disk' in drive B (ie. a floppy disk onto which the incoming data will be recorded).
-- Select 13 from the menu on screen to define that the computer will receive data.
-- Press the F8 function key on the IBM PC.
(This function key instructs the computer to place the incoming data into a file on the 'target disk' as well as display it on the screen as it arrives.)
-- Type: **B:data1.prn**, and press ENTER.
(The characters "B:" in the above name define the disk drive B as the 'target drive' for the incoming data. "data1" is an arbitrary name for the data file on which the data will be recorded; however, this filename is built in the fish farming software programmes, so it should be retained. ".prn" is an extension to the filename which is also necessary.
-- Type: **O**, to overwrite the existing file.
(Since the same file name is used each time -every week-, the incoming 'fresh' data must replace the existing 'old' data in the file and the computer is seeking confirmation of this action.)

Instructions for the OLIVETTI M24, hard disk system:
(as used in this study)

A hard disk is a storage unit for programmes and data capable of holding a great number of computer files, usually up to 10 or 20 Mbytes (1Mb=1,000 Kbytes) of total memory size. It occupies the space of a normal floppy disk drive and is identified as disk drive "C". So, all programmes of the fish farm recording system as well as 'Olitalk' are installed on the machine's hard disk.

In order to have a neat organisation of the computer files on the hard disk, 'addresses' are assigned to them which are called "directories". Each group of similar programmes or data files may have its own directory. Thus, the Olitalk communications software programmes are found under the directory "olitalk".

The procedures are automated for the user and the programmes 'remember' where files or other programmes reside for access. So,

-- Switch on the OLIVETTI M24 computer.
-- Type current date and time as prompted.
-- Enter the command 'OLITALK' in order to activate the communications programme.
-- Select option D from the appearing menu (Basic TTY).
-- Choose the first option (1) from the fresh menu list which specifies the data source for transmission (keyboard).
-- Select again option 1 to specify how the incoming data is displayed (displayed on video).
-- Select option 5 for the destination of the received data (record on disk and display).
-- press ENTER.
-- Type in the destination filename as: data1.prn ("data1" is the arbitrary name of the data file on which the data will be recorded and is built in the fish farming software programmes; ".prn" is a necessary extension to the filename.)

-- press ENTER.

-- the computer displays 'READY'.
The OLIVETTI is then ready waiting to receive data, ie. 'hunting' for any incoming data. When the first data arrive at the RS232 port..

-- Type: O, to overwrite the existing file.
(Since the same file name is used, the incoming 'fresh' data must replace the existing 'old' data in the file.)

At this stage any incoming data is displayed on the screen and stored simultaneously on the 'target' disk in the specified file "data1.prn".

b). HUSKY :

- Switch on.
- Command with the menus to transmit data to a desk-top microcomputer.
- Press ENTER.

<u>When the direct transmission is complete</u>

- Exit from the communications programme on the microcomputer.
- Switch off the HUSKY.
- Disconnect any cables and the gender changer.
- Switch off the microcomputer removing any disks.

<u>Exiting communications on the IBM PC</u> (twin-drive system):

-- Press the F8 function key on the IBM PC.
(This action 'closes' the computer file "data1.prn" which received the data and ends data transmission.)

-- Press the F2 function key to return to the menu.

-- Select option 4 from the appearing menu.

-- Select 8 from the fresh menu to exit the comm's programme.

-- Switch off the micro and remove the disks.

<u>Exiting communications on the OLIVETTI M24</u> (hard-disk system):

-- Press the "ALT" and "Q" keys simultaneously.
(This action 'closes' the computer file "data1.prn" which received the data and ends data transmission.)

-- Select option 0 to exit the comm's programme.

-- Switch off the micro.
When the OLIVETTI runs Olitalk it changes the operating system to the U.S. version. This alters the meaning of some of the keys on the keyboard and the computer cannot run other programmes or understand different instructions.
To restore the keyboard to the U.K. version the computer must be rebooted (restarted). This is most quickly accomplished by pressing the 'reset button' at the side of the machine or by performing the simultaneous keystroke sequence "CTRL", "ALT" and "DEL" whenever work with the computer must continue.

Indirect, long-distance connection over the telephone network.

<u>Requirements for transmission</u>:

a). Transmitting end:

- HUSKY-HUNTER with RS232 interface,
- Modem (eg. the V21 300 bps INMAC Micro Modem).

A modem is used to convert computer digital signals into acoustic signals, compatible with the telephone systems, and vice versa. Modems are used in pairs one at either end.

- Telephone apparatus,
- Communications' software.

b). Receiving end:

- Desk-top PC fitted with
- RS232 port and communications software.
- Modem (eg. the V21 300 bps INMAC Micro Modem),
- Telephone apparatus.

Hardware set-up:

a). Transmitting end:

- Connect the RS232 serial port of the HUSKY to the modem.
- Connect the telephone's plug to the modem and the modem's plug to the wall telephone socket.
- Plug the modem to a mains socket.
- Set the modem switches/buttons to 'Voice' and to 'Originate'.

b). Receiving end:

- Connect the microcomputer's RS232 port to the modem.
- Connect the telephone's plug to the modem and the modem's plug to the wall telephone socket.
- Plug the modem to a mains socket.
- Set the modem switches/buttons to 'Voice' and to 'Answer'.

Long-distance data transmission procedure:

- With the modem switched to 'Voice' and 'Originate', the HUSKY user dials the telephone number of the office where the computer is based.

(When cheap modems are in use, another computer operator must be at the receiving end to answer the phone.)

To answer a call from the remote data terminal and receive the data over the telephone network..

- The microcomputer user at the office should set up the communications' software as for the direct connection.
- Set the Ans/Orig switch on the modem to 'Answer'.
- Answer the ringing telephone.
- Inform the user at the field that the computer is ready and that HUSKY may be instructed to transmit.

- Depress the 'Data' button on the modem and when a low pitched whistle (data carrier signal) is heard..
- Replace the receiver handset. The modem will hold the line.

Then the HUSKY transmits the data via the telephone network to the base microcomputer and the office operator can see the data appearing on the computer screen.

During data transmission the modem has the 'ON', the 'DCD' carrier detect, and the 'TXD' transmit data lights on. (The abbreviations are those used on the INMAC Micro-modem.)

<u>After the telephone transmission is complete</u>.

a). At the HUSKY end:

When communications are finished, the "second level" menu appears on the screen and the 'TXD' light on the modem is off. Then..

- Reset the Voice/Data switch to the 'Voice' position,
- Lift the telephone receiver.

The field (HUSKY) user may ask the colleague at the computer office whether the data was received satisfactorily.
The telephone can be used independently for speech after data transfer if the handset is lifted <u>before</u> switching the modem back to "voice".

If the data was received trouble free, then either

- Switch off the HUSKY, disconnect all hardware and store it safely,

or - continue other operations normally.

In the latter case, it is recommended to switch the HUSKY off and on again in order to power down the interface wich might remain active and weaken the batteries.

b). At the office microcomputer:

When comm's are over, no more data appears on screen and the 'RXD' light on the modem is out.

- Lift the receiver handset of the telephone.
- Move the Voice/Data switch to the 'Voice' position.

Since the telephone line connection is still held, the remote field operator may be contacted to confirm whether the data was received satisfactorily.

- Exit from the communications' programme as after a direct connection.
- Switch off the micro removing any disks, disconnect the hardware (cables, telephone and modem) and store them safely. However, the modem, switched to 'Voice', may be left connected permanently to the telephone.

Fault finding when using the modem

Symptom:	Problem / Solution:
Working but with high level of erroneous data	- The telephone connection should be clean and secure. - There should be no one talking on the telephone line. - The telephone and all extension telephones should be 'On Hook'. - Avoid calls through switchboards - Redial and re-establish connection. - Check telephone plug connection.
No transmission but the power is on	- Check telephone plug connections. - Check that the function switches are in the proper positions. - Data switch depressed.

No telephone dialing tone	- Ensure modem is switched to 'VOICE' position.
Modem not working	- Check power is on. - Check that the modem is plugged into the wall telephone socket and the telephone is plugged into the modem.

1.3. Display the data.

The last option (option 3) of the 'second level' menu, displays the data which is held in memory.
The menu:

```
            INDIVIDUAL UNIT DATA
Input/amend physical data      :  1
Transmit to desk-top or print  :  2
Display the data               :  3
-----------------------------------
         Your choice please:  ?
```

Thus, the stored data can be checked by option 3 and subsequent amendments can be made, if necessary, by the input/amend option 1.

Initially, the programme requires the data file to be identified. The following message is displayed:

```
If you remember the file No - tank name
relationship, press ENTER to continue..
..else
type 'CHECK' to examine the names that
are given to the 40 data files in memory
----------------------------------------
                 Your choice  --- -- >
```

When 'CHECK' is typed the computer lists the file numbers with their names. This facility is already described under the data input section.

If the ENTER key is pressed the computer requests the name of the unit to display the data.

DISPLAY WHICH UNIT (TANK): ?
(Type the respective tank name.)

--- --->

Typing of the tank name is followed by a 'third level' menu:

DATA DISPLAY OPTIONS

1 Weekly data
2 Daily data
3 Specify new unit No.
4 Return to menu

Input your choice ?

It is evident what each option implies.
The data is displayed in the format shown in the examples below for a weekly and a daily data item:

current Tank: XXXXX on file No xx
****

SAMPLE WEIGHT : 100 (Nos/lb)

Type C to continue , or R to return ?

By typing "R" the programme returns to the display options list (third level menu), whereas by typing "C" the next data item is displayed. When the data items are exhausted the programme returns to the menu.

If the choice is to display daily data, the programme asks:

WHICH DAY OF THE WEEK: ?

When the day is specified (a two or three letter abbreviation or a complete name should be typed), the computer proceeds as follows:

```
     Tank: XXXXX  (file xx),  Day: WED
***********************************************

     TOTAL DEAD WEIGHT  (lbs):  0.2

-----------------------------------------------
Type C to continue , or R to return ?
```

a.s.o.

2. Stock records.

The stock control programme for the whole fish farm is accessed via the 'top' menu of the HUSKY software:

```
FISH-TANK RECORDS

Individual units    :  1
Fish - stocks       :  2
------------------------
  Your choice please   ?
```

Option 2 activates the stock programme which functions as a pocket diary for the fish farmer. It may be used irregularly to input data on changes of the fish stock populations and their distribution in the various containers as they happen.
This information on all fish is held in files in the HUSKY's memory which are updated after each input.

The functions that the stock control programme can perform are summarised in the 'second level menu' which lists the routines that the user may activate.

```
OPTIONS:

Clear or Input data      .1
Print or Transmit data   .2
Display the data         .3
--------------------------
     Your choice please   ?
```

2.1. Clear or Input new data.

Define the fish container and update its status.

The HUNTER accepts a breakdown of the farm into sections each of which contains a number of individual fish units (tanks).
Such compartmentalisation of a fish farm is particularly suitable in the case of a hatchery that operates with different fish sizes from several batches in a large number of tanks.

The descriptive names of each farm section, such as "Hatchery building B" are encoded in the programme together with the identification numbers of the tanks that each section includes. Thus, the programme is customised for the particular farm.

The user of the HUNTER is prompted to define the farm section and to specify the number of the unit. Thus, an individual tank is 'located' in the computer memory and the HUNTER is ready to up-date its stock situation.
The screen displays:

```
STOCK :   (unit  xx)
          (farm section  XXXXX)
----------------------------------------
Type 'C' to CLEAR or 'I' to INPUT  ?
```

'Clear' is needed when a tank was recently emptied and is currently vaccant.
Any other entry apart from 'C', or a depression of the ENTER key signals to the computer that data input is intended and the screen display is expanded as follows:

```
STOCK :   (unit  xx)
          (farm section  XXXXX)
---------------------------------------
    Type 'C' to CLEAR or 'I' to INPUT  ?
---------------------------------------
DATE: ?              QUANTITY:
EGG BATCH:           SIZE (Nos/lb.):
VACCINATION STATUS:
```

Coding the fish batch names.

On the hatchery several batches of eggs are introduced in any one year from different sources. Since fish of different origins bear distinct genetic qualities and must not be confused, in the computerised stock records they are identified by short code-names. The fish farmer must retain the same code for a particular batch in order to avoid confusing the computer. For speed and convenience the code-names must be short and evident of the fish type.
For example, a code-name, such as 'Ums86' may be given to fish hatched from mixed sex eggs introduced in 1986 from the USA.

What to know for trouble-free recording.

After each input the cursor jumps to the next item until all five are entered. When the last entry is input the computer saves automatically the data of the tank on its memory and returns to the 'second level menu'. New entries over-write (replace) existing data, so, pressing the ENTER key without typing any data clears the input for the specific tank.
Before pressing the ENTER key after the last entry, the user may abandon data input and avoid replacing the existing data by

depressing the "ESC/BRK" key. This may be useful if typing errors occurred. As said earlier, 'breaking' interrupts the programme's sequence, ignores any new data entries and returns to the menu.

Only the most recent entries are remembered by this computerised diary which provides the up-to-date picture of the fish stock without occupying great computer memory space. Therefore, there are no rules for routine data transmission. Data may be sent to a microcomputer or printed as regularly as necessary according to the frequency with which the stock situation changes on the farm.

2.2. Print or transmit the stock control data.

A single routine is responsible for both printing and transmitting the stock data to a desk-top microcomputer. It is activated by option 2 of the 'second level' menu.
The farm sections and individual units appear with their names or numbers. The user is free to specify the first and last section (unit group) that the HUSKY will print or transmit.
Data printing and transmission can be performed as described in the case of individual unit data.

However, when transmitting to the microcomputer, either to an OLIVETTI or to an IBM PC, the name of the file to accept the stock control data should be **'stock.prn'** This name is recognised by the software programmes installed on the microcomputer which process the stock information.

2.3. Display the records.

It is the third option of the 'second level' stock control menu and initially requires the user to identify the specific fish container as described for the data input.

The computer displays the stock information of the particular unit in the following format:

```
    Fish farm section  MAIN BUILDING
****************************************

Unit No:  23         Date:  30/May/87
Egg batch: Raf87     Quantity:  24000
Vaccination status: no
Size (N/lb):  160
                         [ press ENTER ]
```

By pressing ENTER the 'second level' menu returns on screen and another unit may be defined for display or a different function (input, print or transmit) may be activated.
Thus, it is feasible to check quickly the current stock status of any production unit on the farm.

TECHNICAL ASPECTS OF THE HUNTER AND ITS SOFTWARE

Data variables and data storage.

The input is stored on appropriate variables. There are six variables for data collected weekly and eleven for daily data for each tank. When a week's records are complete the daily variables take part in calculations performed by the software to produce weekly sums or averages. So, in all seventeen weekly data values are ultimately transmitted to the desk-top microcomputer for every individual unit.

The routinely recorded data must be retained in HUSKY until the end of the week when the calculations take place and the data is printed or transmitted to the office microcomputer. During the week HUSKY keeps the data on electronic files secured in a portion of its memory (RAM) assigned as 'the storage RAM', or 'RAM disk' which acts as a storage medium for programmes and data. The software uses a record file for every production unit (tank). The HUSKY user may load and use various application programmes on the machine with no danger to the data record files.

HUSKY is available with various storage memory capacities (RAM disk or RAM file space) and the choice is a personal decision. Nevertheless, investing in excess memory capacity adds flexibility to the system and can be rewarding as the business and its computing needs expand.

File space requirements.

Electronic files are stored on the 'RAM disk', in records of 128 bytes, grouped by 16's into 2k bytes. This means that the smallest file size is 2k bytes and that files expand in size by increments of 2k bytes. The memory space is allocated by the file manager programme kept in ROM.

About HUSKY-HUNTER.

The HUSKY computer (model HUNTER) is a small computer which weighs 1150 grammes with the batteries installed, with dimensions 216mm x 156mm x 32mm.
Its screen can display eight 40 character lines. Both text and graphics can be displayed together. There are five different selectable character sizes and the software supports drawing of lines, boxes, circles etc. Sound is also available and programmable.
The HUNTER's keyboard consists of 58 keys arranged in four rows of 15. They are waterproof sealed rubber keys incorporating alphabetic keys having a QWERTY layout (common typewriter layout), numeric keys as well as function and control keys.

The built in programming language is BASIC, available via a Basic interpreter (a programme that translates to the computer sequentially lines of programme code for execution).

Programmes and data are stored indefinately in battery supported erasable memory (RAM), whereas the operating system is stored separately in a permanent memory area (ROM). The built in OS (Operating System) includes a file manager, the Basic interpreter, and a disk emulator. (DEMOS, ie. Disk Emulating Operating System.)

The power supply for daily use comes from four 'AA' batteries, or rechargeable Ni/Cd ones. The alkaline batteries may have an operating lifetime of 45h.

The type of memory is CMOS low power semiconductor RAM (Complementary Metal-Oxide Semiconductor is a type of electronic memory units which use very little power). It has battery support with soldered in Ni/Cd backup units which are charged from the main batteries when the computer is operating. Their life is 50h when the main batteries are discharged or removed, so, HUSKY must be stored for longer periods with its batteries installed if the memory contents are to be retained.

HUSKY's microprocessor is of the type NSC800-4, executes the Z-80 instruction set (8080 super set) and can run standard CP/M compatible programmes. It is timed at 4 MHz.

Data communications with other devices are feasible via a RS-232 /V24 serial port on standard 25 pin 'D' type connector, which is entirely software controlled and capable of transmission speeds of up to 4800 baud asynchronous.

Battery change on the HUNTER.

Removing the computer batteries does not affect programmes or data stored in memory, since this task is taken over by the inbuilt Ni/Cd units which offer secondary battery power backup for 50h maximum period after the removal of the main batteries. When the batteries are weak, HUSKY gives warnings to the user. If ten consequtive warnings are ignored, HUSKY automatically switches off to conserve battery life. However, when power is restored, programme execution continues from precisely the point of interruption.

When HUSKY detects low battery power it bleeps twice and the top line of the screen displays:

* WARNING BATTERIES ARE LOW *

HUSKY switches off automatically after a period of inactivity which is set to 5 minutes but can be changed. A warning bleep is emitted every 2.5 mins to remind the user that the machine is turned on.

Battery installation procedure:

The batteries are spring-loaded to make contact and are retained in a 'battery tube' by a threaded plug.

- Use a coin to undo the battery plug.
- Place the batteries, positive pole inwards.
- With finger pressure press the battery plug in the battery compartment and turn until thread is started.
- Screw the plug home using the coin.

HUSKY is optionally available with rechargeable cells and a mains (line) powered charger. This arrangement allows the rechargeable batteries to be recharged in the machine, or HUSKY can be powered permanently from the charger by leaving the unit connected.

Restarting the software after a programme error.

If for any reason an error occurs during programme execution the HUNTER exits from the fish farm software and into BASIC mode displaying an error message of the following appearance:

```
* ZZZ ERROR on line  xxxx
READY
```

To re-activate the fish farm programmes and continue operation at this stage:

- Type: RUN"MENU"
- Press ENTER

The 'top level' menu is accessed and programme execution can be resumed.

APPENDIX C

OPERATIONS WITH THE CUSTOMISED LOTUS 1-2-3 WORKSHEETS ON THE IBM PC DESK-TOP MICROCOMPUTER OR THE IBM-COMPATIBLE OLIVETTI M24.

CONTENTS

BRIEF DESCRIPTION OF THE 'LOTUS 123' SOFTWARE
(Release 2)

'1-2-3' is an electronic spreadsheet, graphics, data base programme, which turns the computer's memory into a big **worksheet** ruled into rows and columns -similar to a financial ledger sheet. Each of the spaces in the worksheet -called **cells**- can store a piece of data: a **number** or a **label** which is a series of characters, ie. letters, words, etc., or an istruction to calculate a value -a **formula**.
Every cell on the worksheet has its own **cell address** that describes its column-row location (coordinates). Each particular cell can be 'pointed' by a 'reverse video' highlight indicator called the "**cell pointer**".

The worksheet is kept during operations on the computer's main memory, described as random access memory (RAM).
When the computer is turned off, or a power failure occurs, RAM is erased, so to make a permanent record of the worksheet, it must be saved in a computer file -**worksheet file**- on a magnetic medium, such as a floppy disk or a hard disk.

During a session with the programme the display screen may be typically divided into two sections separated by a "**border**". The border area is a highlighted margin of the worksheet which horizontally contains letters identifying each one of the columns: A, B, C,.. and vertically, at the left edge of the screen, contains the row numbers. Its role is to indicate the current location in the worksheet.

Above the border is the **control panel**, which consists of three lines:
<u>Line 1</u> contains information concerning the pointer location, ie. the row-column coordinates of the cell which the pointer is highlighting, the format, protection status and contents of this cell, etc.
<u>Line 2</u>, the input line, displays the cell entries (letters,

numbers, labels, formulas and functions) as they are typed and edited.
1-2-3 uses this line also to display prompts and menus.
Prompts are instructions to make particular entries.
Menus are lists of command words which activate specific tasks.
Line 3 displays one-line summaries of the 1-2-3 commands offered by the menu. They change in respect to the particular highlighted command in the menu.

Most of the rest of the screen is taken up by a section of the **worksheet.** 1-2-3 uses the last line of the screen to display error messages, the current date and time and other indicators that signal various programme conditions.
Since the entire worksheet is too large to fit on the display screen, only a section (page) of it can be seen at a time, as looking through a **window** onto a small portion of the worksheet. However, this window may be moved easily to different parts of the worksheet.

1-2-3 can create visual representations of data by turning rows or columns of numbers into several kinds of graphs, which are extremely helpful for the recognition of relationships and trends that might not be spotted in the numbers themselves. These graphs can be seen on screen and printed on paper.

The programme provides a facility that allows sequences of keystrokes to be remembered. Such a stored sequence of keystrokes is often called a "**keyboard macro**", or simply just "**macro**". In practice macros provide the tools to adjust -customise- Lotus 123 to specific needs hence, they can be thought as a simple programming language. Their advantage is that no advanced computer programming skills are necessary to customise specific applications but only sufficient practice with 1-2-3. So, programming and programme updating time can be minimised without many sacrifices of computing power. Moreover, this form of 'programming' is open to non-experts.
For example, although 1-2-3 provides a very flexible combination

of commands to create graphs, it may be complicated and time consuming for the busy user to create new graphs each time.
The answer is the customisation of useful graphs which remain 'hidden' in a worksheet and can be viewed instantly using commands in specifically tailored menus.
Using keyboard macros different menus may be defined and displayed on the control panel. So, menus can be tailored to the specific requirements of the user. The personalised commands may be activated in the same way as with standard 1-2-3 menus.

Each macro is attached to one of the letter keys: A,..,Z. When the 'Alt' key is held down and the letter key is depressed, all the keystrokes stored in the macro-sequence are automatically performed, as if typed again. This is how a macro is 'invoked'.
The macro-instructions are entered as common labels in worksheet cells using specific notation and are given special names of the form: /A, /B,.., /Z.
Sometimes a pause is built in a macro to allow the completion of any intermediate stage, eg. typing of data. Whenever the programme pauses during a macro execution, a highlighted "CMD" indicator is displayed at the center of the bottom line of the computer screen.

OPERATIONS WITH THE CUSTOMISED WORKSHEETS
('Lotus 123' -release 2)

Loading Lotus 123 from a hard disk.

The system described here is developed on the OLIVETTI M24, which is a compatible machine with the IBM PC desk-top microcomputer, equipped with a hard disk for mass storage of programmes and data. Lotus 123, communications and linear programming software are installed on the hard disk under file directories of their own.
When the microcomputer is switced on, a "batch" DOS file is automatically activated and asks the current date and time to be entered. Subsequently it prompts the following message on the computer screen in order to allow programme selection or file management operations:

```
***********************************************************
For Lotus123 enter.................................. LOTUS
For Olitalk enter...................................OLITALK
For Lpwye enter.......................................LPWYE
-----------------------------------------------------------
To back-up data-files on floppy disks enter...........DISK
To clear data-files from directories enter...........CLEAR
***********************************************************
```

When the command-word 'LOTUS' is typed the programme is accessed.
First, the "Lotus access menu" appears on the screen providing options, such as '123', 'Printgraph', 'Install', 'Translate', etc. The user of this system should concentrate in the former two.

Selecting '123' starts (boots) the Lotus 123 spreadsheet software and activates the customised fish farm worksheets.

The screen displays the following customised menu list:

The menu offered by the Lotus customised worksheets.

```
          Hello.!
I am your fish records' programme!

Command me master!
****************************************
      -- Prepare transmitted data.                   1
      -- Retrieve a tank-file.                       2
      -- Initiate a new tank-file.                   3
      -- Erase a tank-file.                          4
      -- Check the tank-file list.                   5
      -- Fish-stock control and reporting.           6
      -- Access the Sales/Orders data base.          7
      -- Generate a prediction model.                8
      -- Retrieve a stored prediction file.          9

           -- Get rid of me!                         0
***************************************           --------
                                   Your choice is:  ??
```

In this list ('all-worksheet' menu) all the functions which may be performed by the Lotus-based data system of the fish farm can be found.

Option 1 is a necessary first step before importing to a Lotus worksheet the data which is transmitted to the microcomputer from the field device (HUNTER or SHARP). It commands the computer to arrange the data in the format that Lotus 'expects' to find for importation.

Option 2 accesses on the disk and retrieves the stored worksheet files that represent the units/tanks of the fish farm. (A list of file names appears on the third line of the control panel.)

Option 3 retrieves the 'empty' customised worksheet file (called 'GENERAL') which can be initialised to accept data from a fresh unit/tank.

Option 4 is used for 'housekeeping' of the hard disk. As the data files tend to accumulate some may become obsolete. Such files may be copied on floppies to preserve the farm production history and then removed/erased from the current directory.

Option 5 provides a complete list of all the unit/tank record files that are currently kept on the hard disk.

Option 6 activates the stock reporting worksheet which may produce insurance reports or summary reports for the overall stock status and mortalities as well as information on fish sales and orders.

Option 7 accesses the worksheet which serves as a sales and orders data base for updating.

Option 8 processes data from selected files and estimates predictive equations which express mathematically the relationships among important fish growth factors. These equations are subsequently incorporated in prediction models.

Option 9 accesses for re-examination ('what if?' analyses) previously generated prediction models which are stored on the disk.

Option 0, exits from the 123 customised programmes and returns to the 'Lotus access menu'.

THE CUSTOMISED DATA-RECORDING WORKSHEET

Description and use.

This customised 123 worksheet is used in the fish farm information system to import the data which is transmitted to the microcomputer by the field data collecting device and to perform up-to-date calculations, provide graphs, print and file the accumulating information.

A general-empty worksheet file is recorded on the computer's storage device (floppy or hard disk), which may be retrieved, initialised and then used to import the data from the specific production unit which it will represent thereafter. It must be saved (recorded) on the disk with a proper characteristic file-name.

The worksheet has the usual spreadsheet form. The columns are occupied by the various data items and time increases from top to bottom by weekly intervals-rows. The number of rows -weekly intervals- depends on the duration of the period that the particular unit (tank) is used in a production cycle. The last column of the worksheet provides up to date summary totals and averages.

Each worksheet file should contain information of the production of a single unit over a distinct interval of a particular cycle. Such worksheet files stored on the computer's disks (floppies or hard disk) represent the fish farm's production data separated in distinct growth stanzas of uniform fish suitable for meaningful statistical analyses.
Frequently updated back-up copies of the files should be kept in a safe, separate place.

Appearance on screen.

The customised worksheet's appearance on the computer screen is similar to a typical Lotus 123 worksheet with its border, control panel, etc. Cells, other than those which accept

input, are **'protected'**, that is, an error message appears whenever input is attempted and entries are rejected. Cells which accept data input are **'unprotected'** and are indicated by a brighter appearance on a monochrome screen, or differently coloured on a colour monitor.
On top of each data column a letter and number are displayed, separated by a slash. They indicate the order of the column in the worksheet. Labels and necessary comments are printed as headings on each column.

The customised menu.

The customised worksheet was specifically designed for easy use. A special custom menu provides shortcuts to the Lotus normal menu structure. To recall this menu the user must hold the **"Alt"** key down and depress the letter **"A"** key.
The customised menu is useful for the specific operations performed by the worksheet, such as data input, printing, graphing, and storing the data-file on disk. It includes commands such as 'Store', 'Print', 'Graph', 'View', 'Input', 'Update', 'Quit' and 'Exit', which usually branch further to lower level sub-commands.
For example, the command 'Graph' branches to 'V/Graph' and 'S/Graph' which allow, respectively, to view a graph on screen, or to save it on a graph-file on the disk for subsequent printing.
A command can be selected from the menu either by highlighting with the menu pointer and pressing "Return", or directly by typing its initial letter.

Initialisation of the customised worksheet.

Every time a new file is created to represent a new production unit the 'empty' customised worksheet ('GENERAL') must be retrieved (option 3 of the 'all-worksheet menu').
The prompt screen of the 'empty' worksheet displays the

following information requirements:

This is a weekly fish tank record file.. & Graphics.
It applies to fish farms operating tank culture systems.

Press [Alt] + [A], to display the MENU.

Tank / Unit No : ???

Starting date: day? /month? /year?

Fish stock (species, origin, sex):	????
Initial fish No stocked:	X?
Starting average fish size (Nos/lb):	Y?
Tank water volume (ft^3):	Z?

The missing information is necessary in order to initialise the worksheet and identify the physical production data of this new file.

The custom menu command which activates the initialisation is 'Set-up'.

The pointer jumps to the first position of missing information awaiting input. After each entry it moves to the next location until all entries are complete.

The exact initialisation procedure is as follows:

- Select option 3 from the 'all-worksheet' menu. When the empty worksheet is retrieved,
- Hold the "Alt" key down and depress the "A" key to recall the custom menu.
- Select 'Input' from the custom menu, either by pointing it and pressing the RETURN key or by typing the initial letter 'I'.
- The 'Input' command branches further into subcommands: 'Set-up', 'New-row' and 'Quit'.
- Select 'Set-up'.
- Type in the requested information followed by 'RETURN'.

Date input.

When initialising a worksheet file or when typing data manually, dates must be input using a special notation. This special notation is explained below:

Type the '@' symbol and the characters 'DATE', followed by a bracket which contains the year, month and day separated by commas.
For example, to input the date: 3rd June 1985, type:
@DATE(85,6,3)
In the worksheet this appears as: 3-Jun-85

Importation of transmitted data in the worksheet.

The recorded data on individual units is transmitted by the field device to the microcomputer weekly and is stored on the hard disk under the file name: data1.prn
The filename extension ".prn" is significant because 1-2-3 considers it as a 'print' file suitable for subsequent importation of the data in a worksheet.
Each worksheet must read and copy from the 'data1.prn' file the data for the particular production unit it represents in order to update its status. So, the transmitted data in the 'data1.prn' file must be prepared (segmented) in order to be recognisable by the individual worksheets. This function is activated from the 'all-worksheet' menu by option 1.
The computer arranges the data from all units in a form ready for importation by each individual worksheet. It is a one-off operation after data transmission and prior to updating the worksheet files.
The next step is to retrieve each file individually and update it. The responsible command in the customised menu is 'Update' and the entire procedure is as follows:

- Select option 2 from the 'all-worksheet' menu.

- Retrieve an initialised worksheet file.
- Recall its custom menu using the "Alt" and "A" keys.
- Select '**Update**' from the menu, wait some seconds and..
- Type the "data range" that must be imported in the present worksheet,

  type:

  Range1 (data from file 1)

  Range2 (data from file 2)

  etc..

  according to which unit is represented by the current worksheet file that is being updated.

  (The files 1,2,3,.. are held in the field device's memory representing the production units (tanks) and are transmitted to the microcomputer sequentially.)
- After some seconds the importation of the relevant data is completed, the computer bleeps and shows the beginning -top left corner- of the updated worksheet.

The immediate action that must follow updating of a file is to store it on disk.

Storing the data file on disk.

'Storing' (or 'saving') is the recording of the updated file on the magnetic storage medium of the computer (in this case a hard disk).
The customised command is '**Store**' and so,

- Recall the custom menu.
- Select '**Store**'
- The computer asks for a name to be given to the file. A new, specific name must be given only to a file that was just initialised. For existing up-dated files press ENTER in order to retain the same filename.
- The computer asks whether to 'replace' (overwrite) the old data in the file or to 'cancel' data storage.
- Select '**Replace**'.

The computer stores the new information by replacing the old in the file and 'stamps' it automatically with the current date (last update).

Manual data input.

The customised worksheet is also useful when automatic data transmission and importation are not used. Data can be input manually in the worksheet files to keep them up to date when a field device to collect the data is not available, or the electronic data communications are problematic (regions with bad telephone networks).
The command 'Input' of the custom menu branches to the subcommands: 'Set-up', 'New-row' and 'Quit'.
The first is already examined and the last quits input.
Subcommand '**New-row**' prepares an extra row in the worksheet in order to accommodate the data of the new recording interval which must be typed in.
The procedure is as follows:

- Retrieve the appropriate worksheet file.
- Recall the custom menu.
- Select '**Input**'.
- Select '**New-row**' and wait some seconds.
- When the operation is finished the computer bleeps and shows the biginning (top left corner) of the worksheet.
- A new menu appears automatically on the control panel and suggests the choice of either: 'Recalc', 'Titles' or 'Clear'.

  '**Recalc**' is a useful option during data input in 'fat' worksheets because it blocks the automatic recalculation of the built in formulas after each data entry. Thus, input is quick but no calculated output appears. Calculations take place only after the special "**Calc**" function key is depressed.

  '**Titles**' freezes the column labels as well as the dates on screen in order to help recognise what is

input while 'navigating' through the worksheet.
'**Clear**' rejects both these options and leaves the worksheet unaffected.

- Manual input may then start.

Looking around a worksheet file.

An important facility that the computerised data system offers is the quick retrieval and consultation of the data recorded in the files.
The computer can search in the electronic file directory, isolate and access whichever file is specified and 'open' it on screen for examination. Option 2 on the 'all-worksheet' menu is responsible for file retrieval, whereas when the file is 'opened' the command 'View' of the customised menu facilitates examination of the data in the file.
'View' branches further into the subcommands 'Titles' and 'Clear' which are explained above under manual input. 'Clear' can be used, in addition, to un-do previously activated 'titles' or 'recalc' commands.
The procedure to check the data contents of a file is as follows:

- Retrieve the file.
- Recall the custom menu ("Alt" and "A" keys).
- Select command '**View**'.
- Choose either '**Titles**' or '**Clear**'.
- 'Navigate' around the worksheet.

'Navigating' around the worksheet with the cell pointer.
(IBM PC or compatible keyboards)

In a Lotus worksheet the pointer can be moved to highlight cells, ranges (or commands in menus) in the following ways:

1. Press the '**arrow**' keys alone to proceed one place at a time.

2. Hold the 'ctrl' (control) key down and depress the left or the right 'arrow' keys to proceed one page to the left or to the right respectively.
3. Press the 'pgdn' or the 'pgup' keys to move one page down or up respectively,
4. Type the 'home' key to reach the top left corner of the worksheet.
5. Press the 'end' key first, then hit the 'home' key to go to the lower right corner of the worksheet, ie. to the outmost boundary.
6. Press the 'end' key first, then the left or the right 'arrow' keys to reach the most remote left or right boundary of the worksheet.
7. Depress the 'goto' function key, then type the cell 'address' (column-letter and row-number) of the location to go to and press RETURN.

Printing.

In order to obtain a 'hard copy' (on paper) of the data held in a computer file the command 'Print' is available on the custom menu.
This command branches into: 'O/Print', 'D/Print' and 'Quit'.
'O/Print' provides entire freedom of choosing printing formats, like left or right margins on the paper, page length, etc. The user may also define which area (range) of the data file to print. This command is linked with the standard detailed printing options provided by Lotus.
'D/Print' uses pre-set printing formats (defaulted) and prints the entire data contents of the file in condensed print.
For simple, default printing of the data in a file the steps are as follows:

- Retrieve the file and prepare the printer.
- Recall the custom menu.
- Select 'Print'.

- Choose 'D/Print'.
- The computer highlights the word 'Go' on the control panel and waits.
- If the printer is ready, press RETURN.

Customised graphics.

Graphs coexist with the data in the worksheet file but are invisible unless the programme is instructed to display them. These in-built graphs are flexible and adjust to new data in the file. They illustrate the behaviour of the most important physical production parameters in order to check instantly the progress of a production cycle.
The command in the customised menu which is responsible for displaying or printing the inbuilt graphs is **'Graph'**.
It branches into the subcommands: 'V/Graph', 'S/Graph' and 'Quit'.

Displaying a graph on screen.

The subcommand **'V/Graph'** displays the graphs on screen. It provides the list of all available graphs on the control panel for selection.
The inbuilt graphs are named and are listed below:

	Names:
- Total Week's food	XY O/A & BG O/A
- Actual Average Daily Feed Rate	XY P/A
- Average Week Weight Gain (per fish)	XY Q/A & BG Q/A
- Closing Average Fish Size	XY R/A
- Week Closing Total Biomass	XY V/A & BG V/A
- Average Week Temperature (morning)	XY X/A
- Stocking Density (biomass/ft^3)	XY AC/A & BG AC/A
- Dissolved Oxygen	XY AD/A
- Water pH	XY AE/A
- Actual & Standard Daily Feed Rate	XY N-P/A

The graph names denote the type of the graph, ie. 'XY' for graphs plotted against a vertical 'y' and a horizontal 'x' axes, whereas 'BG' denotes bar-graphs. The letters that follow and are separated by a slash identify the columns which contain the plotted figures along the vertical and the horizontal axes respectively.
Obviously, all graphs show figures plotted against time, since column 'A' contains the succesive weekly dates.

Procedure for displaying an inbuilt graph:

- Recall the custom menu ("Alt" and "A" keys).
- Select 'Graph'.
- Choose 'V/Graph' (view-graph).
- A list of all graph names appears on the control panel for selection. Choose a graph from this list using the highlight pointer and press RETURN.
- The selected graph is displayed on the screen. Press RETURN to go back to the graph list and select another graph to view on screen.
- When all desired graphs are examined hold the "Ctrl" (Control) key down and depress the "Break" key. The computer beeps.
- Press RETURN.

Printing a graph.

The subcommand 'S/Graph' saves (records) a selected graph on the computer's magnetic disk and creates a 'graph file' which contains the particular image. This procedure is necessary in order to print -at a subsequent stage- this image on paper. Obviously, 'graph files' are rigid and are not automatically updated with new data, so, in order to print an updated version of a graph it must be saved on disk again.
The procedure for saving an inbuilt graph in a 'graph file' on disk for subsequent printing is as follows:

- Recall the custom menu ("**Alt**" and "A" keys).
- Select '**Graph**'.
- Choose '**S/Graph**' (save-graph).
- A list of all graph names appears on the control panel for selection. Choose a graph from this list using the highlight pointer and press RETURN.
- The selected graph is displayed on the screen. Press RETURN.
- The computer asks for a name to be given to the 'graph file' which will accept the image. Type a name, preferably indicating the graph type and data plotted, and press RETURN to save the graph.

When a 'graph file' is created on disk, the image that it contains can be printed on paper using a special programme supplied by Lotus, the '**Printgraph**' programme.

How to use 'printgraph':

This programme is activated by the "Lotus access menu", so, the user must select this option instead of '123' when starting Lotus.
In the 'Printgraph' programme the name(s) of the graph file(s) to print can be specified. More than one graphs may be printed sequentially.
All steps in order to print a graph follow below:

- The recent entries to the current worksheet (updating or manual input) must be saved on disk using the command '**Store**' from the custom menu.
- Use command '**Exit**' from the custom menu to access the 'all-worksheet' screen, where the last option (zero) exits '123' and returns to the Lotus access menu.
- Choose option 0 on the 'all-worksheet' menu.
- Select '**Printgraph**' from the Lotus access menu.
- In the Printgraph programme choose the command '**Image-select**'. This provides the list of all the

existing graph files on the disk.

- With the '**arrow**' keys move among the list of graph files and select those to print using the '**space bar**'. Pressing the space bar results in the symbol ' ' to be displayed next to the graph file name and signals a graph which is selected for printing.
- Press RETURN.
- Align the paper on the graphics -dot matrix- printer.
- If the printer is ready select 'Go' and press RETURN.

Graphs are printed using default formats, such as printing resolution, size, etc. and a defined type of graphics printer. These formats and printer definitions may be changed at will using the commands '**Settings**' and '**Hardware**' of the 'Printgraph' programme respectively.
Instructions on these can be found in the Lotus manuals.

Quit.

The command '**Quit**' in the custom menu escapes from it and erases it from the control panel. The standard Lotus menus may be used instead (instructions on the standard Lotus menus are found in the Lotus manuals.)

'Quit' is also contained as an option in most of the customised sub-menus. It returns the custom menu (top menu) on the control panel.

Exit.

The '**Exit**' command of the custom menu erases the current worksheet file from the computer's memory -any data inclusive- and returns to the 'all-worksheet' menu screen.
Since this command clears the current file from the memory (RAM), care must be taken to save updated files on disk before exiting. (Files recorded on disk are not affected when exiting.)

Notes for ..safety!

Caution must be taken not to accidentally lose data that is not recorded on the computer's magnetic disks, or erase from the disks useful computer files.

When files are identified for erasure from the hard disk it must be certain that they are not confused with others which must be retained. The file contents must be checked prior to deletion. Note also, that clear, descriptive file-names help to avoid confusion.
Generally, it is recommended that up-to-date back-up copies of all files are retained, recorded on magnetic tape or floppy disks. Moreover, hard copies (printouts) of all the files may be kept to minimise the possibility of accidental data loss.

When the user exits a worksheet ('Exit' command in the custom menu) or retrieves a new from the disk, all current contents in the computer's memory are destroyed and these may include a file which is updated but not saved!
Switching off the computer or a sudden power failure have exactly the same implications. So, updated files must be saved on disk immediately! ('Store' command.)

If during updating a worksheet file, several serious errors occurred, the file should not be stored but its old version retrieved from the disk and the operation repeated. Errors affect the contents of the current computer memory (RAM) not the disks!

Example printouts.

For illustration purposes a complete printout of a fictitious data file, obtained by the 'D/Print' command, as well as a sample of graphs, produced on a dot-matrix printer, follow on the next pages.

Tank / Unit No : tank 60

Starting date: 13-Oct-86

Fish stock (species, origin, sex):	Batch: R86 Fast growing
Initial fish No stocked:	26,000
Starting average fish size (Nos/lb):	160
Tank water volume (ft3):	200.0

Last update : 08-Jan-87

A / 1	B / 2	C / 3	D / 4	E / 5	F / 6	G / 7
WEEK DATES starting on TUESDAYS	WEEK COUNTER	OPENING FISH Nos.	MORTALITIES total weight lbs.	Apparent MORTALITY RATE %	MORTALITIES Weekly total Nos.	TRANSFERS IN Nos
13-Oct-86	1	26,000	0.21	0.12%	31	0
20-Oct-86	2	25,969	0.15	0.08%	20	0
27-Oct-86	3	25,949	0.77	0.37%	95	0
03-Nov-86	4	25,853	0.27	0.12%	30	0
10-Nov-86	5	25,823	0.26	0.11%	27	0
17-Nov-86	6	25,796	0.31	0.12%	32	0
24-Nov-86	7	25,764	0.02	0.01%	2	0
01-Dec-86	8	25,762	0.13	0.05%	12	0
08-Dec-86	9	25,750	0.13	0.04%	11	0
15-Dec-86	10	25,739	0.05	0.02%	4	0
22-Dec-86	11	25,735	0.00	0.00%	0	0
29-Dec-86	12	25,735	0.13	0.04%	10	0

H / 8	I / 9	J / 10	K / 11	L / 12
TRANSFERS OUT Nos	CLOSING FISH Nos.	OPENING AVERAGE FISH SIZE Nos/lb.	SIZE OF FISH IN (Weighted average) Nos/lb.	SIZE OF FISH OUT (Weighted average) Nos/lb.
0	25,969	160.000	0.0	0.0
0	25,949	138.000	0.0	0.0
0	25,853	130.000	0.0	0.0
0	25,823	118.000	0.0	0.0
0	25,796	104.000	0.0	0.0
0	25,764	102.000	0.0	0.0
0	25,762	100.000	0.0	0.0
0	25,750	95.000	0.0	0.0
0	25,739	90.000	0.0	0.0
0	25,735	82.000	0.0	0.0
0	25,735	79.000	0.0	0.0
0	25,725	75.000	0.0	0.0

M / 13	N / 14	O / 15	P / 16	Q / 17
AVERAGE APPARENT CONVERSION RATIO food units per growth unit:	INTENDED DAILY FEED RATE % (opening biomass)	TOTAL WEEK'S FOOD ------ kgr. ------	ACTUAL AVERAGE DAILY FEED RATE % (average biomass)	AVERAGE GAIN [true] lbs/fish
0.5066	3.0000	5.900	1.0599	0.000989
1.0518	2.5000	5.450	0.8854	0.000440
0.5136	2.3000	4.540	0.6831	0.000754
0.3428	2.3500	4.540	0.6119	0.001131
1.9597	2.3500	4.090	0.5141	0.000178
1.4882	2.0000	3.200	0.3949	0.000184
0.5922	2.2500	3.636	0.4332	0.000526
0.4699	2.3000	3.182	0.3597	0.000580
0.2526	2.1800	3.182	0.3341	0.001079
0.4222	1.5000	2.273	0.2238	0.000461
0.2308	1.8200	1.818	0.1712	0.000675
0.3236	1.4000	1.360	0.1232	0.000360

R / 18	S / 19	T / 20	U / 21	V / 22
CLOSING AVERAGE FISH SIZE sampled weekly Nos/lb.	OPENING TOTAL BIOMASS lbs	BIOMASS INCREASE due to transfers IN lbs	BIOMASS DECREASE due to transfers OUT lbs	CLOSING TOTAL BIOMASS lbs
138.0	162.500	0.000	0.000	188.179
130.0	188.179	0.000	0.000	199.605
118.0	199.605	0.000	0.000	219.094
104.0	219.094	0.000	0.000	248.300
102.0	248.300	0.000	0.000	252.902
100.0	252.902	0.000	0.000	257.643
95.0	257.643	0.000	0.000	271.182
90.0	271.182	0.000	0.000	286.114
82.0	286.114	0.000	0.000	313.893
79.0	313.893	0.000	0.000	325.762
75.0	325.762	0.000	0.000	343.136
73.0	343.136	0.000	0.000	352.402

W / 23	X / 24	Y / 25	Z / 26	AA / 27
TRUE BIOMASS GAIN lbs	AVERAGE WATER TEMPERATURE Centigrade	FEEDING FREQUENCY & METHOD	FOOD TYPE	FOOD QUALITY (overall week) Energy %
25.679	9.7	ADLIB <10< times	NO 3	0.000
11.426	7.4	ADLIB <10< times	NO 3	0.000
19.490	5.8	ADLIB <6< times	NO 3	0.000
29.205	6.0	ADLIB <6< times	NO 3	0.000
4.602	6.0	ADLIB <6< times	NO 3	0.000
4.741	4.0	ADLIB <6< times	NO 3	0.000
13.539	5.0	ADLIB <6< times	NO 3	0.000
14.932	5.2	ADLIB <6< times	NO 3	0.000
27.779	4.4	ADLIB <6< times	NO 3	0.000
11.869	2.8	ADLIB <4< times	NO 3	0.000
17.374	3.4	ADLIB <4< times	NO 3	0.000
9.266	2.5	ADLIB <4< times	NO 3	0.000

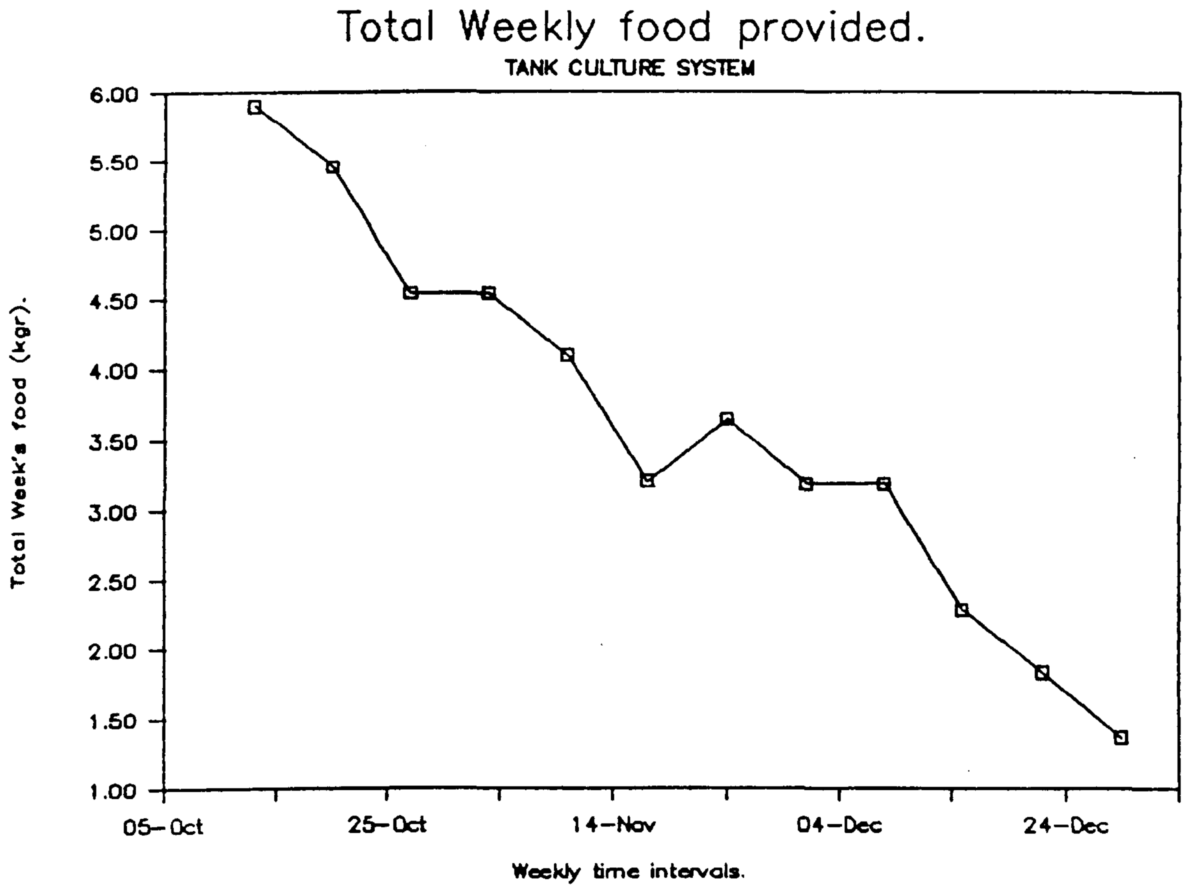
AB / 28 opening STOCKING DENSITY (Fish Nos /ft3)	AC / 29 opening STOCKING DENSITY (biomass lbs/ft3)	AD / 30 DISSOLVED OXYGEN (Weekly average) pa. Inlet % saturation	AE / 31 WATER pH (Weekly average)	AF / 32 WATER FLOW RATE Gallons / sec
130	0.81	0.0000	0.00	0.00
130	0.94	0.0000	0.00	0.00
130	1.00	0.0000	0.00	0.00
129	1.10	0.0000	0.00	0.00
129	1.24	0.0000	0.00	0.00
129	1.26	0.0000	0.00	0.00
129	1.29	0.0000	0.00	0.00
129	1.36	0.0000	0.00	0.00
129	1.43	0.0000	0.00	0.00
129	1.57	0.0000	0.00	0.00
129	1.63	0.0000	0.00	0.00
129	1.72	0.0000	0.00	0.00

AG / 33 OBSERVED DISEASES VARIOUS ANOMALIES HANDLING & TREATMENT	AH / 34 OTHER ENV/TAL CONDITIONS
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////
//////	//////

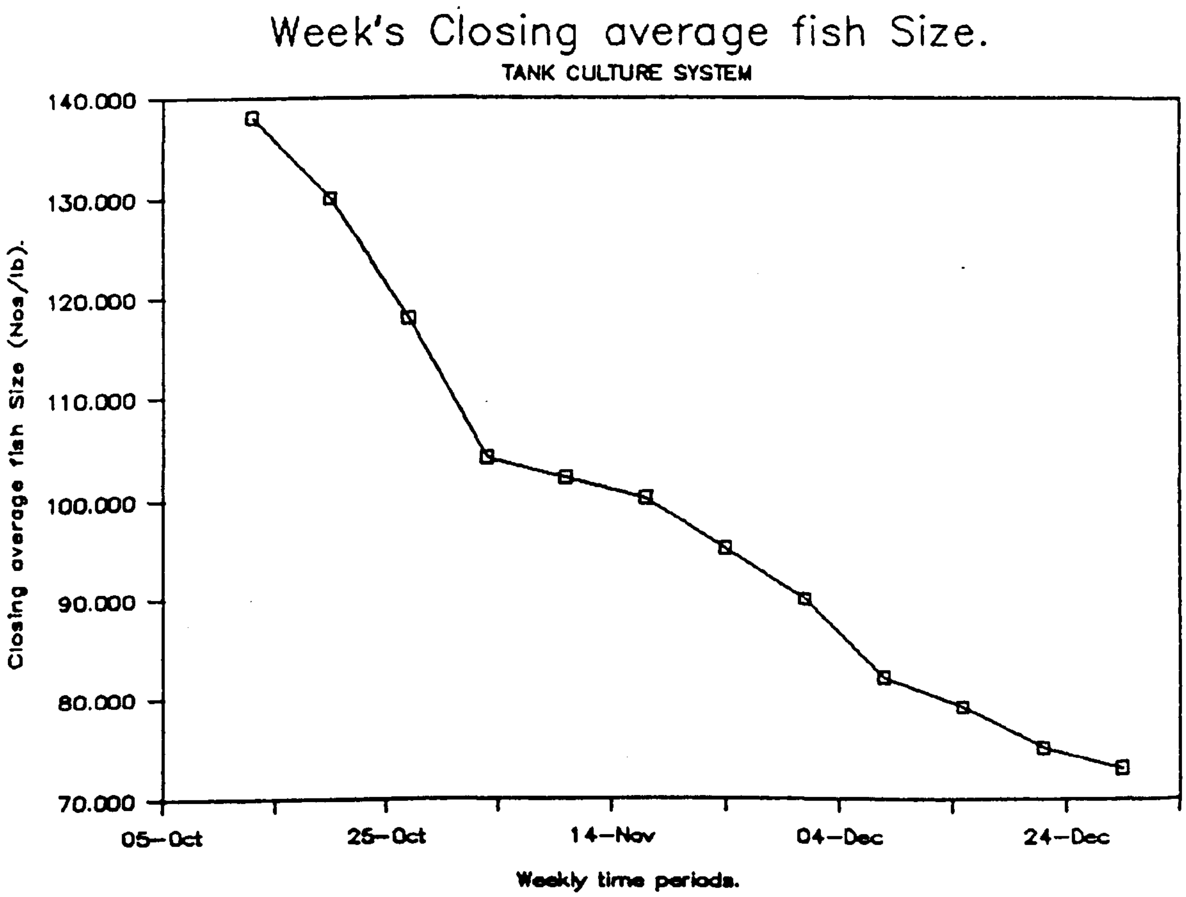
AI / 35

CUMULATIVE RESULTS

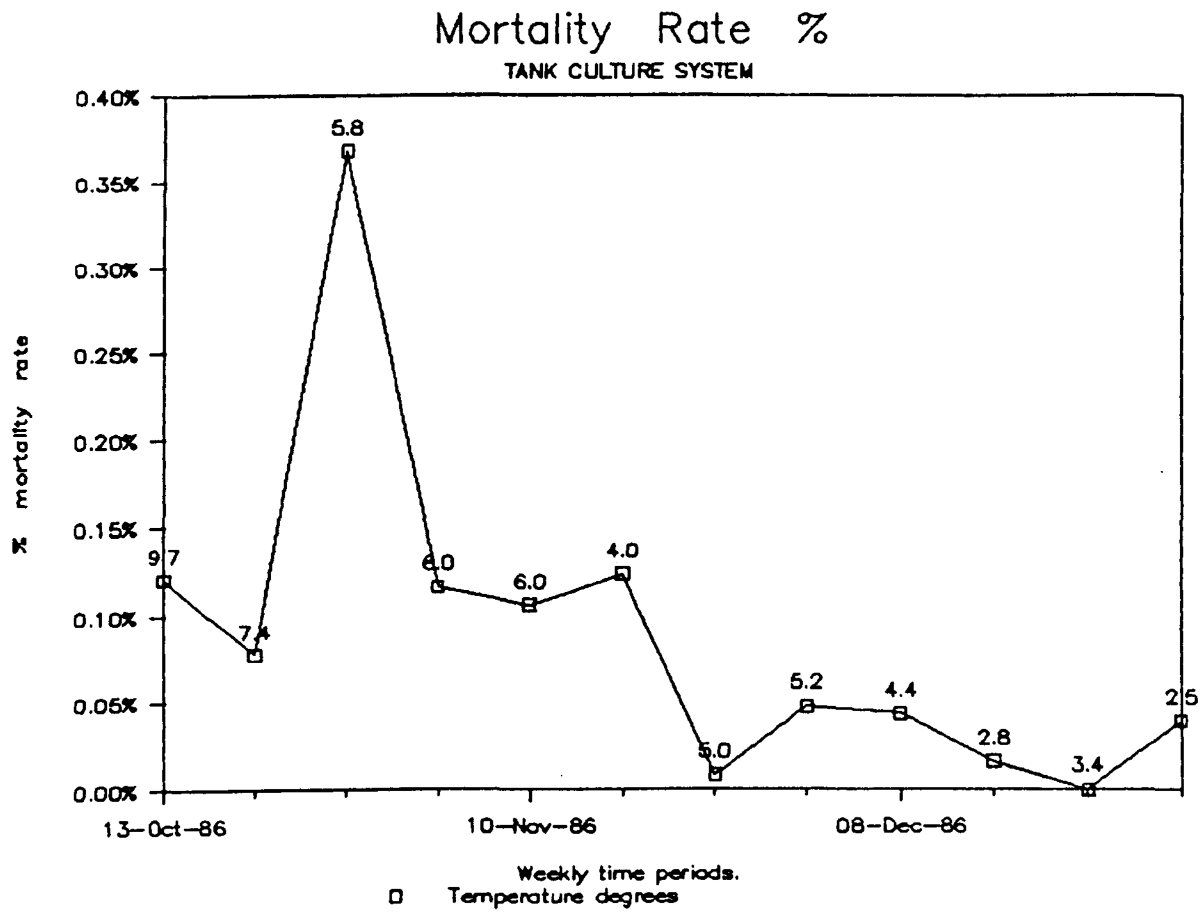
Average apparent F.C.R:	0.5010
Total growth (lbs):	189.902
Gain per fish (lbs):	0.007358
Total food given (kgr):	43.171
Observed mortalities (Nos):	275
Observed dead weight (lbs):	2.44
Apparent Mortality Rate:	1.06%

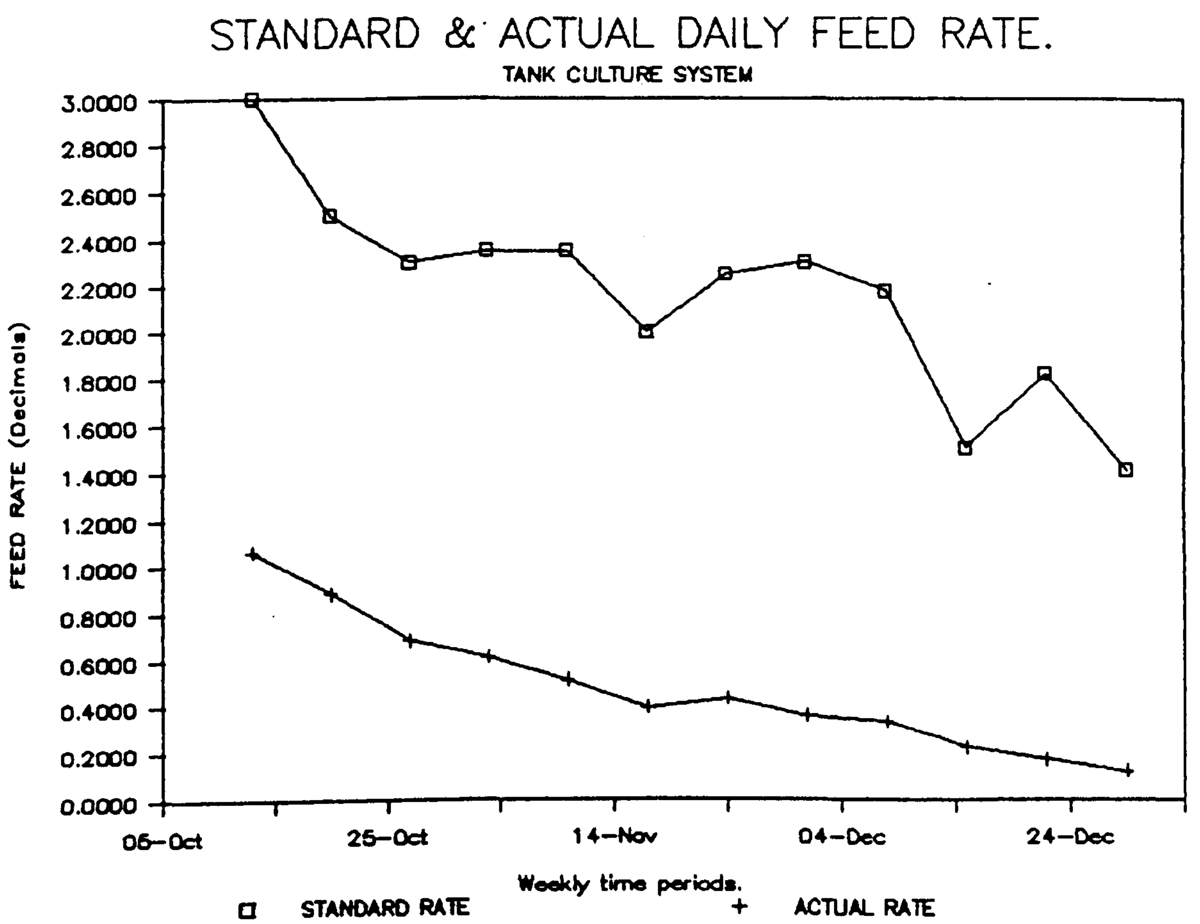


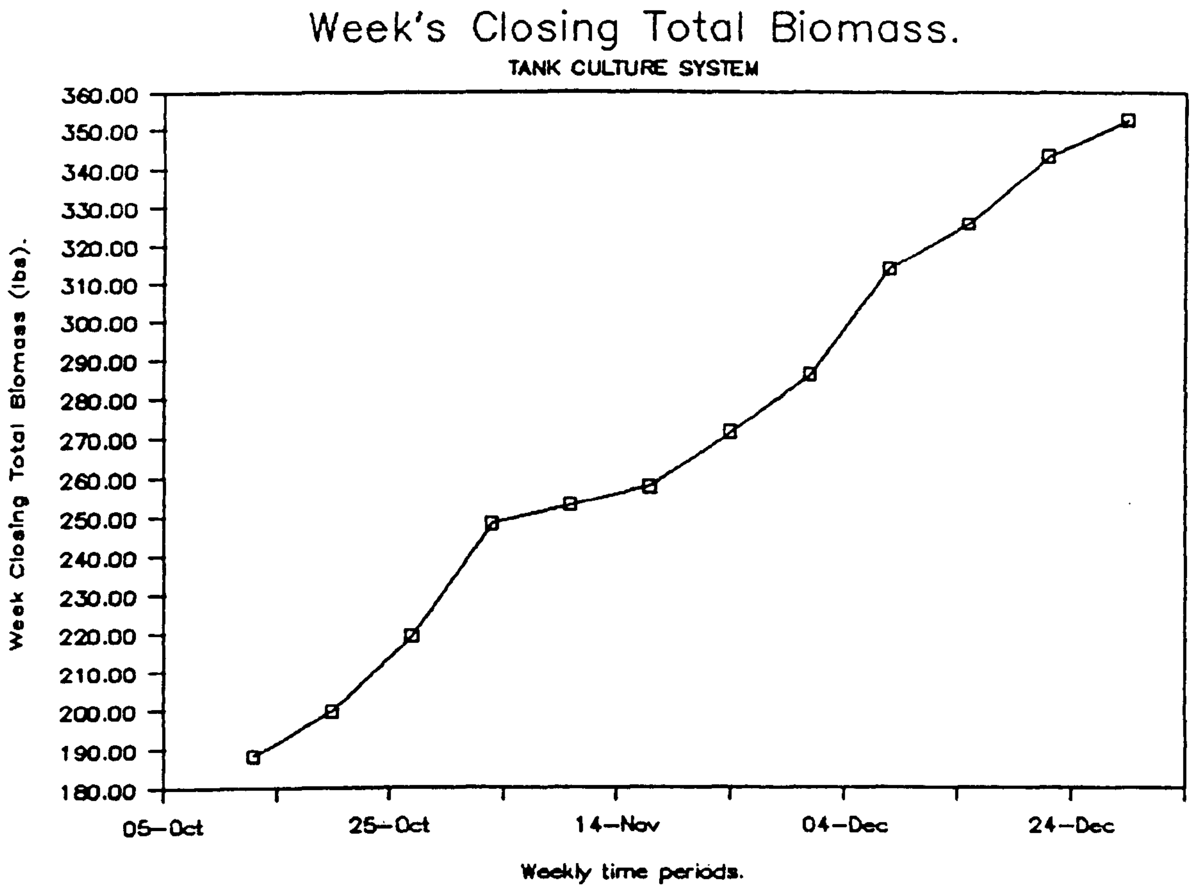
Total Weekly food provided.
TANK CULTURE SYSTEM
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
Total Week's food (kgr).
05-Oct
25-Oct
14-Nov
04-Dec
24-Dec
Weekly time intervals.

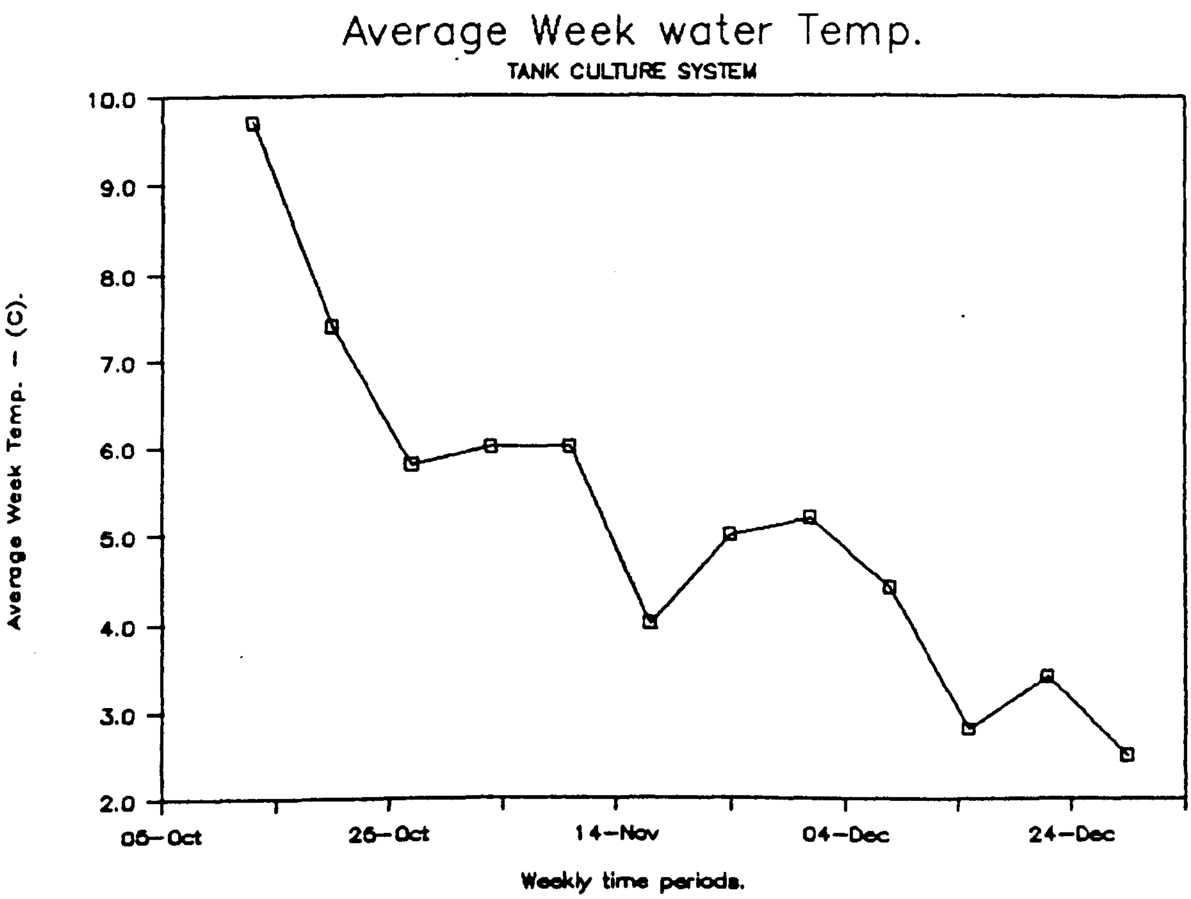


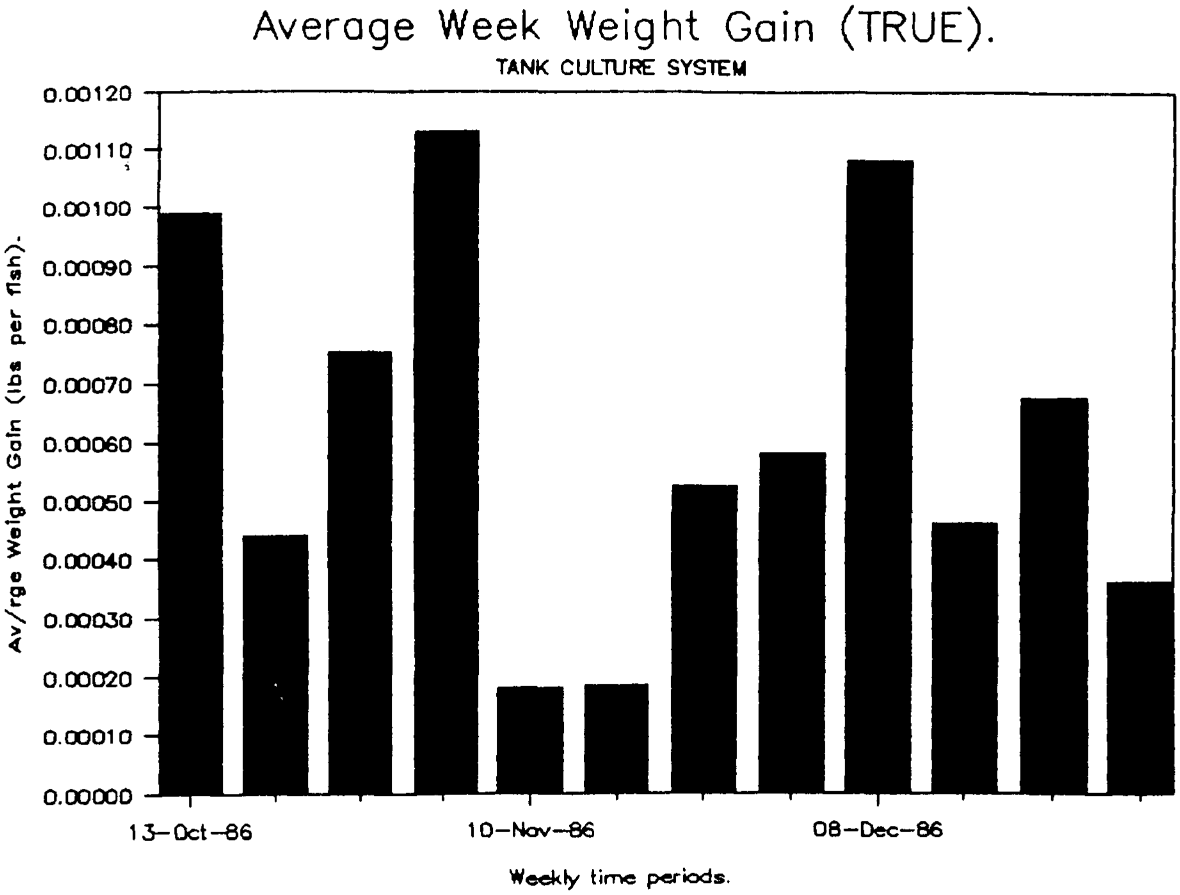
Week's Closing average fish Size.
TANK CULTURE SYSTEM
140.000
130.000
120.000
110.000
100.000
90.000
80.000
70.000
Closing average fish Size (Nos/lb).
05-Oct
25-Oct
14-Nov
04-Dec
24-Dec
Weekly time periods.

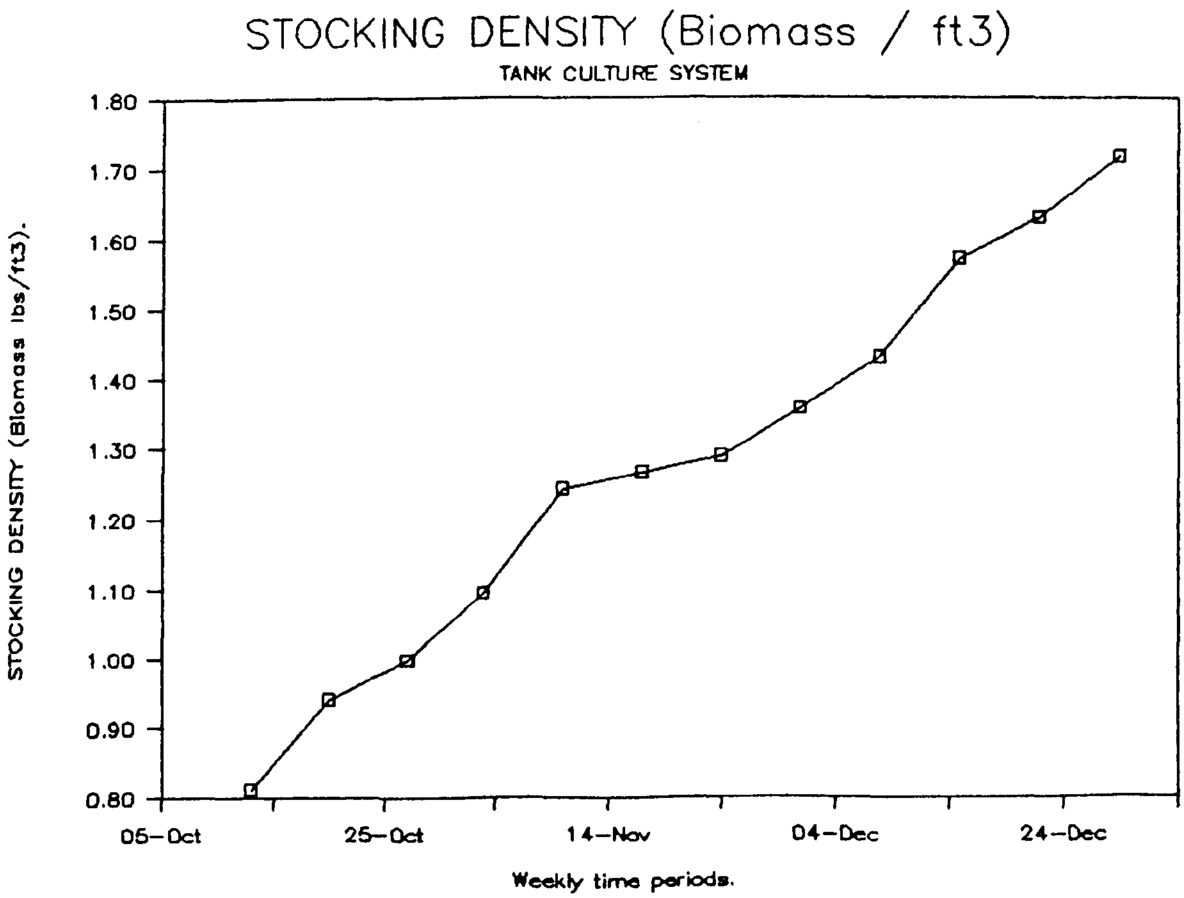

Mortality Rate %
TANK CULTURE SYSTEM
% mortality rate
0.40%
0.35%
0.30%
0.25%
0.20%
0.15%
0.10%
0.05%
0.00%
9.7
7.4
5.8
6.0
6.0
4.0
5.0
5.2
4.4
2.8
3.4
2.5
13-Oct-86
10-Nov-86
08-Dec-86
Weekly time periods.
Temperature degrees


STANDARD & ACTUAL DAILY FEED RATE.
TANK CULTURE SYSTEM
FEED RATE (Decimals)
3.0000
2.8000
2.6000
2.4000
2.2000
2.0000
1.8000
1.6000
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
06-Oct
25-Oct
14-Nov
04-Dec
24-Dec
Weekly time periods.
STANDARD RATE
ACTUAL RATE


Week's Closing Total Biomass.
TANK CULTURE SYSTEM
Week Closing Total Biomass (lbs).
360.00
350.00
340.00
330.00
320.00
310.00
300.00
290.00
280.00
270.00
260.00
250.00
240.00
230.00
220.00
210.00
200.00
190.00
180.00
05–Oct
25–Oct
14–Nov
04–Dec
24–Dec
Weekly time periods.


Average Week water Temp.
TANK CULTURE SYSTEM
Average Week Temp. – (C).
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
05–Oct
25–Oct
14–Nov
04–Dec
24–Dec
Weekly time periods.


Average Week Weight Gain (TRUE).
TANK CULTURE SYSTEM
0.00120
0.00110
0.00100
0.00090
0.00080
0.00070
0.00060
0.00050
0.00040
0.00030
0.00020
0.00010
0.00000
Av/rge Weight Gain (lbs per fish).
13-Oct-86
10-Nov-86
08-Dec-86
Weekly time periods.


STOCKING DENSITY (Biomass / ft3)
TANK CULTURE SYSTEM
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
STOCKING DENSITY (Biomass lbs/ft3).
05-Oct
25-Oct
14-Nov
04-Dec
24-Dec
Weekly time periods.

FISH-STOCK CONTROL AND REPORTING

Overview.

Additional facilities are built around the 'nucleus' of the data system and take advantage of the capabilities offered by existing field data logging devices, such as the HUNTER, which can accept enough information to cover the whole range of production activities that take place on a modern fish farm.

The stock reporting facility provides an easy way to obtain clear pictures of the stock status, identify any increased or unexplained losses and speed the decisions concerning future fish sales. It utilises data which is input by a farm operator in a field device on site and then communicated to the microcomputer for further analysis. (Refer in particular to the use of HUSKY-HUNTER for stock control in appendix B).

The customised worksheets that perform these additional tasks are designed to match the needs and characteristics of a particular fish farm type (trout hatchery), but since their construction utilises Lotus macro-commands, they may be adjusted to suit any situation.
They provide straightforward options activated by simple customised menus which are explained by screen messages. Whenever more details are necessary, intermediate displays provide summarised instructions and caution for potential mistakes.

For complete stock control information must be available of the existing stock and of the fish numbers of each size that are sold or ordered by customers. A fish hatchery receives many orders in advance and the manager must be aware of the stock numbers that are still 'free' for future sales.
On the other hand, an important picture of losses can be gained by comparing the numbers of eggs or fingerlings bought at the beginning of the production cycle with the currently growing

population increased by the numbers sold.
The above information might be summarised in a report to supply quick images of the current stock and mortality status; a job that is suited to a computer.

The sales and orders data-base.

Description.

A customised Lotus worksheet was developed for use as a computerised sales and orders diary with two basic functions. First, to allow data input on stock sales and orders and store it on the computer disk and secondly, to 'lend' this data to a report generation worksheet which prepares stock and mortality reports.
It is a sales and orders data base which includes different types of information (fields) for any one sale or order (record). Each row in the data base represents a record (sale/order), whereas each column is a field.

The fish sales/orders data base is accessed via the 7th option of the 'all-worksheet' menu and looks on screen as follows:

The orders/sales data base
************************** TODAY: 05-Feb-87
Last update: 30-Jan-87

TROUT HATCHERIES.

MONTH	CUSTOMER	BATCH	QUANTITY	SIZE	VACCIN	PRICE	SOLD?
Nov-87	Bloggs	R86	230,000	80	V	??	no
Mar-87	Smiths	U86	50,000	100	V	??	no
Apr-87	Jones	U86	120,000	20	V	??	no
...	....	...	....	...	..	..	..

etc.

The entry in the field titled 'SOLD?' differentiates between orders (no, or n) and sales (yes, or y).
The fish batches must be named with the same code-names that are used when stock data is input to the hand-held device on site. (See appendix B for the stock programme installed on the HUSKY.)

<u>The sales/orders menu.</u>

As soon as the sales/orders data base is retrieved, its customised menu is automatically activated and provides the following options:

'Add'
Add a new record to the data base (at the bottom).

'Delete'
Delete a record from the data base (point at a row and press RETURN).

'Corrections'
Make any detailed corrections to records. Move around the data base, locate the erroneous entry and correct it.

'Store'
Save the updated data base on disk.

'View'
Scan your sales/orders data base.

'Exit'
Exit from the data base and into the 'all-worksheet' menu.
(If not stored prior to exiting, the most recent changes will be lost!)

The information in the data base is secure from accidental overtyping since no change is possible outside the menu.

The user is 'locked' in the custom menu which is automatically restored on the control panel after completion of any task apart, of course, from 'EXIT'.
The menu allows the precise location to be specified prior to deleting or correcting existing entries. The user indicates that a desired location is found (for deletion or correction) by pressing RETURN repeatedly.
For any change to the data base the computer unprotects the selected location (change of colour or brightness), accepts the entry and restores protection.

Stock and mortality reporting.

Description.

This worksheet is retrieved by option 6 of the 'all -worksheet' menu. It automatically compiles the stock information (from file 'STOCK.PRN' transmitted from the HUSKY) as well as the sales/orders information by accessing the sales data-base described above.
This process requires some seconds to be completed and the following message is displayed:

PLEASE WAIT ..I AM VERY BUSY !!

because ..

I am importing the data

Then the reporting worksheet is ready to perform its reporting tasks and prompts the user with the following display:

```
                                                                 (MENU)
Insurance   Allstock  Sales/Orders   FreeStock   PrintData   Exit
-----------------------------------------------------------------------
                                ^
                                :
     look at the menu above ----:

        This is the report generating programme       v.(Nov-86)
-----------------------------------------------------------------------
   I am now at your service ready to produce the stock report you
wish!
Look at the menu options displayed above and select whichever you want.
Below each highlighted menu option you can see a brief explanation of
what that option does.

   Note that the reports will be produced on the printer so..

                       Please  set-up your printer !!
-----------------------------------------------------------------------
```

All the reports are produced on the printer as soon as the computer finishes the calculations. There is no facility to store them on disk, since they are quickly outdated as new information arrives from the farm.

Because the computer is involved in quite complicated calculations the user has to wait for a report to be finished. Messages appear on screen to clarify the stage of current operations, such as:

```
              PLEASE  WAIT ..I AM VERY BUSY !!

      because ..

                      I am generating your report
         or..
                      I am printing
```

When a report is selected, the computer displays explanatory screens of instructions, specifically tailored to each report type. The aim is to guide the user to define the desirable contents-criteria for each report type.
For example, the manager may request a report for a particular

farm site or section of the fish farm, restrict the report to particular species or batches, etc.

These displays are printed in the following pages to offer an idea of the interaction between user and computer. Question marks (??) represent locations where the user may input necessary information.
A report specimen for each type is also printed.

The reporting menu.

Again the user is 'locked' in a customised menu unless 'EXIT' is selected.
The menu items represent the reporting tasks that the worksheet can perform as listed below:

'Insurance'
Generate insurance reports.

'Allstock'
Generate a report on current stocks and mortalities on all farm sites.

'Sales/Orders'
Generate reports on sales and orders.

'FreeStock'
Report on projected stock availability against orders.

'PrintData'
Print the detailed stock data on which the stock reports are based.

The Insurance report.

The display:

```
FISH STOCK INSURANCE REPORT
***************************
FARM:      ??
------------------------
SPECIES  ??            Please input below the batch names you wish to
---------------        include in this report.
         Also, type the insurance values by size, per 1000 fish (assumed
         similar for all batches).

BATCH NAME LIST:      !       INSURANCE VALUES /'000
---------------       !     ----------------------------
     ??               !        Size                                 Value
     ??               !      (Nos/lb)                                 £
     ??               !
     ??               !     2000 -- 500           =                  ??
     ??               !      499 -- 100           =                  ??
     ??               !       99 --  50           =                  ??
     ??               !       49 --  20           =                  ??
     ??               !       19 --   1           =                  ??
---------------------------------------------------------------------------
```

A specimen report:

```
                        FISH STOCK INSURANCE  REPORT
                        ****************************
          Printed on        30-Oct-86
     Data was entered   on    10-28-1986    at   14:08:45

   FARM:   ALL SITES        SPECIES:   RAINBOW TROUT
---------------------------------------------------------------------------
            (Nos/lb)                       Ins. value         Total  ( £ )
Batch       Size range      Fish Nos.      /'000 fish         Insurance value

MS86        499 - 100         20,000         20.00                 400.00
MS86         99 -  50        457,400         30.00              13,722.00
Z86         499 - 100        769,500         20.00              15,390.00
Z86          99 -  50        641,000         30.00              19,230.00
R86        2000 - 500      1,039,000         15.00              15,585.00
R86         499 - 100        697,000         20.00              13,940.00

                         ------------                    -----------------
     Totals :               3,623,900                           78,267.00
```

The current stock and mortality report.

The display:

```
ALL STOCK AND MORTALITY REPORT
******************************
SPECIES  ??            Please input below the batch names you wish to
-------------     include in this report along with their corresponding
numbers of opening stock of eggs and the fish numbers sold to date.

BATCH NAMES              OPENING EGG STOCK            FISH SOLD TO DATE
                               (Nos)                        (Nos)
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
     ??          !               ??            !                  ??
---------------------------------------------------------------------------
    This report  includes the defined batches on ALL farm sites.
---------------------------------------------------------------------------
```

A specimen report.

```
                 ALL STOCK AND MORTALITY REPORT
                 ******************************
         Printed on:                  11-Nov-86
         Based on data gathered on     11-04-1986     at   17:38:2

Size expressed in Nos/lb          SPECIES:      RAINBOW TROUT
---------------------------------------------------------------------------
BATCH        VACCIN           SIZE         QUANTITY      CUM. QUANTITY
Z86           no               550           45000              45,000
Z86           no               550           45000              90,000
...           ..               ...             ...                ....
...           ..               ...             ...                ....
Z86           no               220           26000           1,253,000
...           ..               ...             ...                ....
Z86           no               124           21000           1,321,000

         Opening Egg Nos.                  =                 2,000,000
         Fish Nos. sold to date            =                    60,000

         % losses to date                  =                     30.95
         (Mortality rate)
---------------------------------------------------------------------------
```

The report on sales and orders.

The display:

```
SALES AND/OR ORDERS REPORT
**************************
This option generates reports based on the sales and orders data base.
A report will be produced for any combination of the criteria.
When a criterion is not specified then all records will be shown in the
report which, however, comply with the other criteria.

********************************************
Criteria:
       Customer     Size    Batch      Sold?
          ??         ??      ??          ?
********************************************

   The records will appear sorted according to the month of the year.

  Y*   typed under criterion 'Sold? ' will produce a report on SALES.
  N*   typed under criterion 'Sold? ' will produce a report on ORDERS.

---------------------------------------------------------------------------
```

Specimen report:

```
SALES AND/OR ORDERS REPORT
**************************
Criteria:
       Customer     Size    Batch      Sold?
                                       N*
********************************************
 MONTH   CUSTOMER  BATCH  QUANTITY  SIZE   VACCIN

 Mar-87  Smith     U86     50,000   100    V
 Apr-87  Jones     U86    120,000    20    V
 Nov-87  Bloggs    R86    230,000    80    V
```

The Free Stock (projected stock availability) report.

The display:

```
FREE STOCK REPORT.
*****************

 .  This report gives a rough estimate of fish-stock availability of a
certain fish batch against a future order under negotiation.

FREE STOCK FOR DEMANDED BATCH:

                                 -- --> ??

             Opening Egg Nos :              ??
    Estimated total % losses :             ??? (Estimate of losses up-to
                                                the final sales)

--------------------------------------------------------------------------
```

Specimen report:

```
FREE STOCK FOR DEMANDED BATCH:

                                 -- --> R86

             Opening Egg Nos :         2,000,000
    Estimated total % losses :             30.95  (Estimate of losses up-to
                                                  the final sales)

--------------------------------------------------------------------------

          Sold fish Nos to-date :       60,000
       Fish Nos held at present :    1,321,000
  Estimated % losses (present) :        28.50

-------------------------------------------
    Estimated production (Nos) :    1,162,480
        Remaining orders (Nos) :    1,105,000

-------------------------------------------
              FREE STOCK (Nos) :       57,480
-------------------------------------------
                    printed on :    11-Nov-86
```

GROWTH MODELLING

Description of the customised worksheets.

Modelling of fish growth is based on mathematical concepts which are described in the second chapter of this thesis where emphasis is put on the significance of data selection for meaningful predictions. With a recording system which creates data files of distinct fish life-stanzas growth during these can be modelled.
Option 8 of the 'all-worksheet' menu constructs such models. There are two distinct but linked worksheets for this purpose. First, the **"regression worksheet"**, accesses the data from the stored files on disk and calibrates a set of predictive equations by least squares linear regression.
Secondly, the **"prediction worksheet"**, is automatically activated when the equations are ready and constructs the skeleton of a prediction table which can be expanded at will. What if? analyses can be performed on the table and in-built graphs of the predicted data can be viewed or printed. The tabulated growth predictions may be stored on disk as separate files to allow for future retrieval and new analyses.
Both worksheets work as an integral programme unit with customised menus. They display instructions and messages on the screen in order to guide the user.

A complete example of operations follows in order to demonstrate how a prediction model can be generated, analysed and stored.

A step-wise guide to operations.

- Select option 8 from the 'all-worksheet' menu.
- A screen full of instructions appears. It gives the criteria for data selection (see chapter 2)
- Press RETURN

- The computer requests the names of the files which contain the original data to be analysed.

  The screen display is as follows:

```
  Tank/files' list:              tnk/file?
--------------------------
According to the criteria,          (this area is
define the tank/files to             used to input the
be used in building the              file-names.)
prediction model.
--------------------------
Type: 999 to end the list
and press 'RETURN'.
--------------------------

Tank/file counter:
---------------------    0

Maximum tank/files 100.
--------------------------
```

- Type the file-names followed by RETURN.
  After each file-name is entered the computer updates the file counter and goes to the next location in the input area until '999' is typed.
- Type '999' to end the file list.
- The computer highlights the following message while it compiles the data from the specified files:

```
        *********************
            Please Wait.!
        *********************

 Tank/file data compilation under way...
```

- If during file access the computer realises that a non-existent file-name was typed, it notifies the user, allows for the error to be corrected and resumes computations normally.

The following message appears:

```
I am afraid that you have specified a non existing name.!
       You have to retype the wrong file entry..
...and be more careful.!
*******************************************************************
Press 'RETURN' to continue..
```

- When data compilation is finished the computer indicates that:

```
*********************
    Please Wait.!
*********************

Statistical computations under way...
```

- When the computations are complete, a printout of the statistical details may be printed.
  The computer requests:

```
If you want to print the regression details switch on the
printer now!
      Press 'RETURN' to continue...
```

  (If the printer is not switched on printing is cancelled and the computer proceeds to generate predictions.)
- When printing is finished the computer displays:

```
.. Press 'RETURN' to generate a forecasting model.!
```

- Press 'RETURN'.
  The "regression worksheet" communicates the regression results it produced to the "prediction worksheet" via an intermediate file named 'FISH-STAT'.
  The following message appears:

```
The data and the analysis are being stored
on file 'FISH-STAT'.
```

- Press 'RETURN'.

The "prediction worksheet" is automatically activated and 'reads' the statistical results.
It displays the message:

PLEASE WAIT !!

Reading the information from 'FISH-STAT' file.

- While the user waits, the information is read and the skeleton of the prediction table is constructed. When the computer is ready it displays the assumptions for valid prediction results. (See chapter 2)
- Press 'RETURN'.
- The screen displays the top left section of a small two-row table. The user is locked in a customised menu which allows the table to be extended with more rows/time-intervals, perform What if? analyses, examine graphs, print the table and store the predictions on disks as separate files.

Working with the menu.

- Command '**New-row**' adds a row to the table extending it by one week.
- The computer displays:

PLEASE WAIT !!

Extending the prediction table by one row/week.

- Command '**What if?**' allows to input on the table alternative values for opening fish size or temperature. The pointer can be moved only to the locations that accept entries (unprotected cells). A 'what if?' analysis is finished by pressing 'RETURN'.

- Command **'Tanks'** provides a tabulated analysis of the numbers of tanks of different specifications which may exist on the farm (eg., tanks of different diameters). When this command is selected the user is prompted with the following display:

Tank Nos	Diameter ft	Water level ft	Volume ft^3	Total volume ft^3
?	?	?	xx	xxx
?	?	?	xx	xxx
?	?	?	xx	xxx
?	?	?	xx	xxx
	Maximum capacity ft^3:			xxxxx
	Average Tank-unit ft^3:		xxx	

---> The water level is assumed constant in all tanks throughout production.!

The user is requested to type the missing information in the locations marked above with '?' marks. When entry is finished press 'RETURN'.

- Command **'Print'** can be used to obtain a hard copy of the prediction table at its current state (see an example printout in chapter 2), or print the details of the statistical results on which the predictions are based. Finally, it may print the table of tank types.
In order to perform these tasks 'Print' branches to sub-commands:

'Print-table' , 'Statistics' , 'Tanks'

During printing, one of the following messages appears:

PLEASE WAIT !!

Printing the prediction table.

or..

Printing the data and its statistical analysis.

or..

Printing the fish-tanks' information.

- Command 'Store' saves the prediction table at its current state on a special sub-directory on the hard disk. A name must be given to this 'prediction file'.
- To retrieve a 'prediction file' select option 9 from the 'all-worksheet' menu.
- A 'prediction file' is retrieved in an inactive state, but it displays the message:

"Hold the 'Alt' key down and press 'P' to start.."

This action 'wakes' the custom menu.

- Command 'Graph' may be used in order to view a graph of the predicted data on screen or to save it on disk in a 'graph file' for subsequent printing. The responsible 'Graph' sub-commands are:

    'View-Graph' and 'Save-Graph'

A list of the inbuilt graphs now follows:

	Name:
Projected food conversion ratio	BFR
.... feeding rate (% biomass)	LRATE
.... food consumption	BFOOD
.... water requirements	BWATER
.... stocking density	LDENSITY
.... water temperature	LTEMP
.... growth	LSIZE
Relative tank capacities	PTANKS

- Command 'EXIT' abandons the prediction programme and returns to the 'all-worksheet' menu. (Save valuable prediction tables before exiting !!)

DISK MANAGEMENT OPERATIONS

In the directories or subdirectories of a hard disk data files tend to accumulate as new ones are continuously created and stored. Thus, although there is no storage space limitation, the user may become confused and unable to discriminate between valuable, recent files and unused, old ones.

A facility must be available which performs the following two tasks:
First, copy the old and rarely used files which contain historical information on either floppy disks or other 'remote' areas assigned on the hard disk.
Second, erase all unwanted data-files from a hard disk directory.

These tasks can be accomplished from DOS using **'batch files'**.
That is, away from any programme, groups of instructions (batches) may be given directly to the computer system (DOS) to perform specific jobs, such as copying files from a directory onto a floppy disk, initialising-formating a floppy disk, deleting files from a sub-directory, etc.
The 'batch-files' are given names and are activated by typing these names. The screen prompts messages that explain the role of them.
For example, the batch-files that were created to perform file management on the implemented system can be recognised by the following explanatory displays:

```
************************************************************
For Lotus123 enter.................................... LOTUS
For Olitalk enter....................................OLITALK
For Lpwye enter........................................LPWYE
------------------------------------------------------------
To back-up data-files on floppy disks enter...........DISK
To clear data-files from directories enter...........CLEAR
************************************************************
```

If 'DISK' is typed, further explanations and options are given:

```
*************************************************************************
    1) If the floppy disk is unused you need to initialise (format) it.
       Type 'NEW' and press the RETURN key to start initialisation.

    2) If the disk has been used before, ie. it is already initialised,
     - Type 'LPDATA' and press RETURN to back-up the Lpwye data files.
     - Type '123DATA' and press RETURN to back-up the Lotus data files.
     - Type 'SALES' and press RETURN to back-up the sales/orders dbase.
     - Type 'PREDICT' and press RETURN to back-up the prediction files.
*************************************************************************
      Type 'CANCEL' to abandon these options...
*************************************************************************
```

If 'CLEAR' is typed, the sub-directories which contain the lp- the graph- or the prediction-files may be cleared. However, care must be taken in advance to secure any historically useful files on back-up disks.
The display shows the following:

```
*************************************************************************
Type 'LPCLEAR' and press RETURN to erase all LP data files.
Type 'GRAPHCLEAR' and press RETURN to erase all graph-files.
Type 'PRDCLEAR' and press RETURN to erase all prediction-files.
*************************************************************************
Type 'CANCEL'  and press RETURN if you changed your mind !
*************************************************************************
```